GATE – CIVIL ENGINEERING

Transportation Engineering

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TRANSPORTATION ENGINEERING

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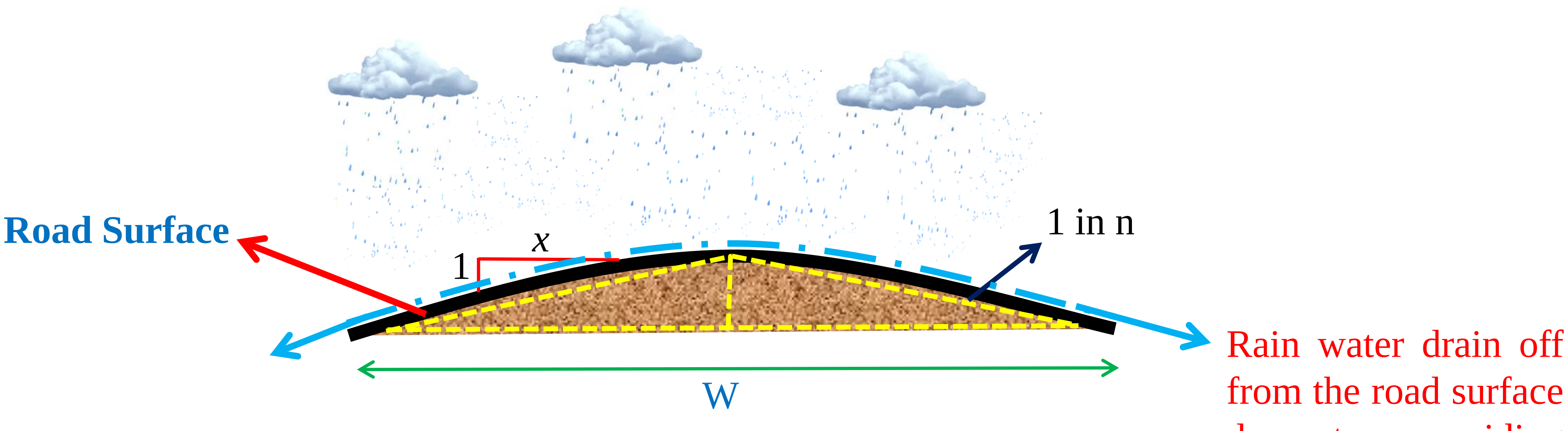
Cross slope or Camber:

- 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.
- To prevent the entry of surface water into the sub grade soil through pavement.
- To prevent entry of water in to the bituminous pavement layers.
- Continued contact with water causes stripping of bitumen from the aggregates and results in deterioration of the pavement layer.



Parabolic Camber

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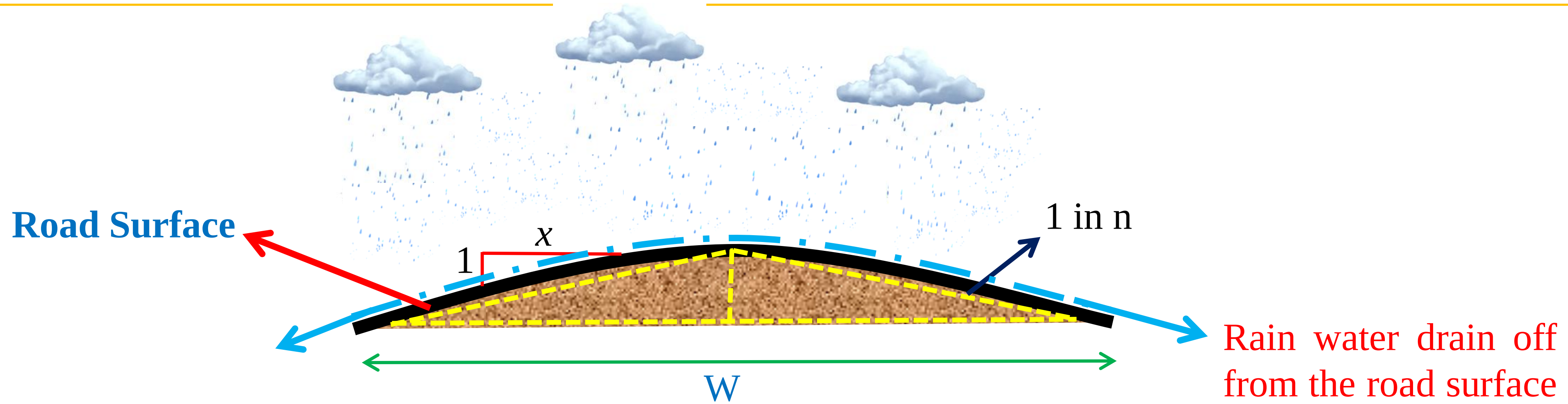


Parabolic Camber

$$Tan\theta = \frac{1}{n} = \frac{h}{\frac{W}{2}} = \frac{2h}{W} \Rightarrow h = \frac{W}{2n}$$

$$y = k.x^2$$

$$At \ \ x = \frac{W}{2}, \ \ y = \frac{W}{2n} \Rightarrow \frac{W}{2n} = k\left(\frac{W}{2}\right)^2$$

$$k = \frac{2}{nW}$$

$$y = \frac{2}{nW}.x^2$$

- 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.
- Skid resistance of the pavement gets decreased.
- Camber is provided on the straight roads by raising the center of the carriage way with respect to the edges, forming a crown or highest point on the center line.

At horizontal curves with super elevation, the surface drainage is effected by raising the outer edge of pavement with respect to the inner edge while providing the desired super elevation.

- Camber designated by 1 in n.
- Camber also expressed as a percentage
- If the camber is x%, the cross slope is x in 100

The camber of pavement depends on

i. Type of pavement surface
ii. The amount of rainfall

Too steep cross slope is not desirable because

i. Transverse tilt of vehicles causes uncomfortable side thrust and a drag on the steering of automobiles.
   - Wheels along the pavement edges causes unequal wear of tyres as well as road surface.
ii. Discomfort causing throw of vehicle when crossing the crown during overtaking operations
iii. Problems of toppling over of highly larden bullock carts and trucks
iv. Formation of cross ruts due to rapid flow of water
v. Tendency of most of the vehicles to travel along the center line.
vi. Erosion of the berms.

Shape of camber - parabolic, elliptic or straight line

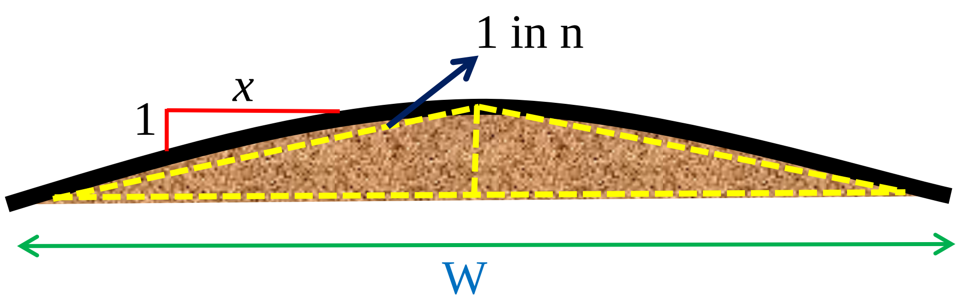
i. Parabolic or elliptic - profile is flat at the middle and steeper towards the edges.

- Preferred by fast moving vehicles as they have to frequently cross the crown during overtaking operation.

