TRANSPORTATION ENGINEERING-I (BCE-28)

Unit 1-Part- II
Highway Geometric Design

By

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➢ ***Introduction:***

- Geometric design of a highway deals with the dimensions and layout of visible features of the highway such as horizontal and vertical alignments, sight distances and intersections.

- The geometrics of highway should be designed to provide efficiency in traffic operations with maximum safety at reasonable cost.

➢ ***Geometric design of highways deals with following elements:***

a. Cross section elements

b. Sight distance consideration

c. Horizontal alignment details

d. Vertical alignment details

e. Intersection elements

a. Cross section elements

i. Pavement surface characteristics

ii. Width of Pavement or Carriageway

iii. Cross Slope or Camber

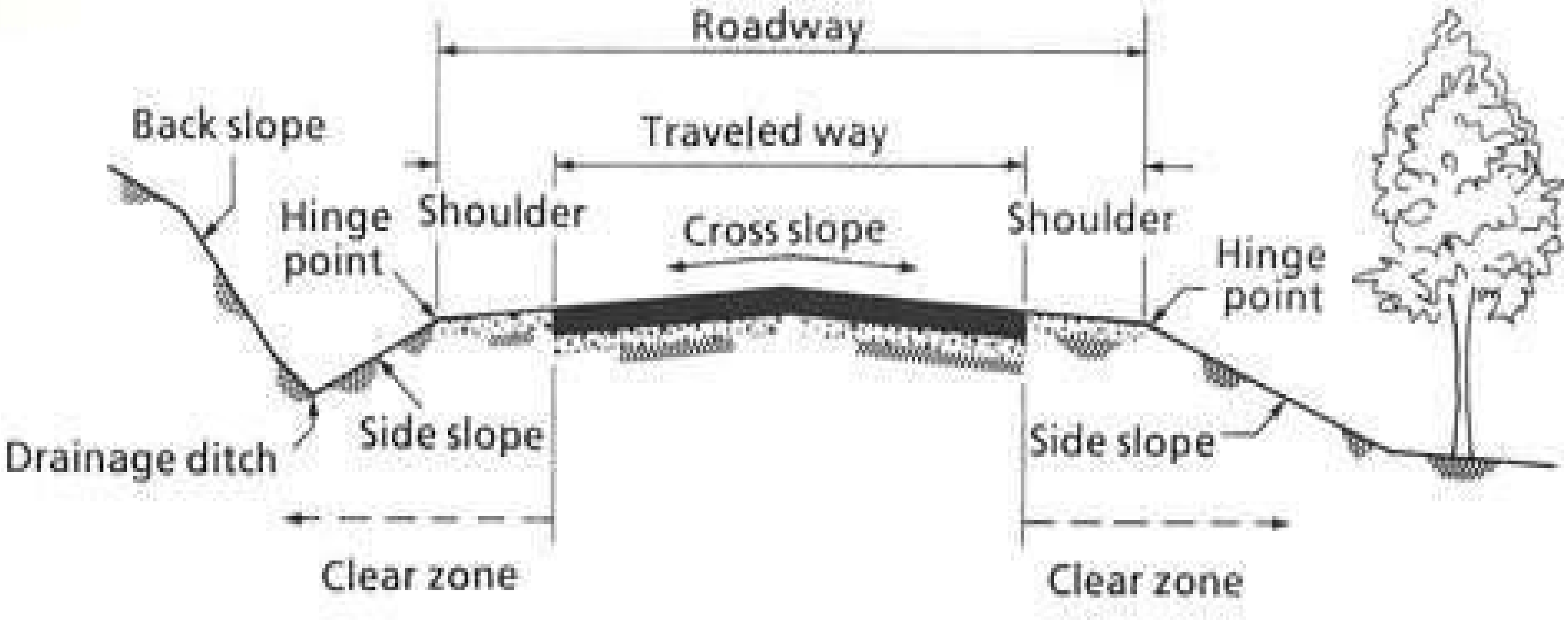
iv. Median or Traffic Separator

v. Kerbs

vi. Road Margins

vii. Width of Formation

Clear zone illustration



Hinge Point	Point where the slope rate changes.
Clear Zone	That area along the side of the traveled way <u>including the shoulder</u> that is available for recovery of an errant vehicle.

i. Pavement surface characteristics:

The important surface characteristics of the pavement are:

- Friction
- Unevenness
- Light reflecting characteristics
- Drainage of surface water

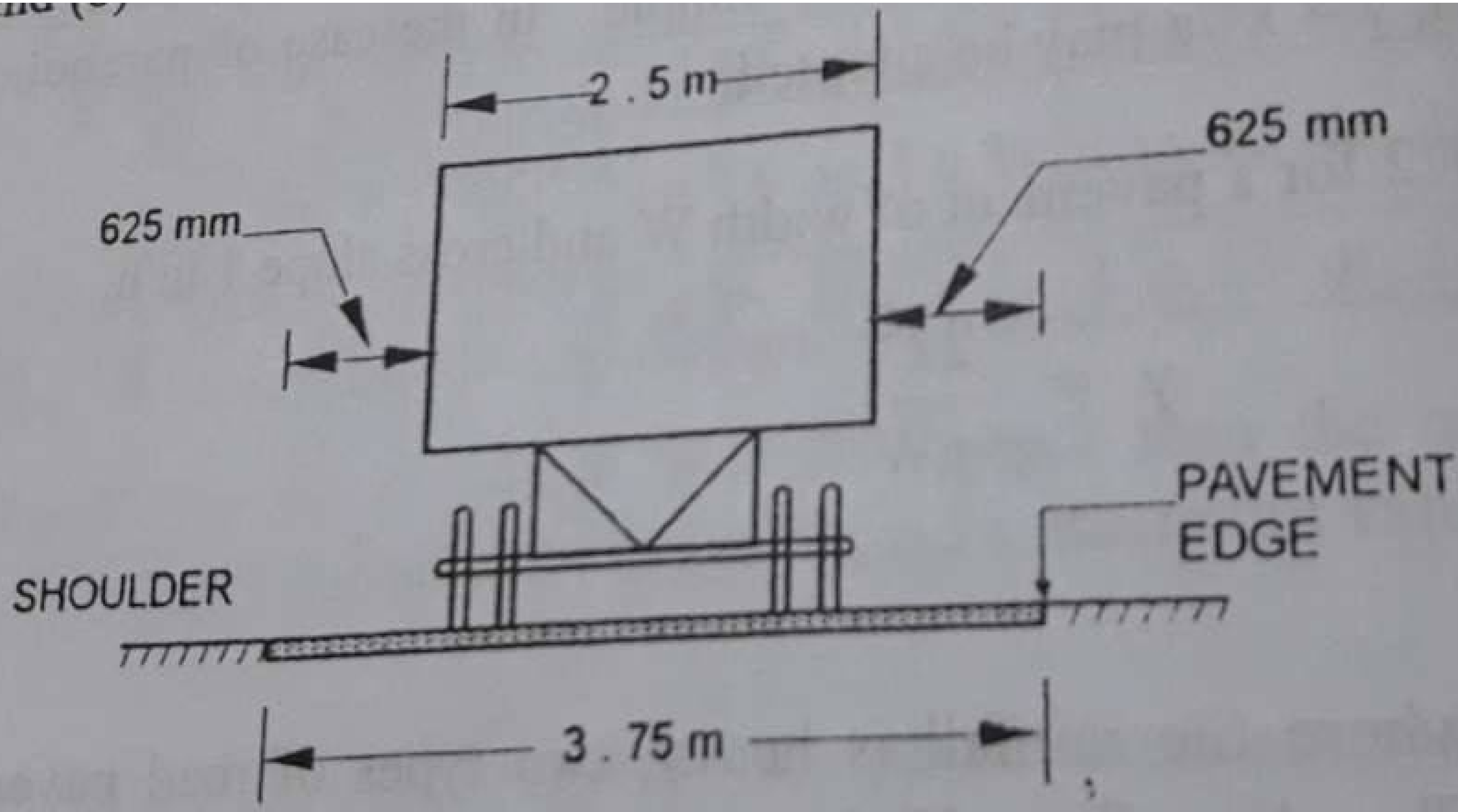
ii. Width of Pavement or Carriageway:

It is total width of road on which vehicles are allowed to move.

- The width of pavement depends on width of traffic lane and number of lanes.

- Width of lane is decided based on maximum width of heavy commercial vehicle (HCV) which is legally permitted to use the roadway.


Two lane two-way road
carriageway



(a) SINGLE LANE PAVEMENT

Fig. 4.2 Lateral placement of vehicles (cont..)

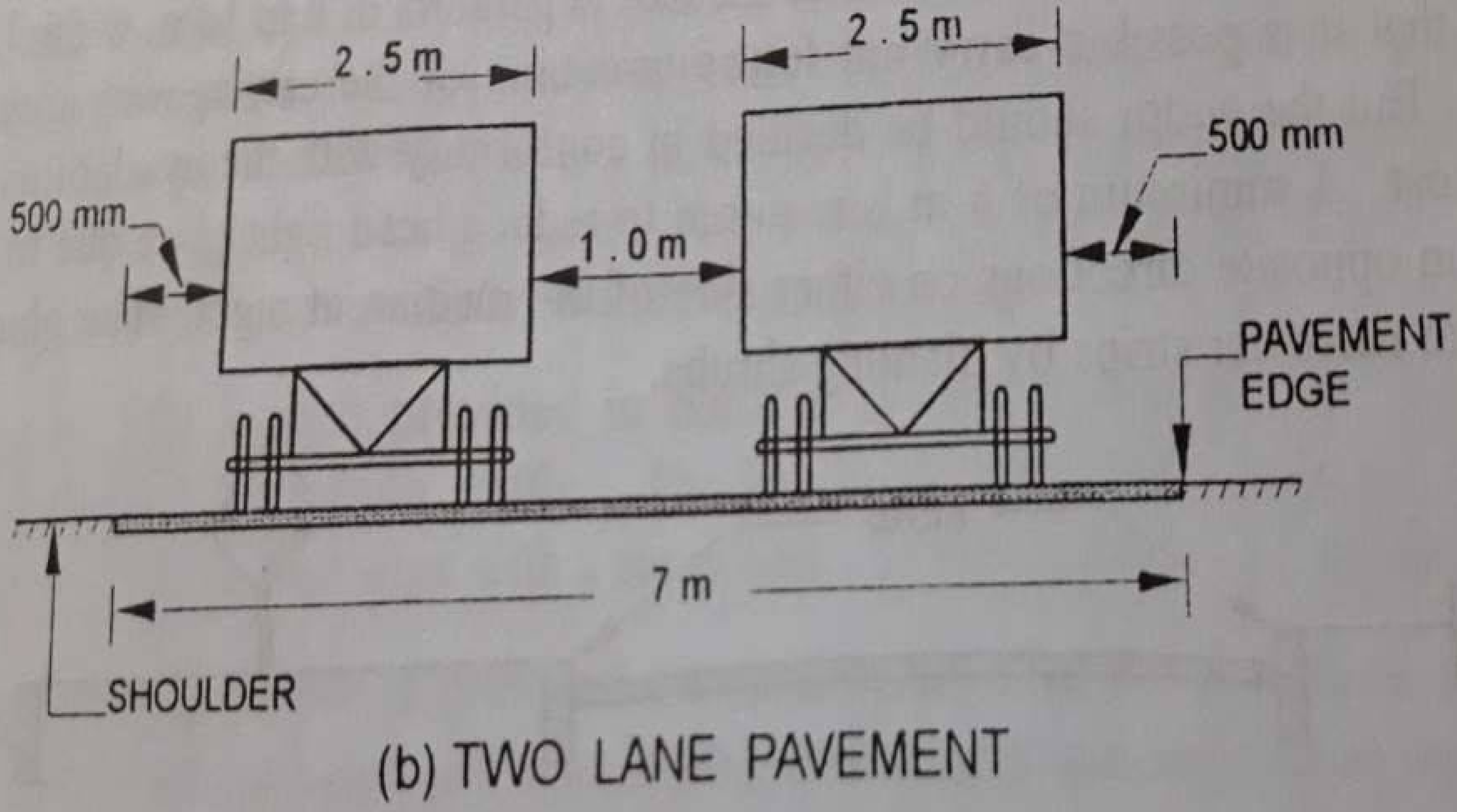


Fig. 4.2 Lateral placement of vehicles

•The width of carriageway for various classes of roads standardised by Indian Roads Congress (IRC) are given below:

Class Of Road	Width Of Carriageway (m)
Single lane road	3.75
Two lanes, without raised kerbs	7
Two lanes, with raised kerbs	7.5
Intermediate Carriageway	5.5
Multi-lane pavements	3.5 per lane

iii. Cross Slope or Camber:

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

- Drainage and disposal of water from pavement is considered important because of the following reason:

a. To maintain stability, surface condition and increase life of pavement.

b. To prevent stripping of bitumen from aggregates.

c.To prevent slipping of vehicles running at high speed.

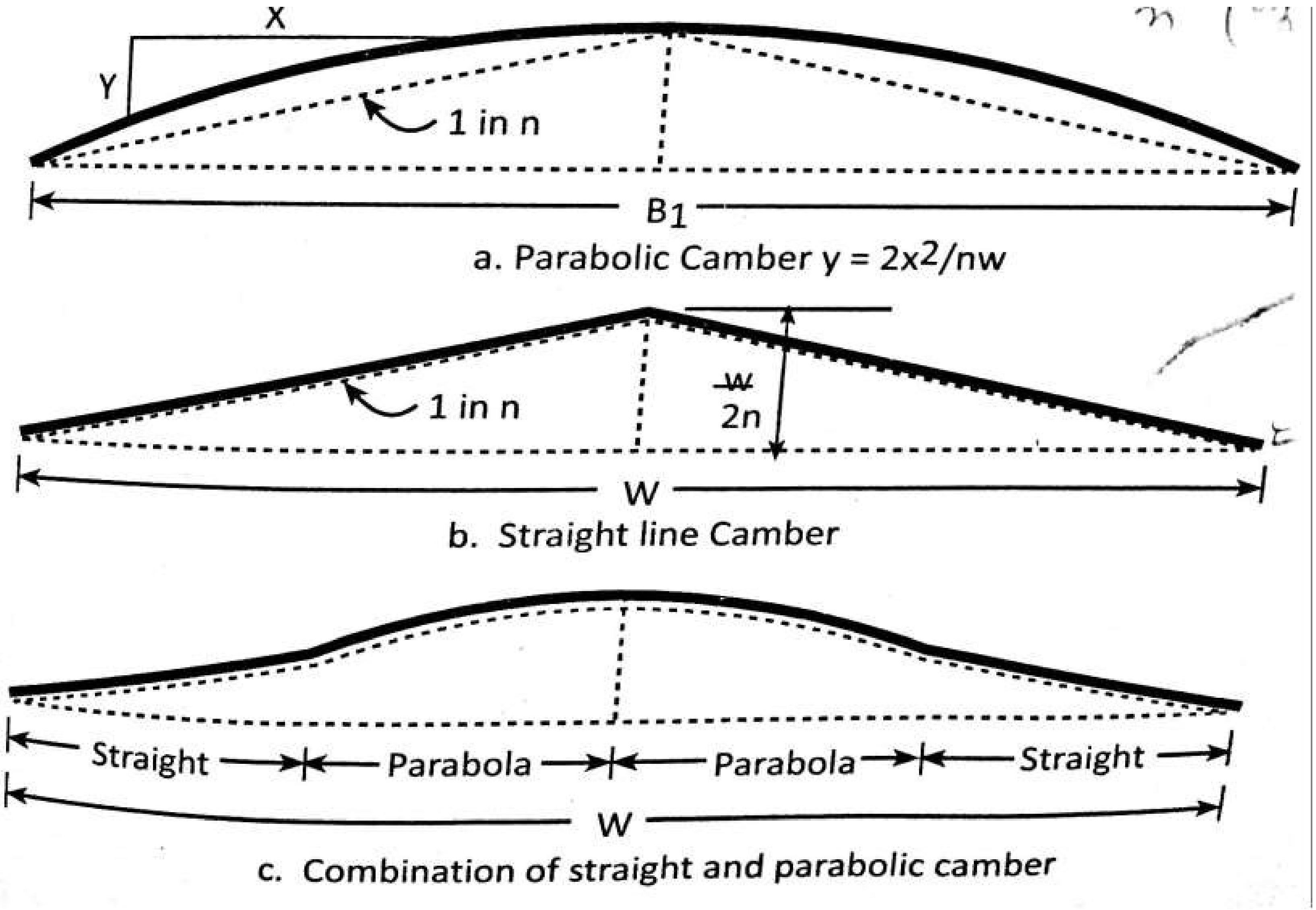
- The rate of camber or cross slope is usually designated by 1 in n or may also be expressed as a percentage.

