UNIT 2

HIGHWAY GEOMETRIC DESIGN

Marketed by
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PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. What are the characteristics of pavement surface?

Answer : Model Paper-III, Q1(d)

The important characteristics of a pavement surfaces are as follows,

1. Friction unevenness
2. Light reflecting and
3. Drainage of surface water.

Q2. What are the various factors which effects unevenness of pavement surface?

Answer : Model Paper-I, Q1(c)

The following are the factors which effects the unevenness on pavement surfaces,

1. Incomplete compaction of fill, subgrade and pavement layers
2. Operations of unsuitable construction equipments
3. Weak preservation practice
4. Inappropriate surface and subsurface drainage
5. Function of inferior pavement material
6. Localized failure due to combination of causes
7. Without the scientific method, the construction is carried out by involving the operations of boulder stones and bricks as soling layer over loose subgrade soil.

Q3. What is skid resistance?

Answer : Model Paper-III, Q1(c)

Skid resistance is a measure of the friction between the pavement surface and the vehicle tyre on wet pavements. For the purpose of safety, the friction coefficient or the skid resistance offered by the pavement surface is significant under different surface and driving conditions. Therefore, for achieving adequate or improved highway safety, designers and maintenance engineers must ensure that the pavements maintain adequate skid resistance.

Q4. What are the factors on which the skid resistance depends?

Answer : Model Paper-II, Q1(c)

The factors on which the skid resistance depends are,

1. Type of pavement surface such as cement concrete bituminous, WBM, surface of earth etc
2. Macro-texture of the pavement surface
3. Different conditions of pavement such as wet or dry, rough or smooth, oil spilled, mud or dry sand on the pavement
4. Tyre's condition and its type
5. Vehicles speed
6. Extent of brake application
7. Pressure and load of tyre
8. Skid type
9. Tyre and pavements temperature
10. Type of aggregate used and the mix design of pavement surface.

Q5. What is a ideal transition curve?

Answer : Model Paper-II, Q1(d)

A curve is said to be an ideal transition curve, if it satisfies the following requirements,

1. Consistent rate of change of centrifugal acceleration
2. Length should be inversely proportional to radius.

Q6. What are the sight distances that are considered by IRC in highway design?

Answer : Model Paper-I, Q1(d)

The following are the sight distance that are to be considered by IRC (Indian Road Congress) in highway design.

1. Intermediate sight distance
2. Head light sight distance.

1. Intermediate Sight Distance

Intermediate sight distance is equal to two times the stopping sight distance and it is adopted to provide limited overtaking chance to fast vehicles.

2. Head Light Sight Distance

Head light sight distance is the distance observable by the driver during the night driving under the lighting of the vehicle head light. Head light sight distance is critical at up-gradients and ascending stretch of the valley curves.

Q7. List the various assumptions in the analysis of safe Overtaking Sight Distance.

Answer : May-17, (R13), Q1(c)

For the analysis of safe overtaking sight distance on highways the following assumptions are considered:

1. The speed of overtaken vehicle (V_b) should be less than design speed of the road (V) i.e., $V_b = V - 16$.
2. When the overtaking vehicle reduces its speed, it observes the other overtaking vehicle entering into overtaking section.
3. Before overtaking, the vehicle should follow the forward vehicle until it understands the clear roadway for overtaking.
4. By increasing the speed to design speed, overtaking must be done and then vehicle must returns fastly to its own lane.
5. While the overtaking vehicle returning to it own lane. It will be alongside of the vehicle coming in the opposite direction.

Q8. Explain super elevation. What are the factors on which the design of super elevation depends?

Answer :

For counteracting the centrifugal force and reducing the tendency of the vehicle to overturn or skid, the pavement's outer edge is raised with reference to the inner edge, which provides a transverse slope throughout the length of the horizontal curve. The transverse inclination to the pavement surface is known as super-elevation or cant or banking.

Super elevation (e) is expressed as the ratio of height of outer edge with reference to horizontal width.

The design of super elevation depends on the following factors,

1. Vehicle's speed on the curves
2. Radius of horizontal curve
3. Lateral frictional resistance between vehicle tyres and road surface.

Q9. Calculate the absolute minimum and ruling minimum radius of horizontal curve for a design speed of 80 kmph.

Answer :

Given that,

Design speed, $V = 80$ kmph

Absolute minimum radius, $R_{min} = \dfrac{V^2}{2.12}$

$$\therefore \quad R_{min} = \frac{80^2}{2.12} = 3019 \text{ metres}$$

Ruling minimum radius, $R_{ruling} = \dfrac{(V+16)^2}{27.5}$

$$= \frac{(80+16)^2}{27.5}$$

$$= \frac{96^2}{27.5}$$

$$= 335.13 \text{ metres.}$$

Q10. Calculate the extra width required for a two lane highway having a horizontal curve of radius 200m, if the design speed is 80 Kmph.

Answer : *May-17, (R13), Q1(d)*

Given that,

Radius of horizontal curve, $R = 200$ m

Design speed, $V = 80$ kmph

Number of lanes, $n = 2$

Let, length of pavement width, $l = 7$ m (since given two lane)

Extra widening required on a horizontal curve given by,

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

$$= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$= \frac{2\times7^2}{2\times200} + \frac{80}{9.5\sqrt{200}}$$

$$= 0.245 + 0.595$$

$$= 0.840 \text{ m}$$

Q11. What are the transition curves? Explain the functions.

Answer : *April-18, (R15), Q1(d)*

For answer refer Unit-II, Q38 and Q40.

PART-B

ESSAY QUESTIONS WITH SOLUTIONS

2.1 IMPORTANCE OF GEOMETRIC DESIGN – DESIGN CONTROLS AND CRITERIA

Q12. Explain the importance of geometric design. List out the various geometric elements to be considered in high way design.

OR

What are the design issues in highway geometrics?

Answer : May-16, (R13), Q1(c)

Importance of Geometric Design

(i) The geometric design of highway deals with the arrangement of dimensions and layouts of highway elements like alignment, sight and intersections.

(ii) The geometric design of highway provide maximum efficiency in traffic operations along with greatest safety at suitable cost.

(iii) The designer of highway improve the existing highway to overcome the necessity of existing traffic and prevent them.

(iv) It is important to plan and design the geometric features of the road during the starting stage of alignment by considering the future growth of traffic and possibility of road extension to provide a standard speed at a later stage.

(v) The geometric design of highway is able to design and built the pavement of road in stages.

The various geometric elements considered in design of highway are as follows,

(a) Elements of cross section of road

(b) Details of horizontal alignment

(c) Intersection elements

(d) Examining the sight distance

(e) Details of vertical alignment.

Q13. Explain the factors which control the geometric elements.

Model Paper-I, Q4(a)

OR

How do you frame design controls in geometrics of highway explain from each feature with specification?

Answer : May-16, (R13), Q1(d)

The factors which controls the geometric elements are as follows,

1. Design speed
2. Design hourly volume and capacity
3. Topography
4. Traffic factors
5. Environmental factors.

1. Design Speed

Design speed is used to control the geometric design elements of highway. Depending upon the type of road the speed is designed, i.e., the speed varies when the class of road is of national highways, major district roads and village roads. This design speed is further improved based on terrain and topographical conditions.

2. Design Hourly Volume and Capacity

Traffic volume changes with change in time. During off peak hour the volume of traffic is minimum when compare to peak hour traffic. The design of roadway resources are proven to be uneconomical for maximum hourly traffic flow (Peak Traffic Volume). Therefore, before designing the road a suitable value of traffic flow is considered which is known as design hourly volume. The value of design hourly volume is adopted from traffic volume studies as per art 5.2.3.

3. **Topography**

The condition of topography effects the geometric design of highways. Depending upon the topographical condition, different classes of roads establish various design standards. For a National/state highway on plain terrain with general cross slope of 10% should maintain a design speed of around 100 kmph and on rolling terrain with general cross slope in between 10 to 25% has to be the design speed of 80 kmph, whereas on mountain terrain with a cross slope of 25 to 60% a design speed of 50 kmph is adopted. In hilly terrain it is essential to provide steeper gradients and sharper horizontal curves due to problem in construction .

4. **Traffic Factors**

The different vehicles used on road and human characteristic of road users are the traffic factors which effects the geometric design of road. The different vehicles like passenger cars, buses, trucks and motor cycles etc, have variable speed and acceleration along with different dimensions (size) and weight which makes the design of road a complex problem. To overcome this problem a standard vehicle is consider whose weight and size are taken into account while designing the road.

The physical, mental and psychological characteristics of driver and pedestrians are the human factors which affects the design of road and traffic behaviours.

5. **Environmental Factors**

The environmental factors like landscaping, air pollution, noise pollution, aesthetics and other local conditions effects the geometric design of road. These can be controlled by providing separate grade of intersections and controlled access in the design of high speed highways and expressways.

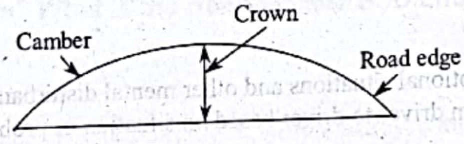
2.2 HIGHWAY CROSS-SECTION ELEMENTS – SIGHT DISTANCE ELEMENTS – STOPPING SIGHT DISTANCE, OVERTAKING SIGHT DISTANCE AND INTERMEDIATE SIGHT DISTANCE

Q14. What is camber and what is its need on pavement? What are factors on which camber is chosen? Give IRC recommendations.

Answer :

Camber

Camber is defined as the rise given to the centre of carriage way (crown) with reference to its edges. It is also called as cross fall or cross slope of the road.



Figure

It is usually provided on the straight roads by raising the center of the carriage way with respect to the edges, which forms a crown (highest point on the centre line). During the provision of expected super elevation by raising the outer edge of pavement with reference to the inner edge, the drainage surface gets affected very badly. Camber is expressed as percentage.

Need of Camber on Pavement

1. It prevents the penetration of surface water into the subgrade soil through the pavements. When the water enters in the subgrade and if the soil gets soaked, then the pavement's life gets adversely affected.
2. Standing water on the pavements leads to skidding as it causes slippery. These conditions causes lack of skid resistance and the vehicles cannot operate at high speed. Therefore, for increasing the skid resistance, camber is provided.
3. The traffic is divided in two directions.
4. The penetration of water into the bituminous pavement layers is prevented.
5. It is also provided for improving the appearance of roads.

The amount of camber to be provided depends on the following factors,

(a) Type of pavement.

(b) Intensity of rainfall of locality.

(a) Type of Pavement

On the impervious pavement surface such as cement concrete or bituminous concrete, a flat camber of 1.7 to 2.0% is sufficient. Steeper cross slope is provided on the previous surface such as bound macadam or earth road.

(b) Intensity of Rainfall of Locality

In the areas where heavy rainfall occur, steeper camber is provided. The recommended values of camber for different types of road surfaces are tabulated below,

S.No.	Type of Road Surface	Range of Camber in Areas of Rainfall Range Heavy to Light
1.	Earth	1 in 25 (4.0%) to 1 in 33 (3.0%)
2.	Water bound macadam and gravel	1in 33 (3.0%) to 1 in 40 (2.5%)
3.	Thin bituminous surface	1 in 40 (2.5%) to 1 in 50 (2.0%)
4.	Cement concrete and high bituminous surface	1 in 50 (2.0%) to 1 in 60 (1.7%)

Q15. Explain PIEV Theory and the total reaction time of driver.

May-17, (R13), Q4(a)

Answer :

PIEV Theory

The total reaction time of the driver is explained clearly with the help of PIEV theory. In this theory, the total reaction time of driver is divided into four categories. They are,

(i) Perception time

(ii) Intellection time.

(iii) Emotion time.

(iv) Volition time.

(i) Perception Time

The time required by the eyes or ears of driver to transmit the situation to the brain through nervous system and spinal cord is termed as 'Perception time'.

(ii) Intellection Time

The time required by the driver to figure out the situation and analyses the different thought, and register new sensations is called 'Intellection time'.