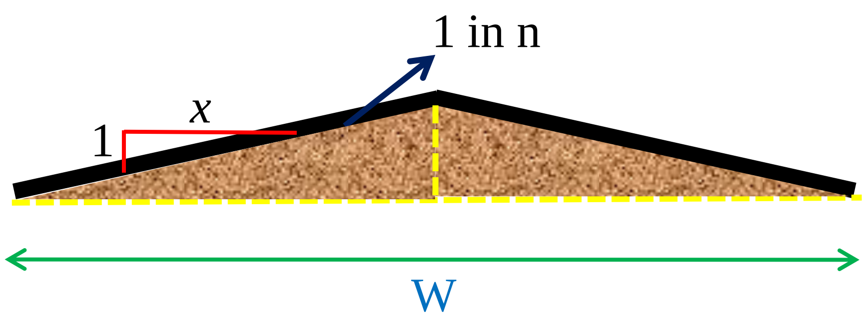
ii. Straight line camber - steel tyred wheel of animal drawn vehicles can cause considerable damage to the pavement surface due to high stresses

- The wheel does not have full contact, increases further the contact stress

iii. Combined camber with parabolic central portion and straight line camber at the edges



Parabolic Camber



Straight line Camber

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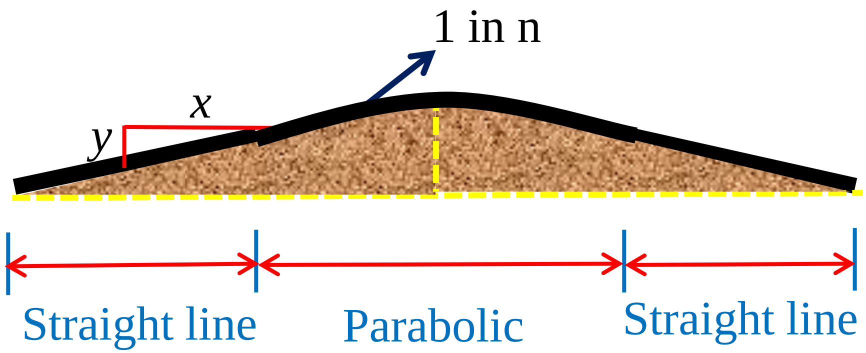


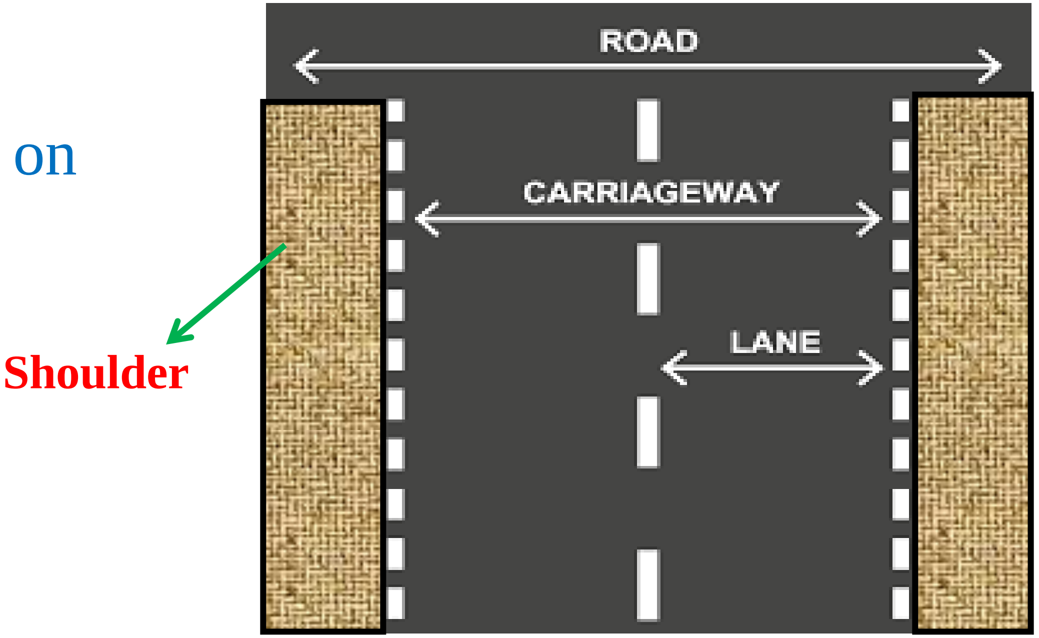
- The cross slope for shoulders should be 0.5% steeper than the cross slope of adjoining pavement , subject to a minimum of 3%.
- Max value of 5% for earth shoulders
- Crown - highest point on the carriage way.
- The camber of road should be approximately equal 1/2 of the longitudinal Gradient.

Recommended values of camber for different type or road surfaces.

S.No	Type of surface	Camber w.r.t rainfall	
		Heavy	light
1	Cement concrete High type Bituminous surface	1 in 50 (2%)	1 in 60 (1.7%)
2.	Thin Bituminous surface	1 in 40 (2.5%)	1 in 50 (2%)
3.	Water Bound Macadam	1 in 33(3%)	1 in 40 (2.5%)
4.	Earth	1 in 25 (4%)	1 in 33(3%)

Width of Pavement or Carriage way

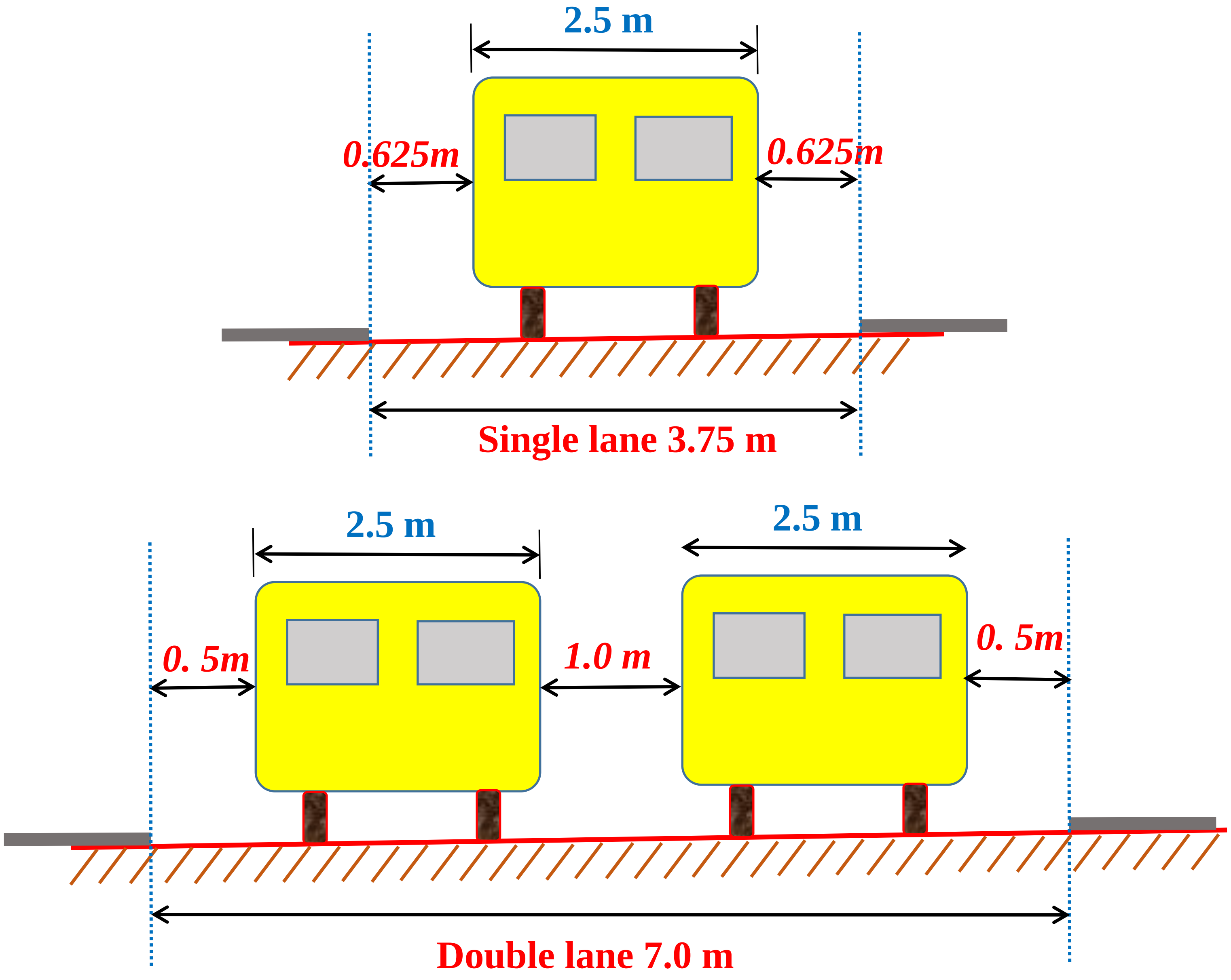
- Pavement or Carriage way width depends on
  i. width of traffic lane
  ii. Number of lanes.
- The lane width is based on
  i. width of vehicle.
  ii. Minimum side clearance.



- Width of single lane is considered as 3.75 m for vehicle of maximum width 2.44 m.
- For pavements having two or more lanes, width of 3.5 m per lane is considered sufficient.

Type of carriage way	Width of carriage way
Single lane	3.75 m
Two lanes, without raised kerbs.	7.0 m
Two lanes, with raised kerbs.	7.5 m
Intermediate carriage way (except on important roads)	5.5 m
Multilane pavements	3.5 m per lane

- The width of single lane or village roads may be decreased to 3.0 m.
- On urban roads without kerbs the single lane width may be decreased to 3.5 m.
- The minimum width recommended for kerbed urban road is 5.5 m to make allowance for a stalled vehicle.



