

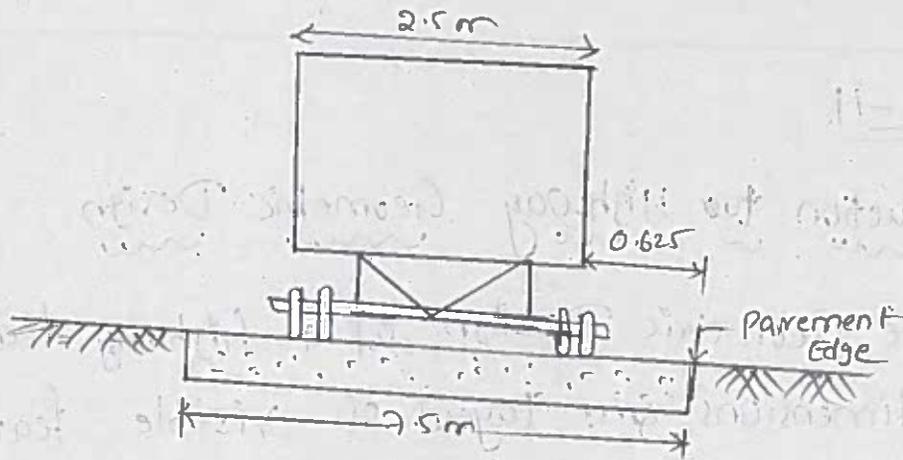
UNIT-11Introduction to Highway Geometric Design

The Geometric Design of a highway deals with the dimensions and layout of visible features of the highway such as alignment, sight distances and intersections.

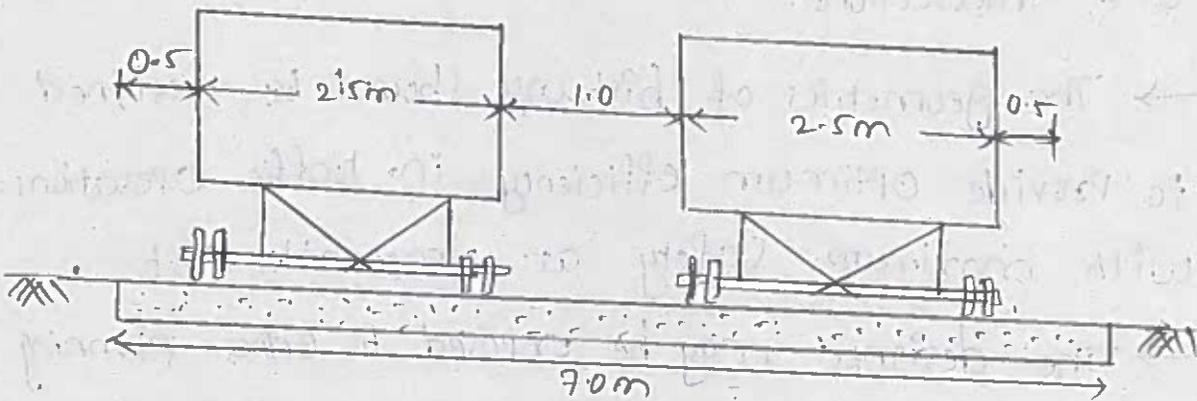
- The geometrics of highway should be designed to provide optimum efficiency in traffic operations with maximum safety at reasonable cost.
- The designer may be exposed to either planning of new highway network or improvement of existing highways to meet the requirements of the existing and the anticipated traffic.

Width of Pavement:-

- The Pavement or Carriage way width depends on the width of traffic lane and number of lanes. The Carriageway intended for one line of traffic movement may be called a traffic lane.
- The maximum width of vehicle as per IRC specifications is 2.44m. [for details refer Art 5.2]
- If a single lane Carriageway of width 3.8m is provided, a side clearance of 0.68m would be obtained.



(a) SINGLE LANE PAVEMENT



(b) TWO LANE PAVEMENT

Fig. Lateral Placement of Vehicles.

Width of Carriageway

	Class of Road	Width of Carriageway.
i)	Single lane	3.75m
ii)	Two lanes, without raised kerbs	7.0m
iii)	Two lanes, with raised kerbs	7.5m
iv)	Intermediate Carriageway	5.5m
v)	Multi-lane Pavements	3.5m Per Lane.

### Cross Slope (or) Camber

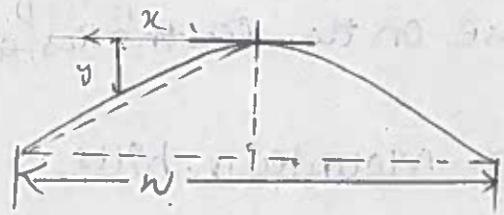
\* Cross slope (or) Camber is the slope provided to the road surface in the transverse direction to drain off the rainwater from the road surface.