- The required camber of a pavement depends on type of pavement surface and amount of rainfall.

•The values of camber recommended by IRC for different types of road surfaces are given below:

Sr.No	Type Of Road Surface	Range of camber in areas of	
		Heavy rainfall	Low rainfall
1	Cement concrete and thick bituminous surface	1 in 50 or 2 %	1 in 60 or 1.7 %
2	Thin bituminous surface	1 in 40 or 2.5%	1 in 50 or 2 %
3	Water bound macadam and gravel pavement	1 in 33 or 3%	1 in 40 or 2.5 %
4	Earth road	1 in 25 or 4%	1 in 33 or 3 %

➤ Shape Of Cross Slope:



iv. Median or Traffic Separator:

Median is provided between two sets of traffic lanes intended to divide the traffic moving in opposite directions.

- The main function of the median is to prevent head-on collision between vehicles moving in opposite directions on adjacent lanes.
- The traffic separators used may be in form of pavement markings, physical dividers or area separators.

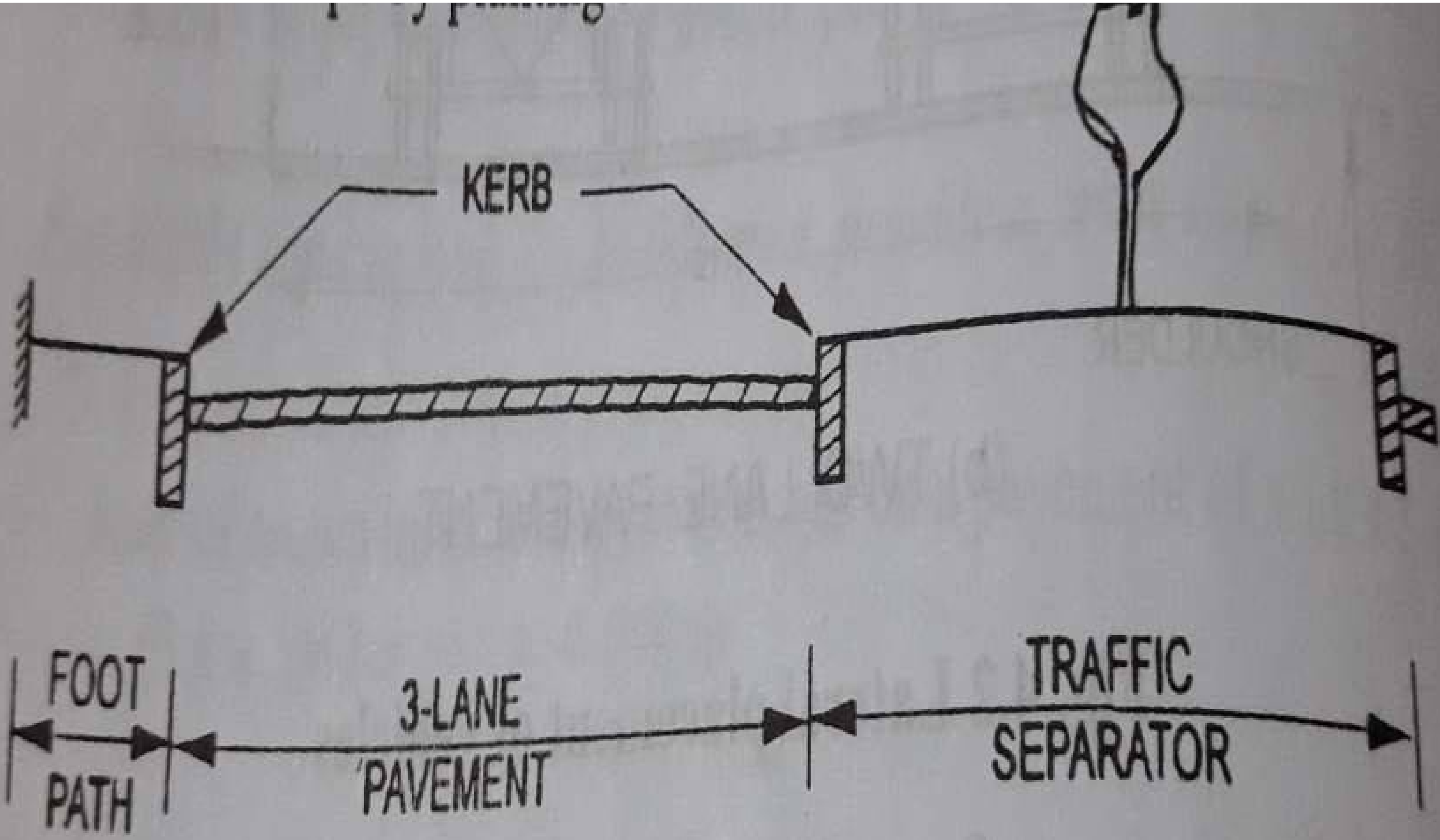


Fig. 4.3 Kerb and traffic separator

- The width of medians for roads standardised by Indian Roads Congress (IRC) are given below:

Sr.No	Type Of Road	Width Of Medians (m)	
		Desirable	Minimum
1	Expressway	15	10
2	Other Highways	5	3
3	At intersection of urban roads	5	1.2
4	On Long Bridges	1.5	1.2

v. Kerbs:

Kerb indicates the boundary between the pavement and median or foot path or shoulder.

- Kerbs may be mainly divided into three groups based on their functions:

a. Low kerb

b. Semi-barrier type kerb

c. Barrier type kerb

vi. Road Margins:

The various elements included in the road margins are:

a. Shoulder
b. Guard rail
c. Foot path
d. Drive way
e. Cycle track
f. Parking lane
g. Embankment slope.

vii. Width of Formation or Roadway:

Width of formation or roadway is the sum of widths of pavement or carriageway including separators, if any and the shoulders.

- Width of roadway are standardised by the Indian Roads Congress.

Sr. No	Road Classification	Roadway Width (m)	
		Plain and rolling terrain	Mountainous and steep terrain
1	National & State Highways a) Single Lane b) Two lane	12 12	6.25 8.80
2	Major District Roads a) Single Lane b) Two lane	9 9	4.75 -
3	Other District Roads a) Single Lane b) Two lane	7.5 9	4.75 -
4	Village Roads ,Single Lane	7.5	4

➢ ***Design of Horizontal Alignment:***

Various design elements to be considered in the horizontal alignment are :

a. Design speed

b. Horizontal curve

c. Super elevation

d. Type and length of transition curves

e. Widening of pavement on curves

f. Set-back distance

a. Design speed

- The design speed is the main factor on which geometric design elements depends.

- The design speed of roads depends upon

i) Class of the road

ii) Terrain

Classification of Terrain

Terrain Classification	**Cross Slope Of Country in %**
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	Greater than 60

Design Speed On highways

Table 4.11 Design speeds on rural highways

Road classification	Design speed in kmph for various terrains							
	Plain		Rolling		Mountainous		Steep	
	Ruling	Min.	Ruling	Min.	Ruling	Min.	Ruling	Min.
Expressways	120	100	100	80	80	60	80	60
National & State Highways	100	80	80	65	50	40	40	30
Major District Roads	80	65	65	50	40	30	30	20
Other District Roads	65	50	50	40	30	25	25	20
Village Roads	50	40	40	35	25	20	25	20

b. 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 centrifugal force acts horizontally outwards through the centre of gravity of the vehicle.

- The centrifugal force is given by the equation:

$$P = Wv^2/gR$$

where,

P=centrifugal force in kg

W=Weight of the vehicle in kg

R=radius of the circular curve in m

v=speed of the vehicle in m/s

g=acceleration due to gravity=9.8 m/s2

- P/W is known as the centrifugal ratio or the impact factor. The centrifugal ratio is thus equal to v^2/gR.
- The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects:

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

ii. Tendency to skid the vehicle laterally, outwards

i. Overturning effect:

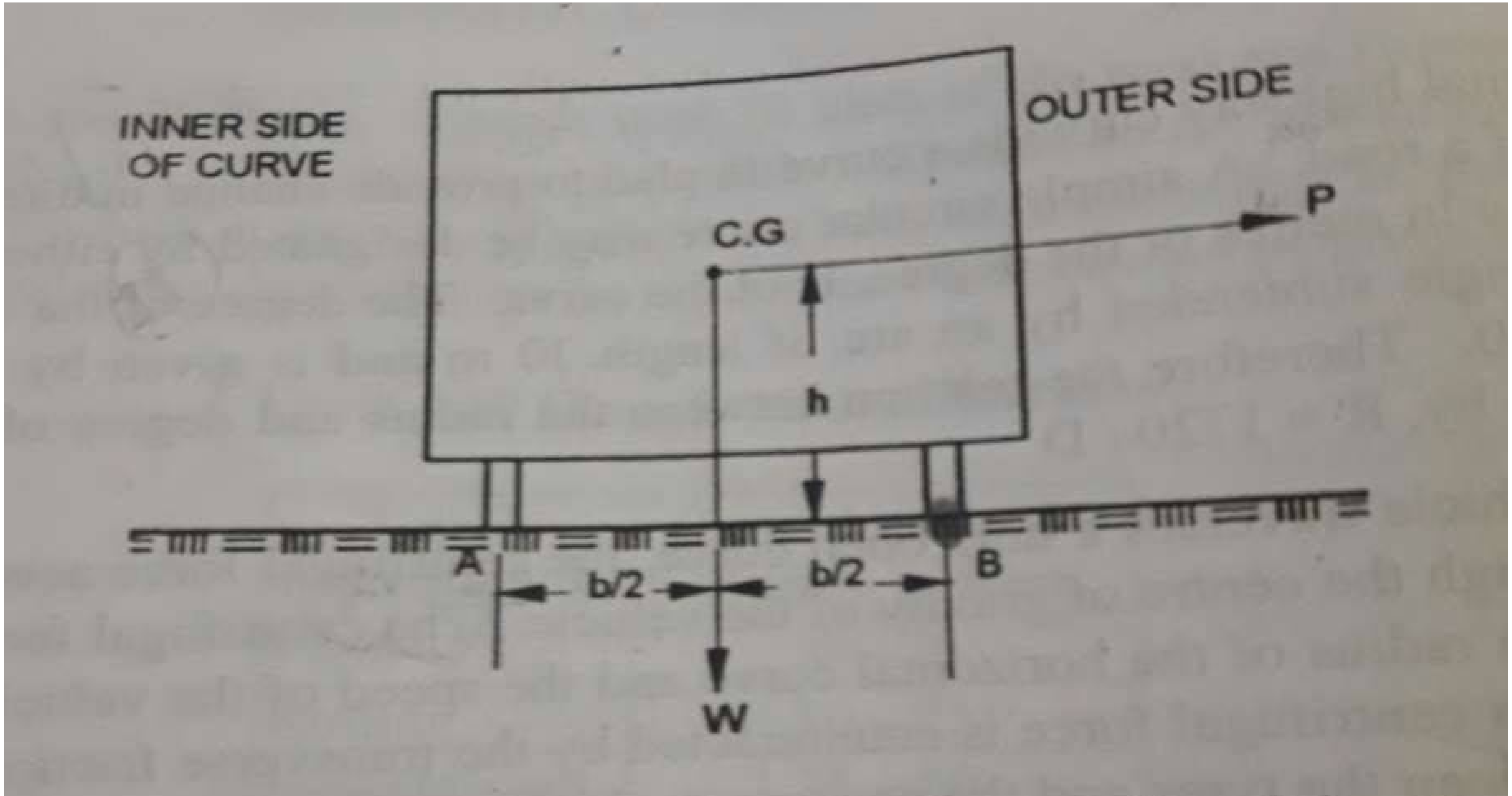
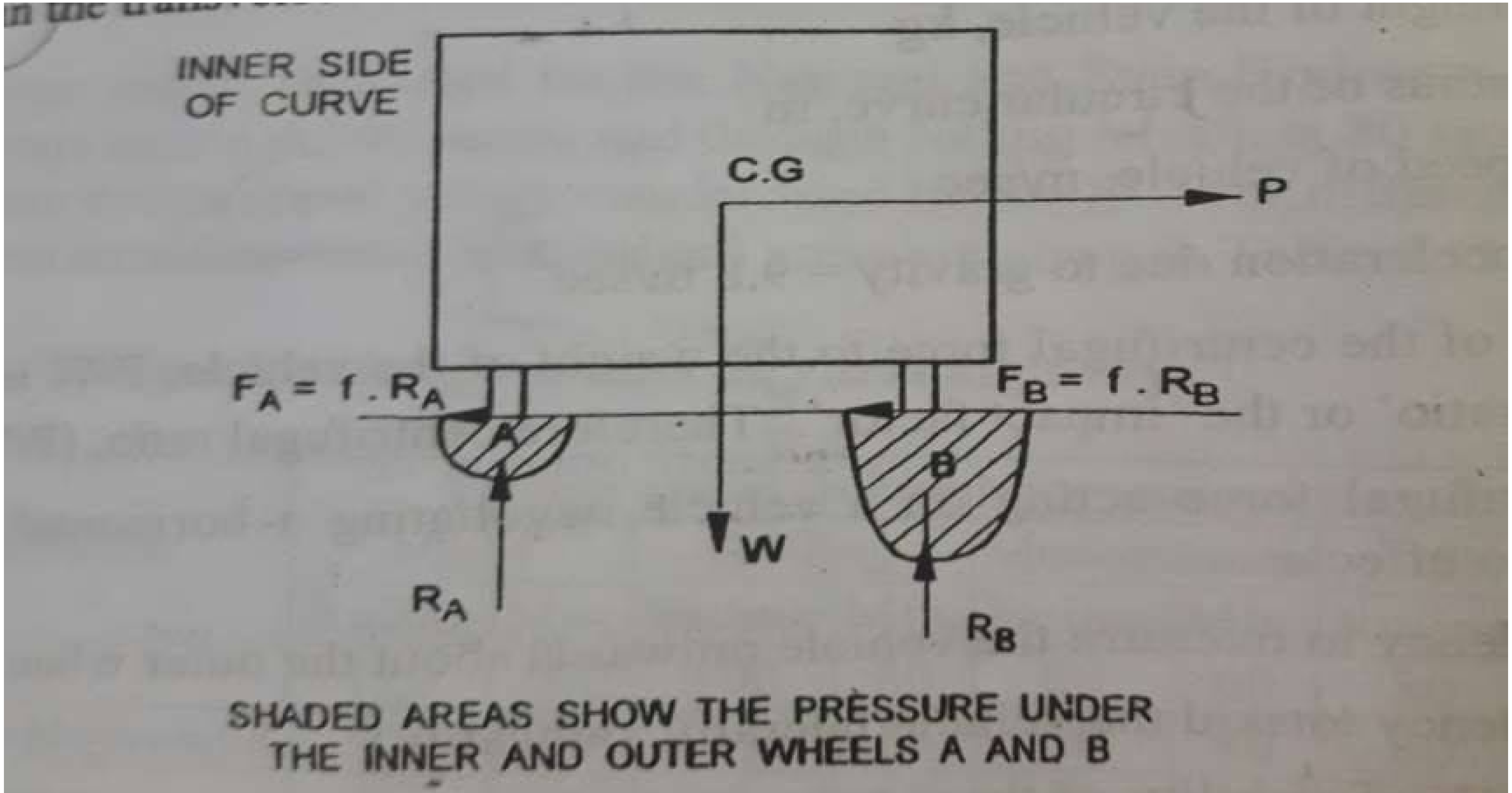


Fig. 4.18 Overturning effect due to centrifugal force

- The equilibrium condition for overturning will occur when $Ph = Wb/2$, or when $P/W = b/2h$.