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Traffic separators or medians

- To prevent head on collision between vehicles moving in opposite direction on adjacent lanes.
- Channelize traffic into streams at intersections.
- Shadow the crossing and turning traffic.
- Segregate slow traffic and to protect pedestrians.
- Medians - dividing the two directions of traffic flow islands or parkways strips.
- Median width

 - Rural areas - 3.0 m absolute minimum
 5.0 m desirable minimum

 - Urban areas - 1.2 m absolute minimum
 5.0 m designable minimum.

Traffic separators

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Kerbs

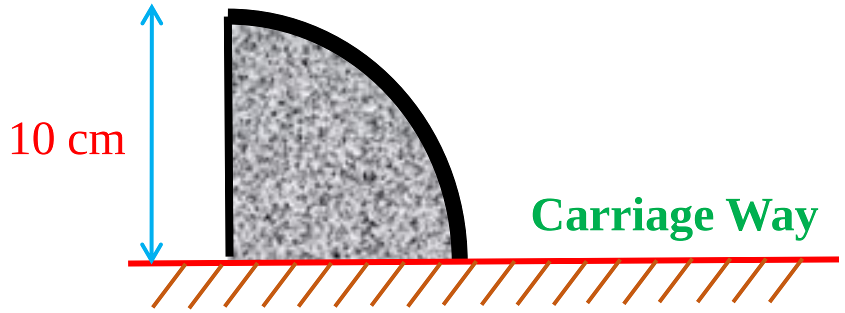
- Kerb is the boundary between the pavement and shoulder.
- It is the dividing line between carriageway and footpath.

Kerb

It is desirable to provide kerbs on urban roads.

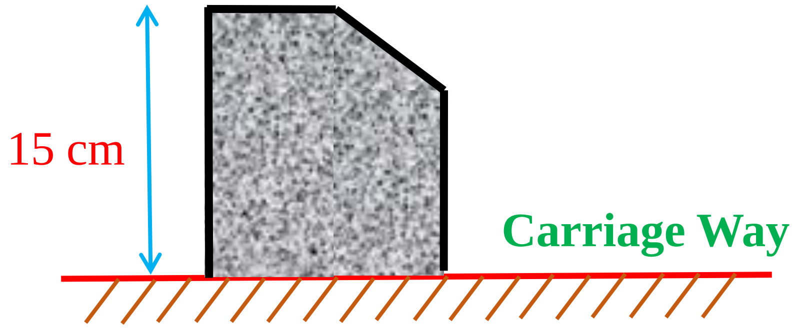
i. Low or mountable kerbs –

- Provided at medians and channelization schemes and is also useful for longitudinal drainage system.
- Height of 10 cm above the pavement edge



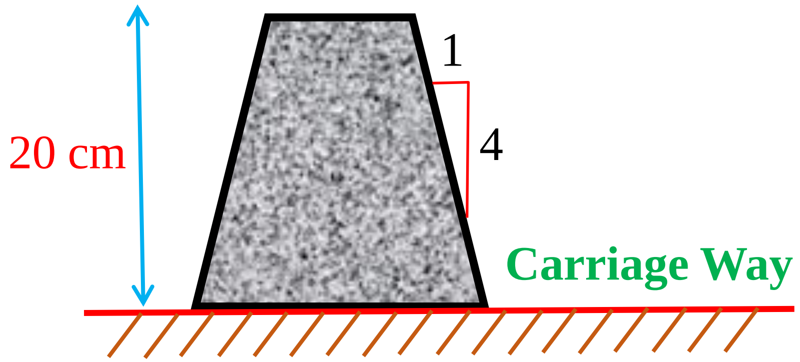
ii. Semi barrier type kerb

- Provided on the periphery of a roadway where the pedestrian's traffic is high.
- Height is 15 cm above the pavement edge..

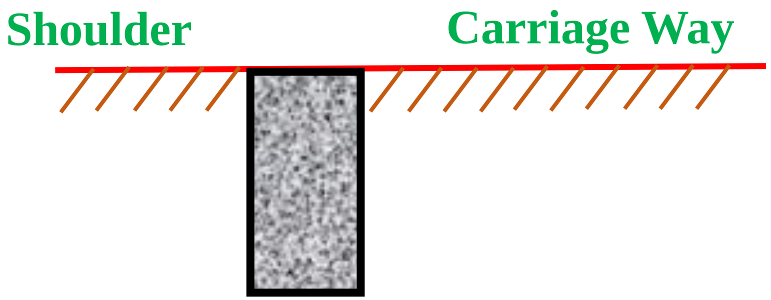


iii. Barrier type kerb:

Provided in built up areas adjacenet to foot Paths-with considerable pedestrian traffic.



iv. Submerged kerb: Provide lateral stability



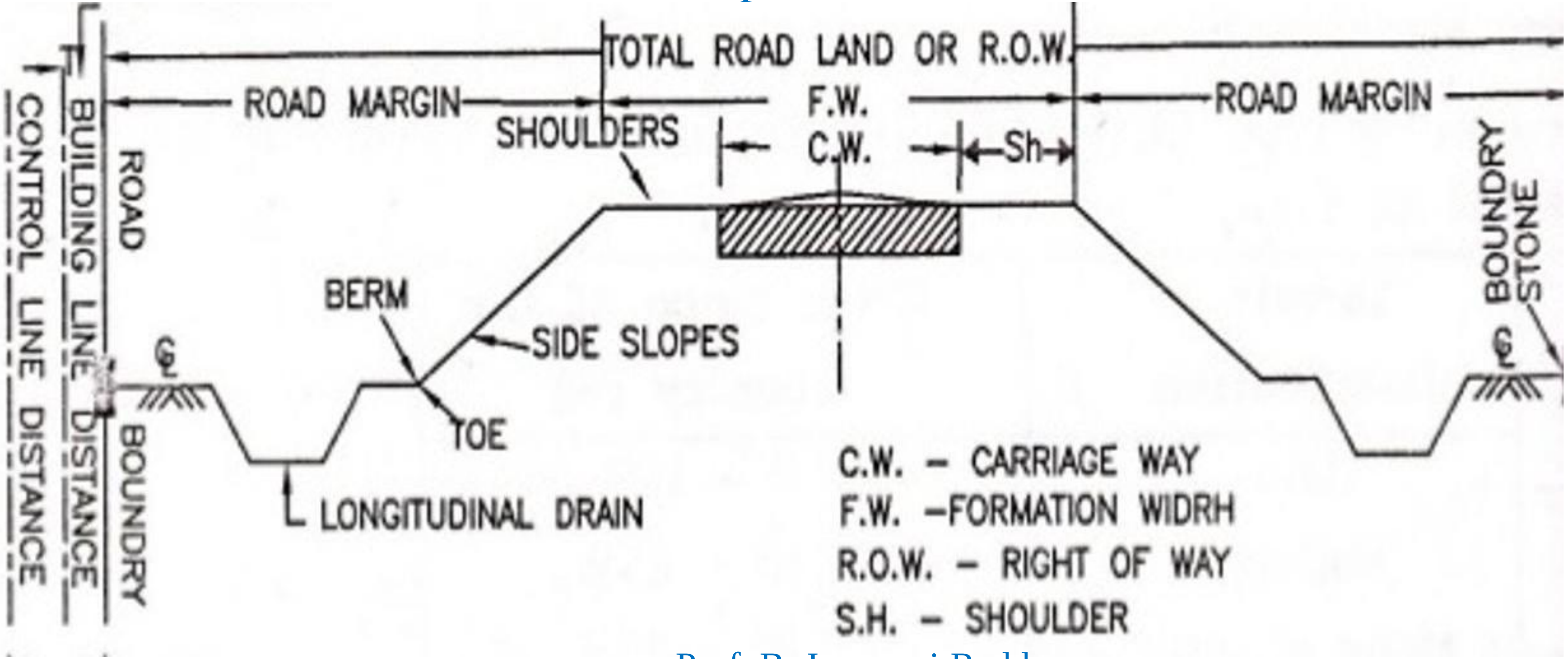
In rural roads submerged kerbs are sometimes provided at pavement edges between the pavement edge and shoulders. These kerbs provide lateral confinement and stability to the granular base course and flexible pavements.

Road Margins:

Shoulders:

Shoulders are provided along the road edge to serve as an emergency lane for vehicle compelled to be taken out of the pavement or roadway.