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

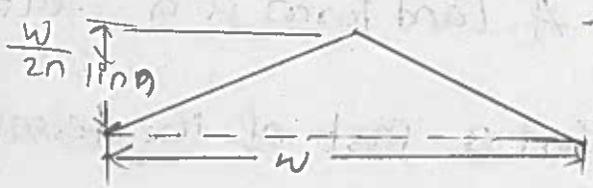
i) To prevent the entry of surface water into the subgrade soil through pavement, the stability, surface condition and the life of the pavement get adversely affected if the water enters in the subgrade and the soil gets soaked.

ii) To prevent the entry of water in the bituminous pavement layers, as continued contact with water causes stripping of bitumen from the aggregates and results in deterioration of the pavement layers.

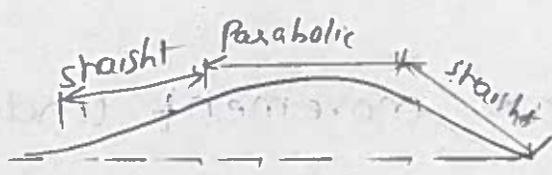
#### Shapes of Cross slope.



(a) Parabolic shape.



(b) Straight line camber.



(c) Combination of straight and parabolic shape.

→ The camber is given a parabolic elliptic or straight line shape in the cross-section. Parabolic or elliptical shape is given so that the profile is flat at the middle and steeper towards edges.

Recommended values of camber for different types of road surfaces.

Sl No	Type of road surface.	Range of camber in areas of rainfall zone. 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%)

### Formation and land

→ A land form is a feature on the earth's surface that is part of the terrain. Mountains, hills, plateaus, and plains are the four major types of land forms.

→ Tectonic plate movement under the earth can create landforms by pushing up mountains and hills.

## Concept of 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 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 speeds.

## 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 vehicle moves forward, the longitudinal skidding takes place which may vary from 0 to 100 Percent.
- When a vehicle negotiates a horizontal curve, if the centrifugal forces lateral skidding takes place.

## Slip:-

Slip occurs when a wheel revolves more than the corresponding longitudinal movement along the roads.

→ Slipping usually occurs 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.

## Elements of geometric design of highways

The geometric design of highway will be considered under the following heads:

1. Dimensions and weights of road vehicles

2. Terrain classification and design speed.

3. Design of the road cross-section

(a) width of carriage way

(b) width of road way

(c) shoulders

(d) median strips

(e) side slopes

(f) combs

(g) Land with building lines and control lines and

(h) cross-section

4. Super-elevation

5. Curves - horizontal (Circular & transition curves)

6. Sight Distances

7. Gradients

8. Curves - vertical (Summit & valley curves)

9. Alignment - horizontal, vertical and lateral and

vertical clearance at under-passes.

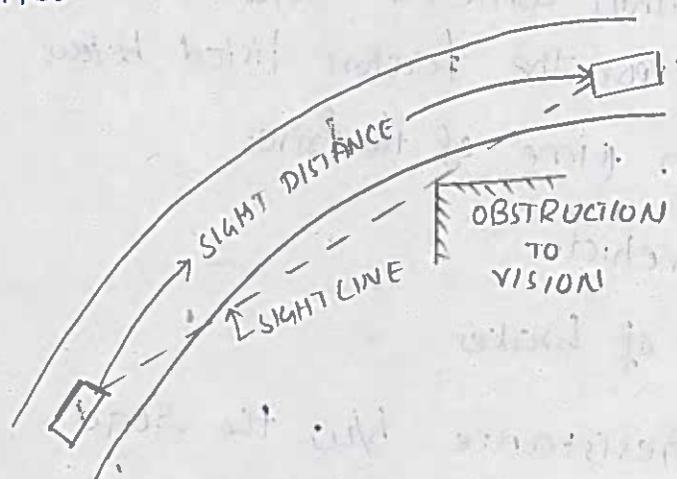
## Sight Distances

→ The safe and efficient operation of vehicle on roads, depends, among other factor on the road length at which an obstruction, if any becomes visible to the driver in the direction of travel.

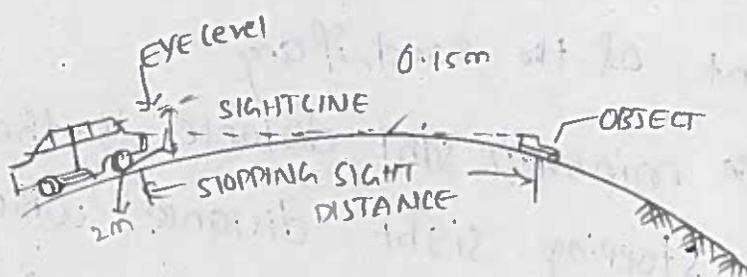
→ Sight distance available from a point is the actual distance along the road surface which a driver from a specified height above the carriageway has visibility of stationary or moving objects.