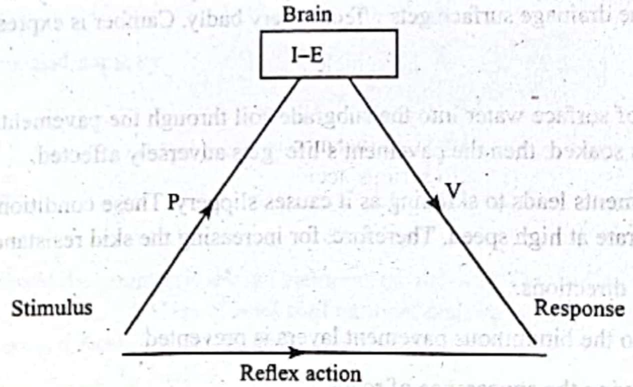
(iii) Emotion Time

The time taken by the driver in emotional situations and other mental disturbances like fear, anger or superstitions etc is called 'Emotion time'. It varies from driver to driver based on situation or problem faced.

(iv) Volition Time

The time taken by the driver for the application of brake is called 'Volition time'.

The PIEV theory in detail is shown in the following figure.



P – Perception

I –Intellection

E – Emotion

V – Volition.

Total Reaction Time of Driver

The time taken by the driver from the instant he views the object to the instant he effectively applies brakes is called 'Reaction time of driver'. This time gap depends on various factors like design speed of the road, etc. The total reaction time is divided into two categories i.e,

(i) Perception time

(ii) Brake reaction time

(i) **Perception Time**

The time taken by the driver from the instant object is visible to driver to the instant he realises that brakes must be applied is termed as "perception time". It varies from driver to driver and depends on various other factors like distance of object speed of the vehicle and environmental conditions.

(ii) **Brake Reaction Time**

This time is a part of total reaction time which depends an factors such as skill of the driver, different problems involved and other environmental conditions.

Q16. What are the sight distance situations that are considered in the design? What are the conditions which are to be satisfied by the standards of sight distance?

Answer :

The sight distance situations that are considered in the geometric design are as follows,

1. Stopping or absolute minimum sight distance.
2. Overtaking sight distance.
3. Safe sight distance entering into the intersection.

Following are the conditions which are to be satisfied by the standards of sight distance.

(a) In the case of any obstruction on the road ahead, driver travelling at a design speed should maintain a sufficient sight distance to avoid collision.

(b) Without creating obstruction or hazard to the traffic coming from the opposite direction, the driver should safely overtake the slower vehicles.

(c) When the driver enters the unsignalised intersection, he should maintain a sufficient visibility for controlling the vehicle in order to avoid collision with the other vehicles.

Q17. What is stopping sight distance? What is the need to have SSD and factors on which it is based?

Answer : **Model Paper-I, Q4(b)**

Stopping Sight Distance

It is defined as the minimum distance required to stop a vehicle safely without its collision with other vehicles or obstructions. Generally, the absolute minimum sight distance is referred as the stopping sight distance. Mathematically, the stopping sight distance of a vehicle moving over a road is the sum of "lag distance" and "breaking distance". "Lag distance" is the distance covered by the vehicle during the total reaction time. "Breaking distance" is the distance through which a vehicle moves in forward direction after applying the brakes. The lag distance depends upon the ability and reaction time of driver and is given by PIEV (Perception, Intellection, Emotion and Violation) theory. The braking distance, on the other hand, depends upon the friction characteristics between the road surface and the vehicle.

Need of SSD

The main requirement of providing the stopping sight distance is to prevent the collision between different vehicles or a vehicle with an obstruction. Such collision may lead to serious accidents and may cause serious injuries to passengers besides damaging the vehicle. The stopping sight distance is also important to easily locate the obstructions (like speed breakers) and hence reduce the speed of the vehicle sufficiently resulting in low impact.

Factors on which the SSD Depends

The stopping sight distance depends upon,

1. **Features of the Road Ahead**

   (a) Horizontal alignment

   (b) Vertical alignment

   (c) Traffic conditions

   (d) Location of obstruction.

2. **Height of the Drivers Eye**

This again is selected on the basis of,

(a) Straight road

(b) Vertical summit.

3. Height of the object measured from the surface of the road.

4. **The Distance of Stopping of the Vehicle After Realising the Obstruction**

This depends upon,

(a) Total reaction time of driver

(b) Vehicle speed

(c) Efficiency of brakes

(d) Frictional force developed between the tyre of vehicle and the road surface

(e) Gradient (either upward or downward) of the road.

Q18. Derive an expression for computing SSD on a level road.

Answer :

Expression for Computing SSD on a Level Road

Lag Distance

During the reaction time, the vehicle is assumed to move with normal speed. If the total reaction time of driver is 't' seconds and design speed is 'v' m/sec then the lag distance will be the product of design speed and the total reaction time

∴ Lag distance = $v.t$ metres.

Braking Distance

The type and condition of tyres and pavement surface are the factors on which the coefficient of friction 'f' depends. With increase in speed, the value of 'f' decreases.

It the road is level, then the braking distance can be achieved by equating the kinetic energy and the workdone in vehicle stopping.

If the maximum frictional force developed is 'F' and 'd' is the braking distance, then the workdone is,

$$F \times d = \mu W d$$

At the design speed, the kinetic energy will be,

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

$$\mu W d = \frac{Wv^2}{2g}$$

$$d = \frac{v^2}{2g\mu}$$

Where,

v – Speed of vehicle in m/sec

d – Braking distance, m

μ – Design coefficient of friction

g – 9.8 m/sec².

Therefore, the stopping distance is,

SD= Lag distance + Braking distance

$$\text{i.e.,} \quad SD = \left[v \times t + \frac{v^2}{2g\mu}\right] \quad \text{... (1)}$$

If the speed is taken as v kmph, then the stopping distance,

$$SD = \left[0.278 \times v \times t + \frac{v^2}{254\mu}\right] \quad \text{... (2)}$$

Hence, for stopping distance at level road, equations (1) and (2) are the general equations.

Q19. What is overtaking sight distance? Discuss about the overtaking zones.

Answer : Model Paper-II, Q5(a)

Over Taking Sight Distance

The least distance accessible to the vision of the driver of a vehicle. Planning to overtake slow moving vehicle along with safety against the traffic of opposite direction is known as over taking sight distance. When all the vehicles travelling on a road maintain the same design speed then the purpose of overtaking is avoided (not required).

Under mixed traffic condition the fast moving vehicle overtake the slow moving vehicles, this process is not applicable through out the length of the road therefore overtaking of slow vehicles with sufficient safety should be adopted at frequent distance intervals. The distance for overtaking sight should be measured along the centre of the road and vision of the driver, it must be equal to 1.2 m from drivers eye to the road surface.

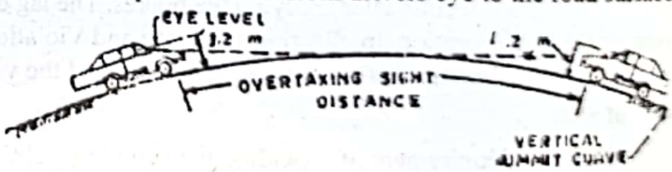


Figure: Showing the Overtaking Sight Distance

Overtaking Zones

Certain zones must be provided along the length of the road for overtaking the vehicles infront of the considered vehicle. These zones are known as "Overtaking zones". Sign posts should also be positioned at the starting point of the overtaking zones for their indication. The distance to be provided for different overtaking zones is as follows,

(a) $3(d_1 + d_2)$ – for one way roads

(b) $3(d_1 + d_2 + d_3)$ – for two way roads.

It is preferable to provide the length of overtaking zone equal to 3 times the overtaking sight distance.

Where,

d_1 – Distance covered by overtaking vehicle during the time (t) sec.

d_2 – Distance covered by overtaking vehicle during the actual overtaking operation.

d_3 – Distance covered by the vehicle coming from the opposite direction during the overtaking operations.

Q20. State factors on which the overtaking sight distance depends. Explain briefly under what circumstances the need to put up sign boards "Overtaking prohibited" is required.

Answer :

The factors on which the overtaking sight distance depends are as follows,

1. Speed of overtaking vehicle, overtaken vehicle and the vehicle reaching from the opposite side
2. Reaction time of the person driving the vehicle and his skills
3. Clear distance between the overtaking and overtaken vehicle
4. Presence of gradient (either upwards or downwards) on the road
5. The rate with which the overtaking vehicles accelerate.

Need of Sign Board

In the construction of highways, the length of road visible to the driver should be safe enough to overtake a vehicle easily. However, some situations may not allow the overtaking of vehicles on the road. Under such circumstances, where the overtaking of vehicles is not safe, sign boards with "overtaking prohibited" written on them should be located before the zone starts.

Q21. Derive an expression for calculating the overtaking sight distance on a highway.

Answer :

Derivation of Expression for Calculating the Overtaking Sight Distance

Consider a vehicle A passing over a two-lane two way road as shown in the figure. Vehicle B is the vehicle to be overtaken and vehicle C is the vehicle coming from opposite direction on other lane. The total overtaking distance 'd' may be assumed to be equal to the sum of distances d_1, d_2, d_3.

i.e., $d = d_1 + d_2 + d_3$

Where,

d_1 – Distance travelled by overtaking vehicle in time period of 't' seconds (reaction time)

d_2 – Distance travelled by overtaking vehicle in the period of 'T' seconds (actual time of overtaking)

d_3 – Distance travelled by vehicle on opposite lane during time 'T' seconds.

Initially, it is assumed that the vehicles 'A' and 'C' move with design speed V(m/s) and vehicle 'B' move with a low uniform speed of V_B(m/s)

Before overtaking the vehicle 'B' vehicle 'A' is assumed to move behind the vehicle 'B' at some safe distance 'h' at an uniform speed of V_B(m/s). During this time, the vehicle 'A' travels a distance of 'd_1' and change its position from 'A_1' to 'A_2'. This distance is therefore given as,

$$d_1 = V_B \cdot t \quad \text{... (1)}$$

Where,

t = Reaction time of driver (= 2 sec).

After travelling a distance 'd_1', the vehicle 'A' accelerate itself, move to the opposite lane and return to its actual lane in time 'T' seconds. During this time, the vehicle changes its position from point 'A_2' to 'A_3' and the straight distance travel is 'd_2'. The final distance between the vehicles of final positions (B_2 and A_3) is also assumed to be 'h' (i.e., the minimum spacing between two vehicles).

The spacing 'h' is calculated using the formula

$$h = (0.7\, V_B + 6)$$

The distance travelled by vehicle 'B' during the time period of 'T' seconds is given by,

$$b = V_B\, T \quad \text{... (2)}$$

$$\therefore \text{ Distance, } d_2 = (b + 2h) \quad \text{... (3)}$$

But the distance 'd_2' depends upon the speed of overtaken vehicle 'B' and acceleration of vehicle 'A'.

$$\therefore\ d_2 = ut + \frac{1}{2}at^2$$

$$d_2 = V_B T + \frac{1}{2}aT^2 \quad \text{... (4)}$$

Equating equations (3) and (4) (by substituting the values of 'a' and 'b')

$$V_B T + 2h = V_B T + \frac{1}{2}aT^2$$

$$\text{or} \quad 2h = \frac{1}{2}aT^2$$

$$\text{or} \quad T^2 = \frac{4h}{a}$$

$$\text{or} \quad T = \sqrt{\frac{4h}{a}} \quad \text{... (5)}$$

Where, $h = 0.7 V_B + 6$

$\therefore \quad d_2 = V_B T + 2h$ ... (6)

Therefore, the distance travelled by the other vehicle 'C' during the time period of 'T' seconds is given as,

$d_3 = (V \times T)$ ... (7)

($\because$ It is moving with a speed of V km/h)

$\therefore$ The overtaking sight distance 'd' is given by,

$$d = d_1 + d_2 + d_3$$

$$= (V_B T) + (V_B T + 2h) + (VT)$$

$$\boxed{d = V_B T + V_B T + 2h + VT}$$ ... (8)

Where,

V_B – Speed of vehicle in m/s

t – Reaction time of driver

V – Design speed in m/s

$T - \sqrt{\dfrac{4h}{a}}$ sec

h – Spacing between vehicles

a – Acceleration in m/sec².

Q22. The stopping sight distance required for a highway is 80 m. Find the required set back distance from centre line of a circular curve of radius 300 m assuming the length of the curve is greater than the sight distance.

