Highway Geometric Design :-

Geometric ~~deg~~ design of highways deals with following elements:

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

⇒ Under cross-section elements :-

↳ width of pavement
↳ formation and land
↳ Surface characteristics
↳ Cross slope of pavement.

⇒ The sight distance or clear distance visible ahead of a driver at horizontal and vertical curves and at intersections govern the safe movements of vehicles.

⇒ The change in the road directions are made possible by introducing horizontal curves. Super-elevation is provided by raising the outer edge of pavement to counteract the centrifugal force developed on a vehicle traversing a horizontal curve; extra pavement width is also provided on horizontal curves.

⇒ Transition curves introduced betⁿ the straight and circular curve.

⇒ The gradients and vertical curves are introduced in vertical alignment.

→ Design of road intersections :-
↳ safe and efficient traffic movement.

(1) Design Controls and Criteria :-

The geometric design of highways depends on the following factors and these factors control the geometric elements.

(i) Design Speed.
(ii) Topography.
(iii) Traffic factors
(iv) Design hourly volume and Capacity.
(v) Enviromental and other factors.

(i) Design Speed :-

↳ Different speed standards depending upon:- importance or class of road such as NH, SH MDR, ODR, VR

↳ The design speed standards are modified depending upon the terrian or topography.

↳ Following geometric design elements are dependent on the design speed for their design:

- Requirement of the pavement surface characteristics
- the cross section element of the road such as width and clearance requirements.
- The sight distance requirements
- the horizontal alignment elements such as radius of curve super-elevation.
- transition curve length and the vertical alignment such as gradient, summit and valley curve length

(ii) Topography or Terrians :-

↳ Terrians are classified based on the general slope of the country across the alignment, as

- plain
- Rolling
- Mountainous
- Steep

↳ The design standards specified for different classes of roads are different depending on the terrain classification. For example, the design or ruling speed of NH and SH on plain terrain with general cross slope upto 10% is 100 kmph whereas the speed on rolling terrain with general cross slope of 10 to 25% is 80 kmph and that on mountainous terrain with cross slope 25 to 60% is 50 kmph.

↳ In hilly terrain, it is necessary to allow for steeper gradients and sharper horizontal curves due to the construction problems.

(iii) Traffic Factors :-

The factors associated with the traffic that affect geometric design of roads are

a) Vehicular characteristics –

The different vehicle classes such as passenger cars, bus, truck, motor cycles, etc. have different speed and acceleration characteristics, apart from having different dimensions and weight.

b) human characteristics –

physical, mental, and psychological characteristics of drivers and pedestrians.

Highway Crosssection Elements :-

1. Pavements Surface characteristics :-

The important surface characteristics of the pavement are the friction unevenness, light reflecting characteristics and drainage of surface water.

a) Friction :-

→ The friction between vehicle tyre and pavement surface is one of the factors determining the operating speed and distance requirements in stopping and accelerating the vehicles.

When a vehicle negotiates a horizontal curve, the lateral friction developed counteracts the ~~centrig~~ centrifugal force and thus governs the safe operating speed.

→ The maximum coefficient of friction comes into play only when the braking efficiency is high enough to partially arrest the rotation of the wheels on application of brakes, at low speed.

→ Skid :-

- Skid occurs when the slide without revolving or when the wheels partially revolve i.e., when the path travelled along the road surface is more than the circumferential movements of the wheels due to their rotation.
- When the brakes are applied, the wheels are locked partially or fully, and if the vehicles moves forward, the longitudinal skidding takes place which may vary from 0 to 100 percent.
- While a vehicle negotiates a horizontal curve, if the centrifugal force is greater than the counteracting forces (i.e. lateral friction and component of gravity due to super elevation) lateral skidding takes place. The lateral skid is dangerous as the vehicle goes out of control to an accident.
- The maximum lateral skid coefficient is generally equal to or slightly higher than the forward skid coefficient in braking tests.

→ Slip :-

- Slip occurs when a wheel revolves more than the corresponding longitudinal movement along the roads.
- Slipping ~~generally~~ usually occurs ~~to~~ in the driving wheel of a vehicle when the vehicle rapidly accelerates from stationary position or from slow speed on pavement surface which is either slippery and wet or when the road surface is loose with mud.

Factors affecting friction or skid resistance:-

The maximum friction offered by pavement surface or the skid resistance depends upon the following factors:-

(i) Type of pavement surface namely, cement concrete bituminous, WBM, earth surface etc.

(ii) Macro-texture of the pavement surface or its relative roughness.

(iii) Condition of pavements namely, wet or dry, smoothened or rough, oil spilled, mud or dry sand on pavement.

(iv) Type and condition of tyre i.e. new with good treads or smoothened and worn out tyre.

(v) Speed of vehicle.

(vi) Extent of brake application or brake efficiency.

(vii) Load and tyre pressure

(viii) Temperature of tyre and pavement,

(ix) Type of skid, if any.

→ The coefficient of friction reduces considerably when the pavement surface is smooth or wet. The coefficient of friction also decreases slightly with increase in temperature, tyre pressure and load.

→ Smooth and worn out tyres offer higher friction ~~factores~~ factors on dry pavement then new tyres with treads because of large areas of contact.

→ But on wet pavements new tyres with good treads give higher friction factors than worn out tyres. This is because the lubricating effect of water on the wet pavement is reduced as the water entrapped between the tyre and pavement escapes into the treads of the tyre.

→ The friction coefficient decreases with skid speed, which in turn depends on the speed of vehicle and brake efficiency.

→ IRC recommended the values of longitudinal friction coefficient for the calculation of stopping distance 0.35 to 0.40 (wet pavement). When the longitudinal friction coefficient of 0.40 is allowed for stopping the vehicle, the resultant retardation is 3.93 m/s^2 which is not too uncomfortable to the passengers.

→ In the case of horizontal curve design, the IRC has recommended the lateral coefficient of friction of 0.15.

(b) Pavement Unevenness:-

→ The pavement surface condition is commonly measured by using an equipment called Bump Integrator in terms of unevenness index, which is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road.

⇒ Unevenness index measured in cm/km.

→ From the test, it has been shown that the unevenness index keep low, and preferably less than 150 cm/km for good pavement surfaces of high speed highways. Value more than 350 cm/km is considered very uncomfortable even at speed of 50 kmph. A value of 250 cm/km is satisfactory upto a speed of about 100 kmph.

⇒ Pavement undulations are sometimes measured using a straight edge in terms of the extent of number of depression or ruts along and across the pavement.

→ An unevenness indicator has been designed and patented by Central Road Research Institute, New Delhi and this equipment is useful to indicate unevenness values from 3 to 20 mm.

→ The unevenness or undulations on pavement surface may be caused by various factors, such as

(i) Inadequate or improper compaction of the fill, subgrade and pavement layers

(ii) un-scientific construction practices including the use of boulder stones and bricks as soling course over loose subgrade soil.
(iii) use of inferior pavement materials
(iv) improper surface and subsurface drainage
(v) use of improper construction machinery
(vi) poor maintenance practices, and
(vii) localized failures due to combination of causes.

2. Cross slope or camber :-

Cross slope or chamber is the slope provided to the road surface in the transverse direction to drain off the rain water from the ~~road~~ road surface.

→ Drainage and quick disposal of water from the pavement surface by providing cross slope is considered important because of two reasons:

(i) To prevent the entry of surface water into the subgrade soil through pavement; the stability, surface condition and the life of the pavement get adversely affected if the water enters in the subgrade and the soil gets soaked.

(ii) 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.

(iii) 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; the skid resistance of the pavement gets decreased under wet condition, rendering it slippery and unsafe for vehicle operation at high speed.

→ The camber is provided on the straight roads by raising the center of the carriageway w.r.t the edges, forming a crown or highest point on the center line.

⇒ The rate of camber or cross slope is usually designed by 1 in n (1 vertical to n horizontal). Camber is also expressed as a percentage. If the camber is x%, the cross slope is x in 100.

→ The required camber of a pavement depends on:
(i) the type of pavement surface, and
(ii) the amount of rainfall.

→ A flat camber of 1.7 to 2.0% is sufficient on relatively impervious pavement surface like cement concrete or bituminous concrete.
In pervious surface like water bound macadam or earth road which may allow surface water to get into the subgrade soil, steeper cross slope is required.

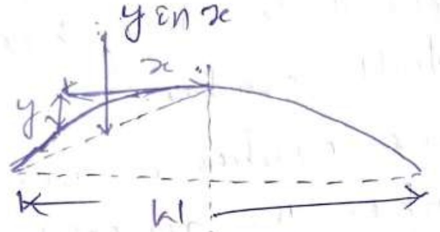
Areas of heavy rainfall → steeper camber are provided.

Shape of Cross slope :-

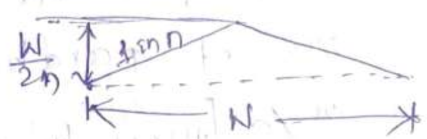
→ The camber is given a parabolic, elliptic or straight line shape on the c/s.

→ Parabolic or elliptic shape (flat at middle and steeper towards edges) is preferred by fast moving vehicles as they have to frequently cross the crown line during overtaking operation on a two lane highway.

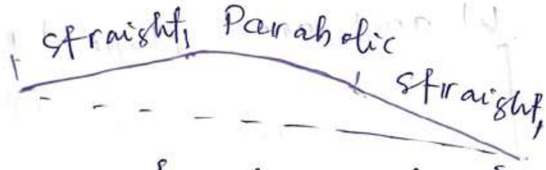
→ When very flat cross slope is provided as in cement concrete pavements, straight line shape of camber may be provided.



Parabolic shape $\left[y = \frac{2x^2}{nW}\right]$



Straight line camber.



combination of straight and parabolic

Type of road Surface	Range of camber in areas of rainfall range: Heavy to Light
1. Cement concrete and high type bituminous surface	1 in 50 (2.0%) to 1 in 60 (1.7%)
2. Thin bituminous surface	1 in 40 (2.5%) to 1 in 50 (2.0%)
3. Water bound macadam, and gravel pavement	1 in 33 (3.0%) to 1 in 40 (2.5%)
4. Earth	1 in 25 (4.0%) to 1 in 33 (3.0%)

→ The cross slope for shoulders should be 0.5% steeper than the cross slope of adjoining pavement; subject to a minimum of 3.0% (and a maximum value of 5.0% for earth shoulder)

Providing Camber in field:-

→ ~~Forming~~ For providing the desired amount and shape of camber, templates of camber boards are prepared with the specified camber.