→ Three sight distance situations are considered in the design:

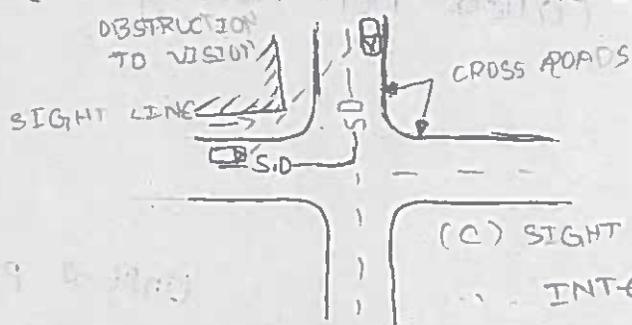
- i) Stopping or absolute minimum sight distance
- ii) safe or absolute minimum sight distance
- iii) safe sight distance for entering into uncontrolled intersections.



(a) SIGHT DISTANCE AT HORIZONTAL CURVE



(b) SIGHT DISTANCE AT VERTICAL SUMMIT CURVE



(c) SIGHT DISTANCE (SD) AT INTERSECTION

## 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 sight distance available on a road for 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 the object above the road surface.

→ Hence the stopping distance available at a summit curve is that distance measured along the road surface at which an object of height 0.15m can be seen by a driver when eye is at a height of 1.2m above the road surface.

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

(a) Total reaction time of the driver

(b) Speed of vehicle

(c) Efficiency of brakes

(d) Frictional resistance b/w the road and the tyres

(e) Gradient of the road, if any.

→ The absolute minimum sight distance is therefore equal to the stopping sight distance, which is also sometimes called non-passing sight distance.

# Overtaking Sight Distance

→ If all the vehicles travel on a road at the design speed, then theoretically there should be no need for any overtaking

→ The Minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety with against the traffic of opposite direction is known as the minimum overtaking sight distance (OSD) or the safe passing sight distances available

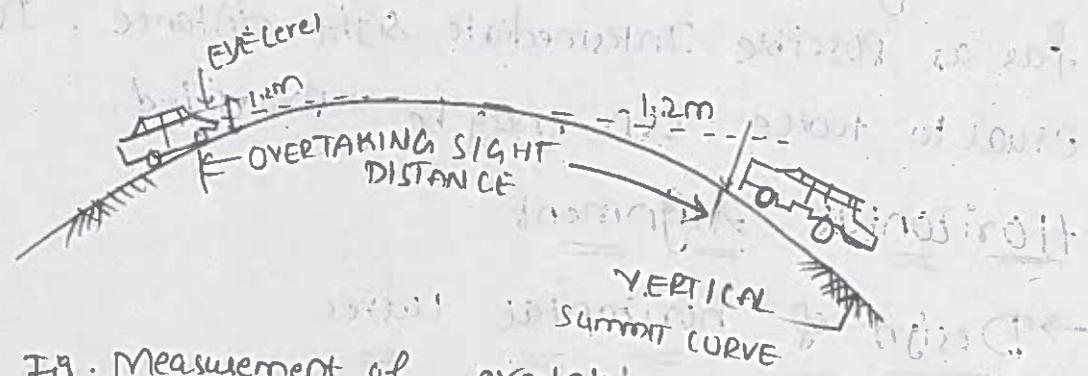


Fig. Measurement of overtaking sight distance

→ Some of the important factors on which the minimum overtaking sight distance required for the safe overtaking manoeuvre depends are:

- (a) Speed of (i) overtaking vehicle  $v_1$ , overtaken vehicle and (ii) vehicle coming from opposite direction, if any
- (b) Distance between the overtaking and overtaken vehicles, the minimum 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.

## Intermediate sight distance:-

→ Sufficient overtaking sight distance should be available on most of the road stretches.

→ On horizontal curves the overtaking sight distance requirements can not always be fulfilled especially on sharp curves, if the safe overtaking sight distance requirements are high.

→ At stretches of the road where required overtaking sight distance can not be provided as far as possible intermediate sight distance, ISD equal to twice SSD may be provided.

## Horizontal Alignment

### Design of horizontal curves

\* The alignment should enable consistent, safe and smooth movement of vehicles operating at design speeds. It is hence necessary to avoid those sharp curves and reverse curves which could not be conveniently negotiated by the vehicles at design speed.

\* A horizontal highway curve is a curve in plan to provide change in direction to the centre line of a road. When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle.

15  
→ The centrifugal force developed depends on the radius of the horizontal curves and the speed of the vehicle negotiating the curve.

Centrifugal force 'P' is given by the equation

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

Here

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<sup>2</sup>

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 with respect to the inner edge, thus providing a transverse slope throughout 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 ratio of the height of outer edge with respect to the horizontal width.