Answer :

Given that,

Stopping sight distance, S = 80 m

Radius of curve, R = 300 m

The half central angle subtended at the centre is given by,

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

$$= \frac{80}{2 \times 300}$$

$$= 0.133 \text{ radians}$$

$$= 0.133 \times \frac{180}{\pi}$$

$$= 7.620°$$

$\therefore$ Set back distance, $m = R - R\cos\dfrac{\alpha}{2}$

$$= 300 - 300 \times \cos 7.620°$$

$$= 300 - 297.350$$

$$\therefore m = 2.65 \text{ m}$$

Q23. Calculate the stopping sight distance for a design speed of 100 kmph. Take the total reaction time 2.5 seconds and the coefficient of friction = 0.35.

Answer :

Given that,

The design speed, V = 100 kmph

Reaction time, t = 2.5 seconds

Coefficient of friction, f = 0.35

The stopping sight distance = $d_1 + d_2$

Where,

d_1 – Distance travelled in meters

d_2 – Braking distance in meters.

$$d_1 = vt$$

$$= 0.278 \times V \times t$$

$$= 0.278 \times 100 \times 2.5$$

$$d_1 = 69.5 \text{ m}$$

$$d_2 = \frac{V^2}{254 \times f}$$

$$= \frac{100^2}{254 \times 0.35}$$

$$d_2 = 112.48 \text{ m}$$

$\therefore$ Stopping sight distance = $d_1 + d_2$

$$= 69.5 + 112.48$$

$$= 181.98 \text{ m}$$

$$\simeq 182 \text{ m}$$

Q24. Calculate the OSD required on a National highway with a design speed of 100 kmph. Take the rate of acceleration as 1.75 kmph/sec and assume any other data required suitably.

Answer :

Given that,

Design speed, V = 100 kmph

Rate of acceleration a = 1.75 kmph/sec

Difference in speed, m = 16 kmph (assuming)

$\therefore$ Speed of overtaken vehicle,

$$V_B = V - m$$

$$V_B = 100 - 16$$

$$V_B = 84 \text{ kmph}$$

Headway,

$$S = 0.20\, V_b + 6$$

$$= 0.20 \times 84 + 6$$

$$= 22.8 \text{ m}$$

Time, $T = \sqrt{\frac{14.4S}{a}}$

$= \sqrt{\frac{14.4 \times 22.8}{1.75}}$

$T = 13.7$ seconds

Distances,

$d_1 = 0.56(V - m)$

$= 0.56(100 - 16)$

$d_1 = 47.04$ m

$d_2 = 0.28\ V_B T + 2S$

$= 0.28 \times 84 \times 13.7 + 2(22.8)$

$d_2 = 367.82$ m

$d_3 = 0.28\ VT$

$= 0.28 \times 100 \times 13.7$

$d_3 = 383.6$ m

Overtaking Sight Distance (OSD),

OSD= $d_1 + d_2 + d_3$

$= 47.04 + 367.82 + 383.6$

OSD = 798.46 m

Q25. The speed of overtaking and overtaken vehicles are 90 kmph and 45 kmph respectively on a two way traffic road. If the time taken by the overtaking vehicle is equal to 7.5 seconds and reaction time of the driver is equal to 2 seconds, calculate the safe overtaking sight distance.

Answer : **Model Paper-III, Q5(b)**

Consider the design speed as the speed of overtaking vehicle *A*.

$V = 90$ kmph

$V = \frac{90}{3.6} = 25$ m/sec

$V_b = \frac{45}{3.6} = 12.5$ m/sec

$V = u + at$

Where, initial velocity of vehicle $u = 0$

$\therefore V = at$

$25 = a \times 7.5$

($\because t$ = time taken by overtaking vehicle = 7.5 sec)

$\therefore$ Acceleration, $a = \frac{25}{7.5}$

$a = 3.33$ m/sec²

$d_1 = V_b \times t_r$

$= 12.5 \times 2$

($\because t_r$ = reaction time = 2 sec)

$= 25$ m

$d_2 = V_b T + 2 \times s$

$s = (0.7\ V_b + 6)$

$= (0.7 \times 12.5) + 6$

$= 14.75$ m

$T = \sqrt{\frac{4 \times s}{a}}$

$= \sqrt{\frac{4 \times 14.75}{3.33}}$

$= 4.20$ sec

$d_2 = (12.5 \times 4.20) + (2 \times 14.75)$

$= 52.5 + 29.5$

$d_2 = 82$ m

$d_3 = V \times T$

$= 25 \times 4.20$

$d_3 = 105$ m

$\therefore$ Safe Overtaking Sight Distance (OSD),

O.S.D is given as,

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

$= 25 + 82 + 105$

$= 212$ m

Q26. Determine the safe overtaking sight distance required for a two lane, two-way traffic road, given the speeds of overtaking and overtaken vehicles are 100 kmph and 70 kmph respectively. The acceleration of overtaking vehicle is 2.4 kmph/sec, spacing between vehicle is 20 m, reaction time of driver is 2 sec adn speed of vehicle coming in the opposite direction is 80 kmph.

Answer : **April-18, (R15) Q5(a)**

Given that,

Overtaking speed, $V = 100$ kmph

$= \frac{100}{3.6} = 27.77$ m/sec

Overtaken speed, V_b = 70 kmph

$$= \frac{70}{3.6} = 19.44 \text{ m/sec}$$

Acceleration,

$$a = 2.4 \text{ kmph/sec}$$

$$= \frac{2.4}{3.6} = 0.666 \text{ m/sec}^2$$

$$d_1 = V_b \times t \text{ (Given, } t = 2 \text{ secs)}$$

$$= 19.44 \times 2$$

$$\therefore d_1 = 38.88 \text{ m}$$

$$d_2 = V_b \times T + 2.S \quad \text{... (1)}$$

$$S = (0.7 \times V_b + 6)$$

$$= (0.7 \times 19.44 + 6)$$

$$\therefore S = 19.608 \text{ m}$$

$$T = \sqrt{\frac{4 \times S}{a}}$$

$$= \sqrt{\frac{4 \times 19.608}{0.666}}$$

$$\therefore T = 10.85 \text{ sec}$$

Now substituting the values of V_b, T and S in equation (1), we get,

$$d_2 = (19.44 \times 10.85) + (2 \times 19.608)$$

$$\therefore d_2 = 250.14 \text{ m}$$

$$d_3 = V.T$$

$$= 27.77 \times 10.85$$

$$\therefore d_3 = 301.304 \text{ m}$$

∴ Overtaking sight distance for two way traffic, O.S.D = $d_1 + d_2 + d_3$

$$= 38.88 + 250.14 + 301.304$$

$$\therefore O.S.D = 590.3245 \text{ m}$$

Q27. There is a horizontal curve of radius 50 m on a stretch of hill road with a gradient of 5.0%. Determine the grade compensation.

Answer :

Given that,

Radius of horizontal curve, R = 50 m

Gradient, n = 5.0%

$$\text{Grade compensation} = \frac{30+R}{R}$$

$$= \frac{30+50}{50}$$

$$\therefore \text{Grade compensation} = \frac{80}{50} = 1.6\%$$

$$\text{Maximum limit of grade compensation} = \frac{75}{R}$$

$$= \frac{75}{50}$$

$$= 1.5\%$$

∴ Compensated gradient = 5.0 – 1.5 = 3.5%

2.3 DESIGN OF HORIZONTAL ALIGNMENT -DESIGN OF SUPER ELEVATION AND EXTRA WIDENING

Q28. List out the design elements to be considered at the horizontal alignment and explain,

(a) Overturning effect

(b) Transverse skidding effect.

Answer : Model Paper-II, Q4(b)

The following are the various design elements that are considered in the horizontal alignment are,

1. Design speed
2. Radius of circular curves
3. Type and length of transition curves
4. Super elevation and
5. Widening of pavement on curves.

(a) Overturning Effect

The overturning of vehicle are caused due to centrifugal force on horizontal curve without super elevation. This overturning moment is equal to product of force and height of the centre gravity of the vehicle above the road surface.

∴ Overturning moment = $P \times h$

This overturning moment is withstand by restoring moment due to weight of the vehicle which is equals to,

Restoring moment = $W.b/2$

Where,

b – Width of the wheel base

W – Weight of vehicle

When $ph = Wb/2$, the equilibrium conditions for overturning are developed. Therefore the centrifugal force ratio is equal to '$b/2$ h a overturning effect is produced.

(b) Transverse Skidding Effect

Transverse skidding effect are developed when the centrifugal force has the tendency to move the vehicle outwards in the transverse direction. When the force develop maximum transverse skid resistance due to friction the vehicle will, skid in transverse direction. Therefore, the equilibrium conditions for transverse skidding resistance is given as,

$$P = F_A + F_B$$

$$= f(R_A + R_B)$$

$$P = fW$$

Where,

P – Centrifugal force

R_A – Normal reaction at wheel A

R_B – Normal reaction at wheel B

f – Friction

W – Weight of vehicle

Therefore, When centrifugal force ratio (P/w) is equal to friction (i.e. lateral coefficient of friction) transverse skidding effect are produces. Therefore to neglect the effect due to overturning and transverse skidding on horizontal curve, the centrifugal force should be less than '$b/2h$' and friction 'f'.

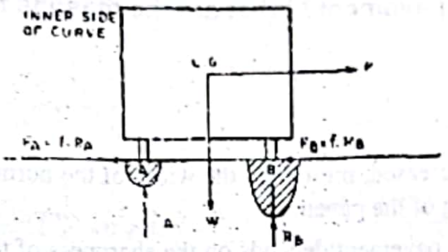


Figure: Showing the Transverse Skidding Effect

Q29. With the help of a neat sketch, explain the attainment of super elevation in the field.

May-17, (R13), Q5(a)

Answer :

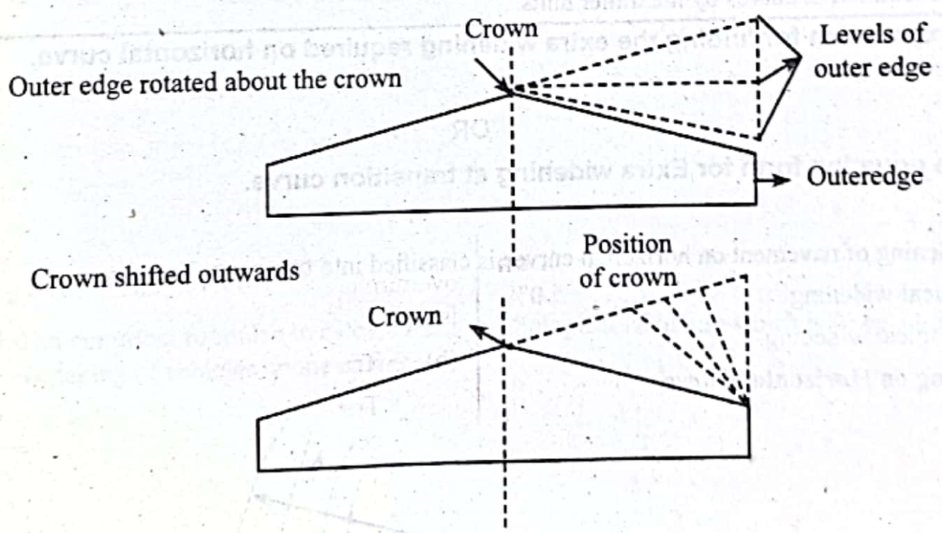
Attainment of super elevation is classified into two parts,

1. Elimination of the crown of the cambered section.
2. Rotation of pavement to attain full super elevation.

1. Elimination of The Crown of The Cambered Section

It is carried out in 2 methods.

In the first method, the outer half of the cross slope is rotated about the crown such that the surface falls on the plane of inner half. The rise of the centre line is constant. The outer half is again rotated to attain uniform cross slope equal to camber as shown in figure.



The second method of elimination is done by shifting the crown outwards. As a result the width of inner half increases. This method is known as diagonal crown method.