→ Forming of a straight line camber is very simple.

→ In case of parabolic camber, the general equation $y = x^2/a$ may be adopted.

where $a = \frac{nW}{2}$ for a pavement of width W and cross slope 1 in n.

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

Width of Pavement or carriageway:-

→ The pavement width depends on the width of traffic lane and number of lanes. The carriageway intended for one lane of traffic movement may be called traffic lane.

→ The lane width is determined on the basis of the width of vehicle and the minimum side clearance which may be provided for safety.

→ Side clearance (↑) (upto a certain limit) → operating speed of vehicle (↑) → Capacity of traffic lane (↑)

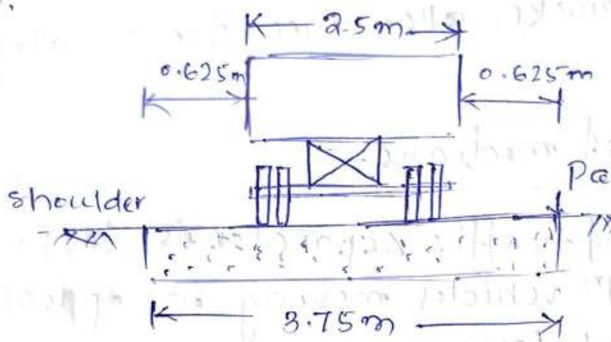
→ For a road having single lane for vehicles of maximum width 2.44m, a width of 3.75m carriage is considered.

→ For pavements having two or more lanes, width of 3.5 per lane is sufficient.

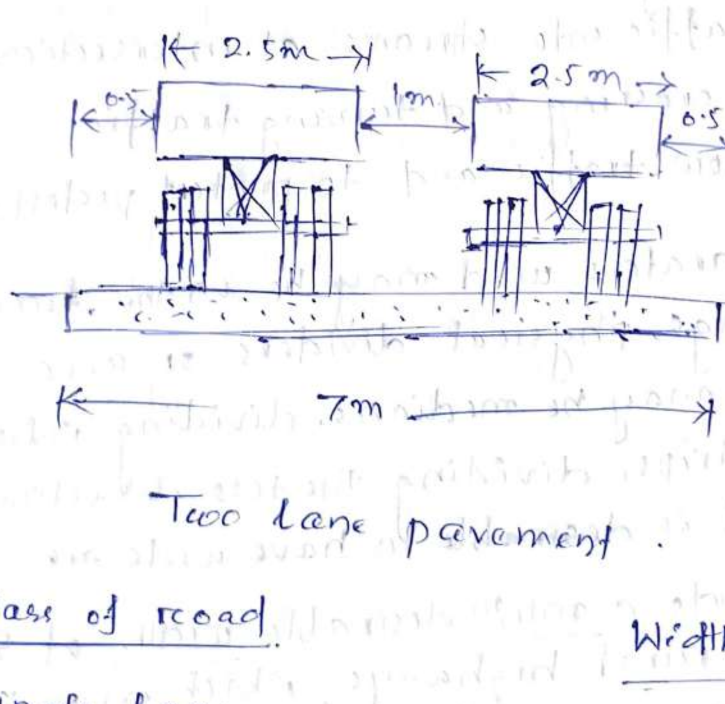
→ The maximum width of vehicles as per IRC is

→ If a single lane carriageway of width 3.75 m is provided, a side clearance 0.68 m would be obtained or 0.65 → .625

→ In the case of two-lane pavement of width 7 m, a minimum clearance betn two lanes of traffic would be 1.06 m for the widest vehicles on the road. 1 m.



Single lane pavement.



Two lane pavement.

class of road	Width of carriageway
1. Single lane	→ 3.75 m
2. Two lanes, without raised kerbs	→ 7.0 m.
3. Two lanes, with raised kerbs	→ 7.5 m.
4. Intermediate carriageway (except on important roads)	→ 5.5 m.
5. Multi-lane pavements	→ 3.5 m per lane.

Notes:-

i. The width of single lane or village roads may be decreased to 3.0m.

ii. On urban roads without kerbs the single lane width may be decreased to 3.5 m and in access roads to residential areas to 3.0m.

iii. The minimum width recommended for kerbed urban road is 5.5m to make allowance for a stalled vehicle.

Traffic Separators of medians:-

→ The main function of traffic separator is to prevent head-on collision betn vehicles moving in opposite directions on adjacent lanes.

→ The separators may also help to

i) Channelize traffic into streams at intersections.

ii) shadow the crossing and turning traffic

iii) segregate slow traffic and to protect pedestrains.

→ The traffic separators used may be in the form of pavement markings, physical dividers or area separa. Area separators may be medians, dividing islands or parkway strips, dividing the two directions of traffic flow. ~~It is desirable to have wide are~~

→ The IRC recommends a minm desirable width of 5.0 m for medians of rural highways, which may be reduced to 3.0m where land is restricted. On long bridges the width of the median may be reduced upto 1.2 to 1.5m. The medians should normally be of uniform width on a particular road but where change in width is unavoidable, a transition of 1 in 15 to 1 in 20 must be provided.

→ The minimum recommended width of medians at intersection of urban roads are 1.2m for pedestrian refuge, 4 to 7.5 m for protection of vehicles making right turn and 9 to 12 m for protection vehicles crossing at grade.
The absolute minimum width of median in urban area is 1.2m and desirable minimum is 5.0m

Kerbs :-

→ Kerb indicates the boundary betn pavement and shoulder, or sometimes islands or foot path or kerb parking space.
→ Kerbs may be mainly divided into three groups based on their functions :-

i) Low or mountable type kerb :-

- Low or mountable type kerbs which through encourage traffic to remain in the through traffic lanes, yet allow the driver to enter the shoulder area with little difficulty.
- The height of this type of kerbs is about 10 cm above the pavement edge with a slope or batter to help vehicle climb the kerb easily.
- This type of kerb is provided at medians and channelization schemes and is also useful for longitudinal drainage system.

(ii) Semi-barrier type kerb :-

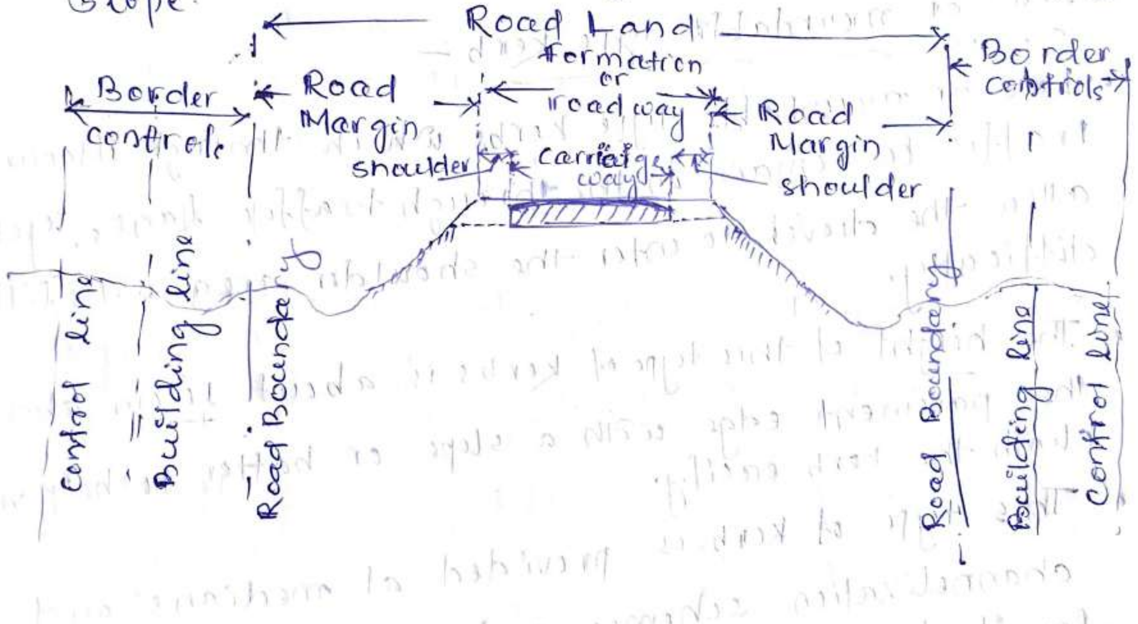
- It is provided on the periphery of a roadway where pedestrian traffic is high.
- This type of kerb has a height of about 15cm above the pavement edge with a batter of 1:1 on the top 7.5m.
- This kerb prevents encroachment of parking vehicles but at acute emergency it is possible to drive over this kerb with some difficulty.

(iii) Barrier type :-

- Barrier type kerb is provided in built-up areas adjacent to foot paths with cosiderable pedestrian traffic.
- The height of kerb stone is about 20cm above the pavement edge with a steep batter of 1.0 vertical 0.25 horizontal.

Road Margins :-

→ The various elements included in the road margins are shoulder, parking lane, frontage road, driveway, cycle-track, footh path, guard rail and embankment slope.



- 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. Shoulders also act as service lanes for vehicles that have broken down. It is desirable to have a minimum shoulder width of 4.6m so that a truck stationed at the side of the shoulder would have a clearance of 1.85m from the pavement edge. The minimum shoulder width recommended by the IRC is 2.5m.

- 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. Also the clearance available b/n the parked vehicles and the edge of adjacent lane is more in the case of parallel parking than in angle parking. The parking lane The width of parking lane is 3 m for parallel parking

- Lay-byes are provided near public conveniences with guide maps to enable the drivers to stop clear off the carriageway. Lay-byes should normally be of 3.0 m width and atleast 30m length with 15m end tapers on both sides.
- Bus-bays may be provided by recessing the kerb to avoid conflict with moving traffic. Bus bays should be located atleast 75 m away from the intersections.

- Frontage roads ~~are provided~~ (also known as an access road, service road or parallel road) are provided to give access to properties along an important highway with controlled access to express way or free way. The frontage roads may run parallel to the highway and are isolated by a separator, with approaches to the through facility only at selected points, preferably with grade separations.

- Drive ways connect the highway with commercial establishment like fuel-stations, service stations, etc. The
- Cycle tracks are provided in urban areas when 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 1.0m for each additional cycle lane.