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

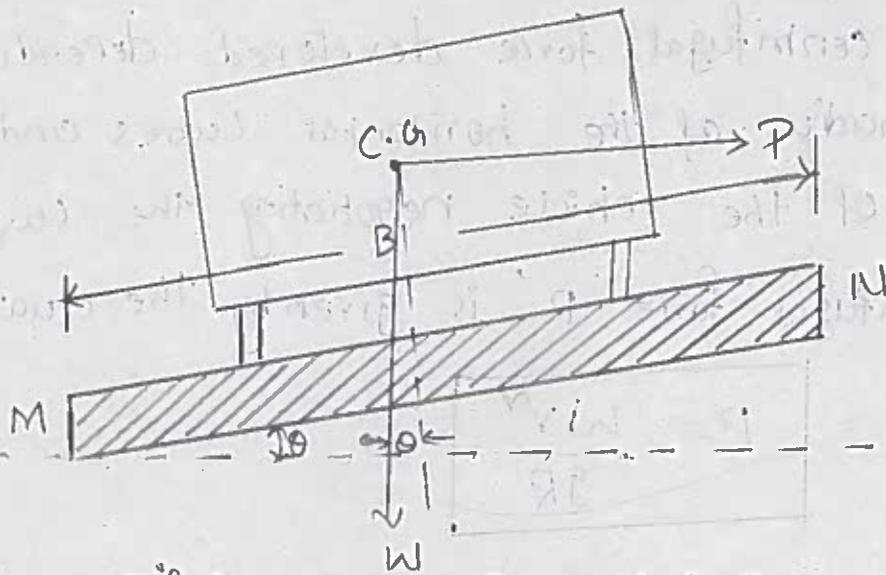


FIG. Super-elevated Pavement Section.

→ In practice the inclination  $\theta$  with the horizontal is very small and the value of  $\tan \theta$  seldom exceeds 0.07. Therefore, the value of  $\tan \theta$  is practically equal to  $\sin \theta$ .

Hence,  $e = \tan \theta \approx \sin \theta = \frac{E}{B}$  which is measured as the ratio of the relative elevation of the outer edge,  $E$  to width of pavement,  $B$ . This is more convenient to measure.

### Widening of pavement on horizontal curves

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

→ The object of providing extra widening of pavement on horizontal curves are due to the following reasons.

(a) An automobile has a rigid wheel base and only the front wheel can be turned. When this vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of the front wheel.

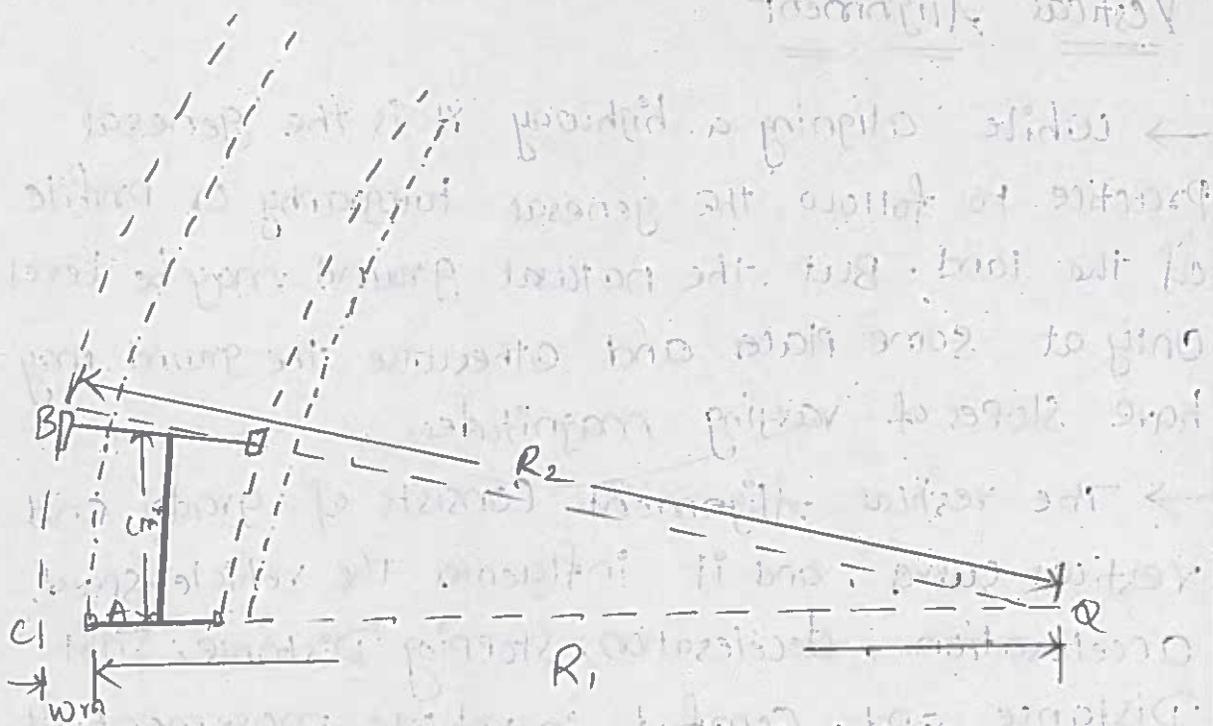


Fig. Mechanical widening on horizontal curve.