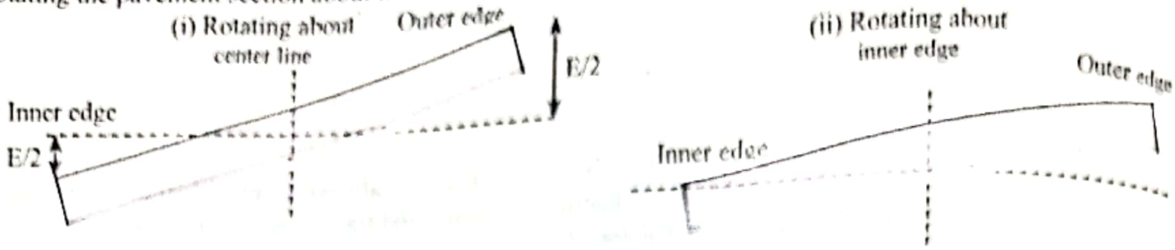
2. Rotation of Pavement

The super elevation of the section is equal to camber if we eliminate the crown of camber. But initially in the design of circular curves. super elevation is more than camber in many cases. So we need to further rotate the pavement to elimate the crown of camber.

It is done in two methods

(i) Rotating the pavement section about centre line

(ii) Rotating the pavement section about inner edge.



Q30. What is extra widening of the pavement? What are the reasons for providing extra width of pavement at horizontal curves?

Model Paper-III, Q4(a)

Answer :

Extra Widening of the Pavement

The width of the carriageway is increased, more than the width of the normal pavement on the horizontal curves. This increased width is called as extra widening of the pavement.

The value of extra widening of the pavement depends on the sharpness of the curve (i.e., the provision for extra width would be greater for sharper curves).

Following are the reasons for providing extra width of pavement at horizontal curves,

1. While driving on curves, drivers have a tendency to keep away from the edge of the carriage way.
2. Due to the psychological effects, the clearance between the vehicles while crossing each other over horizontal curve will be greater than that on a straight road.
3. More space of road is occupied by the vehicle due to turning the front steering wheels, while negotiating a horizontal curve.
4. Vehicle occupies more width of road in the off tracking position (rear wheels not tracing exactly as the front steering wheel).
5. At very high speed of vehicle more width of road is covered due to the occurence of outward slipping of rear wheels.
6. For better visibility and large radius curved path, drivers have a tendency to follow outer edge of the pavement at the initial points of the curve.
7. Extra width is required at curves by the trailer units.

Q31. Derive an expression for finding the extra widening required on horizontal curve.

Model Paper-I, Q5(a)

OR

Develop the equation form for Extra widening at transition curve.

May-16, (R13), Q5(a)

Answer :

The extra widening of pavement on horizontal curves is classified into two parts. They are,

1. Mechanical widening
2. Psychological widening.

Mechanical Widening on Horizontal Curve

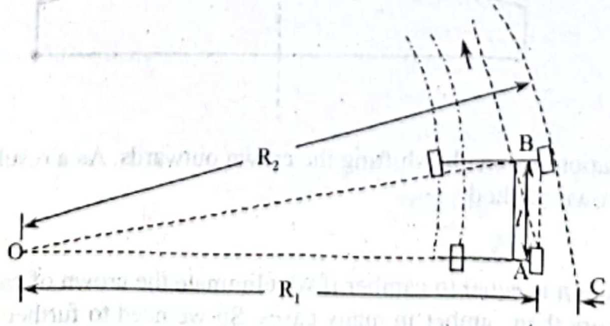


Figure: Mechanical Widening on Horizontal Curve

Let R_1 be the radius of the path traversed by the outer rear wheel. (m)

R_2 be the radius of the path traversed by the outer front wheel. (m)

w_m be the mechanical widening (m)

l be the length of wheel base (m)

From figure, mechanical widening w_m is given as,

$$w_m = OC - OA = OB - OA = R_2 - R_1 \quad ...(1)$$

From ΔOAB, $OB^2 = OA^2 + BA^2$

$$\therefore \quad OA^2 = OB^2 - BA^2$$

$$R_1^2 = R_2^2 - l^2 \quad ...(2)$$

From equation (1), $w_m = R_2 - R_1$

$$R_1 = R_2 - w_m$$

By substituting the value of R_1 in equation (2), we get,

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

$$R_2^2 - 2R_2 w_m + w_m^2 = R_2^2 - l^2$$

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

$$\therefore \quad l^2 = w_m(2R_2 - w_m)$$

$$w_m = \frac{l^2}{2R_2 - w_m}$$

$$\simeq \frac{l^2}{2R}$$

Where, R – Mean radius of the curve.

The above estimated mechanical widening is required for individual vehicle negotiating a horizontal curve along an individual traffic lane.

When number of the traffic lanes are 'n'.

$\therefore$ The mechanical widening required is given as,

$$\boxed{w_m = \frac{nl^2}{2R}}$$

Psychological Widening on Horizontal Curve

IRC recommended an empirical formulae to calculate the psychological widening which is to be additionally provided, for better clearance and overtaking of vehicles on the curves.

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

Where,

V – Design speed (kmph)

The total extra widening is given as,

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

$$\boxed{W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}}$$

Q32. Draw the typical cross-sections of M.D.R in embankment, O.D.R cutting a city road and a national highway in cutting, clearly indicating the width of pavement, road and land.

Answer :

Typical Cross-Sections of Roads

M.D.R in Embankment

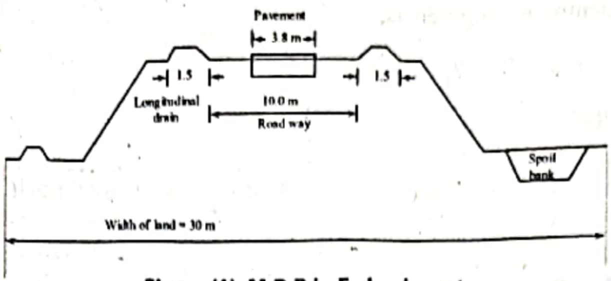


Figure (1): M.D.R in Embankment

O.D.R in Cutting

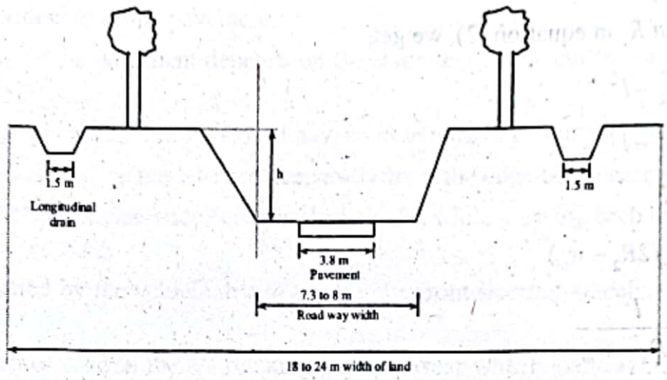


Figure (2): O.D.R in Cutting

City Road in Cutting

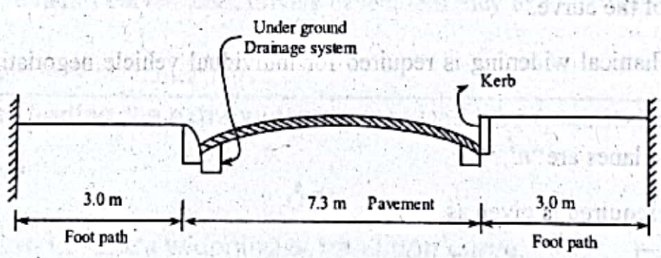


Figure (3): City Road in Cutting

National Highway in Cutting

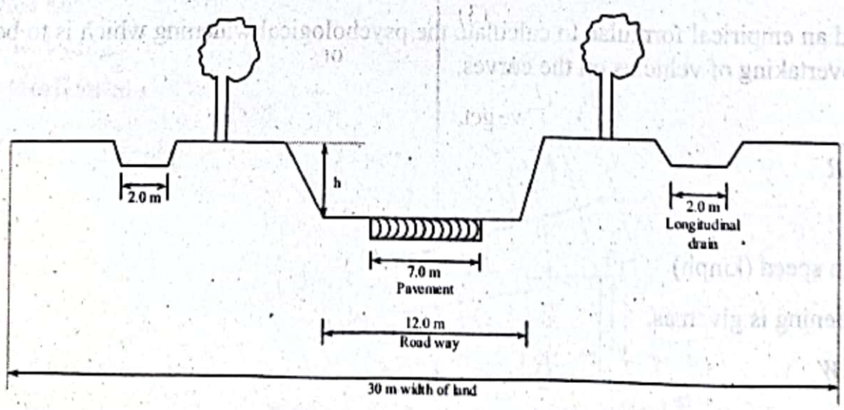


Figure (4): National Highway in Cutting

Q3. Derive an equation for finding the super elevation required, if the design coefficient of lateral friction is 'f'.

OR

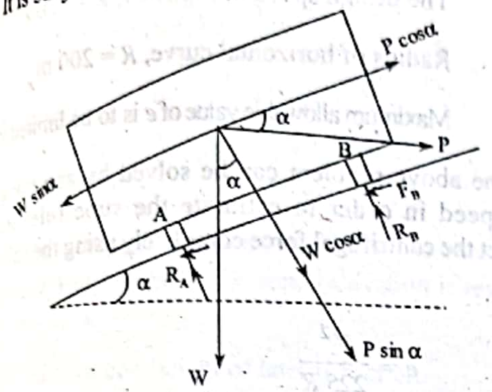
Develop the equation form for super elevation design.

May-16, (R13), Q4(a)

Answer :

Expression for Rate of Super Elevation

A vehicle moving over a horizontal curve is shown in figure. It is subjected to the following forces.



Figure

(a) Self weight (W) (vertical)

(b) Centrifugal force (horizontal)

(c) Frictional force (along the pavement surface in transverse direction).

Due to the super elevation (or cant) provided at the outer side of the road, the centrifugal force is counter balanced by the frictional forces developed at wheels and a component of weight of vehicle. The components of weight of vehicle and centrifugal force along and across the inclined surface of road are also shown in the figure.

Applying equilibrium along the inclined surface of road,

$$P\cos\alpha - W\sin\alpha - F_A - F_B = 0 \quad \text{... (1)}$$

For limiting values of frictional forces,

$$F_A = f(R_A) \quad \text{... (2)}$$

$$F_B = f(R_B) \quad \text{... (3)}$$

Where, f = Coefficient of lateral friction.

Substituting the values of F_A and F_B in equation (1), we get,

$$P\cos\alpha - W\sin\alpha - fR_A - fR_B = 0 \quad \text{... (4)}$$

Considering equilibrium of forces in direction perpendicular to the inclined surface of road,

$$R_A + R_B = W\cos\alpha + P\sin\alpha \quad \text{... (5)}$$

Substituting equation (5) in equation (4), we get,

$$P\cos\alpha - W\sin\alpha - f(W\cos\alpha + P\sin\alpha) = 0$$

or $$P[\cos\alpha - f\sin\alpha] = W\sin\alpha + fW\cos\alpha \quad \text{... (6)}$$

Dividing equation (6) "$W\cos\alpha$" on both sides,

$$\frac{P[\cos\alpha - f\sin\alpha]}{W\cos\alpha} = \frac{W\sin\alpha}{W\cos\alpha} + \frac{fW\cos\alpha}{W\cos\alpha}$$

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

or $$\frac{P}{W} = \frac{\tan\alpha + f}{1 - f\tan\alpha} \quad \text{... (7)}$$

For design purposes,

$$f = 0.15,\ \alpha = 0.07 \text{ and } f\tan\alpha \simeq 0.01$$

$$\therefore\quad 1 - f\tan\alpha = 1 - 0.01$$

$$= 0.99 \simeq 1$$

Equation (7) reduces to,

$$\frac{P}{W} \simeq \tan\alpha + f = e + f \quad \text{... (8)}$$

Where,

e – Rate of super elevation = $\tan\alpha$

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

or $$\frac{P}{W} = \frac{v^2}{gR} \quad \text{... (9)}$$

Substituting equation (9) in equation (8), we get,

$$\frac{v^2}{gR} = e + f \quad \text{... (10)}$$

Where,

v – Vehicle speed (m/sec)

g – Acceleration due to gravity (m/sec^2)

R – Radius of curve (m)

If speed of vehicle (v) is represented in terms of km/h, equation (10) changes to,

$$e + f = \frac{(0.278V)^2}{9.8R} \quad (\because g = 9.8 \text{ m/sec}^2)$$

or $$e + f = \frac{V^2}{127R} \quad \text{... (11)}$$

If coefficient of friction is neglected (or taken equal to zero) equation (10) further reduces to,

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

or $$e = \frac{V^2}{127R} \quad \text{... (12)}$$

The above expression represents that rate of super elevation in terms of speed of vehicle and the radius of horizontal curve.