- This means that there is danger of overturning when the centrifugal ratio P/W or $v^2/g R$ attains a values of $b/2h$.

ii. Transverse skidding effect:



4.19 Transverse skidding effect due to centrifugal force

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

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

- Since P = f W, the centrifugal ratio P/W is equal to ‘f ‘.
- In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction there is a danger of lateral skidding.

•‘f’ is less than ‘b/2h’,the vehicle would skid and not overturn.

•‘b/2h’ is lower than ‘f’, the vehicle would overturn on the outer side before skidding.

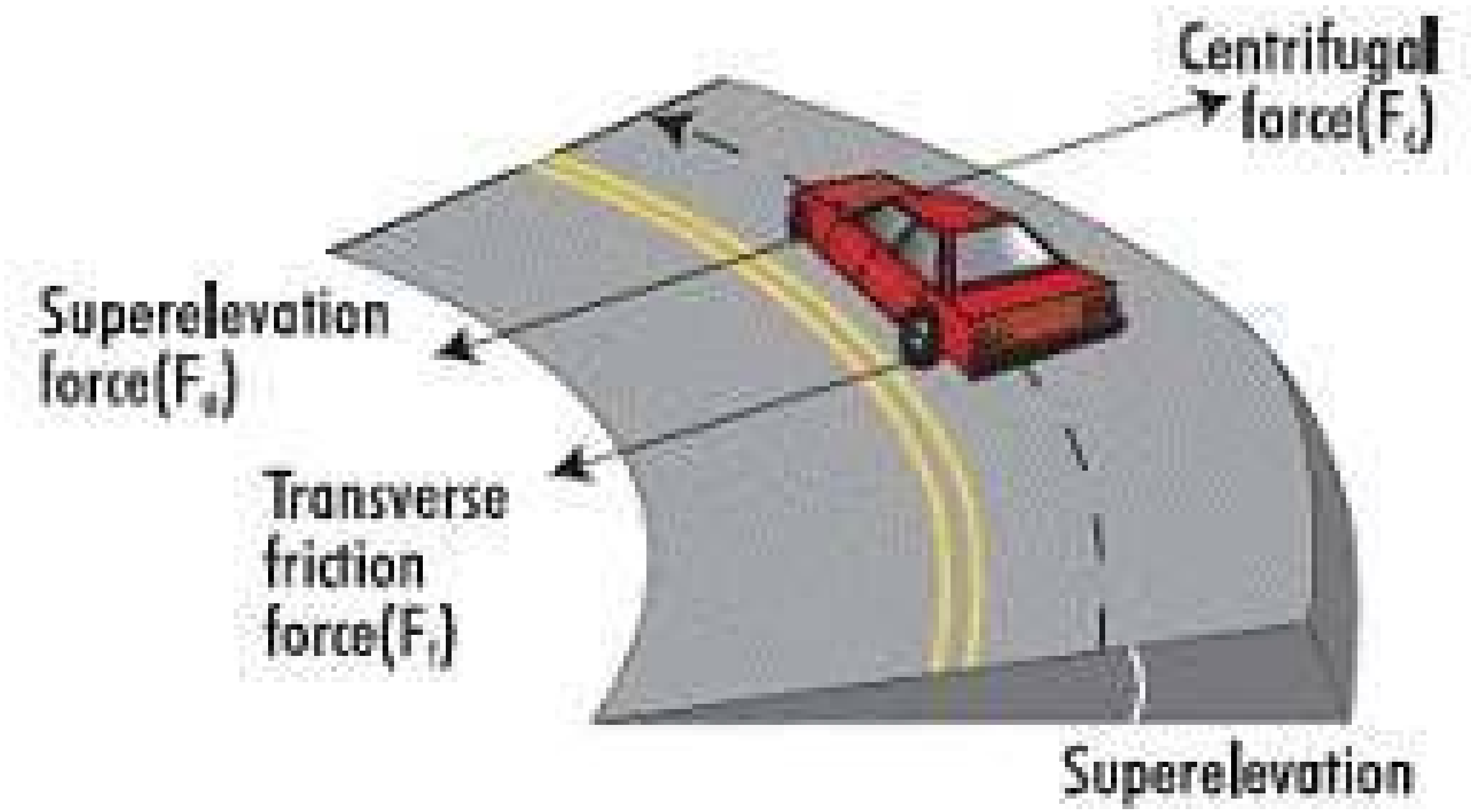
•Thus the relative danger of lateral skidding and overturning depends on whether f is lower or higher than

c. Super elevation (e):

- 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 Super elevation or cant or banking.

•The Super elevation 'e' is expressed as the ratio of the height of outer edge with respect to the horizontal width.



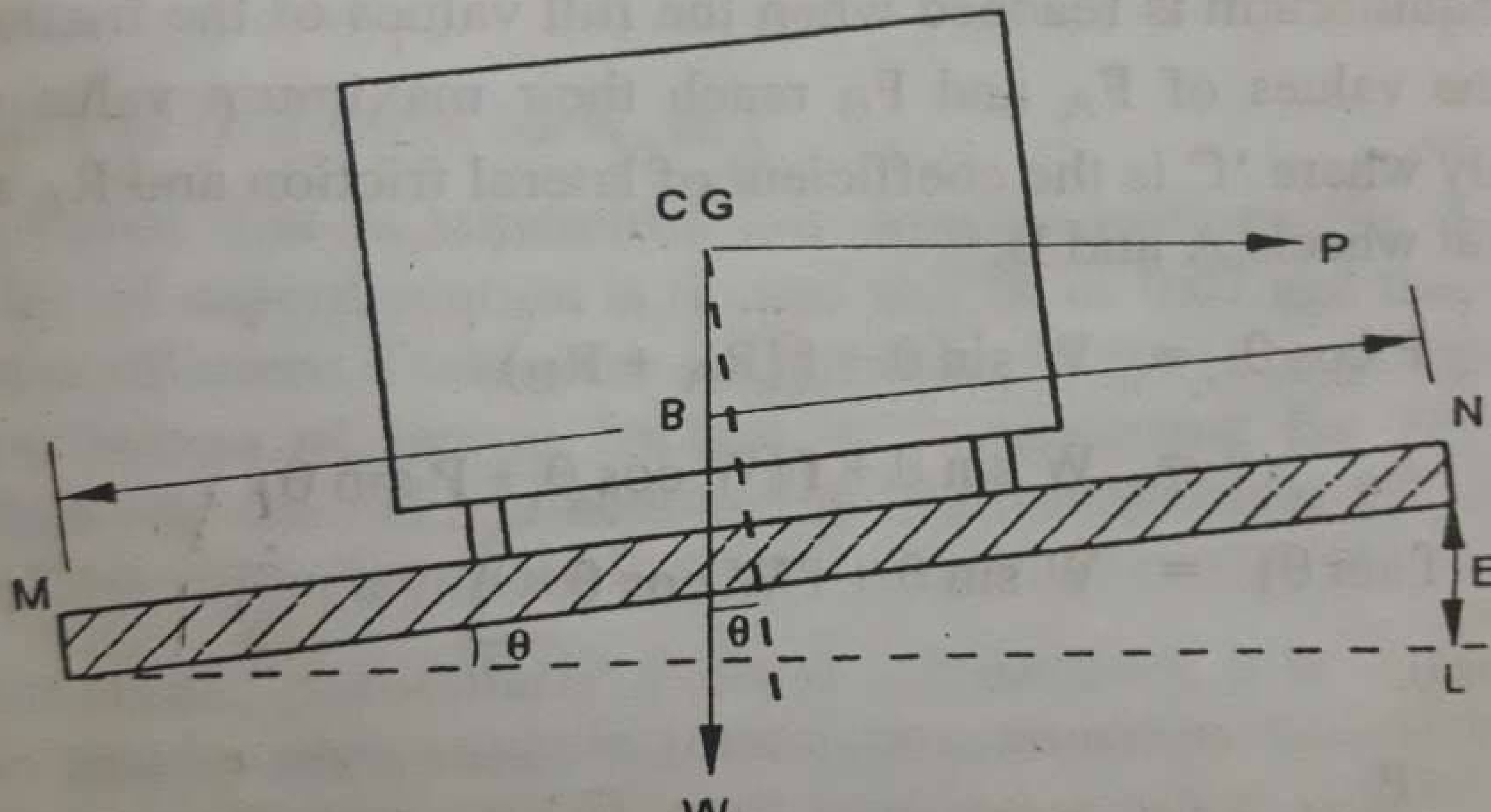


Fig. 4.20 Superelevated pavement section

➢Analysis of Superelevation

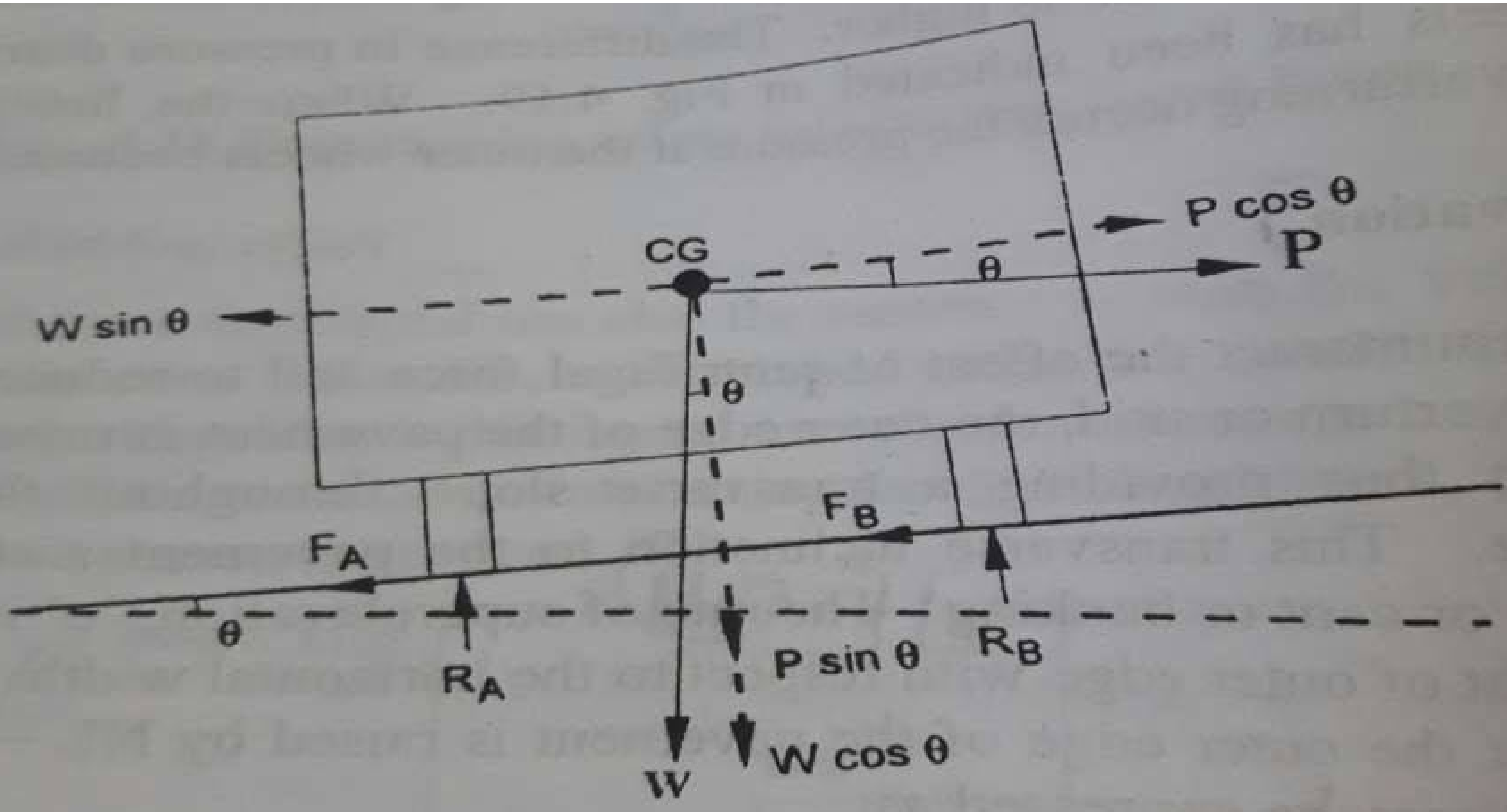


Fig. 4.21 Analysis of superelevation

- For equilibrium condition,

$$P\cos\theta = W\sin\theta + F_A + F_B$$

$$P\cos\theta = W\sin\theta + f.R_A + f.R_B$$

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

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

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

Dividing by $W\cos\theta$,

$$P/W(1 - f\tan\theta) = \tan\theta + f$$

Centrifugal ratio $= P/W = \tan\theta + f / (1 - f\tan\theta)$

- The value of coefficient of lateral friction ‘f’ is taken as 0.15 and tanθ i.e. super elevation seldom exceeds 7-10%.

- Therefore,

  Centrifugal ratio =P/W = tanθ+f

  $$P/W = e + f \quad \ldots\ldots i$$

  $$\text{but } P/W = v^2/gR \quad \ldots\ldots ii$$

- Therefore, the general equation for the design of super elevation is given by,

$$\mathbf{e + f = v^2/gR}$$

- If 'V' speed of the vehicle is in kmph,

$$e + f = V^2/127R$$

where,

e=rate of Superelevation=tanΘ

f = design value of lateral friction coefficient = 0.15

v = speed of the vehicle, m/sec

R = radius of the horizontal curve, m

g = acceleration due to gravity = 9.81 m/sec²

➢Maximum Superelevation

•Indian Roads Congress (IRC) had fixed the maximum limit of Superelevation in plan and rolling terrains and is snow bound areas as 7.0 %.

•On hill roads not bound by snow a maximum Superelevation upto10% is recommended.

•On urban road stretches with frequent intersections, it may be necessary to limit the maximum Superelevation to 4.0 %.

➢Minimum Superelevation

- From drainage consideration it is necessary to have a minimum cross slope to drain off the surface water. If the calculated superelevation is equal to or less than the camber of the road surface, then the minimum superelevation to be provided on horizontal curve may be limited to the camber of the surface.

➢Steps For Superelevation Design

Step-I: The superelevation for 75 percent of design speed is calculated, neglecting the friction.

$$e = (0.75v)^2 / gR \quad \text{.....if 'v' is in m/sec}$$

$$e = (V)^2 / 225R \quad \text{.....if 'V' is in kmph}$$

Step-II: If the calculated value of 'e' is less than 7% or 0.07 the value so obtained is provided.

- If the value of 'e' exceeds 7% or 0.07 then provides maximum superelevation equal to 7% or 0.07 and proceed with step-III or IV.

Step-III: Check the coefficient of friction developed for the maximum value of e =0.07 at the full value of design speed.

$f = v^2/gR - 0.07$ …..if 'v' is in m/sec

$f = V^2/127R - 0.07$ …..if 'V' is in kmph

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

Step-IV: The allowable speed at the curve is calculated by considering the design coefficient of lateral friction and the maximum superelevation.

$$\mathbf{e + f = 0.07 + 0.15 = v_a^2 / gR = V_a^2 / 127R}$$

$$\mathbf{e + f = 0.22 = v_a^2 / gR = V_a^2 / 127R}$$

- Safe allowable speed (v_a or V_a) is calculated as:

$$va = \sqrt{0.22gR} \text{ m/s}$$

$$Va = \sqrt{27.94R} \text{ kmph}$$

•If the allowed speed, as calculated above is higher than the design speed, then the design is adequate and provides a superelevation of ‘e’ equal to 0.07.

•If the allowable speed is less than the design speed, the speed is limited to the allowed speed calculated above and appropriate warning sign and speed limit regulation sign are installed to restrict and regulate the speed.