- (b) At speeds higher than the design speeds when the superelevation and lateral friction developed are not fully able to counteract the outward thrust due to the centrifugal force.
- (c) The path traced by the wheels of a trailer in the case of trailer units, is also likely to be on either side of the central path of the towing vehicle, depending on the speed, rigidity of the universal joints and pavement roughness.
- (d) In order to take curved path with larger radius and to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane.
- (e) While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain a greater clearance between the vehicle, than on straight for increase safety.

# Vertical Alignment

→ While aligning a highway it is the general practice to follow the general topography or profile of the land. But the natural ground may be level only at some places and otherwise the ground may have slopes of varying magnitudes.

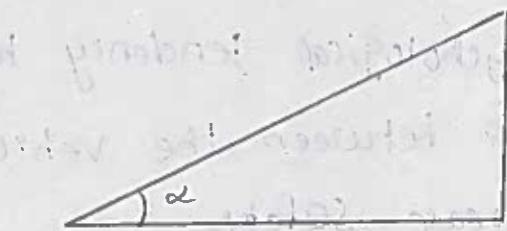
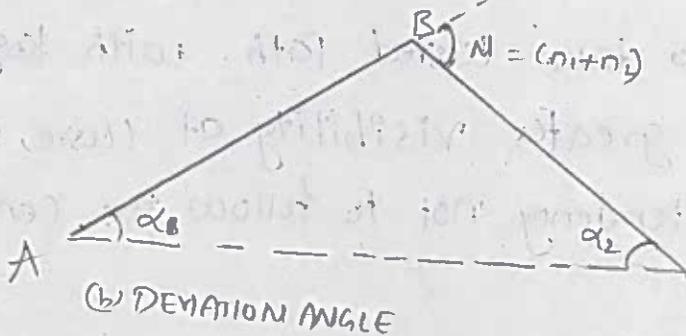
→ The vertical alignment consists of grades and vertical curves, and it influences the vehicle speed, acceleration, deceleration, stopping distance, sight distance and comfort in vehicle movement at high speeds.

## Gradients

→ Gradient is the rate of rise or fall along the length of the road with respect to the horizontal.

→ It is expressed as the ratio of 1 in  $x$  (1 vertical unit to  $x$  horizontal units). Some times the gradient is also expressed as a percentage  $n$  i.e.  $n$  in 100.

Fig. Measure of Gradients.



(a) GRADIENT = 1 in  $x$

=  $\tan \alpha$

=  $n = \frac{100}{x}$  PERCENT UNIT-2 Pg-19/21

→ When the angle of gradient,  $\alpha$  is small the gradient which is  $\tan \alpha$  or  $\tan \alpha$  is approximately equal to the circular measure or  $\alpha$  in radians (rad).  
All angles within the practical range of gradients on roads may be treated as small.

→ The angle which measures the change of direction at the intersection of two grades is called the deviation angle  $N$  which is equal to the algebraic difference between the two grades.

$$N = \angle DBC = \angle BAC + \angle BCA$$

$$= +n_1 - (-n_2) = n_1 + n_2$$

where  $n_1$  is ascending gradient of AB and  $-n_2$  the descending gradient of BC.

→ Gradients are divided into the following categories

- 1) Ruling Gradient
- 2) Limiting Gradient
- 3) Exceptional Gradient
- 4) Minimum gradient.

→ While aligning a highway, the gradient is decided for designing the vertical curve.

→ Very steep gradients are avoided as it is not difficult to climb the grade, but also the vehicle operation cost is increased.

→ The engineer has to consider all aspects such as construction costs, practical problems in construction.

## Compensation in gradient

- According to the IRC the grade compensation is not necessary for gradients flatter than 4.0 percent and therefore when applying grade compensation correction, the gradients need not be eased beyond 4 percent.
- It is necessary that in such cases the total resistance due to grade and curve should not normally exceed the resistance due to the maximum value of the gradient specified.
- This reduction in gradient at the horizontal curve is called grade compensation, which is intended to off-set the extra tractive effort involved at the curve. This, is calculated from the relation:
- Grade Compensation, percent =  $\frac{30+R}{R}$ , subject to a maximum value of 7/R, where R is the radius of the circular curve in metre.