Q34. Present on engineering surveys to be conducted for highway construction?

Answer : May-16, (R13), Q4(b)

On curves, super-elevation is provided to counteract with the centrifugal force and the remaining is counteracted by the lateral friction.

The equation for super-elevation is,

$$e + \mu = \frac{V^2}{127R} \quad \text{... (1)}$$

Where,

e – Rate of super elevation

V – Speed of the vehicle in kmph

R – Radius of the curve in m

μ – Lateral friction coefficient (0.15)

If the super-elevation counteracts with entire centrifugal force, then coefficient of lateral friction, $\mu = 0$. Then,

$$e = \frac{V^2}{127R} \quad \text{... (2)}$$

As per IRC, the super-elevation counteracts with the centrifugal force developed by 75 percent of design speed and the remaining 25 percent is taken care of surface friction.

Then,

$$e = \frac{(0.75\,v)^2}{gR}$$

Where,

ρ – Rate of super-elevation

g – Acceleration due to gravity (m/s²)

R – Radius of the curve (m)

v – Velocity of the vehicle (m/s).

As per IRC, the permissible e_{max} values are,

(i) For plain and rolling terrain including snow bound areas it is 7% (1 in 16).

(ii) For hilly areas not bounded by snow it is 10% (1 in 10).

(iii) For urban area with frequent intersections it is 4% (1 in 25).

If the super-elevation is less than the road camber, then the normal camber should be provided instead of super elevation. In general, snowy curved surfaces provide low coefficients of side friction which results in sliding down of heavy vehicles even if they ar travelling at low speeds. So, lower values of e_{max} should be adopted in such cold and snow falling areas.

Q35. A two-line highway with design speed of 120 kmph is aligned with a horizontal curve of radius 200 m. What is the super-elevation required to maintain this speed? If the maximum super-elevation rate of 0.07 and coefficient of lateral friction of 0.15 is to be provided along with limiting the radius to 200 m, calculate the allowable speed.

Answer : (April-18 (R15) Q4(a) | Model Paper-II, Q5(b))

Given that,

The design speed of highway, $V = 120$ kmph

Radius of horizontal curve, $R = 200$ m

Maximum allowable value of e is to be limited to 0.07

The above problem can be solved by assuming 75% design speed in order to estimate the supe relevation to counteract the centrifugal force completely using the following equation,

$$e = \frac{V^2}{225\,R}$$

$$= \frac{120}{225 \times 200}$$

$$= 0.32 \quad [\because \text{Maximum allowable value of } e \text{ is to be limited to } 0.07]$$

The value of friction developed is to be checked.

$$f = \frac{V^2}{127\,R} - 0.07$$

$$= \frac{120^2}{127 \times 200} - 0.07 - 0.07$$

$$= 0.5669 - 0.07$$

$$\therefore \; f = 0.4969$$

As this value is greater than the maximum allowable safe friction coefficient of 0.15 and also the radius cannot be increased, the speed is to be limited.

The maximum allowable speed [V_a(kmph)] on the given curve is obtained by considering the complete value of design friction coefficient of 0.15.

Thus, maximum allowable speed is given as,

$$V_a = \sqrt{27.94\,R}$$

$$= \sqrt{27.94 \times 200}$$

$$\therefore \; V_a = 74.75 \text{ kmph}$$

Therefore, the speed can be restricted to less than 74 or say 70 kmph at this curve.

Q36. Design the rate of super elevation for a horizontal highway curve of radius 500 m and speed 100 kmph.

Answer :

Given that,

$R = 500$ m

Speed, $V = 100$ kmph

$$\text{Super elevation, } e = \frac{(0.75V)^2}{127R}$$

$$= \frac{(0.75 \times 100)^2}{127 \times 500}$$

$$= 0.088$$

$$= 1 \text{ in } 11.3$$

As this value is greater than the maximum super elevation of 1 in 15, the actual supe relevation is restricted to 1 in 15 (=0.067).

Check for coefficient of lateral friction.

$$f = \frac{V^2}{127R} - 0.067$$

$$= \frac{100^2}{127 \times 500} - 0.067$$

$$= 0.157 - 0.067$$

$$= 0.09 < 0.15$$

∴ Design is safe with 1 in 15 super elevation.

Q37. Calculate the rate of super elevation to be provided at a horizontal curve of radius 400 m on a plain terrain for a design speed of 100 kmph. Is there a need for restricting the super elevation? If so, what is the restricted super elevation rate and find out whether there is need to restrict the speed or not?

Answer :

Given that,

Radius of curve, $R = 400$ m

Design speed, $V = 100$ kmph

Rate of super elevation,

$$e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 100)^2}{127 \times 400}$$

$$= 0.111$$

$$e = 1 \text{ in } 9 > 1 \text{ in } 15$$

∴ The restricted super elevation rate = 1 in 15.

Check

Coefficient of lateral friction,

$$f = \frac{V^2}{127R} - 0.067$$

$$= \frac{100^2}{127 \times 400} - 0.067$$

$$= 0.197 - 0.067$$

$$f = 0.13 < 0.15$$

There is no need to restrict the speed as the coefficient of lateral friction i.e., 0.13 is less than the maximum allowable value of 0.15.

2.4 DESIGN OF TRANSITION CURVES – DESIGN OF VERTICAL ALIGNMENT – GRADIENTS – VERTICAL CURVES

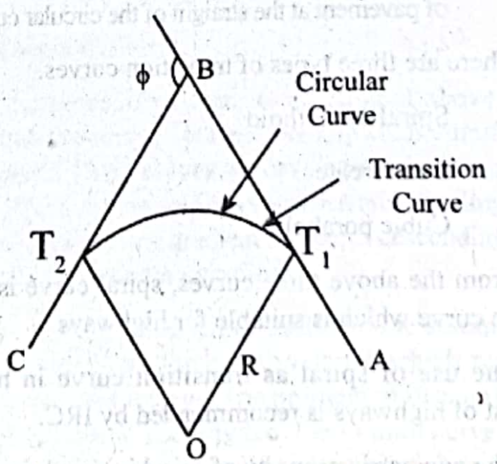
Q38. Write short notes on transition curves.

Answer :

Transition curve is an easement curve having variable radius to reduce super elevation. This curves are introduced on both sides of circular curve. The main purpose of transition curve is to permit the moving of vehicle from tangent section to the curved section and again to the tangent section in a safe and comfortable manner. Therefore the motoristy follows a easy path and the centrifugal force increases or decreases when the vehicle enters and leaves the circular curve respectively. In transition curves the radius of curvature varies from infinity to designed radius, and decrease the disturbance of vehicles on the wrong path (opposite direction) so that a constant speed is maintained and the safety of vehicle at the curve is maximum.

Based on the requirement different types of transition curves are adopted which are as follows,

1. The lemniscate
2. Spiral and
3. Cubic parabola transition curve.

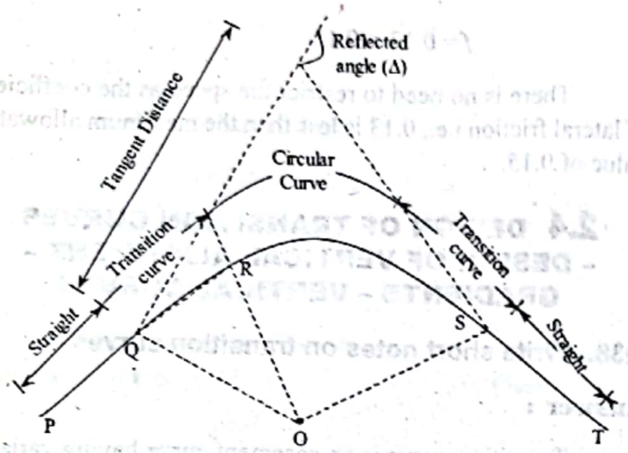


Figure

Q39. Why the transition curves are needed on highway horizontal alignment? Which types of curves more suitable for highways?

Answer : **Model Paper-II, Q4(a)**

Let a car is travelling on the road in which a curve of radius 'R' is taken off from the straight road. A lateral jerk is felt on the vehicle due to centrifugal force which suddenly acts on the vehicles after a tangent point. This creates a discomfort to the passenger and also in steering the vehicle.



Figure

Let QR be the transition curve of length 'L' and PQ be the straight and RS is the circular of radius 'r'.

In between the straight AB and circular curve CD a transition curve 'BC' is introduced.

The function need of transition curve in horizontal alignment of highway are,

- It enables the driver to turn the steering gradually with his own security and comfort.
- To have an aesthetic appearance of road.
- In order to avoid Jerk on the vehicle the centrifugal force is introduced in between the tangent point and beginning of circular curve.
- It provides designed superelevation and extra widening of pavement at the straight of the circular curve.

There are three types of transition curves.

1. Spiral or clothoid
2. Lemniscate
3. Cubic porabola.

From the above three curves, spiral curve is the ideal transition curve which is suitable fcr highways.

The use of spiral as transition curve in horizontal alignment of highways is recommended by IRC.

1. The geometric property of spiral is simple and easy for the calculations and setting out the curves.
2. The spiral curves satisfies the ideal transition requirements.

The equation is written as,

$$R \propto \frac{1}{L}$$

$$R_C L_C = R.L = \text{Constant}$$

$$\therefore L = m.\sqrt{\theta}$$

Here,

θ – Tangent deflection angle

m – Constant

$= \sqrt{2RL_S}$

Q40. What are the objectives of providing transition curves on horizontal curves? Explain. Discuss the methods of computing the length of transition curves.

Answer :

Objects of Providing Transition Curves on Horizontal Curves

The different objectives of providing transition curves on horizontal curves are listed below,

(i) Transition curves provide a smooth and easy means for the vehicle to travel from straight roads to circular curve and vice-versa.

(ii) They help to attain the actual curvature of the curve at junction point, gradually increasing from zero at the tangent point.

(iii) They help to obtain the full super-elevation, gradually increasing from zero at the tangent point to a specified value on the main circular curve.

(iv) They help to introduce an extra-widening of pavement at the start of the circular curve.

Methods of Computing the Length of Transition Curves

The length of transition curves is calculated by following methods,

(i) By super elevation rate

(ii) By time rate

(iii) By rate of change of radial acceleration.

(i) By Super Elevation Rate

Consider the rate of introduction of super elevation as "1 in n" of the curve length.

Let super elevation be 'h' cm. Therefore, the length of transition curve is expressed as,

$$L_i = nh$$

Where,

$h = \frac{Gv^2}{gR}$ and the value of 'n' ranges from 300 to 1200.

(ii) **By Time Rate**

Let,

'x' be the time rate of application of super elevation in cm/sec

'L_s' be the length of transition curve in metres

'h' be the super elevation in cm

'v' be the speed of the vehicle in m/sec.

If the time rate of super elevation i.e., 'x' cm is applied at 1 sec, then the time rate of application of complete super elevation of 'h' cm is "$\frac{h}{x}$" seconds.

$$\therefore \text{say } \frac{h}{x} = t$$

Now,

$$\text{Distance} = \text{Speed} \times \text{Time}$$

$$= v \times t$$

$$= v \times \frac{h}{x}$$

Where, $\boxed{h = \frac{Gv^2}{gR}}$

$$= \frac{v}{x} \times \frac{Gv^2}{gR}$$

$$\boxed{L_s = \frac{Gv^3}{xgR}} \text{ metre.}$$

(iii) **By Rate of Change of Radial Acceleration**

For the calculation of the length of transition curve (L_s), this is the most scientific method. It provides comfort condition for the passengers of the vehicle when the time rate of change of radial acceleration is 0.3 m/s² per second.

It 'v' is the speed of the vehicle on a curved path of radius 'R' then the radial acceleration is,

$$= \frac{v^2}{R}$$

$$\therefore \text{Rate of change of radial acceleration} = \frac{v^2/R}{t} = \alpha$$

$$\therefore t = \frac{v^2}{\alpha R} \quad \text{... (A)}$$

If 'L' is the length of the transition curve and 'v' is the speed of the vehicle then the time taken,

$$t = \frac{L}{v} \quad \text{... (B)}$$

Equating equations (A) and (B),

$$\frac{v^2}{\alpha R} = \frac{L}{v}$$

$$L = \frac{v^3}{\alpha R}$$

$$L_s = L = \frac{v^3}{0.3R}$$

∴ The length of the transition curve is directly proportional to the velocity and inversely proportional to radius of the circular curve.