- also act as service lanes for vehicles that have broken down.
- The minimum width of shoulder as per IRC is 2.5 m.



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Parking lanes:

- Parking lanes are provided on urban roads to allow kerb parking.
- Parallel parking is allowed as it is safer for moving vehicles.

Lay byes:

Lay byes are provided near public conveniences with guide maps to enable drivers to stop clear off the carriageway.

Bus bays:

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

Frontage roads:

Frontage roads are provided access to properties along an important highway with controlled access to express way or free way

- may run parallel to the highway and are isolated by a separator
- provided at grade separators.

Drive ways:

Drive ways Connect the highway with commercial establishments like service stations, fuel stations etc.

Cycle tracks:

Cycle tracks are provided in urban area when the volume of the 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.

Foot path or side walks:

Foot path or side walks provided in urban area when the vehicular as well as pedestrian traffic are heavy.

- to provide protection to pedestrians and to decrease accident.
- Side walks are generally provided on either side at the road.
- minimum width is 1.5 m.

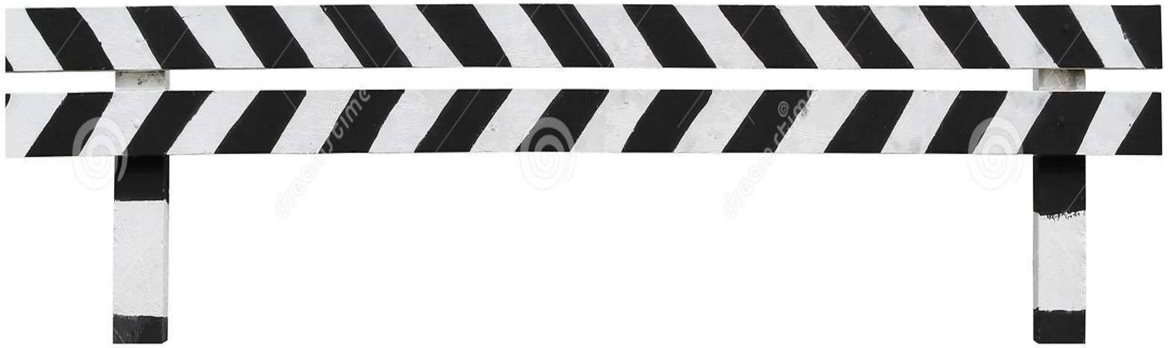
Guard rails:

Guard rails are provided at the edge of the shoulder when the road is constructed on a fill so that vehicles are protected from running off the embankments

- Guard stones are installed (painted with black and white)

Embankment slopes:

Embankment slopes should be as flat as possible for the purpose of safe traffic movement and also for aesthetic reasons.



Guard rails

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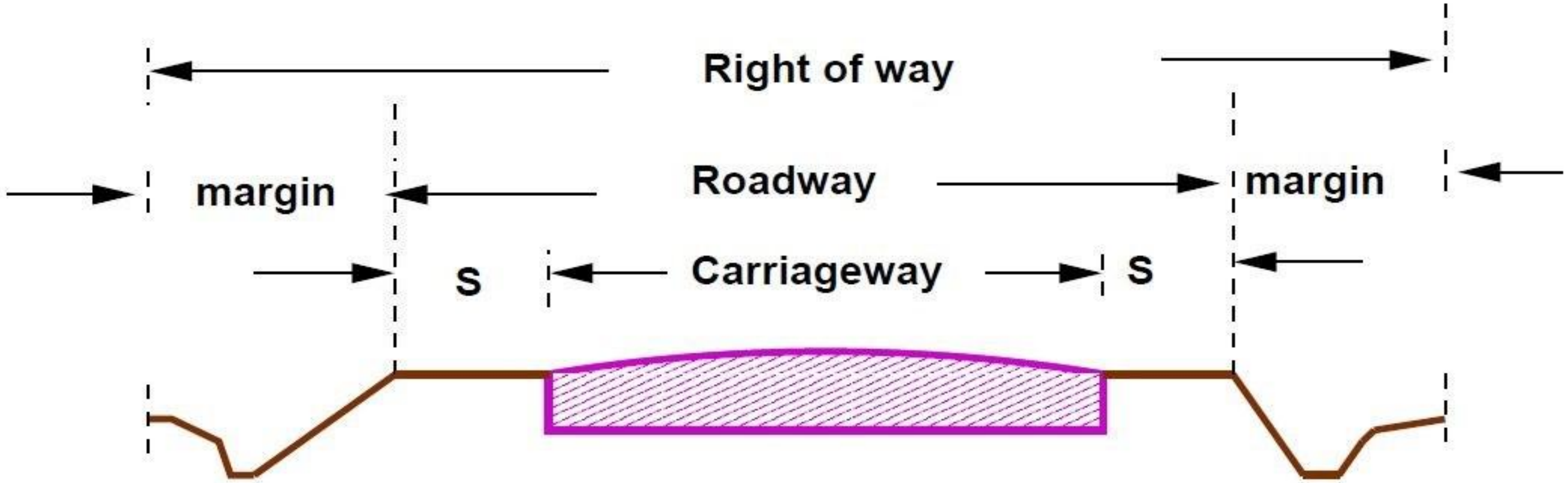
Width of roadway or formation:

- Width of roadway or formation is the sum of widths of pavements or carriageway including separators if any, and the shoulders.
- The minimum roadway width on single lane bridge is 4.25 m



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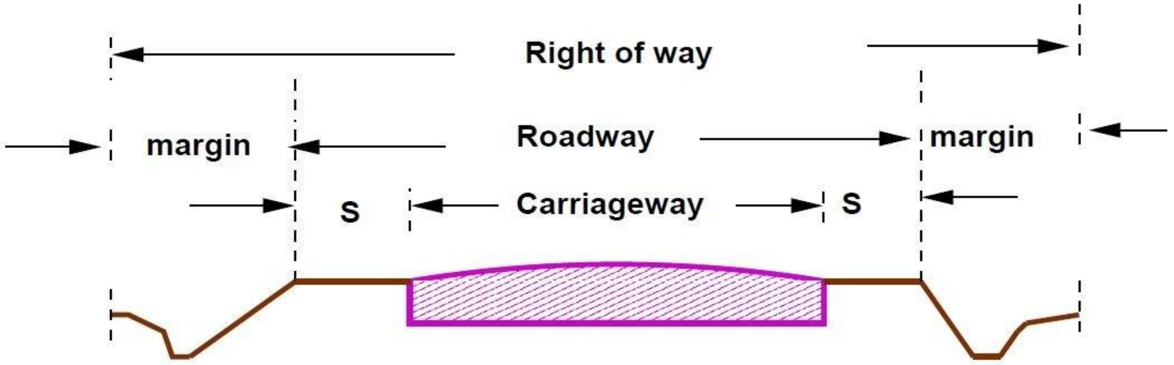
Width of roadway as per IRC.

S.No	Road classification	Road width, m	
		Plain and Rolling terrain.	Mountainous and Steep terrain
1.	National and State Highways		
	a. Single lane	12.0	6.25
	b. Two lanes	12.0	8.80
2.	Major District Roads		
	a. Single lane	9.0	4.75
	b. Two lanes	9.0	-
3.	Other District Roads		
	a. Single	7.5	4.75
	b. Two lanes	9.0	-
4.	Village Roads – Single lane	7.5	4.00

Right of way:

- Right of way is the area of land acquired for the roads, along its alignment
- Land width depends on i. the importance of road, and

  ii. Possible future development
- National and State highways on open plain terrain:
  - Minimum land width = 24.4 m
  - Normal land width = 45 m
  - Maximum land width = 60 m
  - Width between the building lines = 80 m
  - Width between control lines =150 m.