➢ ***Attainment of superelevation in the field:***

The attainment of superelevation may be split up into two parts:

a. Elimination of crown of the cambered section

b. Rotation of pavement to attain full superelevation

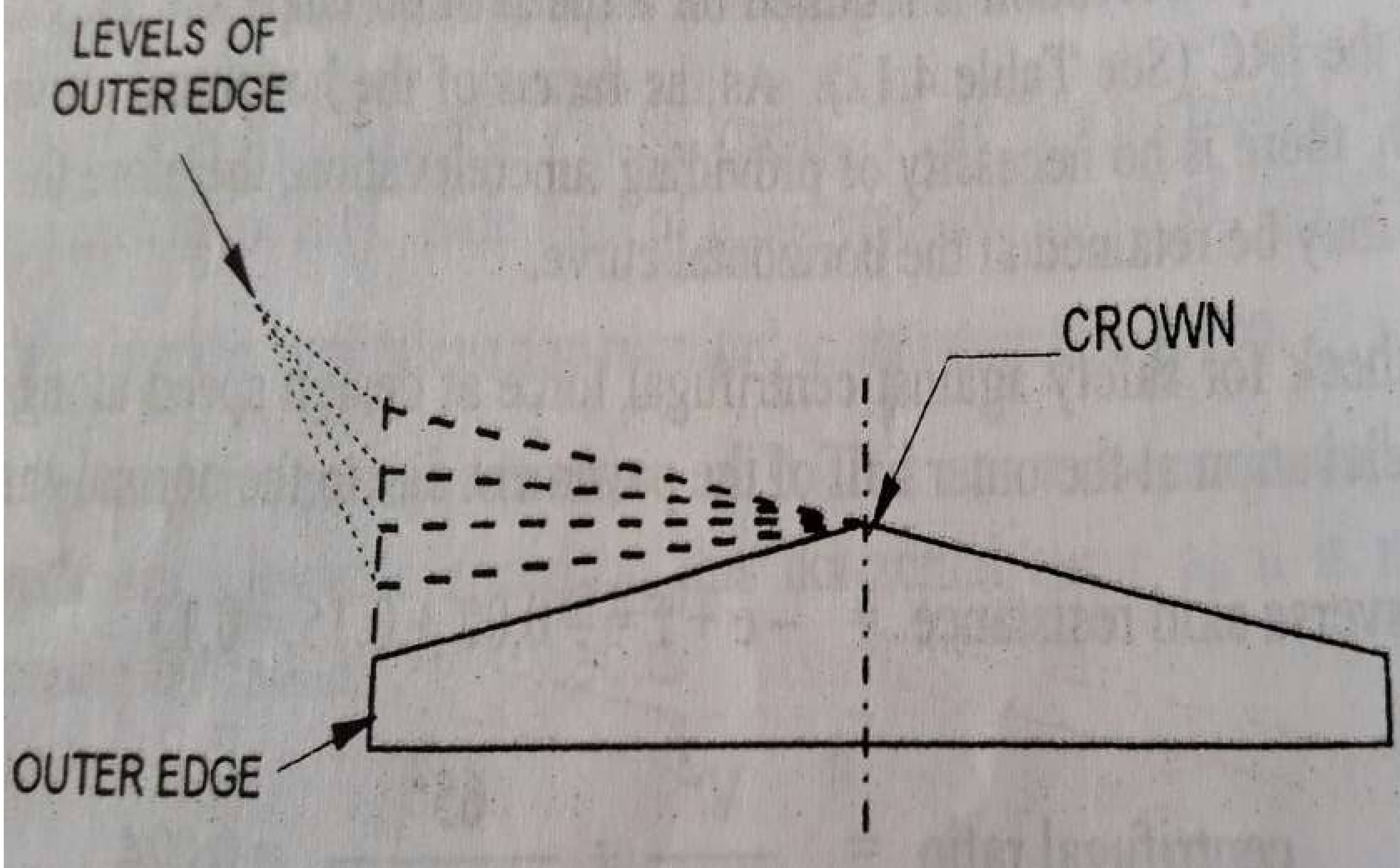
a. Elimination of crown of the cambered section:

1stMethod:Outer edge rotated about the crown

- Disadvantages

Small length of road –cross slope less than camber.

Drainage problem in outer half.



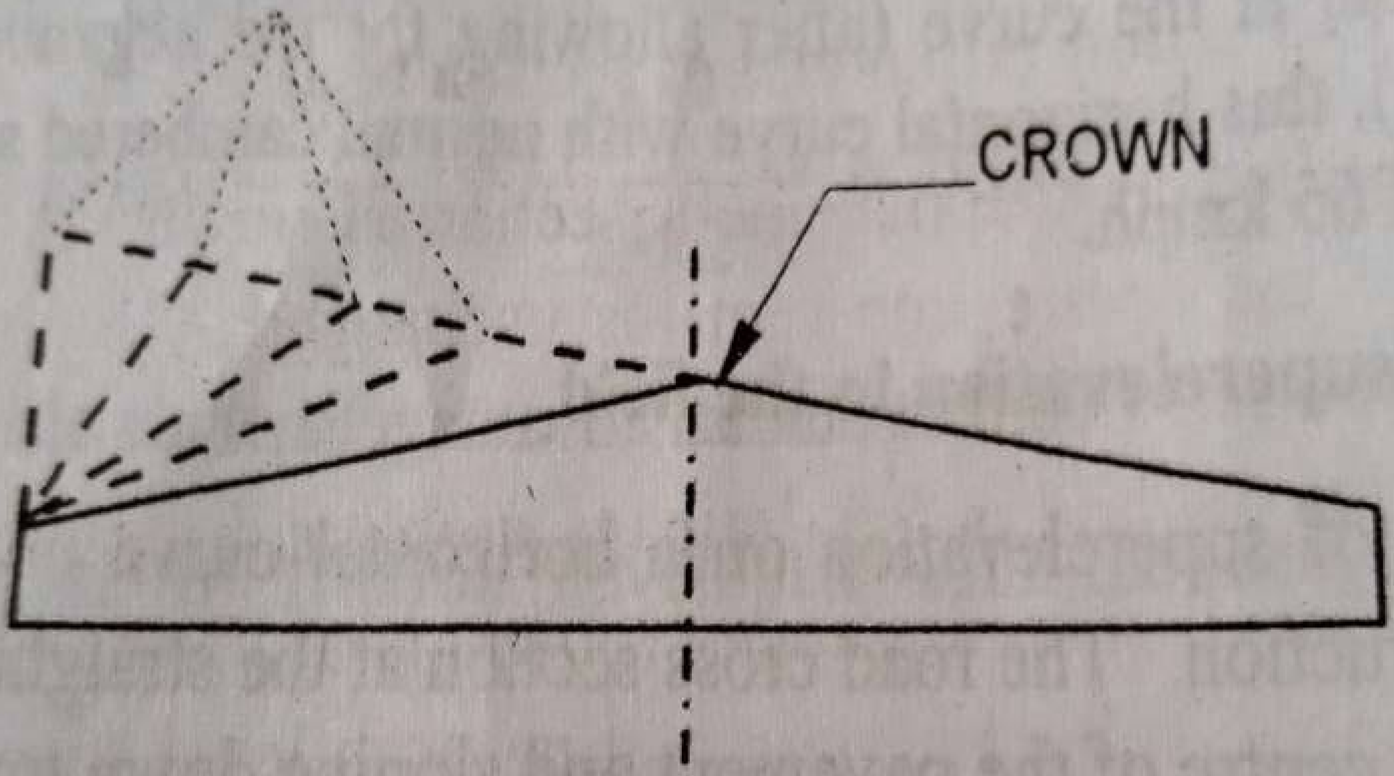
(a) OUTER EDGE ROTATED ABOUT THE CROWN

2ndMethod: Crown shifted outwards

- Disadvantages

Large negative superelevation on outer half.

Drivers have the tendency to run the vehicle along shifted crown.

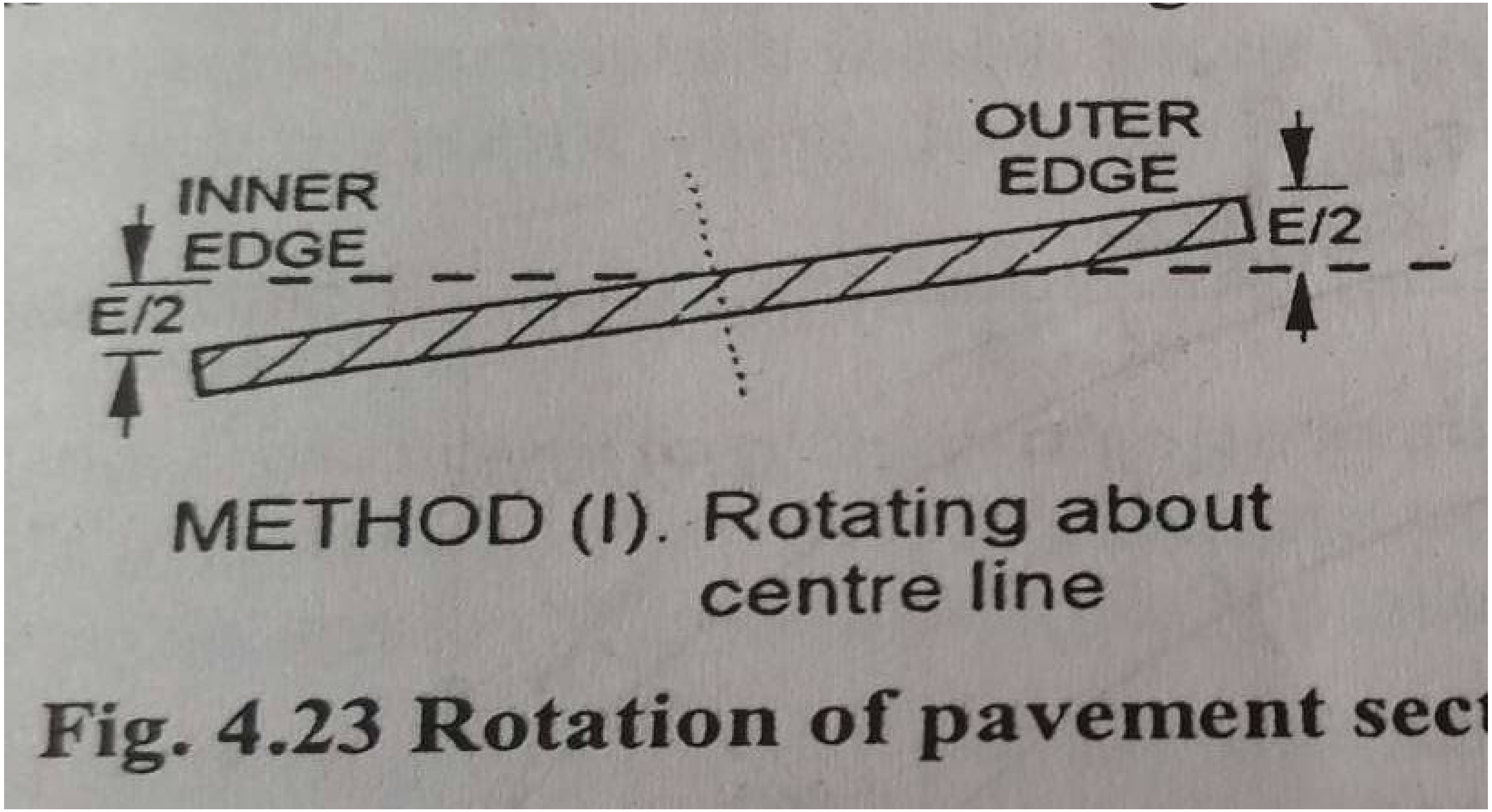


(b) CROWN SHIFTED OUTWARDS

(DIAGONAL CROWN METHOD)

b. Rotation of pavement to attain full superelevation

1st Method: Rotation about the Centre line



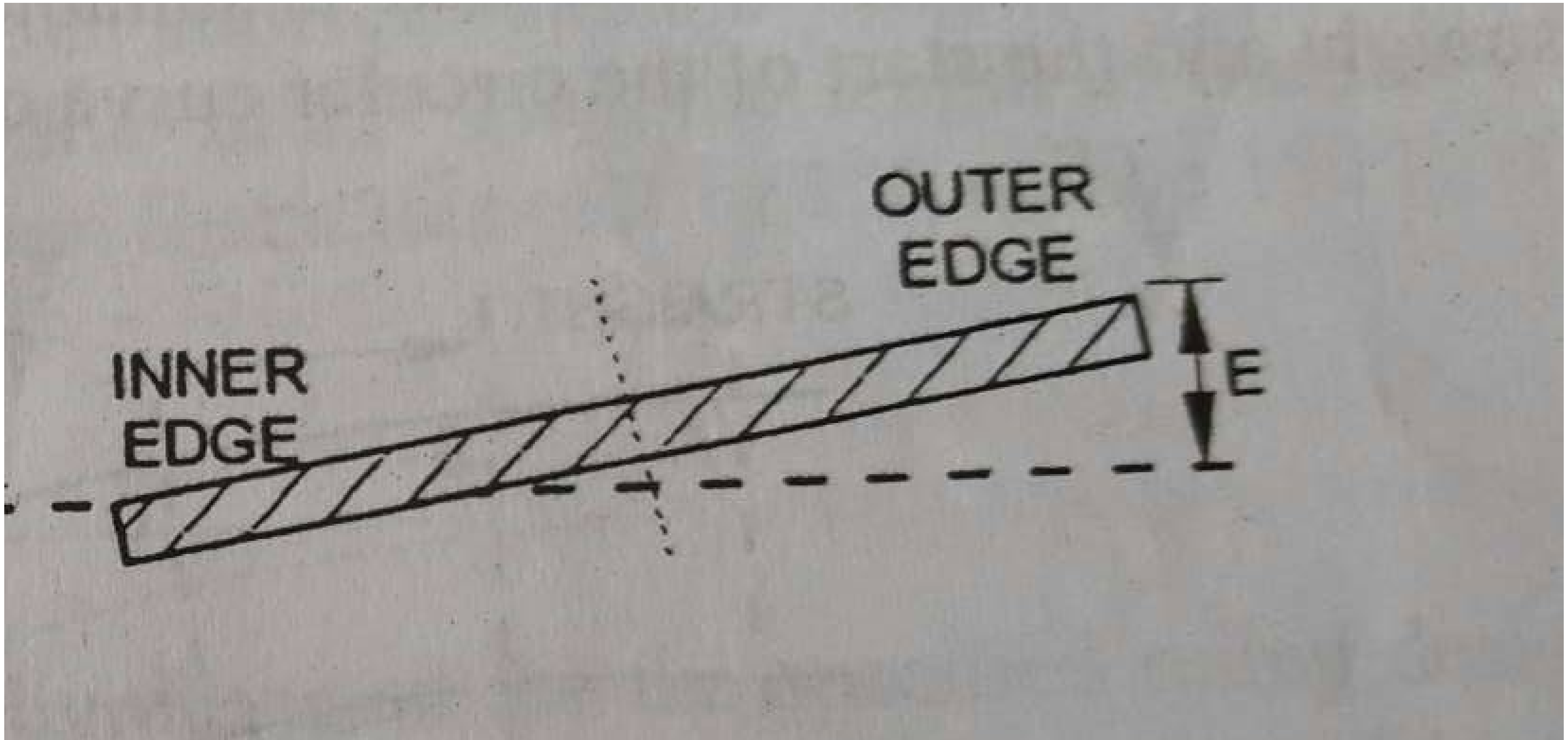
Advantages

- Earthwork is balanced
- Vertical profile of the C/L remains unchanged

Disadvantages

•Drainage problem: depressing the inner edge below the general level

2nd Method: Rotation about the Inner edge



METHOD (II). Rotating about the inner edge

Advantages

- No drainage problem

Disadvantages

- Additional earth filling
- Centre line of the pavement is also raised (vertical alignment of the road is changed)

➢ ***Radius of Horizontal Curve:***

$$\mathbf{e + f = v^2/gR = V^2/127R}$$

- If maxm. Allowable superelevation rate has been fixed as 7% and lateral friction f is 0.15 then,

$$0.07 + 0.15 = v^2/gR = V^2/127R$$

$$\mathbf{0.22 = v^2/gR = V^2/127R}$$

- If design speed is decided ruling and minimum radius is calculated as,

$$\mathbf{R_{ruling} = v^2/g(e + f) = V^2/127(e + f)}$$

$$\mathbf{R_{min} = v'^2/g(e + f) = V'^2/127(e + f)}$$

where,

e=rate of Superelevation

f = design value of lateral friction coefficient
= 0.15

v or V= design speed of the vehicle, m/sec or kmph

v’ or V’= minimum design speed of the vehicle, m/sec or kmph

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

➢ ***Gradients:***

- Gradient is the rate of rise or fall along the

‘ length of road with respect to the horizontal.

- It is expressed as a ratio of 1 in n or also as percentage such as n%.