If the speed of the vehicle is 'v' in km/hr.

$$v = \frac{v \times 1000}{3600} \text{ m/s}$$

$$v = \frac{v}{3.6} \text{ m/s}$$

Length of the transition curve,

$$L_s = \frac{1}{0.3R}\left(\frac{v}{3.6}\right)^3$$

$$L_s = \frac{v^3}{14R}$$

Q41. Define vertical curve. Explain the classification of vertical curves.

Answer : Model Paper-III, Q4(b)

Vertical Curve

When two different or contrary gradients meet in a road alignment, they are connected by a curve in a vertical plane known as vertical curve. The provision of these curves is for securing safety, adequate visibility and comfort to the passengers.

Vertical curves are passengers divided into two types. They are as follows,

(a) Summit curves

(b) Valley curves.

(a) Summit Curves

If the point of vertical intersection is above the road surface, then the curves obtained are known as summit curves or crest curves. These curves are developed when an ascending road intersects a descending road or when an ascending gradient meets another ascending gradient or when a descending gradient meets another descending gradient.

Due to the movement of traffic on the summit curves, an upward centrifugal force is developed which reduces the pressure or tyre and springs. The problem of discomfort to the passengers reduces as the length of the summit curve designed for adequate sight distance would be long enough to reduce the shocks.

Following are the situations for which summit curves are provided.

1. During the intersection of rising slope or grade and falling grade.
2. When a rising grade meets another rising grade.
3. When a rising grade meets a horizontal road.
4. When a falling grade meets a steeper falling grade.

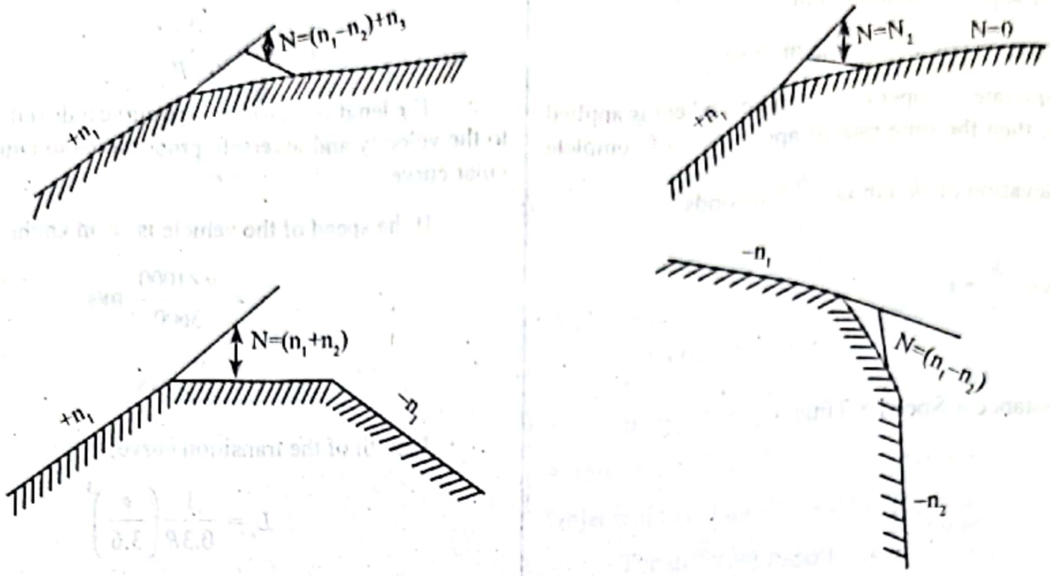


Figure (1): Summit Curves

(b) **Valley Curves**

A vertical curve which has concavity upwards or convexity downwards, then it is known as valley curve.

The available sight distance at valley curve decreases during night driving because of head lights, but in day light the problem for sight does not occur. At the valley curves, the centrifugal force acts downwards which gets added to the weight of the vehicle. Transition curve is the best shape of valley curve for the development of centrifugal force downwards. The preferred shape of vertical valley curve is the cubic parabola.

Impact free movement of vehicles at design speed is one of the most significant factor that is to be considered in the design of the valley curve. From the considerations of cross drainage, the lower point in a valley curve may be located.

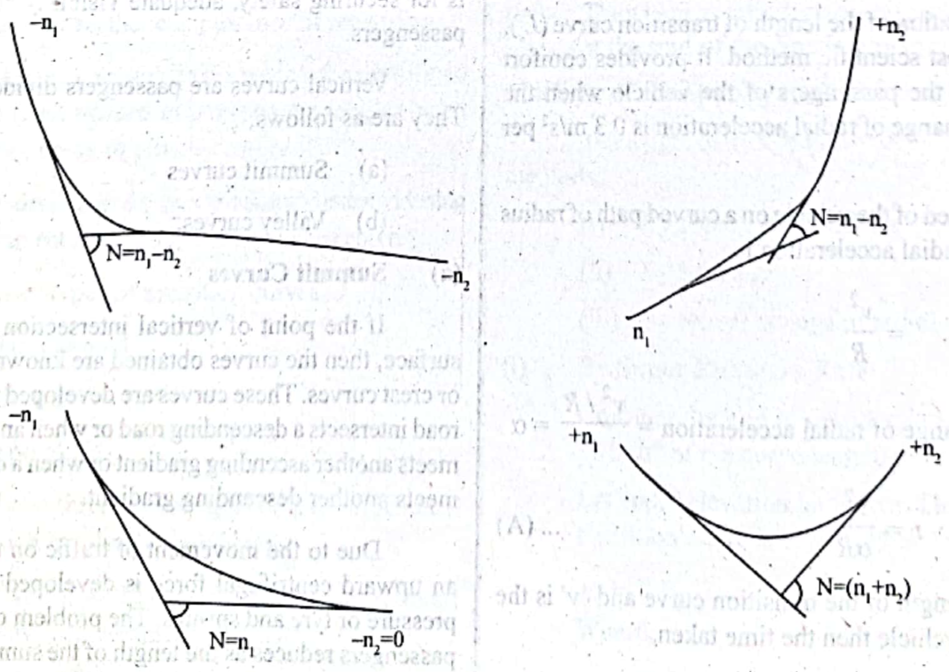


Figure (2): Valley Curves

Following are the situations for which the valley curves are provided,

1. During the intersection of falling gradient and raising grade
2. The meeting of falling gradient with another falling gradient
3. The contact of a falling gradient with horizontal road
4. When a rising gradient meets a steeper raising grade.

Q42. Develop the equation forms for designing the different vertical curves.

Answer : **May-16, (R13), Q5(b)**

The vertical curves are to be provided in the vertical alignment in the highways at the intersections to ease off the vertical profile for high speeds. The vertical curves provided in a highway are divided into two types. They are,

(i) Summit curves

(ii) Sag curves.

(i) Summit Curves

The summit curves are also called as crest curves with upward convexity. It is important to consider sight distance in order to determine the length of the curve.

Case 1

When sight distance is less than the length of the curve (L).

The vertical curves are designed in the form of parabolas. Consider two grade lines at grades $+G_1$ and $-G_2$, intersecting at '0'. The algebraic difference between the grades is given by,

$$G = G_1 - (-G_2)$$

$$= G_1 + G_2 \quad \text{... (1)}$$

Let E_1 and E_2 be the starting and ending points of the curve. Now, any point (P) on the parabola will be at a horizontal distance of 'x' from E_1 and at a vertical distance of y from the grade line for a parabola,

$$y = \frac{x^2}{c} \quad \text{... (2)}$$

$$QE_2 = QR + RE_2$$

$$= G_1\left(\frac{L}{2}\right) + G_2\left(\frac{L}{2}\right)$$

$$= \frac{L}{2}(G_1 + G_2) = \frac{L}{2}(G)$$

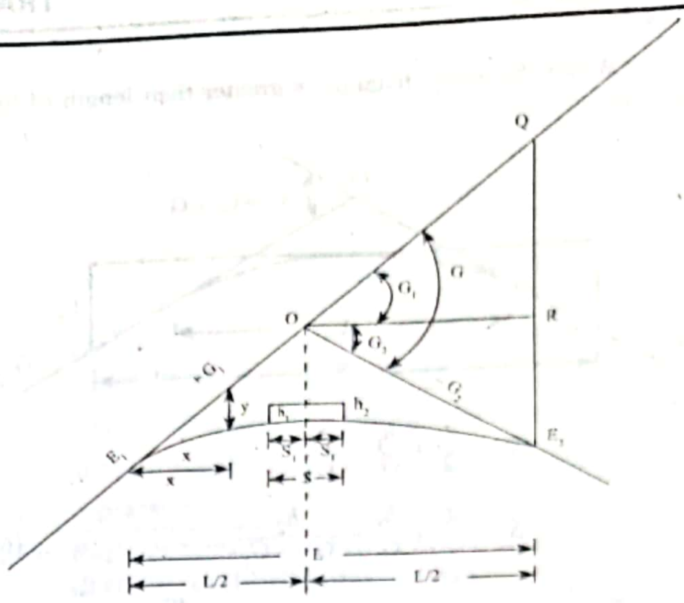
At the end point of curve, E_2

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

from the equation (2)

$$\frac{LG}{2} = \frac{L^2}{C}$$

$$C = \frac{2L}{G} \quad \text{... (3)}$$



Let,

h_1 – Height of driver's eye above the curve

h_2 – Object height on the curve

S_1 – Distance between the apex and driver of the curve

S_2 – Distance between the apex and object of the curve.

$$h_1 = \frac{S_1^2}{C}, \quad h_2 = \frac{S_2^2}{C}$$

($\because$ From the property of parabola)

$$S_1 = \sqrt{Ch_1}$$

$$S_2 = \sqrt{Ch_2}$$

$$S = S_1 + S_2$$

$$= \sqrt{C}(\sqrt{h_1} + \sqrt{2})$$

$$S = \sqrt{\frac{2L}{G}}(\sqrt{h_1} + \sqrt{h_2}) \quad (\because \text{ From equation (3)})$$

On squaring both sides and rewriting the above equation, we get,

$$L = \frac{GS^2}{(\sqrt{2h_1} + \sqrt{2h_2})^2} \quad \text{... (4)}$$

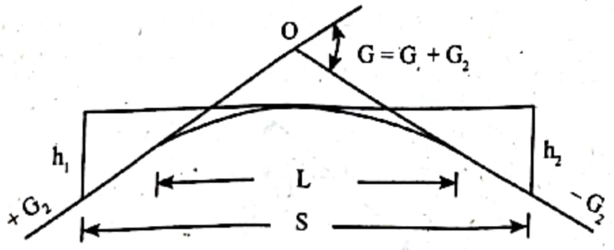
As per IRC, safe stopping distance = 0.15 m. Height of driver's eye above curve = 1.2 m

Then,

$$L = \frac{GS^2}{4.4} \quad \text{... (5)}$$

Case 2

When the sight distance is greater than length of the curve (L)



$$S = \frac{L}{2}+\frac{h_1}{G_1}+\frac{h_2}{G_2}$$

$$S = \frac{L}{2}+\frac{h_1}{G_1}+\frac{h_2}{G-G_1} \quad \text{... (6)}$$

For sight distance to be minimum, $\frac{dS}{dG_1}=0$,

$$\frac{-h_1}{G_1^2}+\frac{h_2}{(G-G_1)^2}=0$$

$$h_1(G-G_1)^2 = h_2 G_1^2$$

$$h_1(G^2-2.G.G_1+G_1^2) = h_2 G_1^2$$

$$G_1^2(h_2-h_1)+2GG_1h_1-h_1G^2=0$$

On solving the above equation we get,

$$G_2 = \frac{-Gh_1+G\sqrt{h_1h_2}}{(h_2-h_1)} \quad \text{... (7)}$$

Substitute G_1 in equation (6), we get,

$$S=\frac{L}{2}+\frac{h_1}{\frac{G\sqrt{h_1h_2}-h_1G}{h_2-h_1}}+\frac{h_2}{G-\left(\frac{G\sqrt{h_1h_2}-h_1G}{h_2-h_1}\right)}$$

On simplifying the above equation, we get,

$$L=2S-\frac{2(\sqrt{h_1}+\sqrt{h_2})^2}{G} \quad \text{... (8)}$$

As per IRC, height of object 'h_2' = 0.15 m

Height of driver's eye 'h_1' = 1.2 m

Then,

$$L=2S-\frac{4.4}{G} \quad \text{... (9)}$$

While considering overtaking (or) intermediate sight distance.