- Footpath or side walks are provided ~~when~~ in urban areas when the vehicular as well as pedestrian traffic are heavy, to provide ~~proved~~ protection to pedestrians and to decrease accidents. The minimum width should be 1.5m and the width may be increased based on the pedestrian traffic volume.

- Guard rails are provided at the edge of the shoulder when the road is constructed on a fill so that the vehicles are prevented from running off the embankment especially when the height of the fill exceeds 3 m.

Width of Roadway or Formation :-

→ Width of formation or roadway is the sum of widths of pavements or carriageway including separators if any; and the shoulders.

⇒ Width of roadway of various classes of roads (IRC)

Road classification	Roadway width, m: Plain and rolling terrain	Roadway width, m: Mountainous and steep terrain
1. NH and SH		
a) Single lane →	12.0 m	→ 6.25 m
b) Two lane →	12.0 m	→ 8.80 m
2. MDR		
a) Single lane →	9.0 m	→ 4.75 m
b) Two lane →	9.0 m	→ —
3. ODR		
a) Single →	7.5 m	→ 4.75
b) Two lanes →	9.0 m	→ —
4. Village roads - single lane →	7.5 m	→ 4.00

Note :- The minimum roadway width on single lane bridge is 4.25 m.

Right of Way :-

→ Right of way is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width and it depends on the importance of road and possible future development.

→ The land width is governed by the following factors:

i. Width of formation depending upon the category of highway and width of roadway and road margins.

ii. Height of embankment or depth of cutting which is governed by the topography and the vertical alignment.

iii. Side slopes of embankment or cutting which depend on the height of the slope, soil type and several other considerations including aesthetics.

iv. Drainage systems and their size, which depends on the rainfall, topography, and run off.

v. Sight distance considerations on horizontal curves, as there is restriction to the visibility on the inner side of the curve due to obstruction such as building structures etc. At sharp curve it is desirable to acquire a wider strip of land in order to avoid obstructions to visibility.

vi. Reserve land for future widening is to be planned in advance based on anticipated future development and increase in the traffic.

→ IRC Recommended land width for different classes of rural roads (metre)

Road classification	Plain and rolling terrain				Mountainous and Steep terrain			
	Open areas		Built up areas		Open areas		Built up areas	
	Normal	Range	Normal	Range	Normal	Range	Normal	Range
1. NH & SH	45	30-60	30	30-60	24	-	20	-
2. MDR	25	25-30	20	15-25	18	-	15	-
3. ODR	15	15-25	15	15-20	15	-	12	-
4. Village roads	12	12-18	10	10-15	9	-	9	-

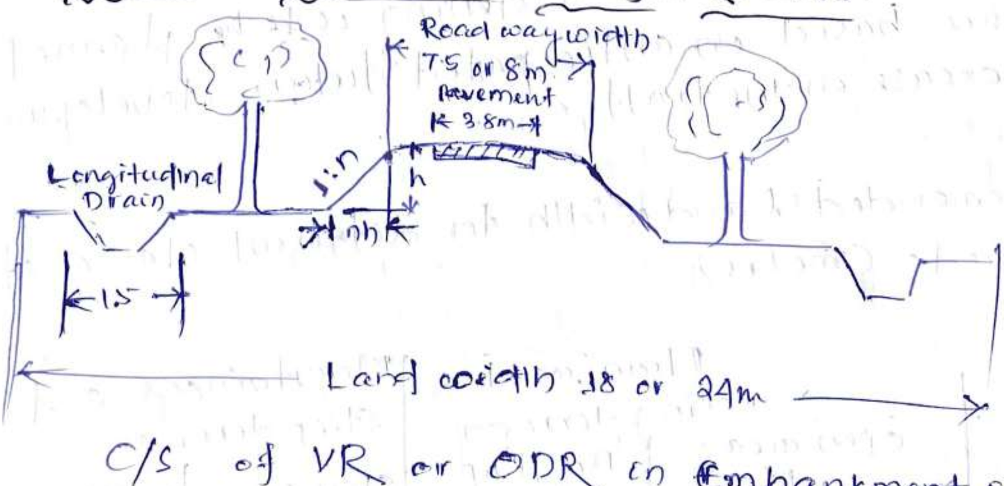
→ IRC Recommended standards for building lines and control lines

Road classification	Plain and Rolling terrain			Mountainous and steep terrain	
	Open area		Built up area	Distance b/w building line and road boundary (set back), m	
	Overall width betn building lines, m	Overall width betn control lines, m	Distance b/w building line and road boundary (set-back), m	Open areas	Built up area
NH & SH	80	150	3 to 6	3 to 5	3 to 5
MDR	50	100	3 to 5	3 to 5	3 to 5
O.D.R	25 /30*	35	3 to 5	3 to 5	3 to 5
V.R	25	30	3 to 5	3 to 5	3 to 5

Note:* If the land width is equal to the width b/w building lines, ~~indicated on~~ the building lines should be set back 2.5 m from the road land boundary.

→ The recommended land width's for different classes of urban roads are, 50 to 60m for arterial roads (high types of urban roads meant for through traffic, with controlled access), 30 to 40 m for sub-arterial roads 20 to 30 m for collector streets and 10 to 20 m for local streets.

Typical Cross-sections of Roads:-

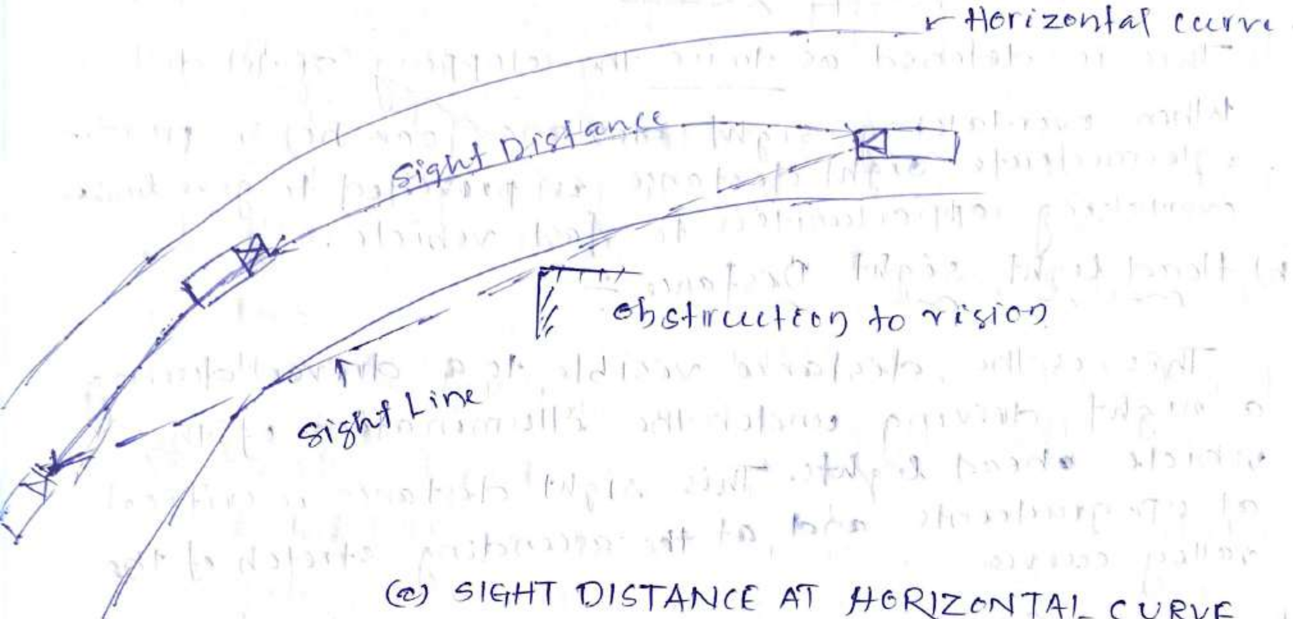


C/S of VR or ODR in Embankment in Rural Area

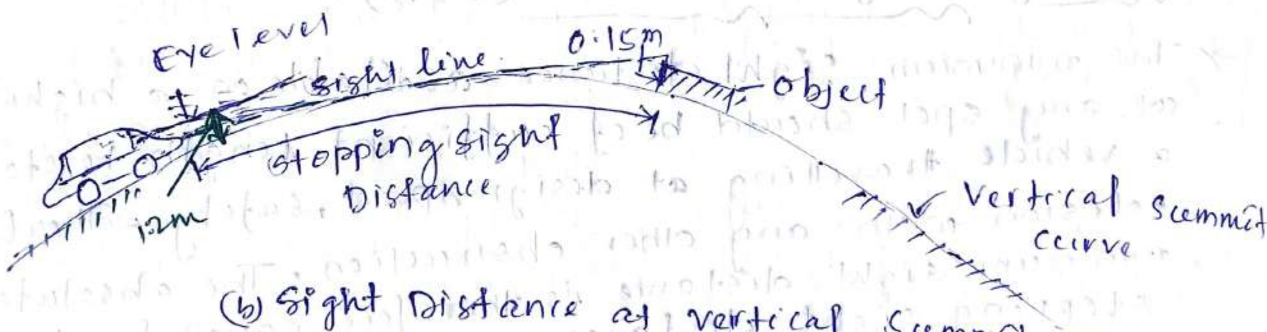
SIGHT DISTANCE :-

→ Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway has visibility of stationary or moving objects. In other words, sight distance is the length of road visible ahead to the driver at any instance.

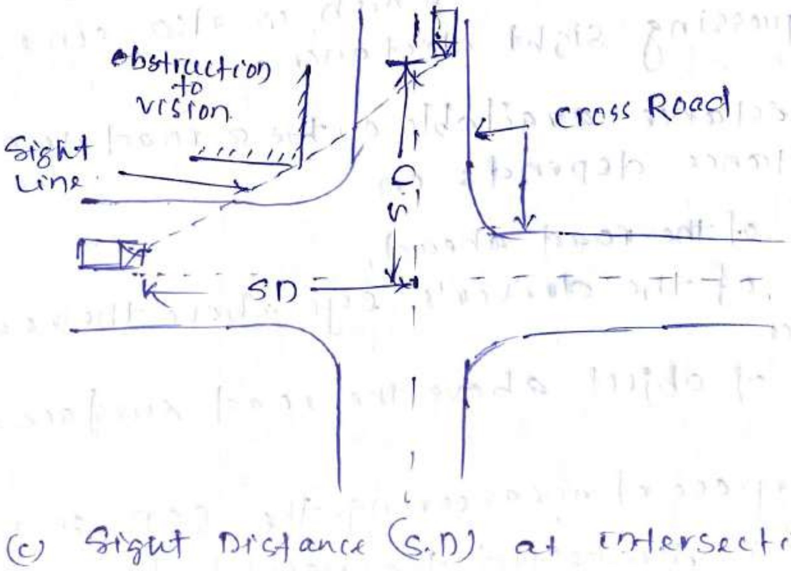
→ Sight distance required by drivers ~~may~~ be ~~caused at horizontal curves~~, by ~~obj~~ applies to both geometric design of highways and for traffic control.