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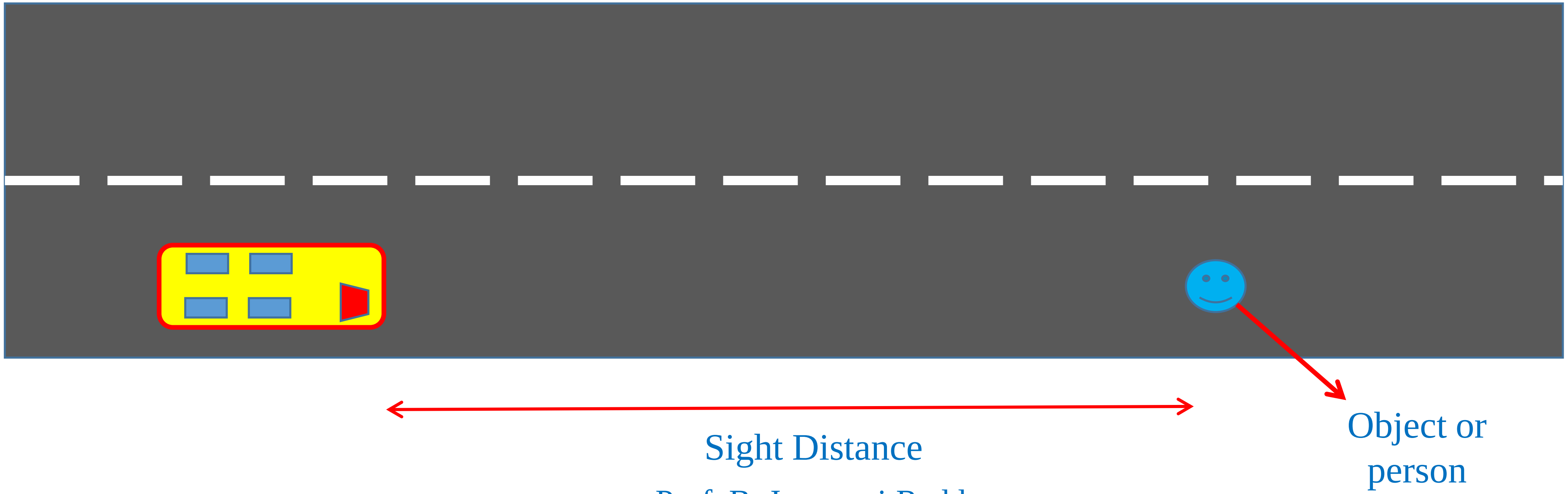
Sight distance:

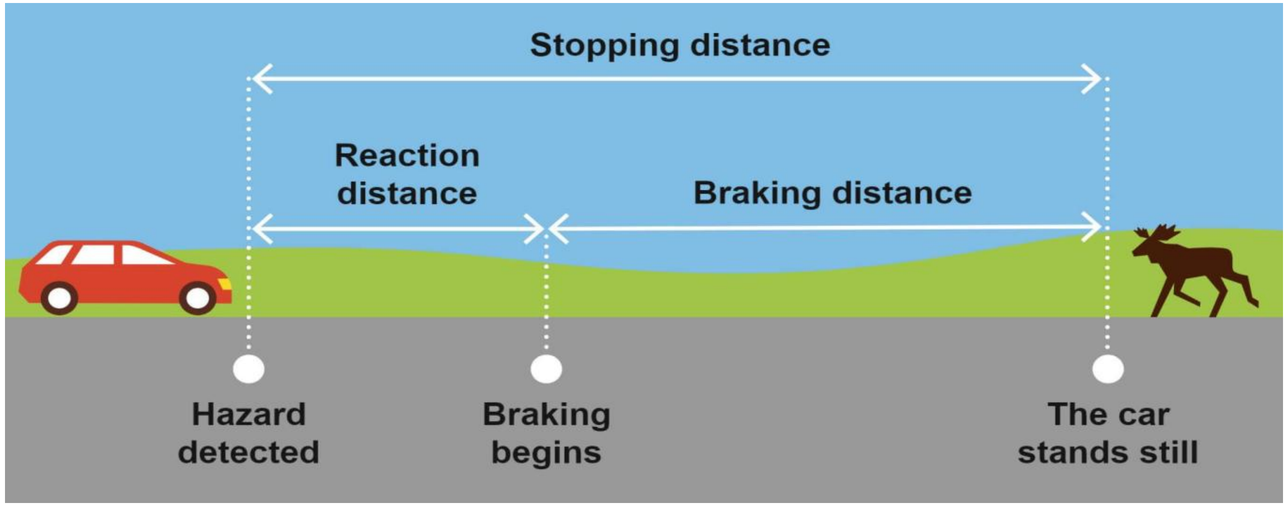
- Sight distance is the length of road a driver needs to be able to see clearly any object or vehicle in front of the road.
- Restricts to sight distance may be caused
  - i. at horizontal curves
  - ii. by objects obstructing vision at the inner side of the road
  - iii. at vertical summit curves or at intersections



- Sight distance required by drivers applies to both geometric design of highways and for traffic control.
- Sight distance situations considered in the design
  i. Stopping or absolute minimum sight distance.
  ii. Safe overtaking or passing minimum sight distance.
  iii. Safe sight distance for entering into uncontrolled intersections.

Stopping sight distance (SSD)

- It is also called absolute minimum sight distance or non passing sight distance.
- The minimum sight distance available on a highway at any spot to stop a vehicle traveling at design speed, safely without collision with any other obstruction.
- The sight distance available on a road to a driver at any instance depends on
  - i. features of the road ahead.
  - ii. height of the driver eye above the road surface
  - iii. height of the object above the road surface.



- IRC has suggested the height of eye of driver as 1.2 m and the object as 0.15 m above the road surface.
- Stopping distance available at a summit curve is the distance measured along the road surface at which an object of height 0.15 m can be seen by a driver where eye is at a height of 1.2 m above the road surface.
- The distance within which a motor vehicle can be stopped depends on
    i. Total reaction time of the driver.
    ii. Speed of vehicle
    iii. Efficiency of brakes.
    iv. Frictional resistance between the road and the tyres.
    v. Gradient of the road.

Intermediate sight distance is defined as twice the stopping sight distance

- When overtaking sight distance can not be provided intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

Total reaction time:

- Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the breaks are efficiently applied.
- Total reaction time = Perception time + Brake reaction time.
- The perception time is the time required for a driver to realize that breaks must be applied
- The time required from the instant the object comes on the line of sight of the driver to the instant he realizes that the vehicle needs to be stopped varies from driver to driver.
- Perception time depends on i. speed of the vehicle
  ii. distance of object
  iii. other environmental conditions
- The brake reaction time depends on i. skill of the driver
  ii. type of the problems, and
  iii. other environmental factors

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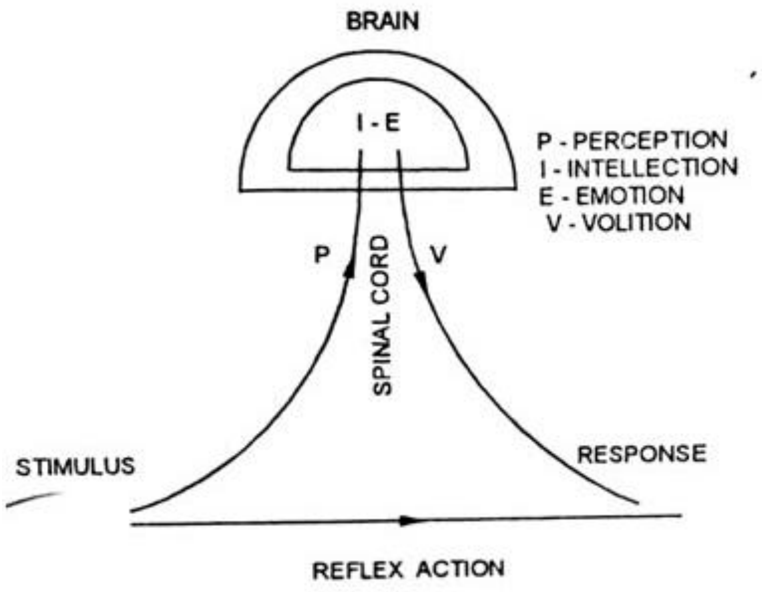
PIEV theory: The total reaction time of the driver is split into

a. Perception b. Intellection c. Emotion d. Volition

- **Perception time:** Perception time is the time required for the sensations received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord.

  - time required to perceive an object or situation

- **Intellection time:** Intellection time is the time required for understanding the situation.



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- **Emotion time:** Emotion time is the time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings such as supersition etc. with reference to the situation.
- **Volition time:** Volition time is the time taken for final action.

The PIEV time of a driver depends on

a. Physical and Psychological characteristics of the driver

b. Type of the problem involved

c. Environmental condition and temporary factors (i.e. motive of the trip, travel speed, fatigue, consumption of alcohol etc.)

- Total reaction time of an average driver : 0.5 sec for simple situation, and
  : 3 to 4 sec for complex situations.

Speed of vehicle:

- Higher the speed of the vehicle, higher will be the stopping distance.