As per IRC, $h_1 = h_2 = 1.2$ m

When

$$L>S,\ L=\frac{GS^2}{9.6} \quad \text{... (10)}$$

$$L<S,\ L=2S-\frac{9.6}{G} \quad \text{... (11)}$$

Sag Curves

The sag curves are also called as valley curves with concavity upwards. The important factor to be considered in determining the length of the curve is the comfort of driver.

$$a=\frac{v^2}{R} \quad \text{... (1)}$$

Where,

a – Radial acceleration in m/s²

v – Speed in m/s

R – Radius in m

As the radial acceleration increases from zero to 'a' in a length of $\frac{L}{2}$

Where,

L – Length of sag curve

Rate of change of radial accleration 'B' is given by,

$$B=\frac{V^2}{13R}\div\frac{L\times3.6}{2V}$$

Where,

V – Speed in kmph

$$B=\frac{V^3}{23.yLR}\text{m/s}^3 \quad \text{... (2)}$$

As per IRC, the recommended value of 'B' is 0.6 m/s³ for design. Then,

$$L=\frac{V^3}{14R}$$

$$\Rightarrow \quad (LR)=\frac{V^3}{14} \quad \text{... (3)}$$

For a transition curve,

$$L=(2RLG)^{1/2} \quad \text{... (4)}$$

Where, G – Algebraic difference between the grades of straights.

Substituting equation (3) in equation (4), we get,

$$L=\left(2\frac{V^3}{14}G\right)^{1/2}$$

$$\therefore \quad L=\frac{V^{3/2}G^{1/2}}{2.65} \quad \text{... (5)}$$

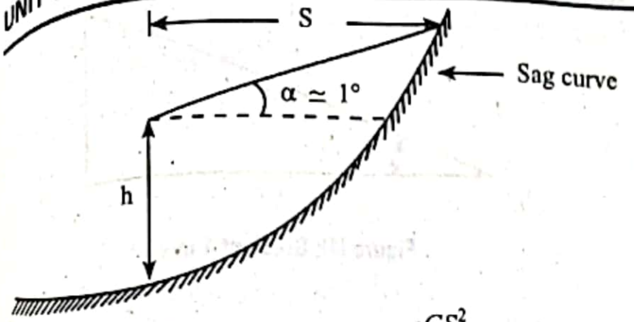
Case (i)

When the sight distance (S) is less than length of the curve (L)

$$G=-G_1-(+G_2) \quad \text{... (6)}$$

As the sag curve represents a parabolic ($y=ax^2$)

$$a=\frac{G}{2L} \quad \text{... (7)}$$



$$h + S\tan\alpha = ax^2 = \frac{GS^2}{2L}$$

On rearranging the above equation, we get,

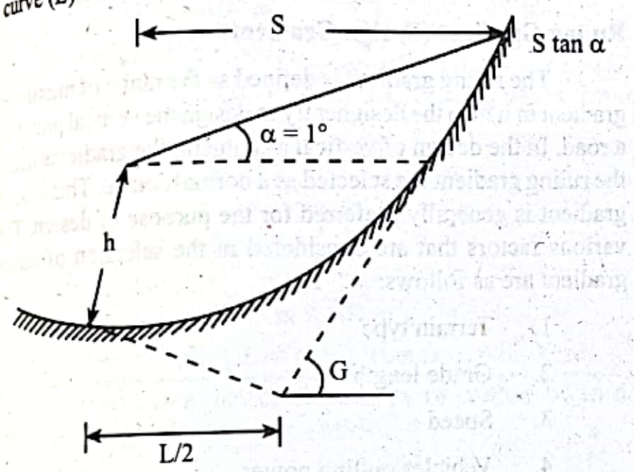
$$L = \frac{GS^2}{2(h+s\tan\alpha)} \quad ...(8)$$

As per IRC, $h = 0.45$ m, $\alpha = 1°$

$$L = \frac{GS^2}{1.5+0.035s} \quad ...(9)$$

Case (ii)

When sight-distance (s) is greater than length of the curve (L)



$$h + S\tan\alpha = \left(S - \frac{L}{2}\right)G$$

As per IRC, $h = 0.75$, $\quad L = 2S - \dfrac{1.5+0.035S}{G}$ ...(10)

$\alpha = 1°$

Q43. What are the factors governing a good vertical alignment?

Answer :

Following are the factors governing a good vertical alignment,

(a) The longitudinal profile should be co-ordinated with the horizontal alignment

(b) Exactly similar profile should be followed by slabs of bridges in both sides as in the case of roads

(c) In vertical alignment, a short valley curve can be dangerous, which also gives a bad appearance

(d) Single long curve should be considered rather than taking two vertical curves in the similar direction, separated by a short tangent

(e) On grades which are long and continuous, steepest grades should be placed at the bottom and flatten the grades close to the top

(f) The selected grade line should be smooth with gradual changes and consistent with the category of road and terrain

(g) Intersections on grades should be avoided for a large extent. In case if they are unavoidable, the approach gradients and the gradient through the intersection should be flattened to the maximum extent

(h) The profile which is of hidden type should be avoided as far as possible as it can be dangerous and gives a bad appearance.

Q44. Explain curve resistance and compensation in gradient on horizontal curves.

Answer :

Curve Resistance

When a vehicle is driven through rear wheels, it moves along a horizontal curve. This causes the variation in the direction of rotation of rear and front wheels. Therefore, the tractive force is lost.

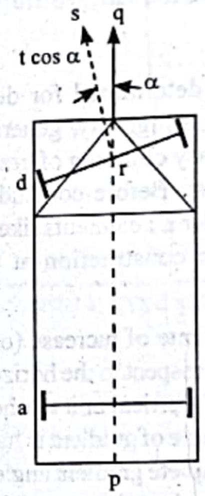


Figure: Curve Resistance for Turning Vehicle

Consider a and b as rear driving wheels that provide tractive force 't' in pq direction. The vehicle is steered by turning the front wheels c and d, which causes the vehicle to move along a horizontal curve. Then rs would be the tangential direction to the horizontal curve.

Thus, available tractive force in this direction $= t\cos\alpha$ $<$ Actual tractive force.

The value of $T\cos\alpha$ will further reduce in the case of sharp turning radius and increased turning angle. Therefore due to turning of vehicle on a horizontal curve, the tractive force is lost which is known as curve resistance. It is dependent on turning angle 'α'.

$$\text{Curve resistance} = (T - T\cos\alpha)$$

or

$$= T(1-\cos\alpha)$$

Compensation in Gradient on Horizontal Curves

When there exists a horizontal curve in addition to the gradient, resistance to fraction due to gradient and curve increases. Therefore, in such situation, the total resistance due to grade and curve should be maintained below the resistance due to the maximum value of the given gradient. This maximum value is considered as ruling gradient in certain cases and limiting gradient for the terrain in some exceptional cases for the purpose of design. If a road with maximum permissible gradient is to be subjected to sharp horizontal curve, then the gradient has to be reduced. This reduction in gradient is for the purpose of compensating the loss of tractive force due to curve and is termed as grade compensation.

Grade compensation = $\frac{30+R}{R}\%$

Subject to maximum value of $\frac{75}{R}$

Where,

R – Radius of circular curve (m)

If the gradients are flatter than 4%, then according to IRC, the grade compensation is not required.

Q45. Write short notes on gradient.

Answer :

Gradients are determined for designing the vertical curves while aligning a highway, generally vertical gradient are neglected due to easy climbing of grade and increasing the vehicle movement cost. Before concluding the gradient, the engineer has to consider all elements like cost of construction, practical problems in construction at the site and vehicle movement cost etc.

Gradient is the rate of increase (or) decrease along the length of the road with respect to the horizontal curve, generally gradient expressed as 1 vertical unit to x horizontal units. When 'α' is minimum then angle of gradient is 'tan α' which is equal to circular measures, complete gradient angles within the practical range are considered to be minimum. Therefore, the gradient value is equal to the tangent of angle with the horizontal.

i.e., $n\% = \tan\alpha$

This rising gradient are consider to have positive sign and are denoted by $+n_1$, $+n_2$ whereas the falling gradients are denoted as $-n_3$, $-n_4$ etc. This falling gradients have negative sign. At the intersection of two grades the change in direction of angles represents the "deviation angle (N) which is equal to algebraic difference between two grades,

i.e., Deviation angle, $N = \angle BAC + \angle BCA$

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

$$N = n_1 + n_2$$

Where,

n_1 – Rising gradient of AB

n_2 – Falling gradient of BC.

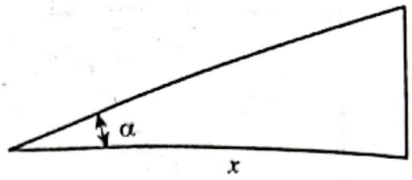


Figure (1): Gradient 1 in x

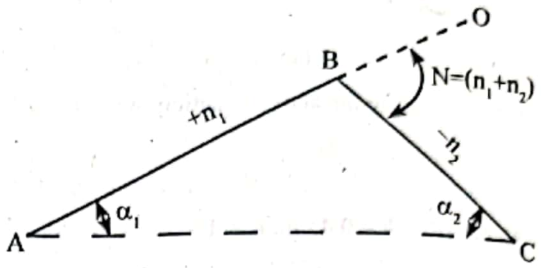


Figure (2): Deviation Angle

Q46. Explain the ruling, maximum and exceptional gradients.

Answer : Model Paper-III, Q5(a)

Ruling Gradient (Design Gradient)

The ruling gradient is defined as the range of maximum gradient in which the designer try to design the vertical profile of a road. In the design of vertical alignment, the gradients under the ruling gradient are selected as a normal course. This type of gradient is generally preferred for the purpose of design. The various factors that are considered in the selection of ruling gradient are as follows:

1. Terrain type
2. Grade length
3. Speed
4. Vehicles pulling power
5. Existence of horizontal curves.

The ruling gradient values recommended by IRC are,

(a) 1 in 30 on plain and rolling terrain

(b) 1 in 20 on mountainous terrain

(c) 1 in 16.7 on steep terrain.

Maximum Gradient

The maximum gradient is considered as the steepest gradient that can be provided on any type of road.

Exceptional Gradient

In certain cases, a gradient have to be provided that should be even steeper than the limiting gradient. This type of gradient is called as exceptional gradient. It is generally provided in undesirable conditions. It should not exceed 50-60 m in 1 km length of the road. The exceptional gradient values recommended by IRC are as follows,

(a) 1 in 15 for plain and rolling area

(b) 1 in 12 for hilly areas.

Q47. A vertical summit curve is formed when an ascending gradient of 1 in 25 meets another ascending curve of 1 in 100. Find the length of the summit curve to provide the required stopping sight distance for a design speed of 70 kmph.

Answer :

Given that,

$$n_1 = +\frac{1}{25},\quad n_2 = +\frac{1}{100}$$

Deviation angle, $N = \frac{1}{25} - \frac{1}{100}$

$N = 0.03$

Speed, $V = 70$ kmph

Stopping Sight Distance (SSD) is given as,

$$\text{SSD} = 0.278 \times V \times t + \frac{V^2}{254 \times f} \quad \ldots (1)$$

Assume, $t = 2.5$ sec, $f = 0.35$ for $V = 70$ kmph

By substituting the above values in equation (1), we get,

$$\text{SSD} = 0.278 \times 70 \times 2.5 + \frac{70^2}{254 \times 0.35}$$

$\text{SSD} = 104$ m

Assuming, $L < \text{SSD}$

The general equation for the length of the parabolic summit curve, when it is less than the sight distance is given as,

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

$$= 2 \times 104 - \frac{4.4}{0.03}$$

$= 61.33 \text{ m} < 104$ m

Therefore, length of summit curve, $L = 61.33$ m

Q48. There is a horizontal curve of radius 50 m on a stretch of hill road with a gradient of 5.0%. Determine the grade compensation.