(a) SIGHT DISTANCE AT HORIZONTAL CURVE



(b) Sight Distance at vertical summit curve



(c) Sight Distance (S.D) at intersection

→ Three sight distance situations are considered in the design:

(i) Stopping or absolute ~~sight~~ minm sight distance

(ii) Safe overtaking or passing sight distance, and

(iii) Safe sight distance for entering into uncontrolled intersections.

→ Apart from the above 3 situations, the following sight distances are considered by the IRC on highway design:

a) Intermediate Sight Distance :-

This 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 vehicle.

b) Head Light Sight Distance :-

This is the distance visible to a driver during a night driving under the illumination of the vehicle ahead lights. This sight distance is critical at up-gradients and at the ascending stretch of the valley curves.

Stopping Sight Distance (SSD) :-

→ The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle travelling at design speed, safely without collision with any other obstruction. The absolute minimum sight distance is therefore equal to the stopping sight distance, which is also some times called non-passing sight distance.

→ 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's eye above the road surface

iii) height of object above the road surface.

→ For the purpose of measuring the SSD or visibility ahead, 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.

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

i) Total reaction time of driver
ii) Speed of driver
iii) Efficiency of brakes
iv) Frictional resistance betn the road and the tyres
v) Gradient of the road, if any.

i) 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 brakes are effectively applied.
- The stopping distance increases with increase in reaction time of the driver.
- The total reaction time may be split up into two parts.
  a) perception time
  b) brake reaction time

- The perception time 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 brake reaction time depends on several factors including the skill of the driver, the type of the problems and various other environmental factors. Often the total brake reaction time of driver is taken together.

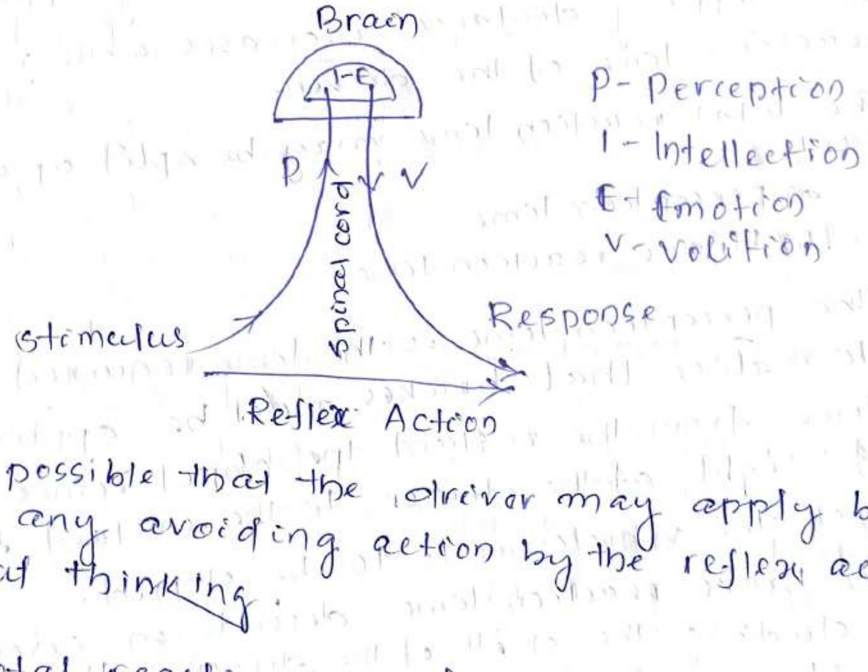
- PIEV Theory:-
  According to this theory the total reaction time of the driver is split into four parts, viz., time taken by the driver for:
  a) Perception
  b) Intellection
  c) Emotion, and
  d) Volition

a) Perception time is the time required for the sensation received by the eyes or ears to be transmitted to the brain through the nervous system and spinal cord. In other words, it is the time required to perceive an object or situation.

b) Intellection time is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

c) Emotion time is the time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings such as superstition etc. with reference to the situation.

d) Volition time is the time taken for the final action.



Reflex Action

It is possible that the driver may apply brakes or take any avoiding action by the reflex action, even without thinking.

- The total reaction time of an average driver may vary from 0.5 second for simple situations to as much as 3 to 4 seconds or even more in complex problems.

(ii) Speed of Vehicle :-

→ The stopping distance depends very much on the speed of the vehicle.

→ Higher the speed, higher will be the stopping distance.

(iii) Efficiency of Brakes :-

→ To avoid skidding, the braking forces should not exceed the frictional force betn the wheels and tyres.

→ Braking efficiency 100% → result 100% skidding which is dangerous, as it is not possible to control a skidding vehicle.

(iv) Frictional resistance b/w road and tyres :-

→ The braking distance increases with decrease in skid resistance.

→ IRC has specified a design friction coefficient of 0.35 to 0.4 depending upon the speed to be used for finding the braking distance in the calculation of SSD.

Analysis of Stopping Distance :-

The stopping distance of a vehicle is the sum of:

i) the distance travelled by the vehicle during the total reaction time known as lag distance and

ii) the distance travelled by the vehicle after the application of the brakes, to a dead stop position which is known as braking distance.

Stopping Distance = Lag distance + braking Distance

(i) ~~Lag Distance = v.t~~

~~$= V \times \frac{1000 \times 3600}{3600} t$~~

v = design speed in ~~km/h~~
t = total reaction time in ~~seconds~~.

(i) Lag Distance $= V \times \frac{1000}{3600} \times t$

V = design speed in kmph
t = total reaction time in sec.

⇒ **Lag Distance = 0.278 Vt meters.**

→ The IRC recommended the total reaction time $t = 2.5$ secs for the calculation of stopping distance

(ii) Braking Distance :-

→ The value of coefficient of friction 'f' decreases with increase in speed.

→ IRC recommends the following f-values for design

Speed kmph	20 to 30	40	50	60	65	80	100
Longitudinal coefficient of friction 'f'	0.4	0.38	0.37	0.36	0.36	0.35	0.35

For level road,

the braking distance may be obtained by equating the work done in stopping the vehicle and kinetic energy.

Work done against friction force in stopping the vehicle $= F \times l$

$= f \times W \times l$

F = max^m frictional force developed

l = braking distance

W = total weight of vehicle

Kinetic energy at design speed v m/s

$= \frac{1}{2} mv^2 = \frac{1}{2} \frac{W}{g} \cdot v^2$

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

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

$\Rightarrow \boxed{l = \frac{v^2}{2gf}}$ v in m/sec

l = braking distance, m

v = speed of vehicle, m/sec

f = design coefficient of friction

= 0.4 to 0.35 depending on speed, from 30 to 80 kmph

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

SD = LD + BD

$$\Rightarrow SD = vt + \frac{v^2}{2gf} \rightarrow v \text{ in m/sec.}$$

If speed is V kmph.

$$SD = \left[0.278Vt + \frac{V^2}{254f}\right]$$

} general eqn for SD at level

Stopping distance at slopes :-

→ Braking distance is decrease in ascending gradient ~~where as~~ and increase in descending gradient case.

Braking Distance

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

v in m/sec

If speed is V kmph

$$l = \frac{V^2}{254(f \pm n\%)}$$

$$\therefore SD = 0.278Vt + \frac{V^2}{254(f \pm n\%)}$$

V in kmph

where n% is gradient, +ve sign for ascending gradient and -ve sign for descending gradient.

Note:- The minm SSD = stopping distance in one way-traffic lanes and also in two-way traffic roads when there are two or more traffic lanes.

ISD = 2 x stopping distance → on roads with restricted width or on single lane roads when two-way movement of traffic is permitted.

for gradient is level n = 0.

Overtaking Sight Distance (OSD) :-

→ 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 is known as the minimum overtaking sight distance (OSD) or the safe passing distance available.

→ Some of the important factors on which the minm OSD required for the safe overtaking manoeuvre depends, are:

a) Speed of
   i) overtaking vehicle
   ii) overtaken vehicle, and
   iii) the vehicle coming from opposite direction if any

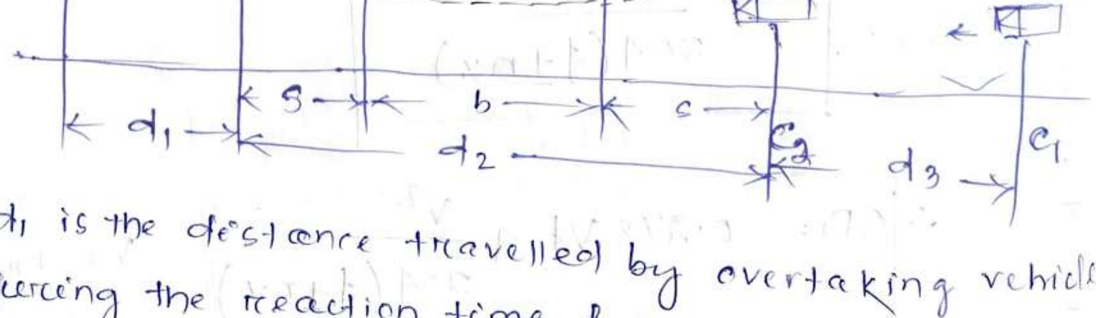
b) distance betn the overtaking and overtaken vehicles; the minm spacing depends on the speed

c) skill and reaction time of the driver

d) rate of acceleration of overtaking vehicle

e) gradient of the road, if any

Analysis of OSD :-



i) d_1 is the distance travelled by overtaking vehicle during the reaction time t sec of the driver from A_1 to A_2.

ii) d_2 is the distance travelled by the vehicle A fr

A_2 to A_3 during the actual overtaking operation, in time T sec

(iii) d_3 is the distance travelled by on-coming vehicle C from C_1 to C_2 during the overtaking operation of A, i.e. T sec

Design speed of A : v m/sec or V kmph

Uniform speed of B : V_b m/sec or V_b kmph

Design speed of C : v m/sec or V kmph.