Efficiency of brakes:

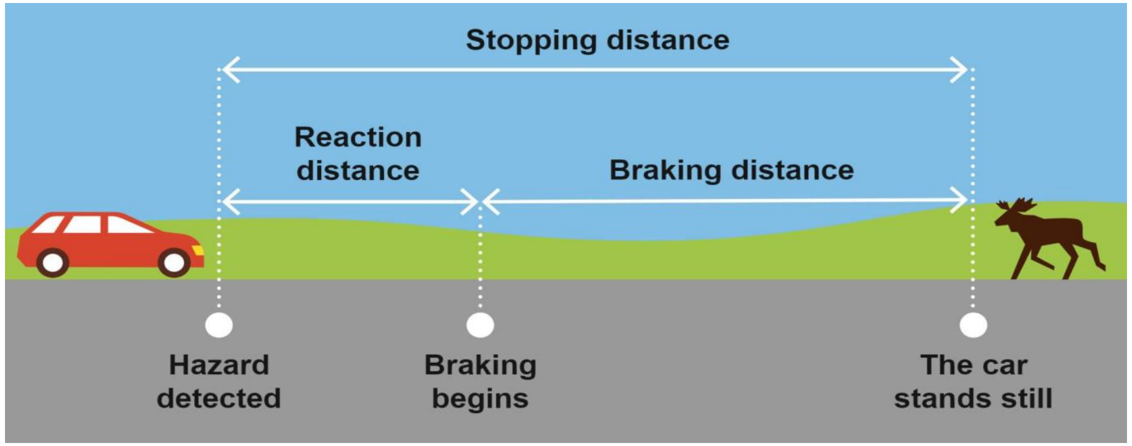
- The braking efficiency is said to be 100 percent if the wheels are fully locked preventing them from rotating on application of the brakes.
- To avoid skid, the braking forces should not exceed the frictional force between the wheels and tyres.
- The braking distance increases with decrease in skid resistance.
- Friction coefficient as per IRC: 0 .35 to 0.4 (8 to 30 kmph)

Analysis of stopping distance:

- Stopping Distance = Lag Distance + Braking Distance
- Lag distance is the distance traveled by the vehicle during the total reaction time.
- Braking distance is the distance traveled by the vehicle after the application of brakes to a dead stop position.
- Lag distance = $v.t$ meters

v : design speed in m/sec

t : total reaction time of the driver in sec.



Lag distance = $0.278V.t$ meters

V : Design speed, kmph

- IRC recommended value of the reaction time = 2.5 sec
- Braking distance may be obtained by equating the workdone in stopping the vehicle and the kinetic energy

Braking distance = $\dfrac{v^2}{2gf} = \dfrac{V^2}{254f}$

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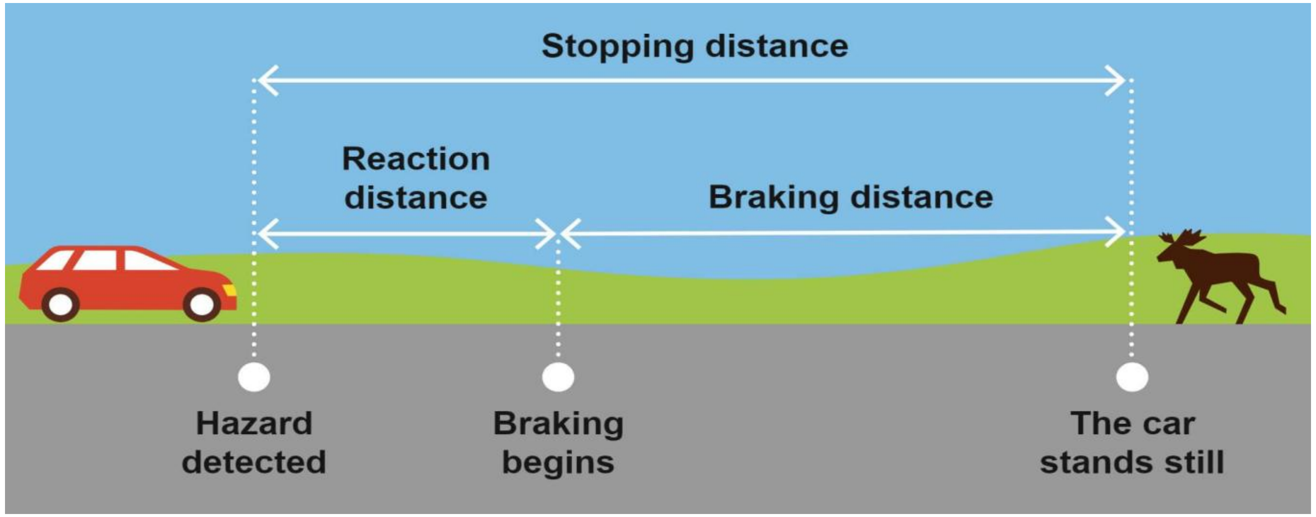
Stopping Distance

$$SD = v.t + \frac{v^2}{2g\ f}, \quad v \text{ is in m/s}$$

$$SD = 0.278\ V.t + \frac{V^2}{254\ f}, \quad V \text{ is in Km/h}$$



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Stopping distance at slopes

For an ascending gradient + n%, the breaking distance decreased because of the component of gravity adds to the breaking action

Component of gravity acting parallel to the surface = $W \sin\alpha = W \tan\alpha = \frac{Wn}{100}$

Equating work done and kinetic energy, $\left(fW + \frac{Wn}{100}\right) l = \frac{1}{2}\frac{W^2 v^2}{g}$

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

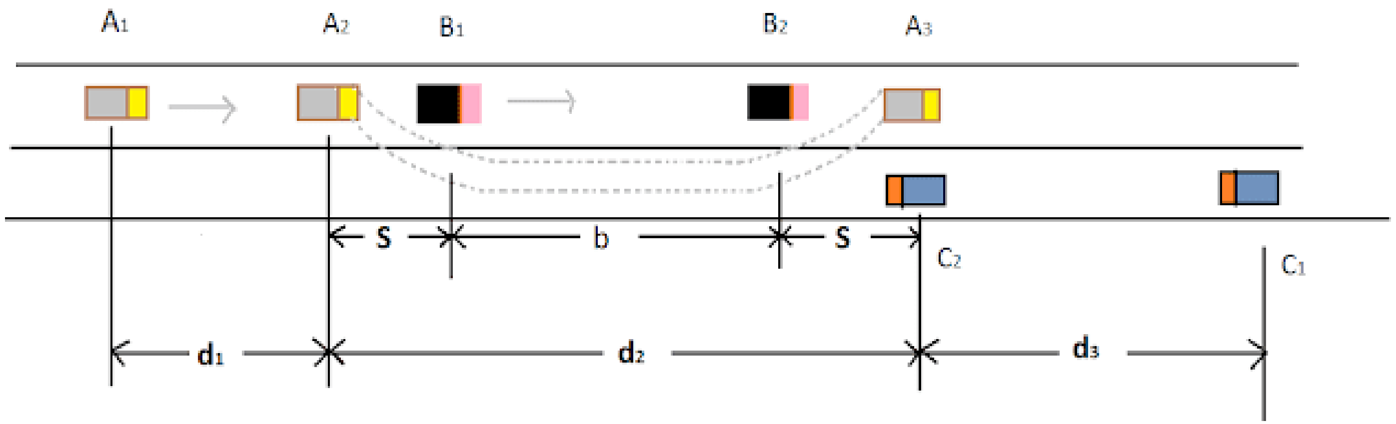
For descending gradient of – n%, the braking distance increases as the component of gravity opposes the braking force.