## Design of Summit Curve

- Summit curves with convexity upward are formed in any one of the case illustrated in fig. The deviation angle between the two intersecting gradients is equal to the algebraic difference between them.
- The only problem in designing summit curves is to provide adequate sight distances.
- The deviation angle will be maximum when an ascending gradient meets with a descending

meets gradient i.e  $N = (n_1 - (-n_2)) = (n_1 + n_2)$

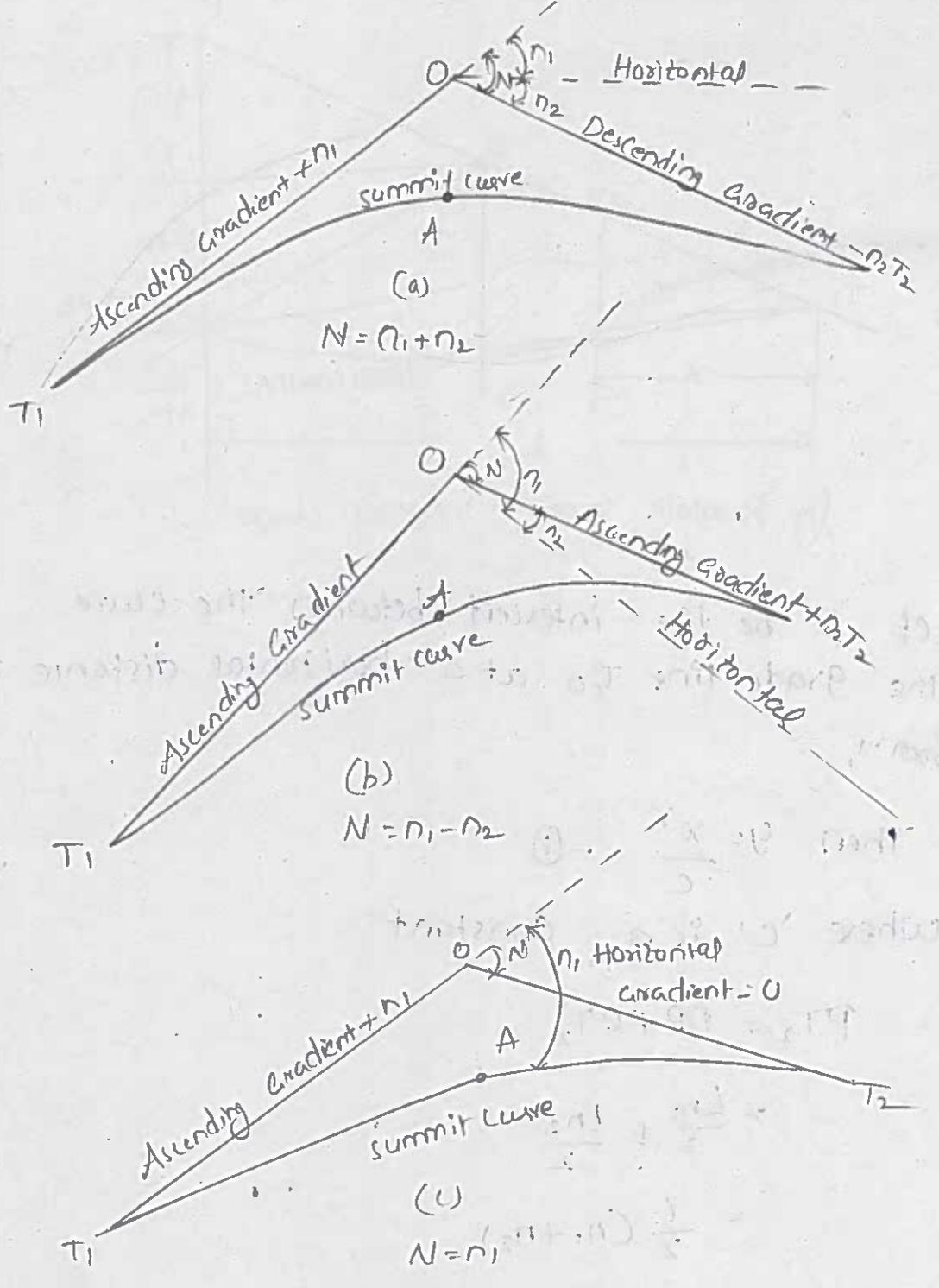


Fig Summit Vertical Curves, showing deflection angles.

→ let  $T_1O$  and  $T_2O$  be the two intersecting grade lines having grade angles  $n_1$  and  $n_2$  respectively as shown in fig.