⇒ It may be assumed that the vehicle A is forced to reduce its speed to the speed v_b of the slow vehicle B and moves behind it allowing a space s, till there is an opportunity for safe overtaking operation

∴ $d_1 = v_b t$ m. t = reaction time of the driver in seconds.

in V_b kmph $\quad$ v_b in m/s

$d_1 = 0.278 V_b t$ in m

→ 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

$s = (0.7 v_b + 6)$, m $\quad$ v_b in m/sec.

→ Let T be the duration of actual overtaking. The distance travelled by B during the overtaking operations = b = $v_b T$ m.

~~alt b = $\frac{V_b}{T}$~~, m $\quad$ v_b in m/sec

Thus $d_2 = b + 2s$

→ The time T may be calculated by equating the distance d_2 to $(v_b T + \frac{1}{2} a T^2)$, using the general formula for the distance travelled by an uniformly accelerating body with initial speed v_b m/sec and 'a' is the acceleration in m/sec².

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

$\Rightarrow b + 2s = V_b T + \frac{1}{2} a T^2$

$b = V_b T$ and therefore $2s = \frac{aT^2}{2}$

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

Hence $d_2 = V_b T + 2s$ m V_b in m/sec

⇒ The distance travelled by vehicle C moving at design speed V m/sec during the overtaking operation of vehicle A i.e. during time T is

$d_3 = V \times T$ m   V in m/sec.

$$OSD = d_1 + d_2 + d_3$$

$$OSD = V_b t + V_b T + 2s + VT$$ m (V_b, V in m/s unit)

In kmph Unit;

$$OSD = 0.28 V_b t + 0.28 V_b T + 2s + 0.28 V.T$$

V_b = speed of overtaking vehicle, kmph
t = reaction time of driver = 2 secs.
V = speed of overtaking vehicle on design of kmph

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

s = spacing of vehicles

⇒ $S = (0.2 V_b + 6)$

A = acceleration, kmph/sec

→ In case the speed of overtaken vehicle V_b is not given, the

$$V_b = (V - 16) \text{ kmph}$$

$$V_b = (V - 4.5) \text{ m/sec}$$

→ $OSD = (d_1 + d_2 + d_3)$, when two-way traffic exits,

→ $OSD = (d_1 + d_2)$ → on divide highways and on roads with one way traffic regulation, as no vehicle is expected from the opposite direction.

→ On divided highways with four or more lanes, IRC suggested that it is not necessary 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.

Effect of grade on OSD :-

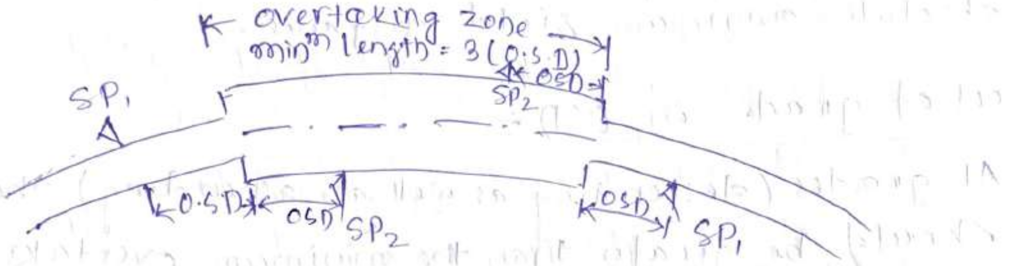
At grades (descending as well as ascending) the OSD should be greater than the minimum overtaking distance required at level.

Overtaking Zone :-

It is desirable to ~~construct~~ construct highway 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 can not be provided. In such zones where overtaking or passing is not possible or not safe, sign posts should be installed including 'No passing' or 'overtaking Prohibited' before such restricted zones starts. But the overtaking opportunity for vehicles moving at design speed should be given at frequent intervals. These zones which are meant for overtaking are called overtaking zones.

→ Sign posts should be installed at sufficient distan in advance to indicate the start of the overtaking zones; this distance may be equal to (d_1+d_2) for one-way roads and $(d_1+d_2+d_3)$ for two-way roads.

→ The minimum length of overtaking zone should be three time the safe overtaking distance i.e $3(d_1+d_2)$ for one-way roads and $3(d_1+d_2+d_3)$ for two-way roads. It is desirable that the length of overtaking zones is kept five times the overtaking sight distance.



OSD = overtaking sight distance
= (d_1+d_2) for one-way roads
= $(d_1+d_2+d_3)$ for two-way roads

SP_1 = Sign post 'overtaking zone ahead'.
SP_2 = Sign post 'overtaking zone end'

Intermediate Sight Distance :-

→ In case of vertical summit curves, it is possible to provide sight distance requirements by suitably designing the vertical alignment. At stretches of the road where required OSD can not 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 assum both the height of the eye level of the driver and

the object to be 1.2 m above the road surface.

Sight Distance at Intersections :-

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

i) Enabling the approaching vehicle to change speed

ii) Enabling the approaching vehicle to stop

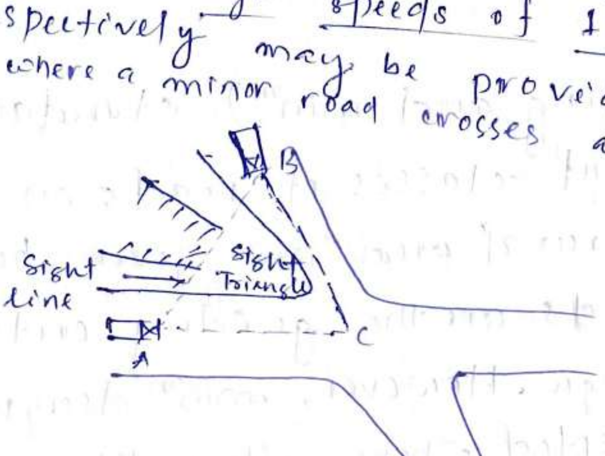
iii) Enabling stopped vehicle to cross a main road

→ The IRC recommended that at uncontrolled intersections, sufficient visibility should be provided such that the sight distance of each road is atleast equal to the SSD corresponding to the design speed of the road. If the sight triangle available is less than the desirable min^m size due to unavoidable reasons, the vehicle approaching the intersection may be warned or controlled by suitable signs.

→ At rotaries the sight distance should be at least equal to the safe stopping distance for the design speed of the rotary. At signalized intersections, the above three requirements are not applicable.

→ At priority intersections where a minor road crosses a major road, the traffic on the minor road may be controlled by stop or give-way sign to give priority to

→ IRC recommends that a min^m visibility distance of 15m along the minor road and a distance of 220, 180, 145 and 110m along the major road and corresponding to the design speeds of 100, 80, 65, and 50kmph respectively may be provided where a minor road crosses a major road (In priority intersection).



Design of Horizontal Alignment :-

→ Various design factors to be considered on the horizontal alignment are design speed, radius of circular curve, type and length of transition curves, superelevation and widening of pavement on curves.

(1) Design Speed :-

→ The design speed is the main factor on which geometric design elements depends. The sight distance, radius of horizontal curve, superelevation, extra widening of pavement, length of horizontal transition curve and the length of summit and valley curve are all dependent on design speed.

→ The design speed of roads depends upon

i) class of the road, and

(ii) terrian.

→ The terrians have been classified as plain, rolling, mountainous and steep, depending on the cross slope of country.

Terrian classification	cross slope, percent
plain →	0 - 10
Rolling →	10 - 25
Mountainous →	25 - 60
steep →	~~above~~ greater than 6

→ The design speed (ruling and min^{m}) standardiz by the IRC for different classes of roads on different terrian in rural areas are given below. The ruling design speeds are the guiding criteria for the geometric design. However, min^{m} design speeds ~~are~~ may be accepted where site conditions or economic considerations warrant.

Road classification	Design speed in kmph for various terrain							
	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 recommend design speeds for different classes of urban roads are:

i) for arterial roads 80 kmph
(ii) sub arterial roads 60 kmph.
(iii) collector streets 50 kmph
(iv) local streets 40 kmph

2. Horizontal Curve :-

→ 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 a horizontal curve, the centr centrifugal force acts horizontally outwards through the centre of gravity of the vehicle. This centrifugal force is counteracted by the transverse frictional resistance developed by the tyres and pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle.

Centrifugal force. $P = \frac{Wv^2}{gR}$ ~~in kg~~

P = centrifugal force, kg
W = weight of the vehicle, kg

R = radius of curve, m

v = speed of vehicle, m/sec

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

→ The ratio of $\frac{P}{W}$ is known as the centrifugal ratio or the impact factor.

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

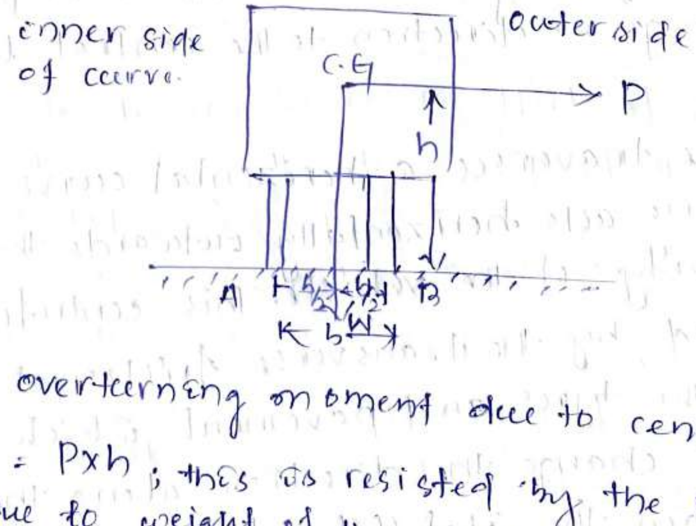
→ The centrifugal force acting on a vehicle negotiating a horizontal curve has two effect:

i) Tendency to overturn the vehicle outwards about the outer wheels and

ii) Tendency to skid the vehicle laterally, outwards.