➢ ***Types Of Gradients:***

- Gradients are divided into four categories:

‘

a. Ruling gradient

b. Limiting gradient

c. Exceptional gradient

d. Minimum gradient

a. Ruling gradient:

- Ruling gradient is the maximum gradient within which the designer attempts to design the vertical profile of a road.
- Ruling gradient is also known as 'Design gradient'.
- For selection of ruling gradient factors such as type of terrain, length of the grade, speed, pulling power of vehicle etc are considered.

b. Limiting gradient:

- Steeper than ruling gradient. In hilly roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, it depends on

a. Topography

b. Cost in constructing the road

c. Exceptional gradient:

- Exceptional gradient are very steeper gradients given at unavoidable situations.
- They should be limited for short stretches not exceeding about 100 m at a stretch.

Type of terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and rolling	3.3 % 1 in 30	5% 1 in20	6.7 % 1 in 15
Mountainous and steep having elevation more than 3000 m above MSL	5% 1 in20	6 % 1 in 16.7	7 % 1 in 14.3
Mountainous and steep having elevation more than 3000 m above MSL	6 % 1 in 16.7	7 % 1 in 14.3	8 % 1 in 12.5

d. Minimum gradient:

- This is important only at locations where surface drainage is important.
- Camber will take care of the lateral drainage.
- But the longitudinal drainage along the side drains require some slope for smooth flow of water.

- Therefore minimum gradient is provided for drainage purpose and it depends on the rainfall, type of soil and other site conditions.

- A minimum of 1in500 may be sufficient for concrete drain and 1in 200 or 1 in 100 for open soil drains.

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. OR
- It is the length of road visible ahead to the driver at any instance.

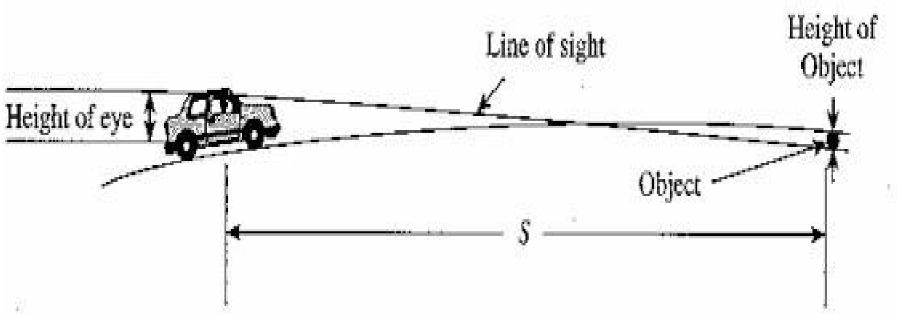
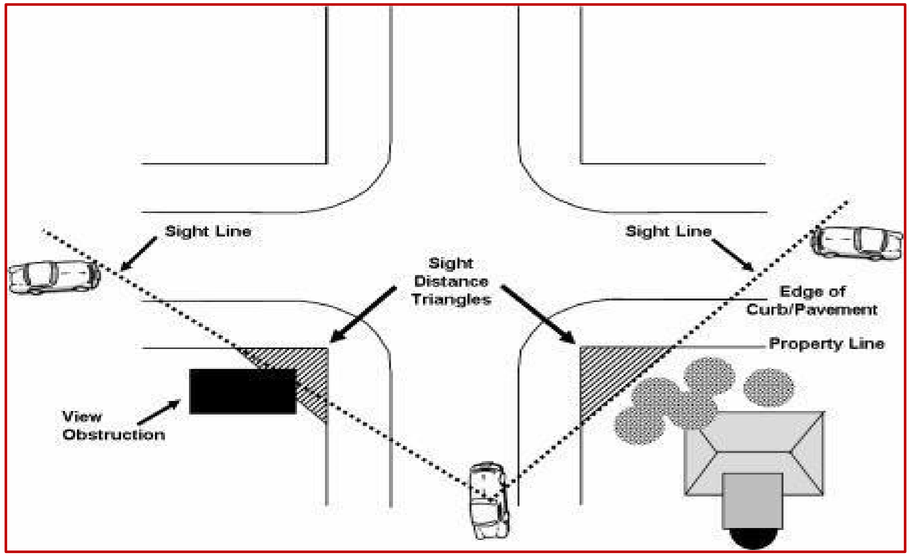


FIGURE 4.8
Stopping sight distance diagram for crest vertical curve.



Types of sight distance

- Stopping or absolute minimum sight distance(SSD)
- Safe overtaking or passing sight distance (OSD)
- Safe sight distance for entering into uncontrolled intersection.
- Intermediate sight distance
- Head light sight distance

Stopping sight distance:

- The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

Over taking sight distance:

- 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 sight distance.

Sight distance at intersection:

- Driver entering an uncontrolled intersection (particularly unsignalised Intersection) has sufficient visibility to enable him to take control of his vehicle and to avoid collision with another vehicle.

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 vehicles.

Head light sight distance:

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

Stopping Sight Distance

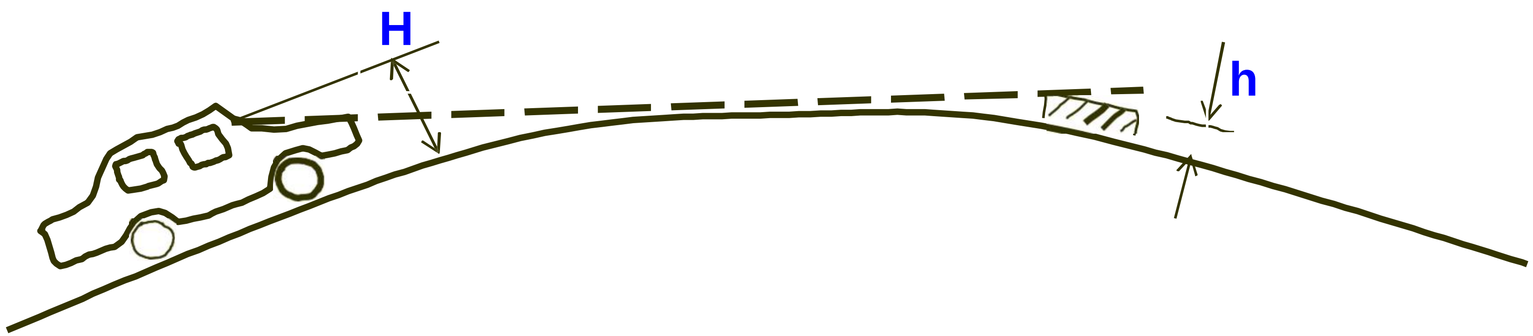
- SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

It depends on:

- Feature of road ahead
- Height of driver's eye above the road surface(1.2m)
- Height of the object above the road surface(0.15m)

Criteria for measurement

- Height of driver's eye above road surface (H)
- Height of object above road surface(h)



IRC

- H = 1.2m
- h = 0.15m

Factors affecting the SSD

- Total reaction time of driver
- Speed of vehicle
- Efficiency of brakes
- Frictional resistance between road and tyre
- Gradient of road

Total reaction time of driver:

- It is the time taken from the instant the object is visible to the driver to the instant the brake is effectively applied, it divide into types
  1. Perception time
  2. Brake reaction time

Perception time:

- It is the time 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.

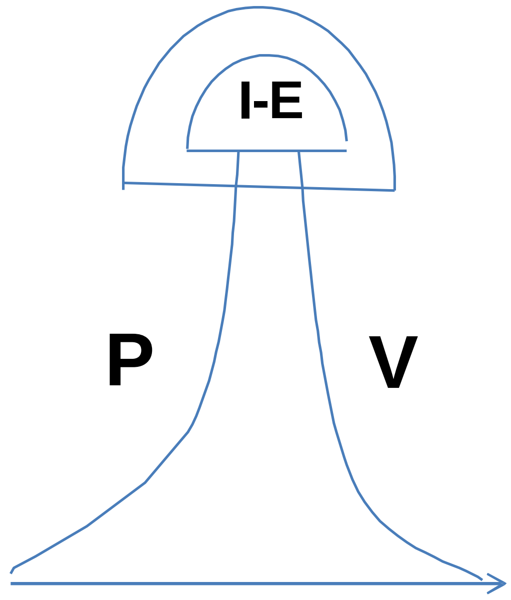
Brake reaction time:

- The brake reaction also depends on several factor including the skill of the driver, the type of the problems and various other environment factor.
- Total reaction time of driver can be calculated by "PIEV" theory

“PIEV” Theory

Total reaction time of driver is split into four parts:

- P-perception, I-intellection
- I -
- E-Emotion
- V-Volition



Perception

- It 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 chord.

Intellection:

•It is the time required for understanding the situation.

Emotion:

- It is the time elapsed during emotional sensation and disturbance such as fear, anger or any other emotional feeling such as superstition etc, with reference to the situation.

Volition:

- It is the time taken for the final action

Total reaction time of driver may be vary from 0.5 sec to 4 sec

Analysis of SSD

- The stopping sight distance is the sum of lag distance and the braking distance.

Lag distance:

- It is the distance, the vehicle traveled during the reaction time
- If ‘V’ is the design speed in m/sec and ‘t’ is the total reaction,

. Where “v” in m/sec t=2.5 sec.
Lag distance=v.t m/sec

Lag distance=0.278 V.t meters Where “v” in Kmph,
T= time in sec=2.5 sec

Braking distance :

- It is the distance traveled by the vehicle after the application of brake. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.
- work done against friction force in stopping the vehicle is F x l = f W l, where W is the total weight of the vehicle.
- The kinetic energy at the design speed of v m/sec will be ½ m. v^2

Braking distance= $v^2/2gf$

SSD=lag distance + braking distance

$$SSD=0.278V.t + v^2/254f$$

Table 2.6: Coefficient of longitudinal friction					
Speed, kmph	30	40	50	60	>80
Longitudinal coefficient of friction	0.40	0.38	0.37	0.36	0.35

- Two-way traffic single lane road: SSD=2*SSD
- In one-way traffic with single or more lane or two-way traffic with more than single lane: Minimum SSD= SSD

Example-1

- Calculate the safe stopping sight distance for design speed of 50kmph for(a) two-way traffic on two lane road (b)two-way traffic on single lane road

.Solution

SSD=.278VT +V 2/2gf

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

(b) Stopping sight distancefor two way traffic with single lane=2*61.4= 122.8 m

Example-2

- Calculate the minimum sight distance required to avoid a head on collision of two cars approaching from opposite direction at 90 and 60kmph.coefficient friction of 0.7 and a brake efficiency of 50%, in either case

- Example 3: Calculate the stopping sight distance on a highway at a descending gradient of 2% for design speed of 80 kmph, assume other data as per IRC specification..

➢ ***Overtaking Sight Distance:***

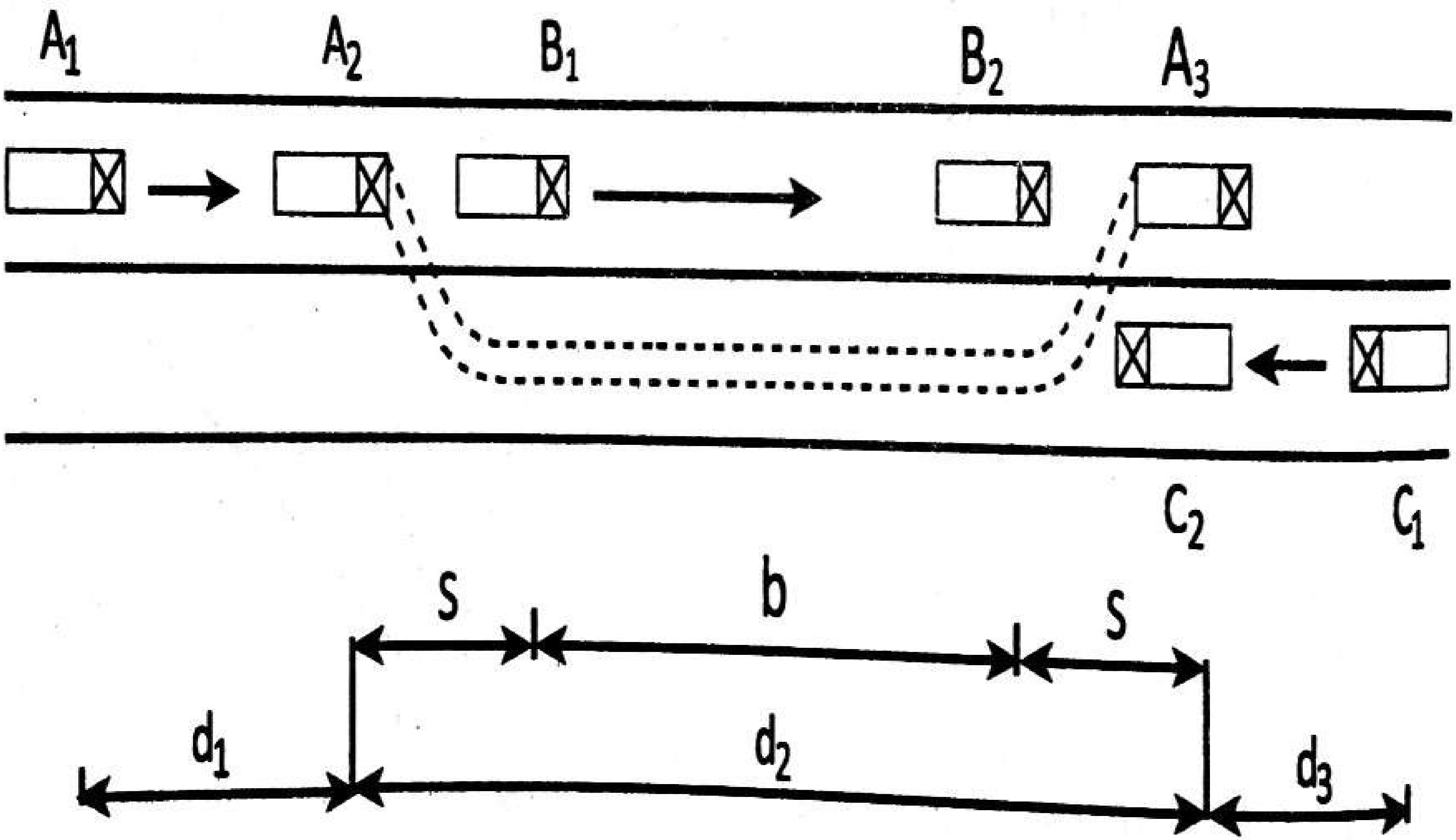
The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against traffic of opposite direction is known as minimum overtaking sight distance or safe passing sight distance available.

➢ ***Factors on which overtaking sight distance depends:***

•Minimum OSD required for the safe overtaking depends on:

a. Speed of overtaking, overtaken vehicle and vehicle coming from opposite direction if any.
b. Skill and reaction time of the driver.
c. Distance between overtaking and overtaken vehicles.
d. Rate of acceleration of overtaking vehicle
e. Gradient of the road if any.

➢*Analysis of OSD on a two lane road with two way traffic:*



- From A_1 to A_2, the distance ‘d_1’ (m) travelled by overtaking vehicle A at reduced speed ‘v_b’ (m/s) during reaction time ‘t’ (sec),

$$d_1 = v_b \times t$$

- IRC suggest reaction time t of driver as 2 sec ,

$$d_1 = 2v_b$$

- From A_2 to A_3, vehicle A starts accelerating, shift to adjoining lane, overtakes vehicle B, and shift back to its original lane during overtaking time ‘T’ (sec) and travel distance ‘d_2’ (m).