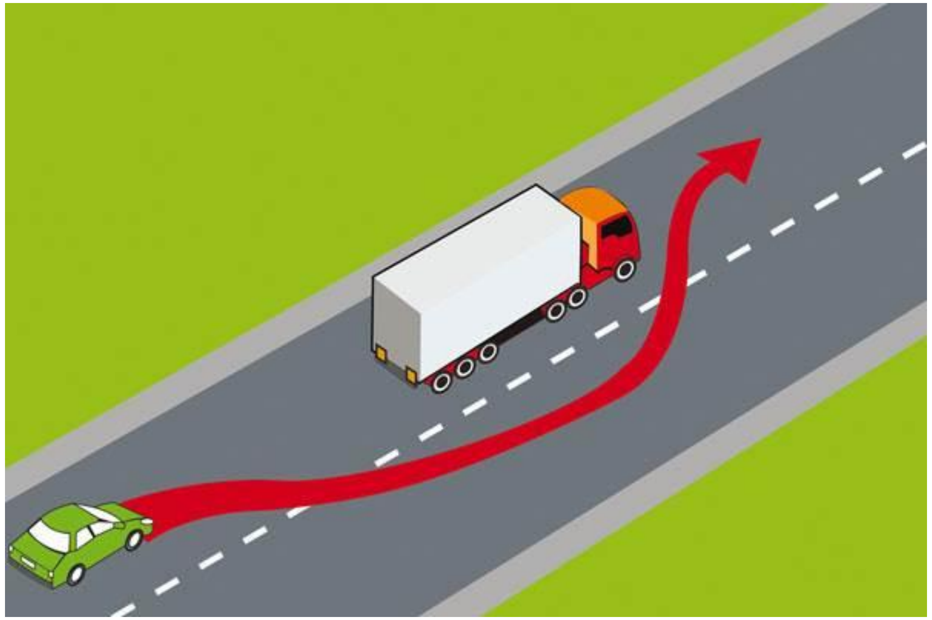
$$SD = v.t + \frac{v^2}{2g\left(f \pm 0.01n\right)} \qquad SD = 0.278\,Vt + \frac{V^2}{254(f \pm 0.01n)}$$

- The minimum stopping distance = stopping distance in one way traffic lanes and also in two way traffic roads when there are two or more traffic lanes.
- The minimum stopping sight distance = 2 × stopping distance on roads with restricted width or on single lane roads when two way movement of traffic is permitted.

Overtaking Sight Distance (OSD)

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





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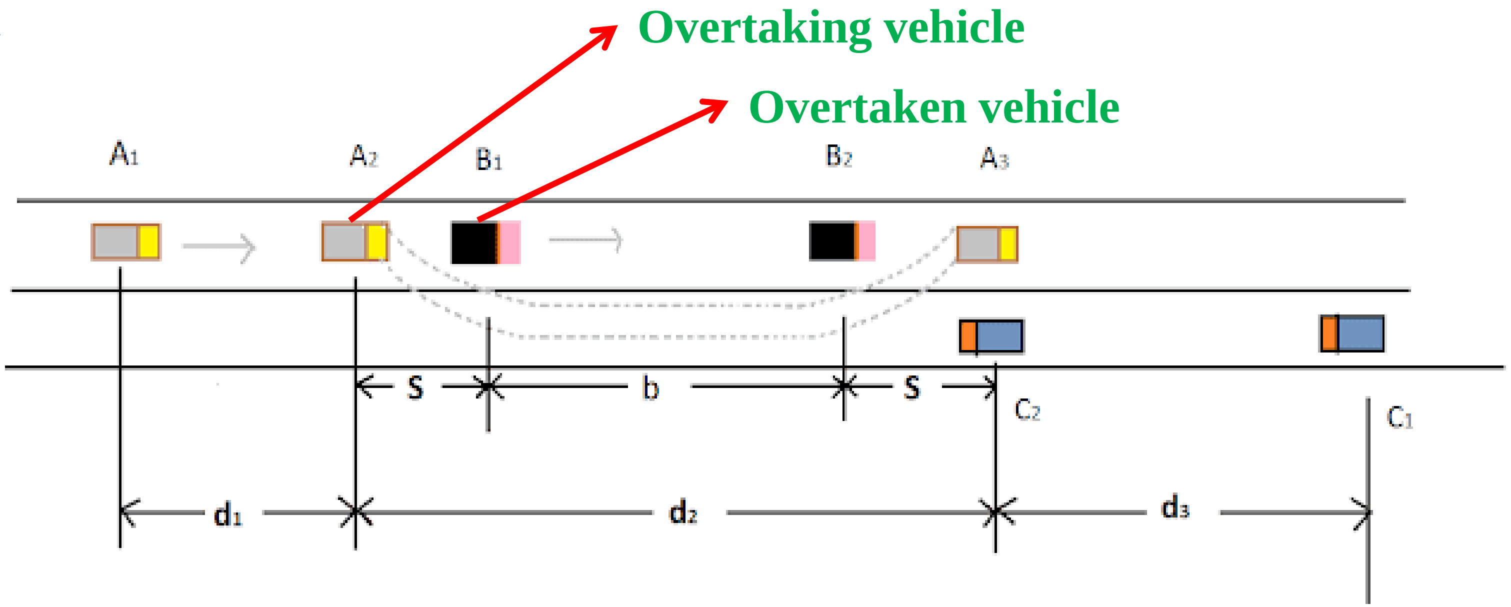
- Factors depends on the minimum overtaking sight distance are
  a. speed of i. overtaking vehicle,
  ii. overtaken vehicle,
  iii. the vehicle coming from opposite direction
  b. distance between overtaking and overtaken vehicles
  c. skill and reaction time of the driver
  d. rate of acceleration of overtaking vehicle
  e. gradient of the road



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- In a two lane road the opportunity to overtake depends on the frequency of vehicles from the opposite direction and the overtaking sight distance available at any instant.
- Reaction time of the driver is 2 sec.

$$OSD = d_1 + d_2 + d_3$$

$$OSD = v_b.t + (v_b.T + 2s) + v.T$$

$$T = \sqrt{\frac{4s}{a}} \text{ sec} \qquad s = 0.7\, v_b + 6$$

a : acceleration, m/sec^2

$$OSD = 0.278 V_b.t + 0.278 V_b.T + 0.278 V.T$$

V_b: Speed of overtaken vehicle, kmph

t : Reaction time of driver = 2 sec

V : Speed of overtaking vehicle or design speed, kmph

$$T = \sqrt{\frac{4\times 3.6S}{A}} = \sqrt{\frac{14.4S}{A}}$$

T: Time taken by vehicle A for the overtaking operation from position $A_2 to A_3$

T depends on i. speed of overtaken vehicle B, and

ii. Acceleration of overtaking vehicle A.

S: spacing of vehicle = 0.2 V_b + 6

A : acceleration, kmph/sec.

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The speed of the overtaken vehicle may be assumed as

$V_b = (V - 16)$ kmph or $v_b = (v - 4.5)$ m/sec

where V: design speed in kmph.

v : design speed in m/sec.

- Acceleration of overtaking vehicle depends on the make of the vehicle, its condition, load and the speed.

OSD = $d_1 + d_2$ (on divided highways and on roads with one way traffic regulation)

= $d_1 + d_2 + d_3$ (on two way roads)

- On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the usual OSD.
- Sight distance on any highway should be more than the SSD.

Effect of grade in OSD

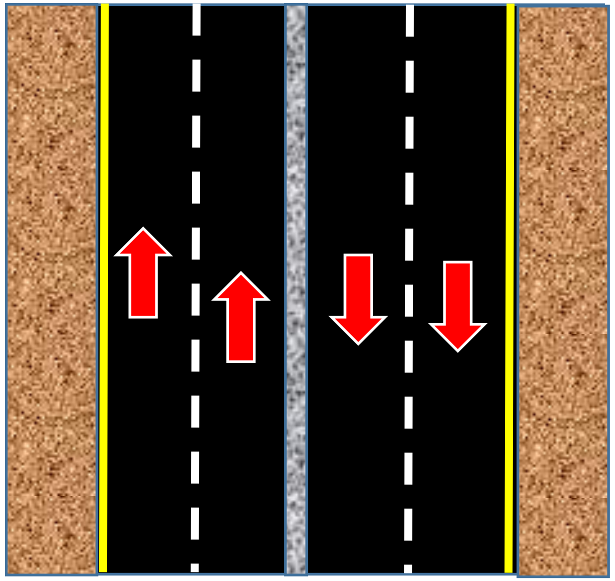
- At grades both descending as well as ascending, the overtaking sight distance should be greater than the minimum overtaking distance required at level.
- In down grades though it is easier for the overtaking vehicle to accelerate and pass the overtaken vehicle may also accelerate and cover a greater distance devising the overtaking time.
- In up grades the acceleration of the overtaking vehicle will be less and hence passing will be difficult.

Overtaking zones:

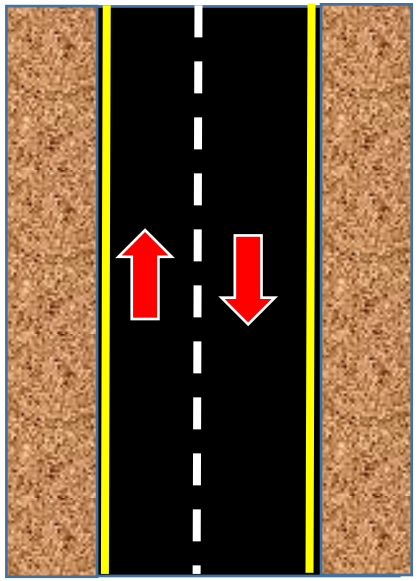
- Overtaking zones are meant for overtaking
- Minimum length of overtaking zone = 3.OSD

  $= 3.(d_1 + d_2\ )$ for one way roads

  $= 3.\ (\ d_1 + d_2 + d_3)$ for two way roads
- Desirable length of overtaking zone = 5.OSD



One way roads



Two way roads

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Design of horizontal alignment:

Factors to be considered in the horizontal alignment are

i. design speed .

ii. radius of circular curves.

iii. type and length of transition curves.

iv. super elevation and widening of pavements on curves.