The analysis of ~~those~~ stability of those two condition against overturing and and transverse skidding of the vehicles negotiating horizontal curves without superelevation are given below.

(i) Overturning effect :-



The overturning moment due to centrifugal force P = P×h ; this is resisted by the restoring moment due to weight of the vehicle W and is equal to $\frac{Wb}{2}$

where b = width of the wheel base or the wheel track of the vehicle.

The equilibrium condition for over-turning will occur when $Ph = \frac{Wb}{2}$

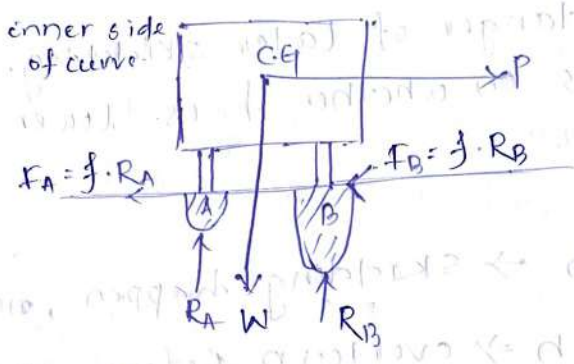
$$\Rightarrow \boxed{\frac{P}{W} = \frac{b}{2h}}$$

This means that there is danger of overturning when the centrifugal ratio $\frac{P}{W}$ or $\frac{v^2}{gR}$ attains a values of $\frac{b}{2h}$.

ii) Transverse skidding effect :-

~~The centrifugal force developed has also the tendency~~

If the centrifugal force P developed exceeds the maximum possible transverse skid resistance due to friction, the vehicle will start skidding in the transverse direction.



Shaded area show the pressure under the inner and outer wheels A and B

The equilibrium condition for the transverse skid resistance developed is given by

$$P = F_A + F_B = f(R_A + R_B) = fW$$

$$\Rightarrow \boxed{\frac{P}{W} = f}$$

f is the coefficient of friction b/w tyre and the pavement surface in the transverse direction, ~~R_A and~~ $R_A + R_B = W$, as no superelevation has been provided

→ When the centrifugal ratio attains a value equal to the coefficient of lateral friction there is a danger in lateral skidding.

→ Thus to ~~attain~~ avoid overturning and lateral skidding on a horizonal curve, the centrifugal ratio should always be less than $b/2h$ and 'f'.

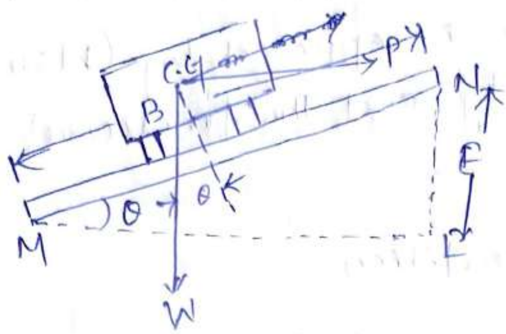
→ The vehicle negotiating a horizontal curve with no superelevation has to fully depends on the coefficient of friction 'f' to resist the lateral skidding. The centrifugal force may be enough to cause overturning or lateral skidding of the vehicle if either the speed of the vehicle is high or the radius of the curve is less. In such case the vehicle would skid and not overturn if the value of 'f' is less than $b/2h$. On the other hand the vehicle would overturn on the outer side before skidding if the value of $b/2h$ is lower than 'f'. Thus the relative danger of later skidding and overturning depends on whether f is lower or higher than $b/2h$.

$f < b/2h$ → skidding happen, not overturn
$f > b/2h$ → overturn before skidding.

3. Superelevation :-

→ In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised w.r.t the inner edge, that providing a transverse slope through the length of the horizontal curve. This transverse inclination to the pavement surface is known as superelevation or cant or banking.

→ The superelevation 'e' is expressed as the the ratio of height of the outer edge ~~to the~~ w.r.t the horizontal width.



$$e = \frac{NL}{ML} = \tan\theta$$

In practice the inclination θ with the horizontal is very small and the value of tan θ seldom exceeds 0.07. Therefore $\tan\theta = \sin\theta$

$$\therefore e = \tan\theta = \sin\theta = \frac{E}{B}$$ (B = width of pavement)

Analysis of superelevation :-

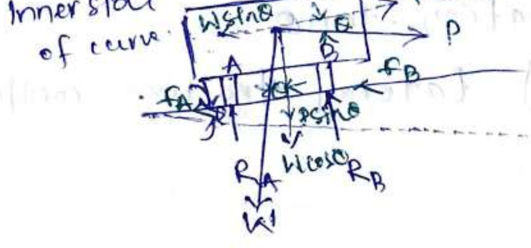
The forces acting on the vehicle while moving on a circular curve of radius R metres, at speed v m/sec are

i) the centrifugal force $P = \frac{Wv^2}{gR}$ acting horizontally outwards through the center of gravity.

(ii) the weight W of the vehicle acting vertically downwards through the C.G.

(iii) the frictional force developed betn the wheels and the pavement counteracts transversely along the pavement surface towards the center of the curve.

The centrifugal force is opposed by corresponding value of the friction developed and by a component of the force of gravity due to the superelevation provided.



Considering the equilibrium of the components of forces acting parallel to the plane, (P cosθ) the component of centrifugal force is opposed by (W sinθ) the component of gravity and the frictional forces f_A and f_B.

For equilibrium condition

$$P\cos\theta = W\sin\theta + f_A + f_B$$

$$= W\sin\theta + f R_A + f R_B$$

$$= W\sin\theta + f(R_A + R_B)$$

$$= W\sin\theta + f(W\cos\theta + P\sin\theta)$$

i.e. $P(\cos\theta - f\sin\theta) = W\sin\theta + f W\cos\theta$

Dividing by W cosθ,

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

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

The value of coefficient of lateral friction, f is taken as 0.15 for design purposes.
The value of tanθ or transverse slope due to superelevation seldom exceeds 0.07 or about 1/15. Hence the value of tanθ is about 0.07. Thus the value of (1 − f tanθ) in the above eqn is equal to 0.99 ≈ 1.0.

Therefore $\boxed{\frac{P}{W} \approx \tan\theta + f = e + f}$

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

$\therefore \boxed{e + f = \frac{v^2}{gR}}$ when v in m/sec.

e = rate of superelevation = tanθ.
f = design value of lateral friction coefficient = 0.15

If v is in kmph

$$e + f = \frac{v^2}{127R}$$

v = speed in kmph
R = radius, surfaces.

→ If, f = 0, then equilibrium superelevation required to counteract the centrifugal force fully will be given by

$$e = \frac{v^2}{gR} = \frac{v^2}{127R}$$

If 'e' is provided according to this formula, the pressure on the outer and inner wheels will be equal; but this will result in a very high value of superelevation.

→ If e = 0, (in some types of intersections it is not possible to provide 'e') and in such cases the friction counteracts the centrifugal force fully; with no superelevation, the allowable speed of the vehicle negotiating a turn should be restricted to the condn.

$$f = \frac{v^2}{gR} = \frac{v^2}{127R}$$

$$\Rightarrow V = \sqrt{127 f R}$$

→ Thus 'e' depends on R, V, f.

Maximum Superelevation :-

From the practical view point it will be necessary to limit the max^m allowable superelevation to avoid very high values of 'e'. And this is particularly necessary when the road has to cater for mixed traffic, consisting of fast and slow traffic.

e_{max} =
- 0.07 i.e. 7% for plain and rolling terrains and is bounded by snow.
- 0.10 ie 10% → for hilly Area (snow not bounded)
- 0.04 ie 4% → for urban roads with frequent intersections

Superelevation Design :-

As a compromise and from practical considerations it is suggested that the superelevation should be provided to fully counteract the centrifugal force due to 75 % of the design speed, (by neglecting lateral friction developed) and limiting the max superelevation to 0.07 (except on hill roads, not bound by snow. where maxm allowable value is 0.1

Step-I

The superelevation for 75% of design speed (v m/sec or V kmph) is calculated neglecting the friction

$$e = \frac{(0.75v)^2}{gR} \quad \text{or} \quad \frac{(0.75V)^2}{127R}$$

i.e. $$e = \frac{V^2}{225R}$$ V in kmph.

Step-II

If the calculated value of 'e' is less than 7% or 0.07 the value so obtained is provided. If e > 0 then provide the maxm 'e' = 0.07 and proceed to n Steps.

Step-III

Check the coefficient of friction developed for the maxm value of e = 0.07 at the full value of desig speed,

$$f = \frac{v^2}{gR} - 0.07$$ v in m/sec

or $$f = \frac{V^2}{127R} - 0.07$$ V in kmph

If the value of 'f' calculated is less than 0.15, the superelevation of 0.07 is safe for the design speed. If not, calculate the restricted speed as given in Step IV.

Step - IV :- As an alternate to Step(III), the allowable speed (V_a m/sec or V_a kmph) at the curve is calculated by considering the design coefficient of lateral friction and max^m superelevation, i.e.

$$e + f = 0.07 + 0.15$$

$$= 0.22 = \frac{V_a^2}{gR} = \frac{V_a^2}{127R}$$

$$\Rightarrow \boxed{V_a = \sqrt{0.22gR} = \sqrt{2.156R}} \text{ m/sec}$$

$$\text{or } \boxed{V_a = \sqrt{27.94R} \text{ kmph}}$$

If V_a is higher than the design speed, then the design is adequate and provide a superelevation of 'e' equal to 0.07.

If $V_a <$ design speed, the speed is limited to the allowable speed V_a kmph.

4. Radius of Horizontal Curve :-

→ The ruling minimum radius of the curve for ruling design speed v m/sec, or V kmph is given by

V = ruling

$$R_{ruling} = \frac{v^2}{(e+f)g} \rightarrow v \text{ m/sec}$$

$$R_{ruling} = \frac{V^2}{127(e+f)} \rightarrow V \text{ kmph}$$

→ When the minimum design speed V' kmph is adopted instead of ruling design speed V kmph, the absolute minimum radius of horizontal curve R_{min} is given by

$$\boxed{R_{min} = \frac{V'}{127(e+f)}}$$

v and V = rcelling design speeds, in m/sec and Kmph respectively.

V' = minm design speed, kmph

e = rate of superelevation ; the maxm value of e = 0.07 at all the regions

f = design value of transverse skid resistance or coefficient of friction = 0.15

5. Widening of Pavement on Horizontal Curves:-

On horizontally curves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width.