Let  $T_1$  to  $T_2$  be the simple parabolic curve between the tangent points  $T_1$  and  $T_2$

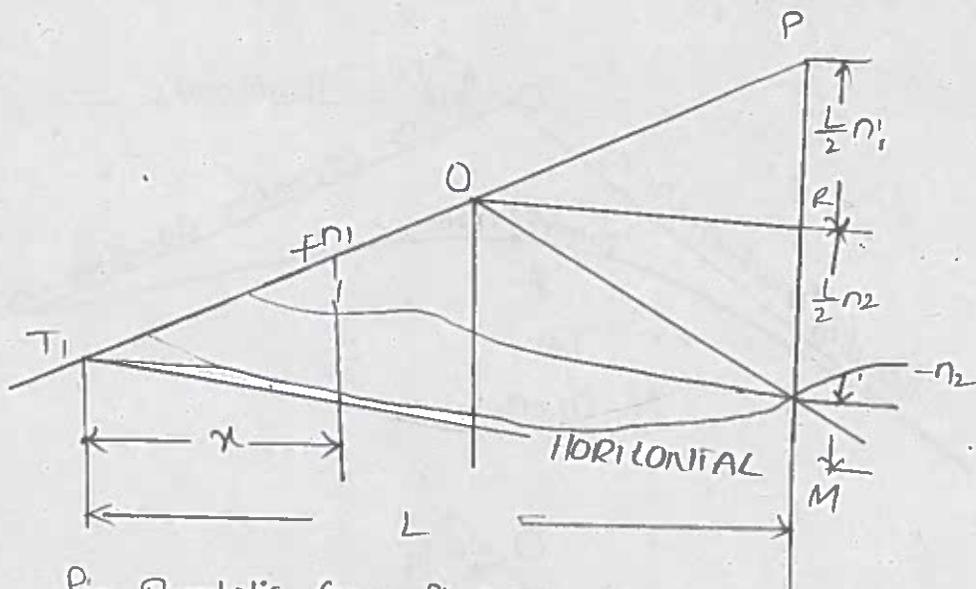


Fig. Parabolic Summit vertical curve

Let 'y' be the intercept between the curve and the grade line  $T_1O$  at a horizontal distance  $x$  from  $T_1$ ,

$$\text{Then } y = \frac{x^2}{c} \quad \text{--- (1)}$$

where 'c' is a constant

$$\begin{aligned} PT_2 &= PR + RT_2 \\ &= \frac{Ln_1}{2} + \frac{Ln_2}{2} \\ &= \frac{L}{2} (n_1 + n_2) \\ &= \frac{L}{2} N \end{aligned}$$

At the end point  $T_2$  of the curve.

$$x = L \text{ and } y = PT_2 = \frac{L}{2} N$$

Sub these values in eqn (1) we get

$$\frac{LN}{2} = \frac{L^2}{c}$$

$$c = \frac{2L}{N}$$

# Valley curves

→ A vertical curve, concave upwards, is called a valley curve. This is formed when a descending gradient increases intersects an ascending gradient or when a descending gradient meets another descending gradient or when a descending gradient joins a horizontal path.