Design speed:

- The overall design of geometrics of any highway is a function of the design speed.
- Design speed of roads depend upon i. class of the road, and
  ii. terrain.

Terrain classification	Cross slope of the country %
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	> 60

Design speed on Rural Highways

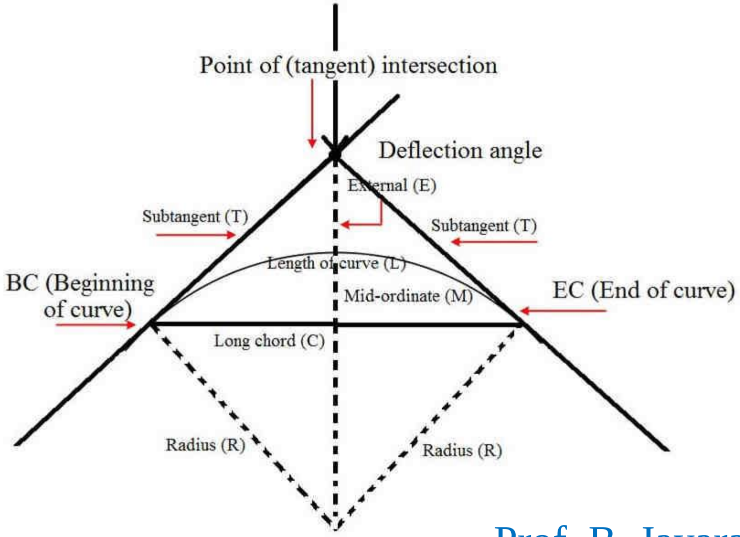
Road classification	Design speed, kmph							
	Plain		Rolling		Mountainous		Steep	
	Ruling	min	Ruling	min	Ruling	min	Ruling	min
NH and SH	100	80	80	65	50	40	40	30
MDR	80	65	65	50	40	30	30	20
ODR	65	50	50	40	30	25	25	20
VR	50	40	40	35	25	20	25	20

The recommended design speeds for different classes of urban roads are

a. Arterial roads 80 kmph
b. Sub-arterial roads 60 kmph
c. Collector streets 50 kmph
d. Local streets 30 kmph

Horizontal curves:

- A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road.
- When a vehicle traverses on a horizontal curve, the centrifugal force acts horizontal outwards through the center of gravity of the vehicle.
- Centrifugal force is counteracted by the transverse frictional resistance developed between the tyres and the pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle.



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

P: Centrifugal force, kg

W: Weight of the vehicle, kg

R: Radius of the circular curve, m

V: Speed of the vehicle, m/sec

g: acceleration due to gravity=9.8 m/sec ^{2}

- Centrifugal ratio or the impact factor is the ratio of the centrifugal force to the weight of the vehicle.

Centrifugal ratio= $\frac{v^2}{gR}$

- The effects of centrifugal force acting on a vehicle on horizontal curve

    i. Tendency to overturn the vehicle outwards about the outer wheels

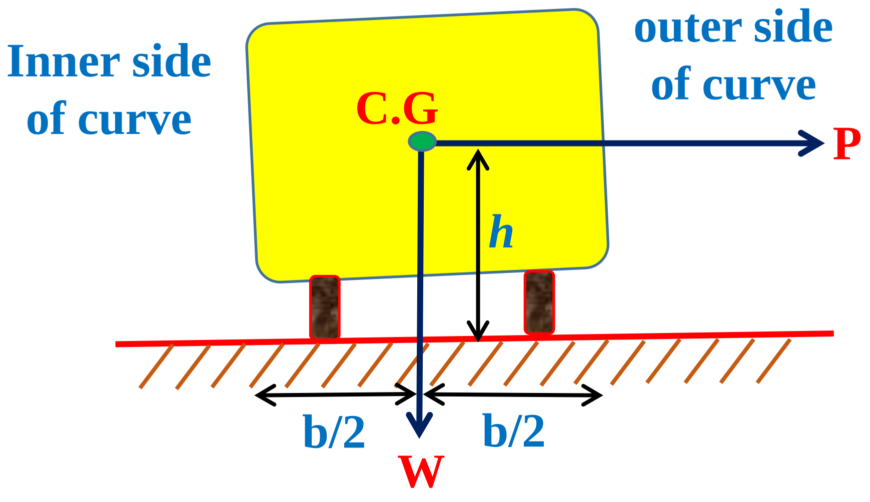
    ii. Tendency to skid the vehicle laterally, outwards.

- The magnitude of centrifugal force depends on

    i. radius of the horizontal curve, and

    ii. speed of the vehicle

i. Overturning effect:



- Overturning due to centrifugal force.
- Overturning moment due to centrifugal force = $P.h$
- Resorting moment due to weight of the vehicle = $W.\frac{b}{2}$

$$P.h = W.\frac{b}{2} \quad ; \qquad \frac{P}{W} = \frac{b}{2h}$$

- Overturning takes place when the centrifugal ratio $\geq \frac{b}{2h}$

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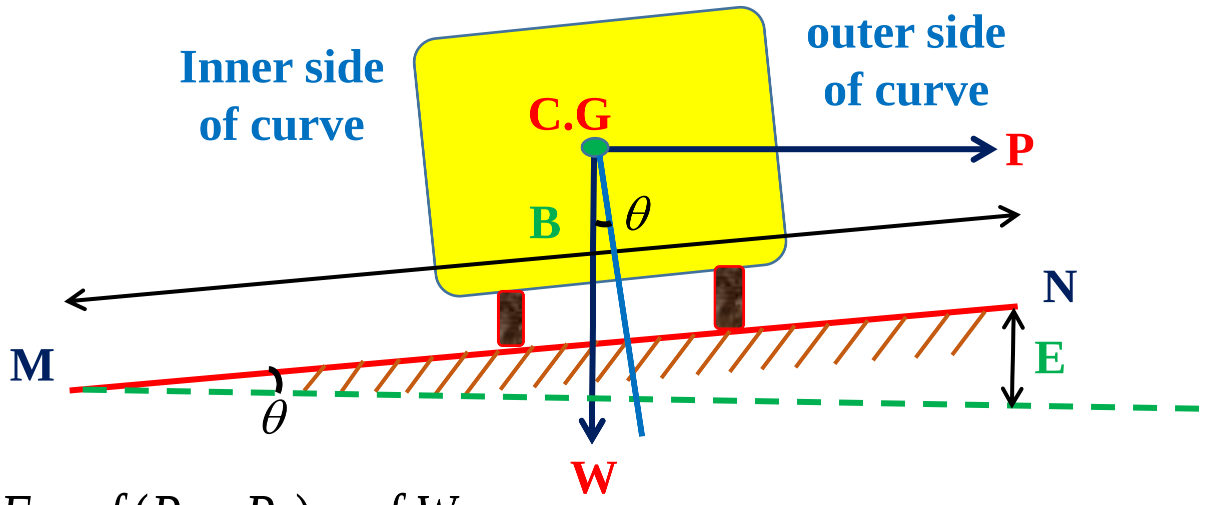
ii. Transverse skidding effect: When the centrifugal force P developed exceeds the maximum possible transverse skid resistance due to friction, the vehicle will start skidding in the transverse direction.



$$P = F_A + F_B = f(R_A + R_B) = f.W$$

f : Coefficient of friction between the tyre and the pavement surface in the transverse direction.

Centrifugal force $= \dfrac{P}{W} = f$

Centrifugal ratio $\geq f$, lateral skidding occurs.

To avoid overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than $\frac{b}{2h}$ and also f.

The centrifugal force may cause overturning or lateral skidding of the vehicle if either the speed of the vehicle is high or the radius of the curve is less.

$f < \frac{b}{2h}$ Skidding occurs

$f > \frac{b}{2h}$ Overturning occurs

The pressure on the outer wheels will be higher due to the centrifugal force acting outwards and hence the reaction R_B at the outer wheel would be more. $(R_B > R_A)$

Limiting equilibrium condition for overturning occurs when the pressure at the inner wheel becomes equal to zero.