→ The required extra widening of the pavement at the horizontal curves We depends on the length of wh based of the vehicle l, radius of the curve negotiated and the psychological factor which is a function of th speed of the vehicle and the radius of the curve.

→ When the radius is less than about 300m, then the extra width of pavement is provided on horizontal curve

Analysis of Extra widening :-

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

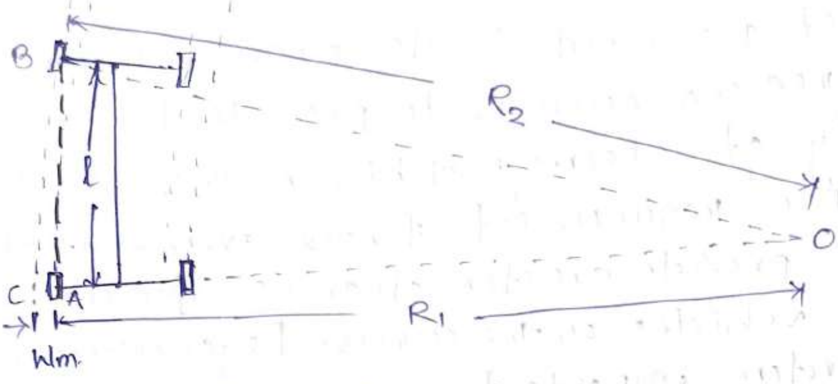
i) mechanical and

ii) psychological widening.

$W_e = W_m + W_{ps}$

i) Mechanical Widening:-

→ The widening required to account for the off-tracking due to the rigidity of wheel based is called mechanical widening (W_m).



R_1 = radius of the path traversed by the outer rear wheel, m

R_2 = radius of the path traverse by the outer front wheel, m

W_m = off-tracking or the mechanical widening, m

l = length of wheel base, m

$W_m = OC - OA = OB - OA = R_2 - R_1$

From ΔOAB, $OA^2 = OB^2 - BA^2$

$$R_1^2 = R_2^2 - l^2$$

But $R_1 = R_2 - W_m$

$$(R_2 - W_m)^2 = R_2^2 - l^2$$

$$\Rightarrow l^2 = W_m(2R_2 - W_m)$$

$$\therefore W_m = \frac{l^2}{2R_2 - W_m}$$

$$= \frac{l^2}{2R} \text{ (approximately).}$$

} For one vehicle negotiating a horizontal curve along one traffic lane

R = mean radius of the curve.

In a road having 'n' traffic lanes, as 'n' vehicles can travel simultaneously, the total mechanical widening required is given by

$$W_m = \frac{n l^2}{2R}$$

(ii) Psychological Widening :-

Extra width of pavement is also provided for psychological reasons such as, to provide for greater maneuverability of steering at higher speeds, to allow for the extra space requirements for the overhangs of vehicles and to provide greater clearance for crossing and overtaking vehicles on the curves. Psychological widening is therefore important in pavements with more than one lane.

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

V - design speed, kmph
R - radius of curve, m

$\therefore W_e = W_m + W_{ps}$

i.e. $$W_e = \frac{n l^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

n = number of traffic lanes.

l = length of wheel base of longest vehicle, m.
The value of l may normally be taken as 6.1 m or 6 m for commercial vehicles, if not known.

Extra width of pavement at horizontal curve

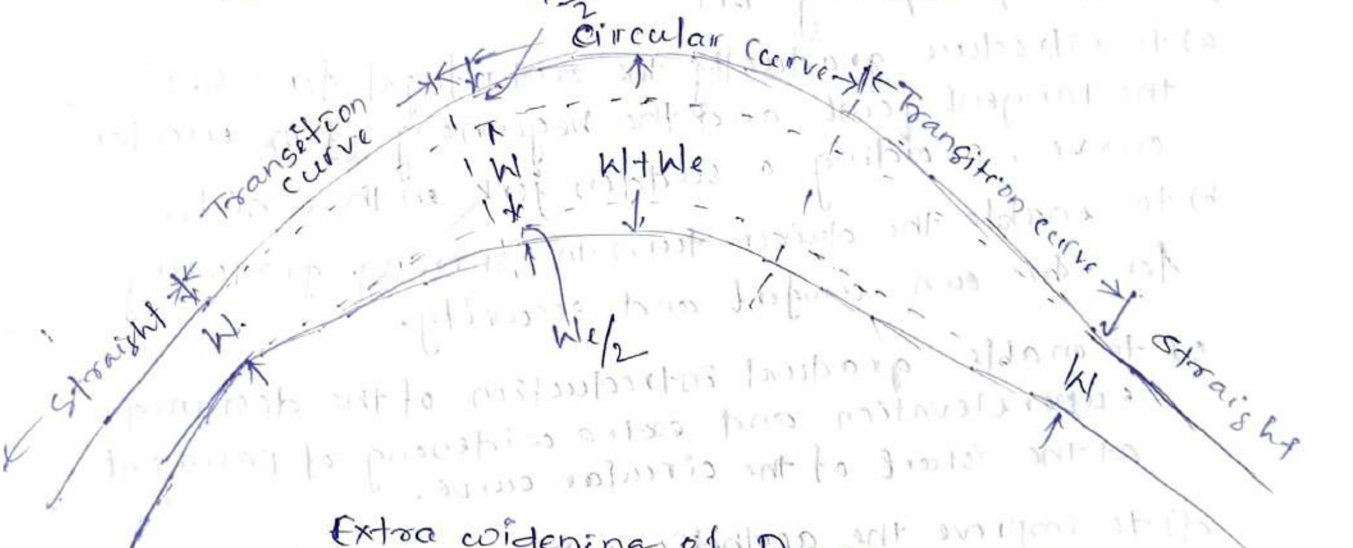
Radius of curve (m)	Up to 20	20 to 40	41 to 60	61 to 100	101 to 300	Above
Extra width (m)						
Two - lane	1.5	1.5	1.2	0.9	0.6	Nil
Single lane	0.9	0.6	0.6	Nil	Nil	Nil

Note :- For multilane roads, the pavement widening is calculated by adding half the extra width of two-lane roads to each lane of the multi-lane road.

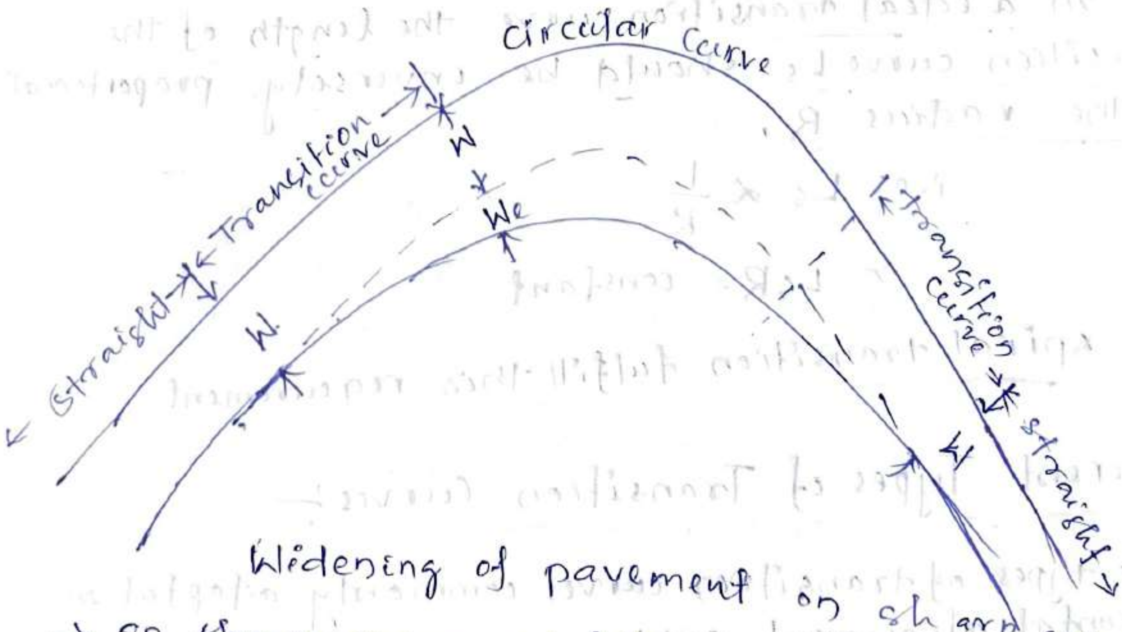
Methods of

→ The widening is introduced gradually, starting from the beginning of the transition curve or the tangent point, and progressively increased at uniform rate, till the full value of designed widening W_e is reached at the end of transition curve where full values of superelevation is also provided.

→ $W_e/2$ each on inner and outer sides of curve.



Extra widening of Pavement on Horizontal curve



Widening of pavement on sharp curve

→ On sharp curves of hill roads the extra widening W_e may be provided in full on inside of the curve.

→ On horizontal circular curves without transition curves, 2/3 W_e is provided at the end of the straight section, i.e. before the start of the circular curve and the remaining 1/3 W_e is provided on the circular curve beyond the tangent point as in case of superelevation. In such cases, the widening is provided on the inside of the curve

6. Horizontal Transition Curve :-

The functions of transition curves in the horizontal alignment of highway are:

a) to introduce gradually the centrifugal force betn the tangent point and the beginning of the circular curve, avoiding a sudden jerk on the vehicle.

b) to enable the driver turn the steering gradually for his own comfort and security.

c) to enable gradual introduction of the designed superelevation and extra widening of pavement at the start of the circular curve.

d) to improve the aesthetic appearance of the road.