•From A_2 to A_3, the distance ‘d_2’ (m) is further split into three parts viz;

$$d_2 = (s+b+s)$$

$$d_2 = (b+2s)$$

•The minimum spacing ‘s’ (m)between vehicles depends on their speed and is given by empirical formula,

$$s=(0.7v_b + 6)$$

•The distance covered by the slow vehicle B travelling at a speed of ‘v_b’ (m/s) in time ‘T’(sec) is,

$$b= v_b \text{ X } T$$

- The overtaking time 'T' (sec) is calculated as;

$$d_2=(b+2s)=(vbT+aT^2/2)$$

$$b=vb\ T \quad , \quad 2s=aT^2/2$$

$$T = \sqrt{4s/a}$$

•From C_1 to C_2, distance travelled by vehicle C moving at design speed 'v' (m/s) during time 'T' (sec) is given by,

$$d_3=v \times T$$

- Thus overtaking sight distance (OSD) is,

$$OSD=(d_1+d_2+d_3)$$

$$OSD= (v_b \, X \, t) + (v_b \, X \, T +2s) +(v \, X \, T)$$

- If speed is in kmph,

$$OSD= (0.28V_b \, X \, t)+(0.28V_b \, X \, T+2s)+(0.28V \, X \, T)$$

- In case speed of overtaken vehicle is not given it is assumed 16 kmph less than design speed of the highway.

where,

s=spacing of vehicles

t=reaction time of driver = 2sec

v =design speed in m/sec

V= design speed in kmph

v_b=initial speed of overtaking vehicle in m/sec

Vb=initial speed of overtaking vehicle in Kmph

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

A=average acceleration in kmph/sec

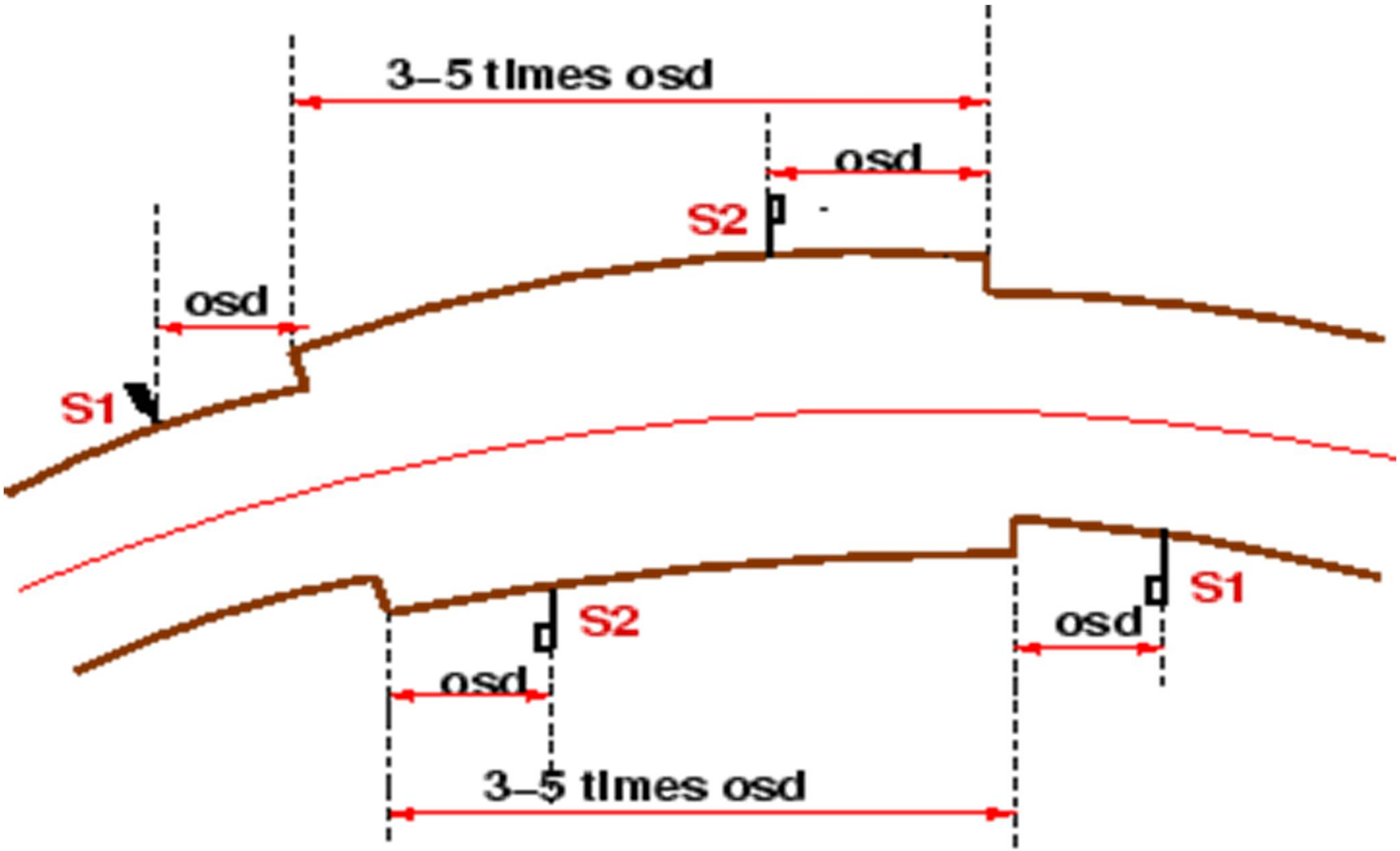
a=average acceleration in m/sec2

➢ ***Overtaking Zones:***

- Overtaking opportunity for vehicles moving at design speed should be given at frequent intervals as possible.

- These zones which are meant for overtaking are called overtaking zones.

- The minimum length of overtaking zone should be three times safe overtaking sight distance i.e.3OSD.



S1–– Overtaking zone begin

S2––End of Overtaking zone

Example-1

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

a) Calculate safe overtaking sight distance
b) Calculate the minimum and desirable length of overtaking zone
c) Draw the neat-sketch of the overtaking zone and show the position of the sign post.

Example-2

Calculate the safe overtaking sight distance for a design speed of 96 kmph, assume all other data suitable

➢ ***Widening of pavement on horizontal curves:***

On horizontal curves, especially when they are Less than 300m radii, it is common to widen the pavement slightly more than the normal width.

- Widening is needed for the following reasons:

a. An automobile has a rigid wheel base and only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.

b.While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

c.For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.

b.At higher speed superelevation and lateral friction cannot counteract centrifugal force and skidding may occur.

➢ ***Analysis of extra widening on horizontal curves:***

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

a. Mechanical widening/Off tracking

b. Psychological widening

a. Mechanical widening/Off tracking (Wm):

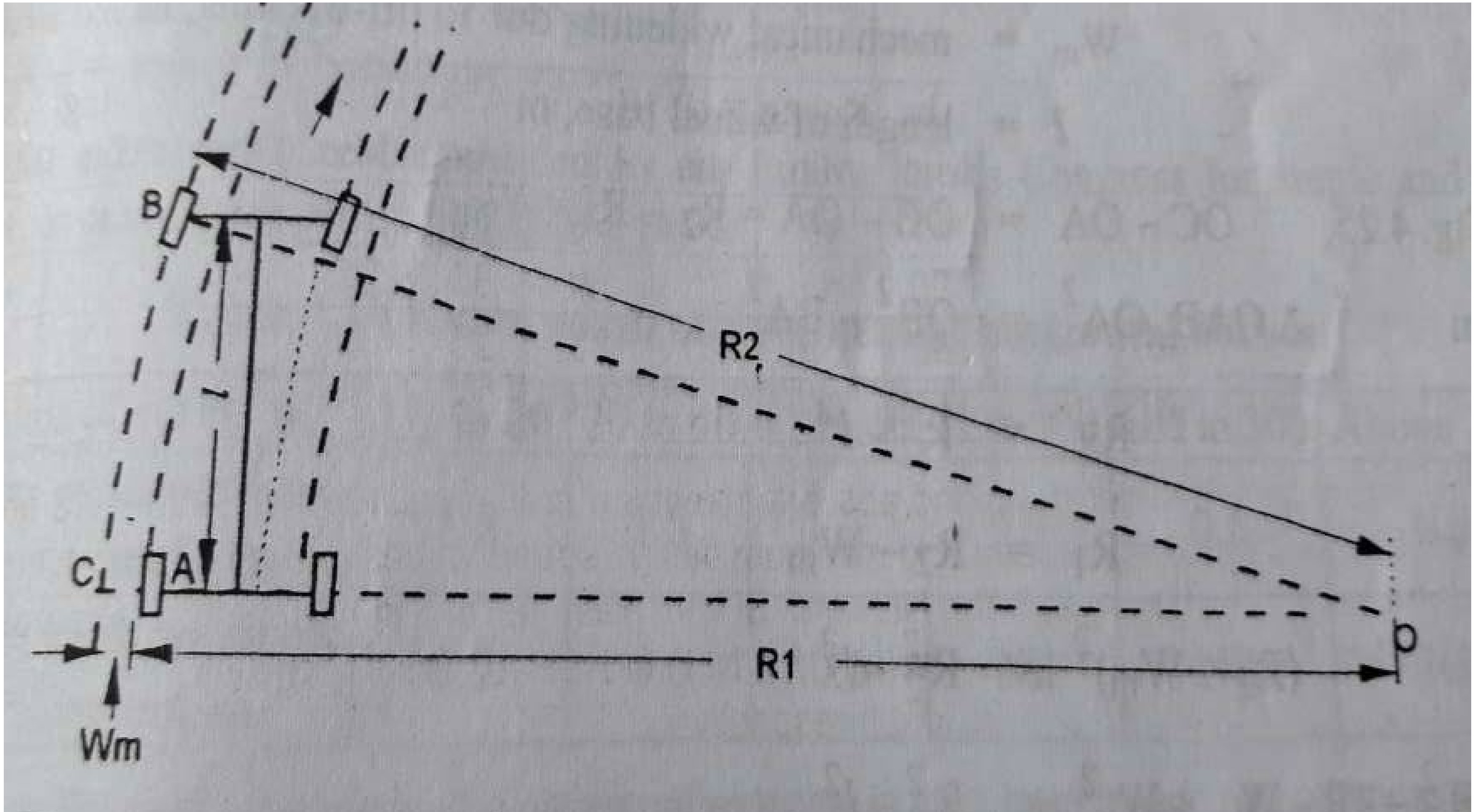


Fig. 4.25 Off-tracking and mechanical widening on horizontal curve

Consider

OA=R1=radius of the path traversed by the outer rear wheel,m

OB=R2=radius of the path traversed by the outer front wheel,m

Wm=mechanical widening due to off-tracking, m

l=length of wheel base,m

R=mean radius of the horizontal curve, m

$$OB-OA= R_2 - R_1 =Wm$$

From ΔOAB, $OA^2 = OB^2 - BA^2$

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

But , $R_1 = R_2 - Wm$

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

$$R_2^2 - 2R_2Wm + Wm^2 = R_2^2 - l^2$$

$$l^2 = Wm\,(2R_2 - Wm)$$

$$Wm = l^2 / (2R_2 - Wm)$$

$$\mathbf{Wm = l^2 / 2R}$$

•If road having ‘n’ traffic lanes and ‘n’ vehicles can travel simultaneously, mechanical widening reqd. is given by,

$$\mathbf{Wm = nl^2 / 2R}$$

b. Psychological widening (Wps):

An empirical formula has been recommended by IRC for deciding the additional psychological widening.

- The psychological widening is given by the formula:

$$Wps = \frac{V}{9.5\sqrt{R}}$$

- The total extra widening is given by,

$$We = Wm + Wps$$

$$We = nl2/2R + V/9.5\sqrt{R}$$

where,

n=no. of traffic lanes

l = length of wheel base =6.1 or 6 m

V=design speed kmph

R = radius of the horizontal curve, m

➢ ***Horizontal Transition Curve:***

A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve.

- The rate of change of radius of the transition curve will depend on the shape of the curve adopted and the equation of the curve.

cessary.

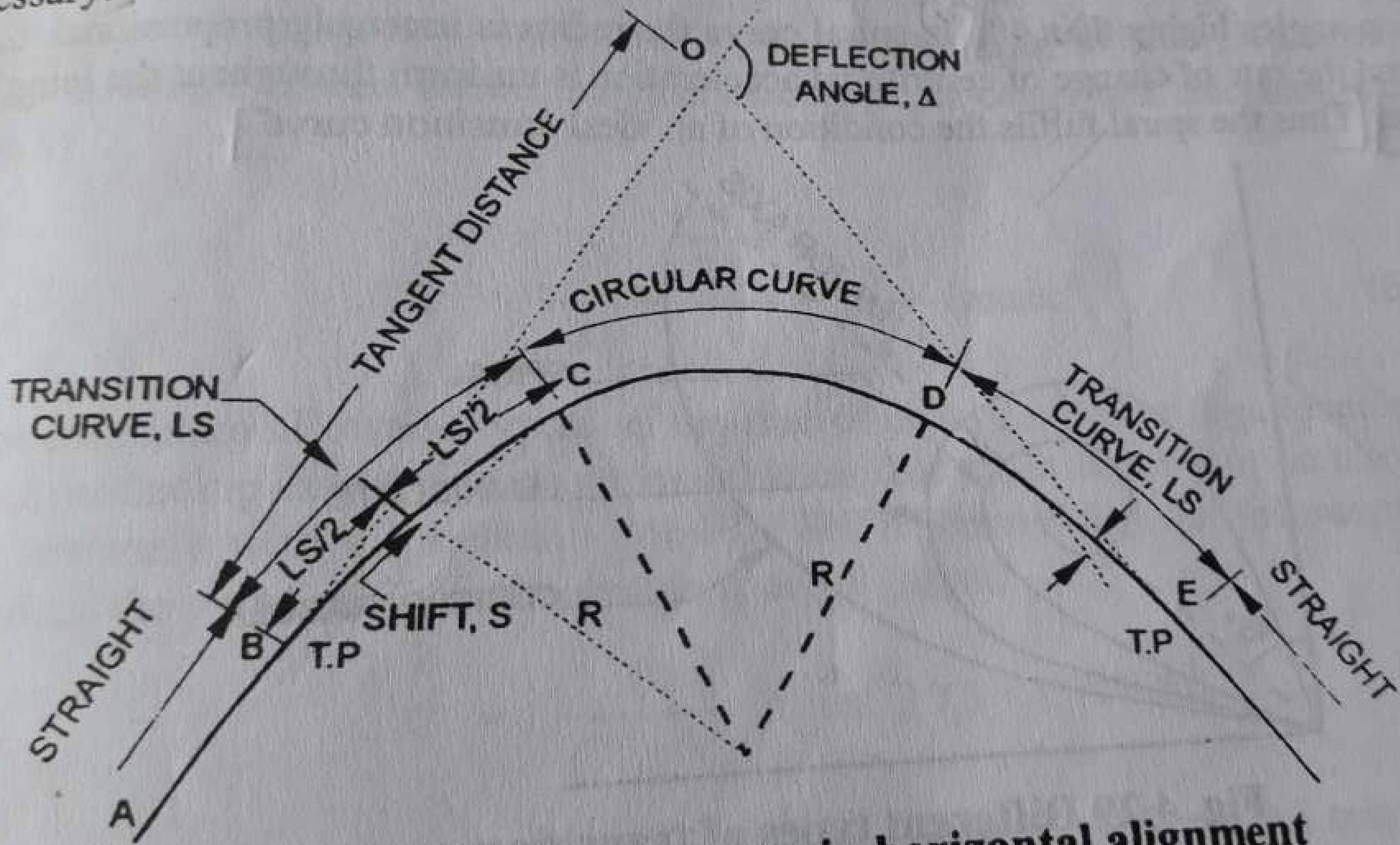


Fig. 4.28 Transition curve in horizontal alignment

➢ ***<u>Objects of providing transition curve:</u>***

A transition curve which is introduced between straight and a circular curve will help in:

a. Gradually introducing centrifugal force.

b. Gradually introducing designed superelevation.

c. Gradually introducing extra widening.

d. To enable the driver turn steering gradually for his own comfort and safety.