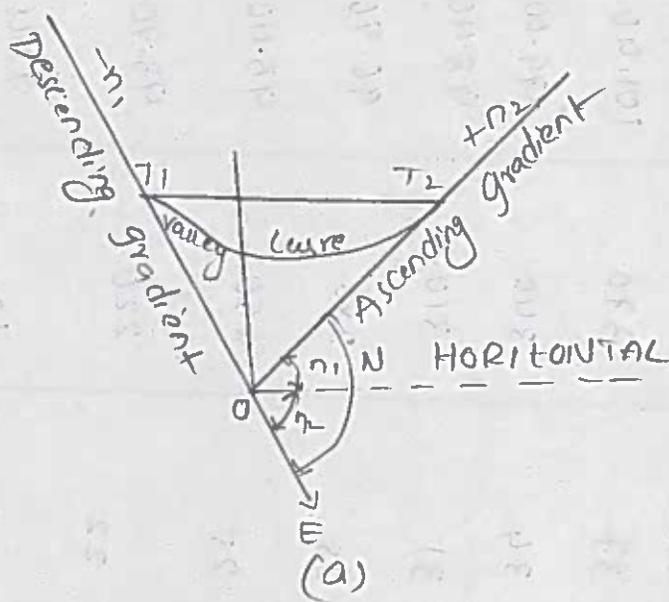
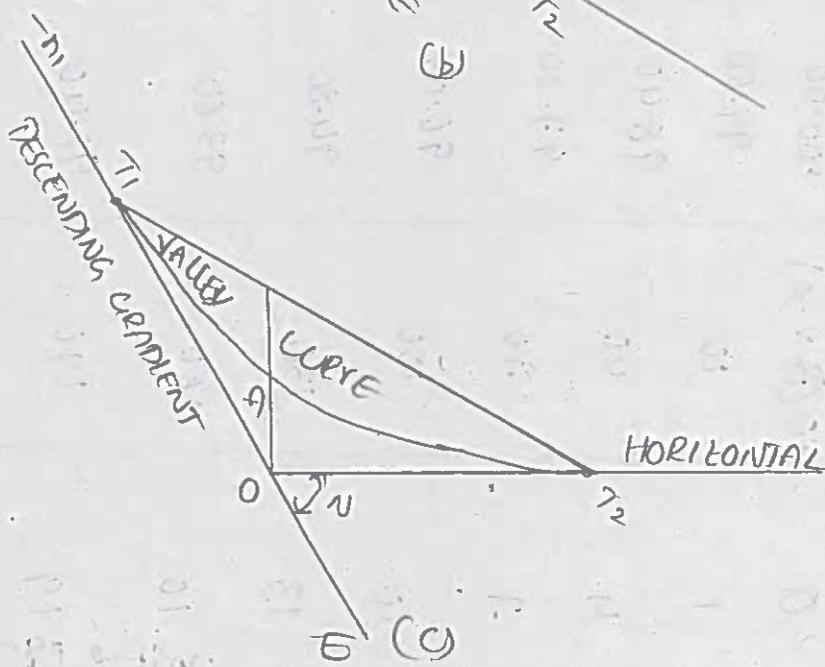
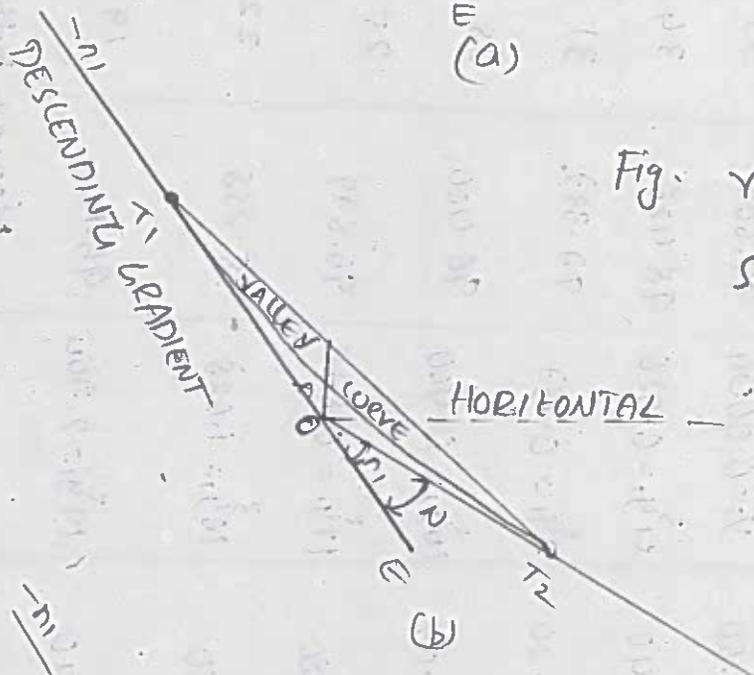


Fig. Valley curves showing total deflection angles.



# Design for valley curve

First half of the curve (in 25)      Second half of the curve (in 20)

No. of stations from B.V.C	Chainage B.V.C from (m)	R.L. of point on first grade line (m)	Ordinate h/w curve & 1 <sup>st</sup> grade curve (m)	R.L. of Station on Curve (m)	No. of stations from B.V.C (m)	Chainage from B.V.C (m)	R.L. of point on 2 <sup>nd</sup> grade line (m)	R.L. of station on curve (m)
Read downwards		Fall down Per 10m						
0	0 (B.V.C)	100.00	0.000	100.000	08	380	101.90	101.900
1	10	99.60	$y_1 = 0.0004$	99.600	37	370	101.40	101.400
4	40	98.40	$w_3 y_1 = 0.026$	98.426	34	340	99.00	99.926
7	70	97.20	$3y_1 = 0.137$	97.337	31	310	98.40	98.9537
10	100	96.00	$10y_1 = 0.400$	96.400	28	280	96.90	97.300
13	130	94.80	$13y_1 = 0.529$	95.679	25	250	95.40	96.279
16	160	93.60	$16y_1 = 1.638$	95.238	22	220	93.90	95.538
19	190	92.40	$19y_1 = 2.900$	95.144	19	190	92.40	95.144
							Base 0.5m	
							Per 10m	

Nearest to third  
Read decimal upwards

$$= 380 \left[ \frac{0.04}{2 \times 0.09} \right]^{1/2}$$

= 179.13m from the beginning of the curve.

Intercept between the curve and the tangent

$$= \left[ \frac{179.13}{10} \right]^3 \times 0.0004$$

$$= 2.299m$$

level along the tangent at 179.13m from the beginning of the curve.

$$= 100.00 - 0.04 \times 179.13$$

$$= 92.84m$$

level of the lowest point

$$= 92.84 + 2.299$$

$$= 95.139m.$$

Integration of Horizontal and Vertical Curves

→ The overall appearance of a highway can be enhanced considerably by judicious combination of the horizontal and vertical alignments.

→ Plan and profile of a road should not be designed independently but in unison so as to produce an appropriate three-dimensional effect.

→ Proper coordination in this respect will ensure safety, improve utility of the highway and contribute to overall aesthetics.