⇒ ~~The~~ In a ideal transition curve the length of the transition curve L_s should be inversely proportional to the radius R,

$$\text{i.e. } L_s \propto \frac{1}{R}$$

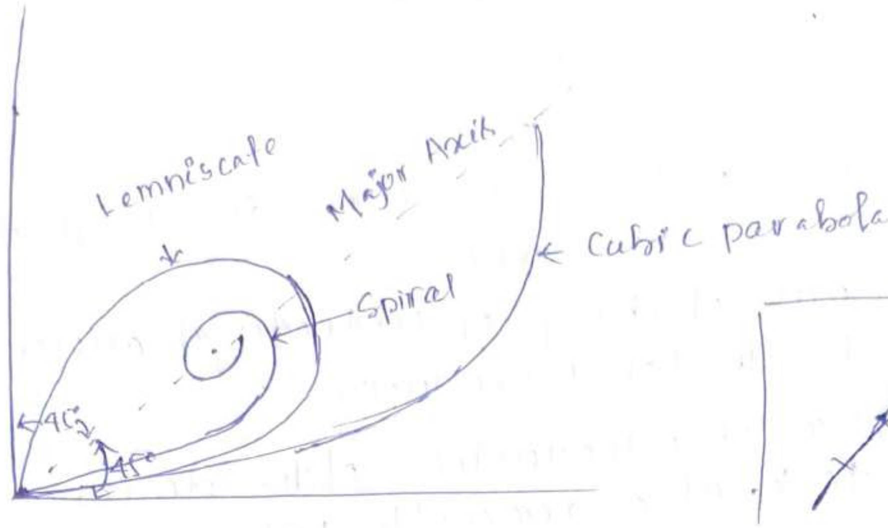
$$\Rightarrow L_s R = \text{constant}$$

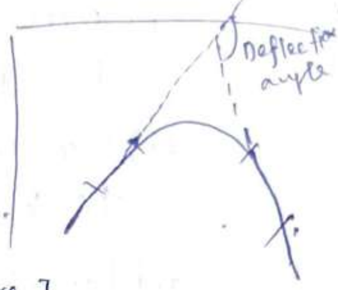
The spiral transition fulfill this requirement.

Different Types of Transition Curves :-

The types of transition curves commonly adopted in horizontal alignment are:

- a) Spiral (also called clothoid)
- b) ~~Lemis~~ Lemniscate
- c) Cubic Parabola





[Different types of transition curve]

→ All 3 curves follow almost the same path upto deflection angle of 4°, and practically there is no significant difference even upto 9°.

In all these curves, R decreases as L_s increases. But the rate of change of radius and hence the rate of change of centrifugal acceleration is not constant in the case of lemniscate and cubic parabola, especially at deflection angles higher than 4°. In spiral curve the radius is inversely proportional to the length and the rate of change of centrifugal acceleration is uniform throughout the length of the curve. Thus the spiral fulfills the condn of an ideal transition curve.

→ The IRC recommends the use of the spiral as transition curve in the horizontal alignment of the highways due to the following reasons:

i) The spiral curve satisfres the requirements of an ideal transition.

ii) The geometric property of spiral is such that the calculations and setting out the curve in the field is simple and easy.

The eqn of spiral may be written as:

$$L \cdot R = L_s \cdot R_c = \text{constant}$$

Therefore $\boxed{L = m\sqrt{\theta}}$

$\boxed{m = \text{constant} = \sqrt{2RL_s}}$ and is the tangent deflection angle in radius.

Length of transition Curve :-

The length of transition curve is designed to fullfill three conditions, viz.:

i) rate of change of centrifugal acceleration to be developed gradually.

ii) rate of introduction of the designed superelevati to be at a reasonable rate

iii) minimum length by IRC emprical formula

i) Rate of change of centrifugal acceleration :-

Let the length of the transition curve be L_s metre if 't' is the time taken in seconds to traverse this transition length at uniform design speed of v m/sec, $t = \frac{L_s}{v}$.

The maximum centrifugal acceleration of v^2/R is introduced in time 't' through the transition length L_s and hence the rate of change of centrifugal acceleration 'C' is given by

$$C = \frac{v^2}{R \cdot t} = \frac{v^2}{R\frac{L_s}{v}} \quad \text{v in m/sec}$$

$$\text{or} \quad C = \frac{v^3}{L_s \cdot R} \ (\text{m/sec}^3) \quad \text{--- (1)}$$

⇒ The IRC has recommended the following equation for finding the value of 'C' for the design speed V kmph

$$C = \frac{80}{(75+V)} \ \text{m/sec}^3, \ [0.5 < C < 0.8] \quad \text{--- (2)}$$

i.e. the minimum and maximum values of C are limited to 0.5 and 0.8 respectively.

The length of transition curve L_s

$$L_s = \frac{v^3}{CR} \quad v \text{ in m/sec} \quad -(3)$$

If the design speed is V kmph

$$L_s = \frac{V^3}{(3.6)^3 CR}$$

i.e.

$$L_s = \frac{V^3}{46.5\,CR} = \frac{0.0215V^3}{CR} \quad -(4)$$

(ii) Rate of introduction of superelevation :-

If high value of superelevation is to be introduced

$$L_s = \begin{cases} 150E \rightarrow \text{for plain and Rolling Terrian} \\ 100E \rightarrow \text{for Built up Area} \\ 60E \rightarrow \text{for hilly Area} \end{cases}$$

E = Raise of outer line of road w.r.t. centre line

e = rate of superelevation designed

W = normal pavement width

W_e = extra widening provided at the circular curve.

∴ Total width $B = W + W_e$

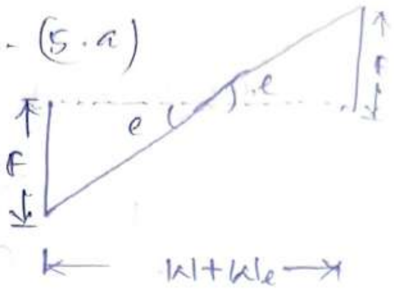
The total raising of pavement w.r.t to inner edge

$$E = e \cdot B = e\,(W + W_e)$$

→ If it is assumed that the pavement is rotated about centre line after neutralizing the camber, then the maximum amount by which the outer edge is to be raised at the circular curve w.r.t the centre $= \frac{E}{2}$. Hence allowing a rate of change of superelevation of 1 in N (where min^m value of N = 150 to 60), the length of transition curve

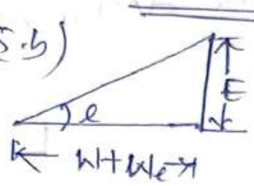
rotate with centre line

$$L_S = \frac{EN}{2} = \frac{eN}{2}(W + W_e) \quad -(5.a)$$



⇒ If the pavement is rotated about the inner edge

$$L_S = EN = eN(W + W_e) \quad -(5.b)$$



(iii) By Emprical formula:-

According to the IRC standards, the length of horizontal curve L_s should not be less than the value given by the following equation for the terrian classifications:

a) For plain and rolling terrian:

$$L_S = \frac{2.7 V^2}{R} \quad -(6.a)$$

b) For mountainous and steep terrian:

$$L_S = \frac{V^2}{R} \quad -(6.b)$$

The length of transition curve for the design should be the highest of the three values.

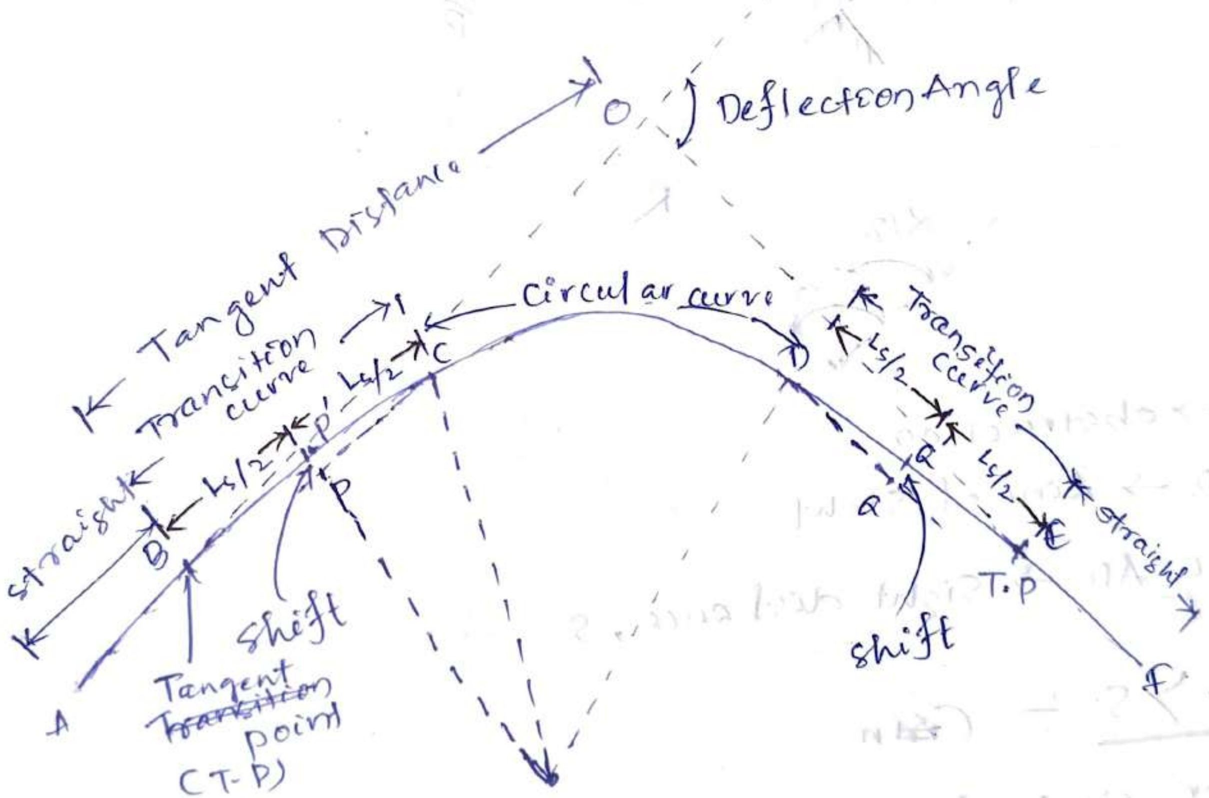
Design Step:-

a) Find the length of transition curve based on allowable rate of change of the centrifugal acceleration ~~Eq. 2, 3 and 4~~) (Eqn 2 and 3 or 4)

b) Find the length of transition curve based on rate of change of superelevation (Eq 5 or Eq. 6)

(c) Check for the minm required value of Ls as per Eqn 6.a or 6.b.

(d) Adopt the highest value of Ls given by (a), (b), and (c) above as the design length of transition curve.



$$\text{Shift } S = \frac{L_s^2}{24R}$$

PCDQ are original circular curve of radius R

PP' = QQ' = Shift

[Transition Curve in Horizontal Alignment]