- ***<u>Length of transition curve:</u>***

The length of transition curve is designed to fulfill three conditions:

a. Rate of change of centrifugal acceleration to be developed gradually

b. Rate of introduction of designed superelevation

c. Minimum length by IRC empirical formula

a. Rate of Change of centrifugal acceleration:

- The length of transition curve is calculated as:

$$Ls = \frac{v3}{CR}$$ ……if 'v' is in m/sec

$$Ls = \frac{0.0215V3}{CR}$$ ……if 'V' is in kmph

where,

$$C = \frac{80}{75+V} \frac{m}{sec3} \quad (0.5 < C < 0.8)$$

where,

Ls=length of transition curve, m

C=allowable rate of change of centrifugal acceleration

V = design speed in kmph

v = design speed in m/sec

R = radius of the circular curve, m

b. <u>Rate of introduction of superelevation:</u>

- If the pavement is rotated about the center line:

$$\mathbf{Ls=EN/2=e\ N/2(W + We)}$$

- If the pavement is rotated about the inner edge:

$$\mathbf{Ls= EN= e\ N(W + We)}$$

where,

W = width of pavement

We = extra widening

E=total raised pavement= e. B

B=total width of pavement=(W + We)

Rate of change of superelevation of 1 in N

N=150,100,60

c. ***Minimum Length by IRC empirical formula:***

- According to IRC standards:

a. For plane and rolling terrain:

$$Ls = \frac{2.7V2}{R}$$

b. For mountainous and steep terrain:

$$Ls = \frac{V2}{R}$$

➢ ***Shift of transition curve:***

- If the length of transition curve is ‘Ls’ and the radius of the circular curve is ‘R’, the shift ‘S’ of transition curve is given by;

$$S = \frac{Ls2}{24R}$$

➢ ***Set Back Distance:***

•Set back distance is the distance from centre of ‘ horizontal curve to an obstruction on inner side of the curve.

•Set back distance is required to provide adequate sight distance on the horizontal curve.

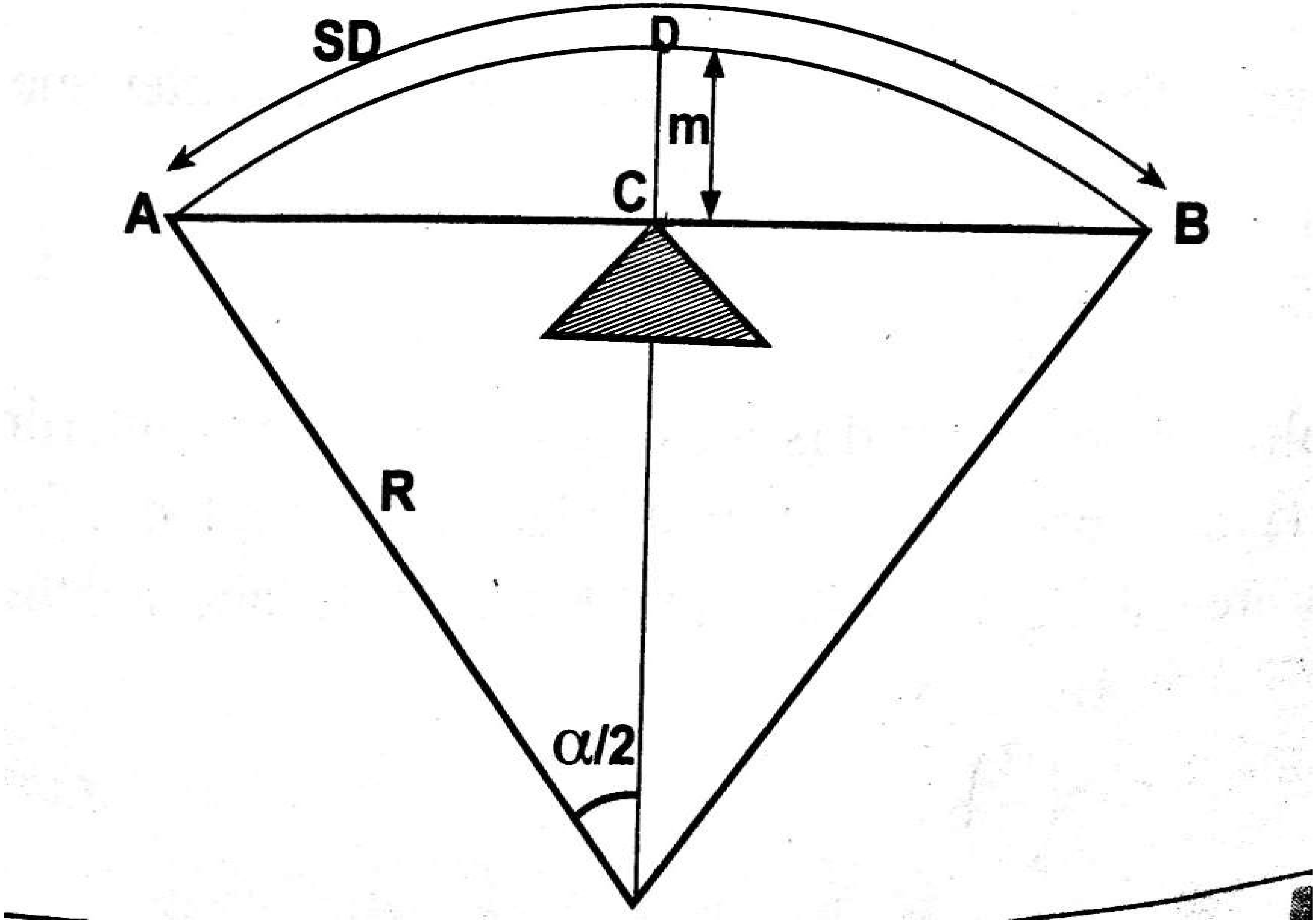
•Obstruction to the sight distance on horizontal curve may be buildings, trees, cut slopes on the inner side of curve.

•On narrow road, the sight distance is measured along the centre line of road.

‘ •On wider road, the sight distance is measured along the centre line of inner side lane.

- Set back distance depends on:

a. Required sight distance, S
b. Radius of horizontal curve, R
c. Length of the curve, Lc


SD
D
m
C
A
B
R
α/2

➢ ***Analysis of Set back distance:***

- Two cases are considered for the analysis:

a. When length of curve is more than Sight distance **(Lc>S)**

b. When length of curve is less than Sight distance **(Lc<S)**

➢ ***Case I:When Lc>S:***

- For narrow Road:

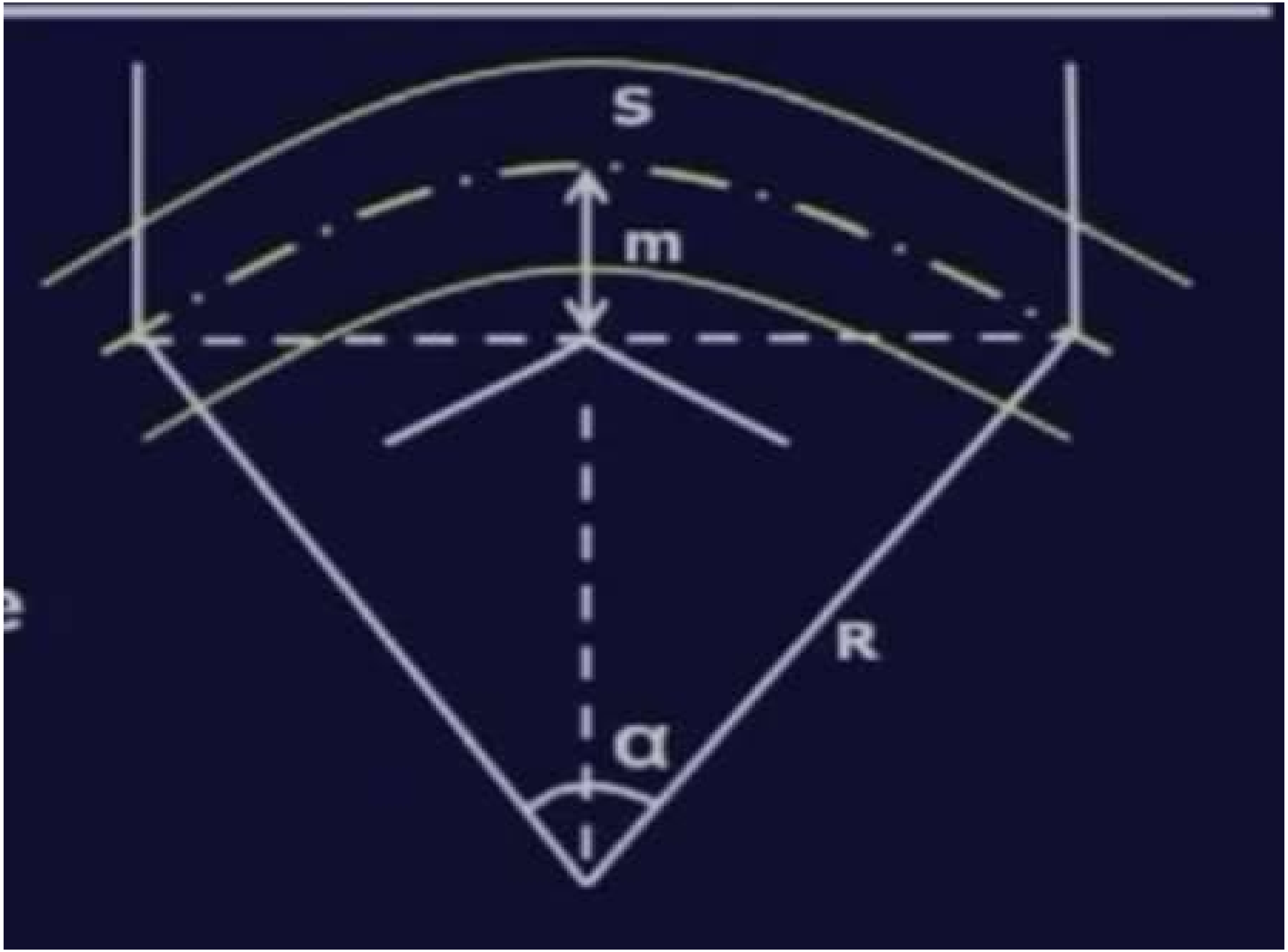
‘

$$\frac{\alpha}{2} = \frac{S}{2R} \text{ radians}$$

$$\frac{\alpha}{2} = \frac{180S}{2\pi R} \text{ degree}$$

Set back distance (m) for narrow road is given by:

$$m = R - R\frac{\cos\alpha}{2}$$


S
m
R
α

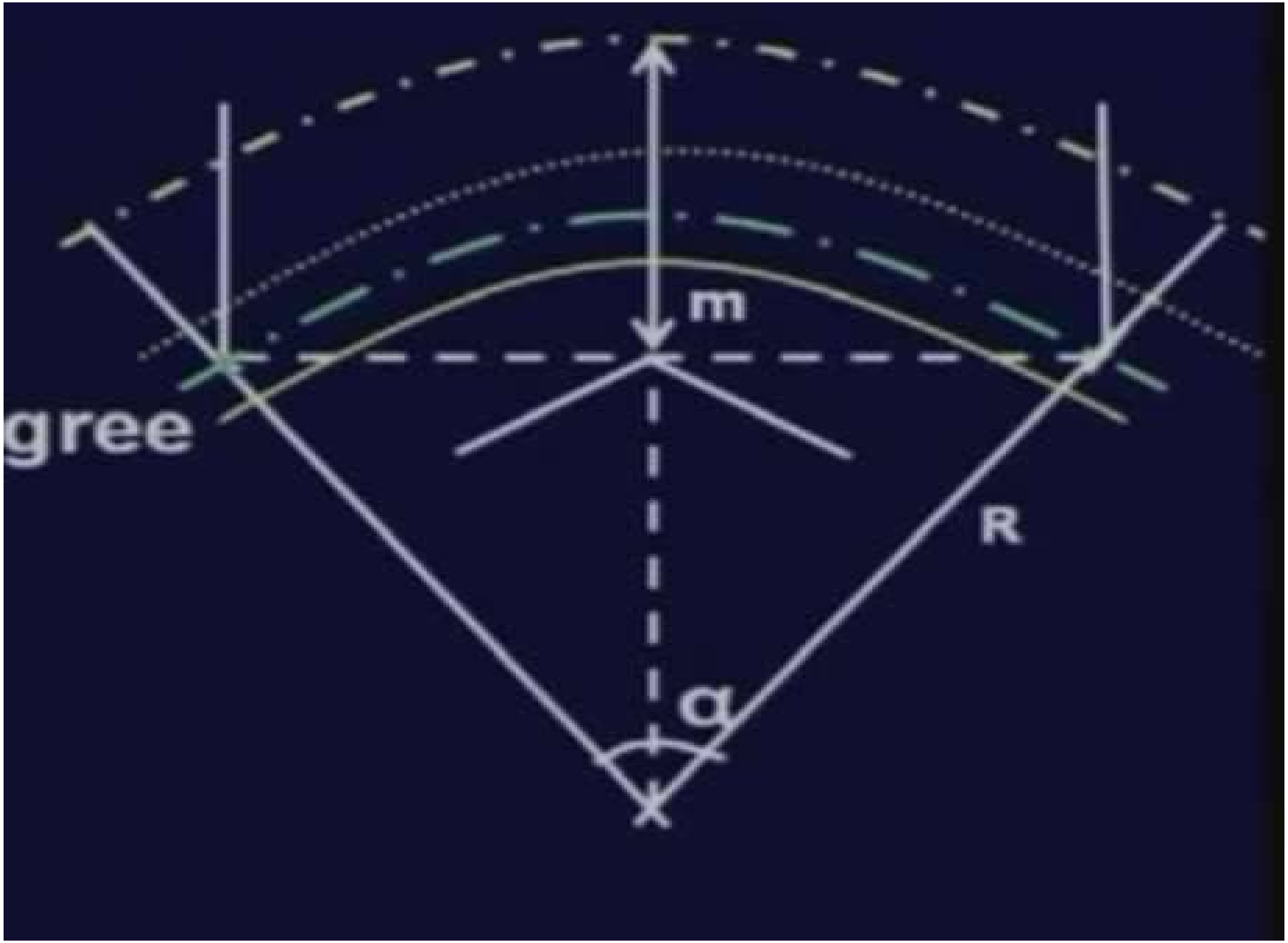
- For wider Road:

$$\frac{\alpha}{2} = \frac{S}{2(R - d)} \text{ radians}$$

$$\frac{\alpha}{2} = \frac{180S}{2\pi(R - d)} \text{ degree}$$

Set back distance (m) for wider road is given by:

$$m = R - (R - d)\frac{\cos\alpha}{2}$$


m
gree
R
α

where,

α =angle subtended by the arc

m=set back distance, m

R=radius of curve, m

S=Sight Distance, m

d=distance between centre line of road and centre line of inner lane

➢ ***Case II:When Lc<S:***

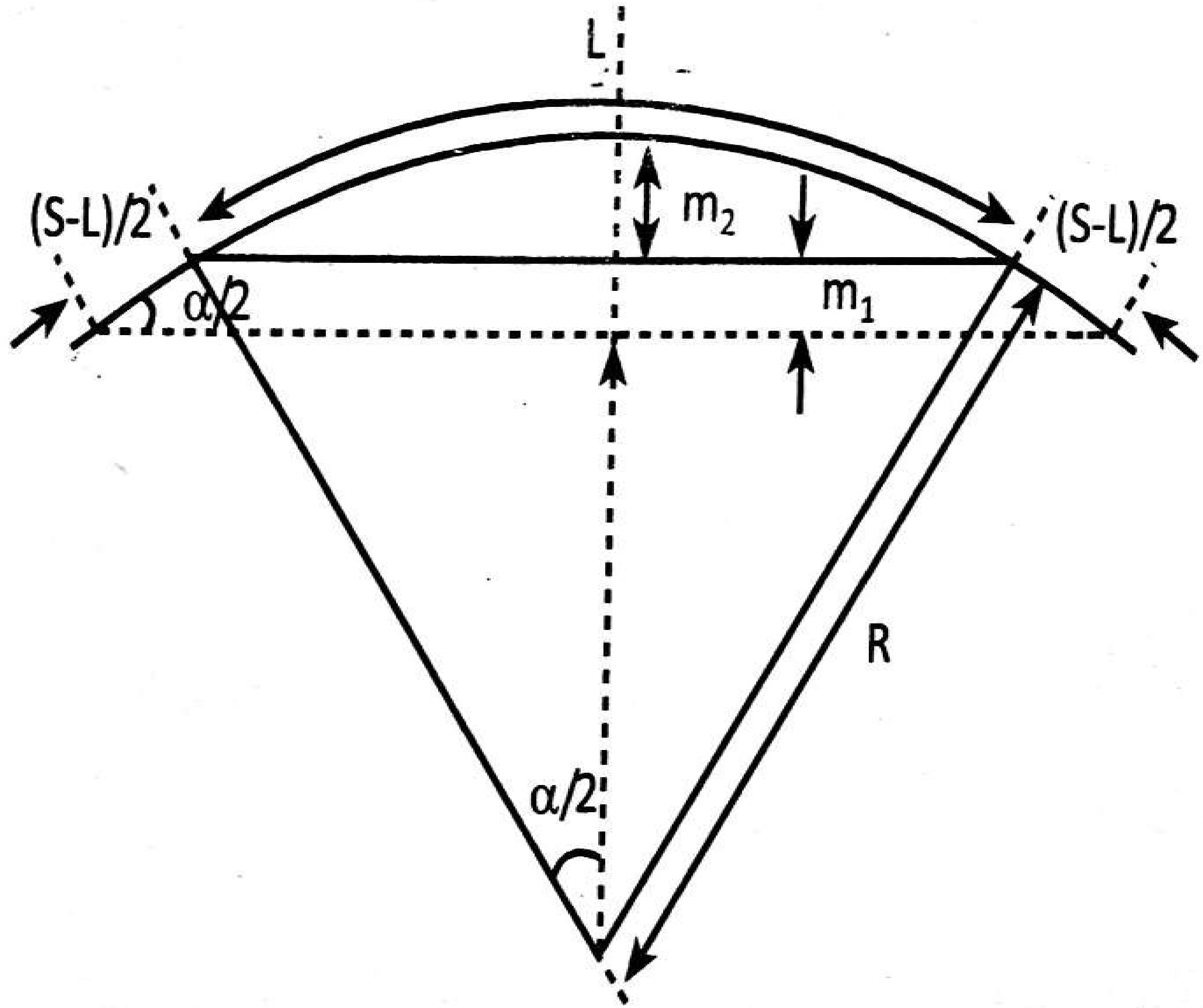
- For narrow Road:

$$\frac{\alpha}{2} = \frac{Lc}{2R} \text{ radians}$$

$$\frac{\alpha}{2} = \frac{180Lc}{2\pi R} \text{ degree}$$

Set back distance (m) for narrow road is given by:

$$m = R - R\cos\frac{\alpha}{2} + \frac{(S - Lc)}{2}\sin\frac{\alpha}{2}$$


L
m2
(S-L)/2
(S-L)/2
α/2
m1
R
α/2

- For wider Road:

‘

$$\frac{\alpha}{2} = \frac{Lc}{2(R-d)} \text{ radians}$$

$$\frac{\alpha}{2} = \frac{180Lc}{2\pi(R-d)} \text{ degree}$$

Set back distance (m) for wider road is given by:

$$m = R - (R-d)\cos\frac{\alpha}{2} + \frac{(S-Lc)}{2}\sin\frac{\alpha}{2}$$

➢ ***Vertical Alignment:***

- The vertical alignment is the elevation or profile of the centre line of the road.
- The vertical alignment consists of grades and vertical curves.
- The vertical alignment of a highway influences:

i. Vehicle speed
ii. Acceleration and deceleration
iii. Sight distance
iv. Vehicle operation cost
v. Comfort while travelling at high speeds

➢Grade Compensation:

- When sharp horizontal curve is to be introduced on a road which has already maximum permissible gradient, then gradient should be decreased to compensate for loss of tractive efforts due to curve.
- This reduction in gradient at horizontal curve is called grade compensation.

Grade compensation, % = 30+R/R

- IRC gave the following specification for the grade compensation:

1. Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.
2. The maximum grade compensation is limited to 75/R%.

$$\text{Compensated gradient} = \text{ruling gradient} - \text{grade compensation}$$

➢ ***Vertical Curves:***

• The vertical curves used in highway may be

‘ classified into two categories:

a. Summit curves or crest curves

b. Valley curves or sag curves

a. Summit curves or crest curves:

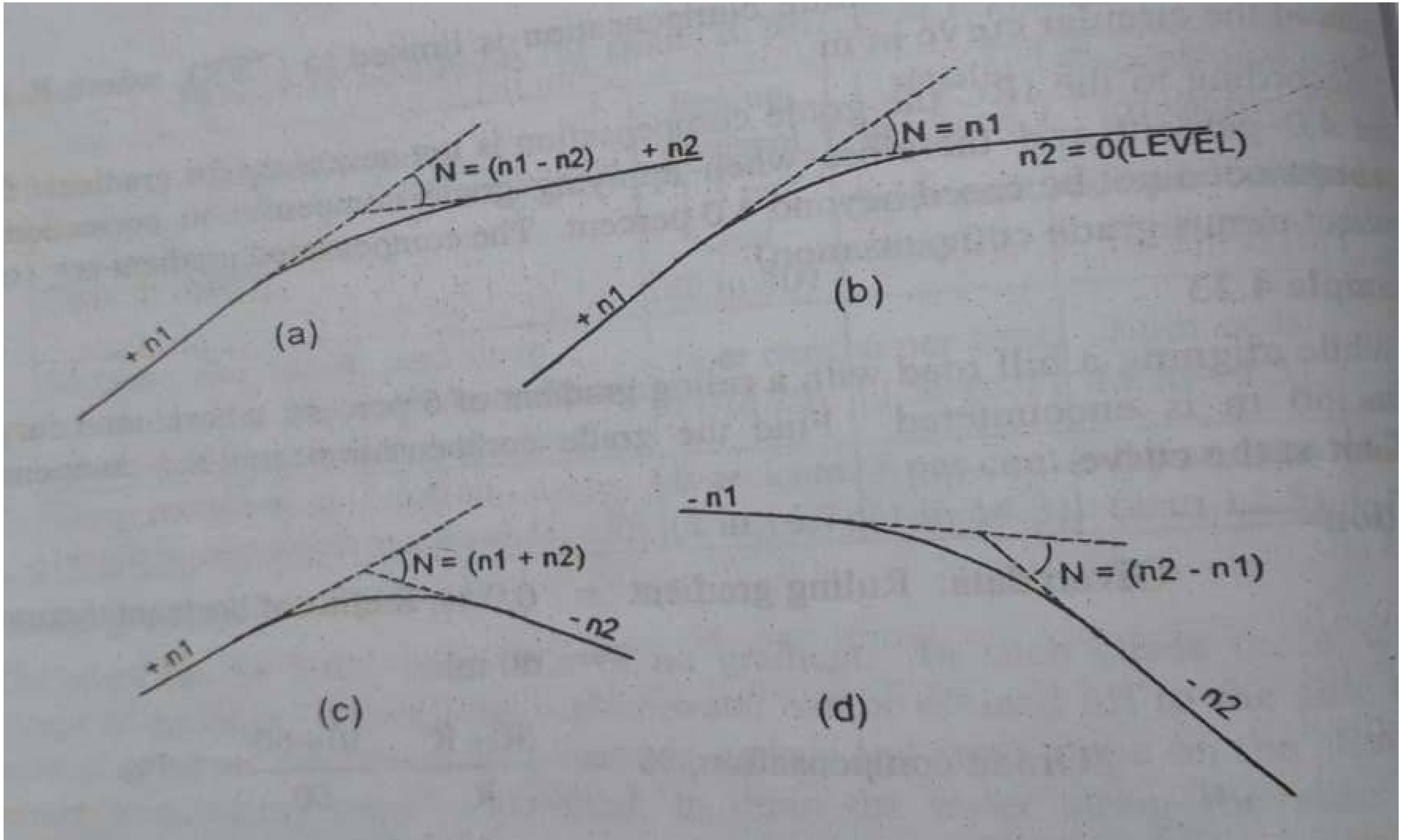


Fig. 4.34 Types of summit curves

b. Valley curves or sag curves:

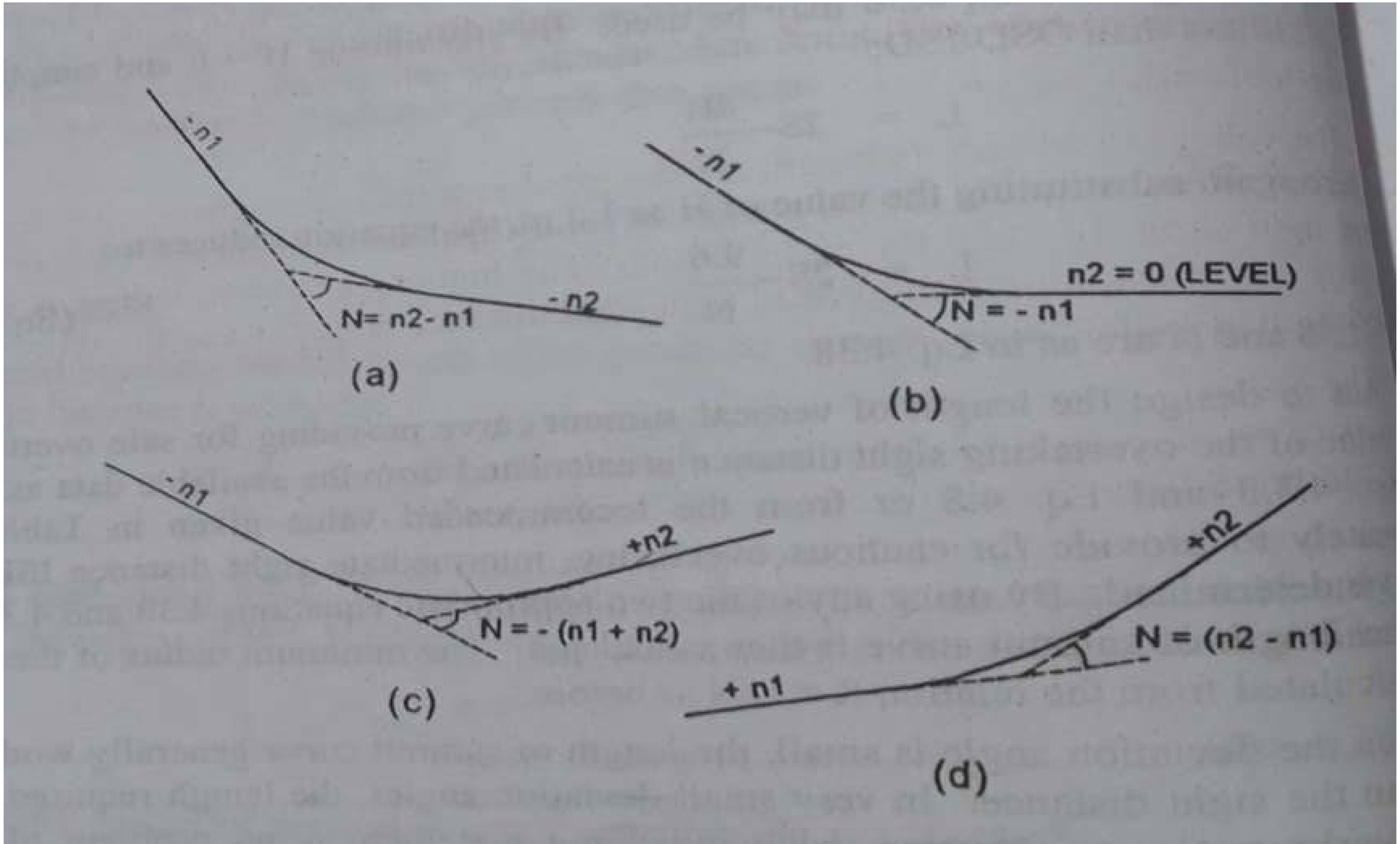


Fig. 4.36 Types of valley curves

➢ ***Length of summit curve:***

- While designing the length the parabolic summit curves, it is necessary to consider SSD and OSD Separately.

- Length of summit curve for stopping sight distance (SSD):

Two cases are considered in deciding the length:

a. When L>SSD

b. When L<SSD

a. When L > SSD

The general equation for length of curve is given by:

$$L = \frac{NS2}{[\sqrt{2H} + \sqrt{2h}]2}$$

- Substituting the value of H=1.2m and h=0.15m,

$$L = \frac{NS2}{4.4}$$

b. When L < SSD

The general equation for length of curve is given by:

$$L = 2S - \frac{\left[\sqrt{2H} + \sqrt{2h}\right]2}{N}$$

- Substituting the value of H=1.2m and h=0.15m,

$$L = 2S - \frac{4.4}{N}$$

•The minimum radius of the parabolic summit curve is calculated from relation **R=L/N**

- Length of summit curve for overtaking sight distance (OSD):

Two cases are considered in deciding the length:

a. When L > OSD

b. When L < OSD

a. When L > OSD

The general equation for length of curve is given by:

$$L = \frac{NS2}{8H}$$

- Substituting the value of H=1.2m,

$$L = \frac{NS2}{9.6}$$

b. When L < OSD

The general equation for length of curve is given by:

$$L = 2S - \frac{8H}{N}$$

- Substituting the value of H=1.2m,

$$L = 2S - \frac{9.6}{N}$$

where,

N= deviation angle i.e. algebraic difference between two grade

H=height of driver eye above carriageway i.e. 1.2 m

h=height of object above carriageway i.e. 0.15 m

L=length of summit curve, m

S=sight distance i.e. SSD or OSD

➢ ***Length of valley curve:***

•The important factors to be considered in valley

‘

curve design are:

a.Impact free movement of vehicles at design speed or comfort to passenger.

b.Providing adequate sight distance under head lights of vehicles for night driving

c.Locating lowest point of valley curve for providing suitable cross drainage facilities

•The valley curve and its length are designed as a transition curves to fulfill two criteria:

‘

a. Allowable rate of change of centrifugal Acceleration or comfort conditions

b. Required head light sight distance for night driving

a. Length of valley transition curve for comfort condition:

‘ Total length of valley curve is given by:

$$L = 2\left[\frac{Nv3}{C}\right]^{1/2}$$

If ‘V’ is in kmph,

$$L = 0.38(NV3)^{1/2}$$

where,

v or V= design speed in m/sec or kmph

C=allowable rate of change of centrifugal acceleration=0.6 m/sec3

L=length of valley curve=2Ls

N= deviation angle i.e. algebraic difference between two grade

b. Length of valley curve for head light sight distance:

- The length of valley curve for head light sight distance may be determined for two condition:

a. When L > SSD

b. When L < SSD

a. When L > SSD

The general equation for length of valley curve is given by:

$$L = \frac{NS2}{[1.5 + 0.035S]}$$

b. When L < SSD

The general equation for length of valley curve is given by:

‘

$$L = 2S - \frac{[1.5 + 0.035S]}{N}$$

where,

N= deviation angle i.e. algebraic difference between two grade

L=total length of valley curve, m

S=SSD, m

vertical summit curves, it is possible to provide the sight distance requirements by suitably designing the vertical alignment. At stretches of the road where required overtaking sight distance can not be provided as per Table 4.7, as far as possible *Intermediate Sight Distance*, ISD equal to twice SSD may be provided. (Refer Table 4.5). The measurement of the ISD may be made assuming both the height of the eye level of the driver and the object to be 1.2 metres above the road surface.

Example 4.6

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

(a) calculate safe overtaking sight distance

(b) mention the minimum length of overtaking zone and

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

Solution

(a) Overtaking sight distance for two way traffic

$$= d_1 + d_2 = d_3 \tag{4.5}$$

Assume the design speed as the speed of overtaking vehicle A

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

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

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

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

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

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

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

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

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

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

$$\text{O.S.D} = d_1 + d_2 + d_3$$

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

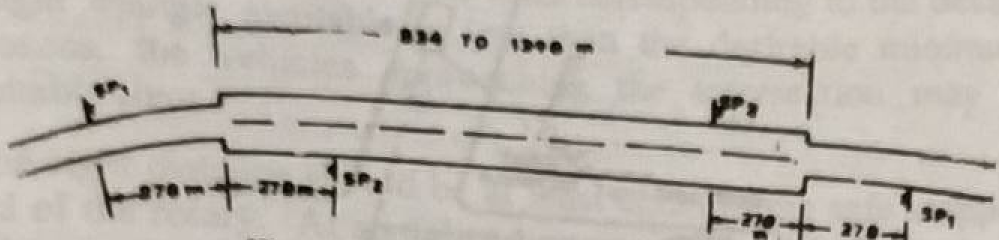
(b) Minimum length of overtaking zone = 3 (OSD)

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

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390 m

----Continued

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



SP_1 - Sign Post "Overtaking Zone Ahead"

SP_2 - Sign Post "End of Overtaking Zone"

Fig. 4.16 Overtaking Zone (Example 4.6)

Example 4.4

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

Solution

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

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

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

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

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

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

Alternatively, using Eq. 4.4

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

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