Answer :

Given that,

Radius of horizontal curve, $R = 50$ m

Gradient, $n = 5.0\%$

$$\text{Grade compensation} = \frac{30 + R}{R}$$

$$= \frac{30 + 50}{50}$$

$\therefore$ Grade compensation $= \frac{80}{50} = 1.6\%$

Maximum limit of grade compensation $= \frac{75}{R}$

$$= \frac{75}{50}$$

$= 1.5\%$

$\therefore$ Compensated gradient $= 5.0 - 1.5 = 3.5\%$

According to IRC a minimum 4% compensated gradient should be provided.

Q49. A vertical summit curve is formed at the intersection of two gradients, (+) 2.5 and (–) 4.5 percent. Design the length of summit curve to provide a stopping sight distance for a speed of 80 kmph. Assume suitable data.

Answer :

Given that,

$n_1 = +2.5$

$= \frac{2.5}{100} = 0.025$

$n_2 = -4.5$

$= \frac{-4.5}{100} = -0.045$

Speed, $V = 80$ kmph

Deviation angle, $N = 0.025 - (-0.045)$

$= 0.07$

Stopping Sight Distance (SSD) is given as,

$$SSD = 0.278 \times V \times t + \frac{V^2}{254 \times f} \quad \text{... (1)}$$

Assuming $t = 2.5$ sec, $f = 0.35$ for $V = 80$ kmph,

By substituting the above values in equation (1), we get,

$$SSD = 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35}$$

$SSD = 128$ m

Assuming $L < SSD$

The general equation for the length of the parabolic summit curve, when it is less than the sight distance is given by,

$$L = 2S - \frac{4.4}{N} \quad \text{... (2)}$$

By substituting the values of S_{and} N in equation (2), we get,

$$L = 2 \times 128 - \left(\frac{4.4}{0.07}\right)$$

$= 256 - 63$

$L = 193 \text{ m} > 128 \text{ m}$

As this value is greater than SSD of 128 m, assume L is greater than SSD.

$L > SSD$

The general equation for the length of parabolic summit curve, when it is greater than the sight distance is given by,

$$L = \frac{NS^2}{4.4} \quad \text{... (3)}$$

By substituting the values of N and S in equation (3), we get,

$$L = \frac{0.07 \times 128^2}{4.4}$$

$L = 261 \text{ m} > 128 \text{ m}$

Therefore, length of summit curve = 261 m

Q50. An ascending gradient of 1 in 90 meets a descending gradient of 1 in 110. A summit curve is to be designed for a speed of 70 kmph so as to have an overtaking sight distance of 460 m. Calculate the true length of summit curve.

Answer :

Given that,

$n_1 = +\frac{1}{90}$,, $n_2 = -\frac{1}{110}$

$\therefore$ Deviation angle, $N = \frac{1}{90} - \left(-\frac{1}{110}\right) = \frac{2}{99}$

Overtaking sight distance, $OSD = 460$ m

Speed, $V = 70$ kmph

Assume, $L < OSD$

The general equation for the length of the parabolic summit curve, when it is less than OSD is given as,

$$L = 2s - \frac{9.6}{N} \quad \text{... (1)}$$

Substituting the values of s and N in equation (1), we get,

$= 2 \times 460 - \frac{9.6 \times 99}{2}$

$= 444.8$ m

$\therefore$ $L \simeq 445 \text{ m} < 460 \text{ m}$

$\therefore$ The true length of summit curve, $L = 445$ m.

Q51. Calculate the length of vertical valley curve required between -1/30 and +1/25 grades for a speed of 80 Kmph to satisfy comfort and head-light sight distance requirements.

Answer : May-17, (R13), Q5(b)

Given that,

Speed, V = 80 kmph

$V = 80 \times \frac{5}{18}$ m/sec

$= 22.2$ m/sec

Descending gradient, $n_1 = \frac{-1}{30}$

Ascending gradient, $n_2 = +\frac{1}{25}$

Assume, allowable rate of centrifugal acceleration $C = 0.6$ m/sec^3

Deviation angle, $N = n_1 - n_2$

$= \frac{-1}{30} - \frac{1}{25}$

$= \frac{-11}{150}$

(i) Condition for Comfort

$$L = 2\left[\frac{NV^3}{C}\right]^{1/2}$$

$$= 2\left[\frac{11}{150}\times\frac{22.2^3}{0.6}\right]^{1/2}$$

$$= 2[1337.24]^{1/2}$$

$$= 2[36.568]$$

$$= 73.14 \text{ m}$$

(ii) Condition for Head Light Sight Distance

Assume, $t = 2.5$

Coefficient of friction, $f = 0.35$

$$\text{Stopping sight distance (SSD)} = vt + \frac{v^2}{2gf}$$

$$= 22.2 \times 2.5 + \frac{22.2^2}{2\times 9.8\times 0.35}$$

$$= 127.3 \text{ m}$$

If $L > SSD$,

$$L = \frac{NS^2}{1.5+0.35S}$$

$$= \frac{11\times 127.3^2}{150(1.5+0.35\times 127.3)}$$

$$= 199.5 \text{ m}$$

Therefore, assumption is correct.

The highest value obtained from the above conditions is taken as the length of valley curve.

$\therefore \quad L = 199.5$

$\simeq 200$ m

Q52. Calculate the length of transition curve using the following data:

Design speed =65 Kmph, Radius of circular curve = 220m, pavement width including extra widening = 7.5 m, allowable rate of introduction of super elevation (pavement is rotated about the centerline) is 1 in 150.

Answer : May-17, (R13), Q4(b)

Given that,

Design speed, $V = 65$ kmph

Radius of a horizontal curve, $R_c = 220$ m

The rate of super elevation about centre line = 1 in 150

Width of pavement, $B = 7.5$ m

(a) Length of transition curve as per rate of centrifugal acceleration is given by,

$$L_s = \frac{v^3}{C.R_c}$$

$$= \frac{0.0215\,V^3}{C.R_c}$$

$$C = \frac{80}{75+v}$$

$$= \frac{80}{75+65}$$

$$= \frac{80}{140}$$

$$C = 0.571$$

The minimum and maximum values of C are limited to 0.5 and 0.8.

Hence, adopt $C = 0.57$

$$L_s = \frac{0.0215v^3}{C.R_c}$$

$$= \frac{0.0215\times65\times65\times65}{0.57\times220}$$

$$= 47.08 \text{ m}$$

(b) Length of transition curve by allowable rate of super elevation.

$$e = \frac{(0.75V)^2}{127R}$$

$$= \frac{0.75\times0.75\times65\times65}{127\times220}$$

$$= 0.085$$

The value of super-elevation obtained is high and should be restricted to 0.07.

$$f = \frac{V^2}{127R} - e$$

$$= \frac{65^2}{127\times220} - 0.07$$

$$= 0.15 - 0.07$$

$$= 0.081$$

The value of friction (f) obtained is less and should be restricted to 0.15.

Due to super-elevation raise of pavement $= 0.07 \times 7$

$$= 0.49 \text{ m}$$

$$\text{Raising of outer edge} = \frac{E}{2} = \frac{eB}{2} = \frac{0.07\times7.5}{2} = 0.26 \text{ m}$$

$$\text{Length of transition curve, } L_s = \frac{EN}{2}$$

$$= 0.26 \times 150$$

$$= 39 \text{ m}$$

(c) According to IRC, $L_s = \frac{2.7V^2}{R}$

$$= \frac{2.7\times65^2}{220}$$

$$= 51.9 \text{ m}$$

Consider highest value among the obtained three values,

$\therefore$ Length of transition curve = 51.9

$$\simeq 52 \text{ m}$$

Q53. A national highway passing through rolling terrain in heavy rain fall area has a horizontal curve of radius 500 m. Design the length of transition curve assuming suitable data.

Model Paper-I, Q5(b)

Answer :

Given that,

$R = 500$ m

Assume design speed, $V = 80$ kmph

Normal pavement width, $B = 7$ m

Allowable rate of change of centrifugal acceleration,

$$C = \frac{73}{64+V}$$

$$= \frac{73}{64+80}$$

$$= \frac{73}{144}$$

$$C = 0.507 \qquad \text{(1 in 150)}$$

(a) Length of transition by allowable rate of change of centrifugal acceleration is given by,

$$L_s = \frac{V^3}{CR}$$

$$= \frac{V^3}{46.5CR}$$

$$= \frac{80^3}{46.5 \times 0.507 \times 500}$$

$$= \frac{512000}{11787.75}$$

$$= 43.43 \text{ m}$$

(b) Length by allowable rate of distribution of super-elevation,

$L_s = E \times 150$ (Assume total rise wrt inner edge).

$$E = (W + W_e)e$$

$$e = \frac{(0.75V)^2}{127R}$$

$$= \frac{(0.75 \times 80)^2}{127 \times 500}$$

$$= \frac{3600}{63500}$$

$$= 0.05$$

Assuming number of traffic lanes = 2

And wheel base = 6 m,

Total pavement width, $B = W + W_e$

$$= W + \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$= 7 + \frac{2 \times 6^2}{2 \times 500} + \frac{80}{9.5\sqrt{500}}$$

$$= 7 + 0.072 + 0.376$$

$$\therefore \quad B = 7.448 \text{ m}$$

$$L_s = 7.448 \times 0.05 \times 150$$

$$= 55.86 \text{ m}$$

Q54. A highway is designed for a speed of 70 kmph and a horizontal curve of 350 m radius is planned at a location on the road. The road is a two lane road and the super elevation is to be provided by rotating the pavement about the inner edge. The rate of introduction of super elevation is 1 in 160. Compute the length of transition curve to be provided if the longest wheel base expected is 6.3 m.

Answer :

Given that,

Design speed, $V = 70$ kmph

Horizontal curve radius, $R = 350$ m

Number of traffic lanes, $n = 2$

Length of wheel base, $l = 6.3$ m

Assuming, normal pavement width, $W = 7$ m

Length of transition curve by allowable rate of distribution of super-elevation is given by,

$$L_s = E \times 160$$

Where,

$$E - (W + W_e)e$$

$$e = \frac{(0.75V)^2}{127R}$$

$$= \frac{(0.75 \times 70)^2}{127 \times 350}$$

$$\therefore e = 0.062$$

Total pavement width,

$$B = W + W_e$$

$$= W + \frac{nl^2}{2R} + \frac{V}{9.5\times\sqrt{R}}$$

$$= 7 + \frac{2\times 6.3^2}{2\times 350} + \frac{70}{9.5\times\sqrt{350}}$$

$$\therefore B = 7.51 \text{ m}$$

$$\therefore E = 7.51 \times 0.062$$

$$= 0.466 \text{ m}$$

Length of transition curve,

$$L_s = E \times 160$$

$$= 0.466 \times 160$$

$$\therefore L_s = 74.6 \text{ m}$$

Q55. Find out the minimum length of transition curve required and the shift required to join the transition curve with circular curve of radius 200 m, for a road passing through rolling terrain. Given design speed 65 kmph, carriage way width 7.5 m, rate of super elevation 1 in 150 and the road is rotated about the center line to achieve super elevation.

Answer : **April-18, (R15) Q5(b)**

Given that,

Design speed, $V = 65$ kmph

Radius of circular curve, $R = 200$ m

Type of terrain = Rolling

Carriage way width, $W = 7.5$ m

Road rotate about center line, $\theta = 1$ in 150

Assume, super-elevation, $e = 0.07$

(a) Length of transition curve as per allowable rate of change of centrifugal acceleration (C);

$$C = \frac{80}{75 + v}$$

$$= \frac{80}{75 + 65}$$

$$= 0.57 \text{ m/s}^2$$

It lies between 0.5 & 0.8, (hence OK)

$$\therefore \quad L_t = \frac{V^3}{46.5\, CR}$$

$$= \frac{65^3}{46.5 \times 0.57 \times 200}$$

$$= 51.80 \text{ m}$$

(b) L_t by allwable rate of introduction of super-elevation,

$$e = \frac{V^2}{225\, R}$$

$$= \frac{65^2}{225 \times 200}$$

$$= 0.0939\ (> 0.07)$$

So, adopt $e = 0.07$

Check for frictional resistance,

$$f = \frac{V^2}{127\, R} - e$$

$$= \frac{65^2}{127 \times 200} - 0.07$$

$$= 0.0963\ (< 0.15)$$

Hence Ok.

$\therefore$ The value of $e = 0.07$ is safe for design speed 65 kmph

Total raise of outer edge w.r.t. centre line;

$$\frac{E}{2} = \frac{ew}{2}$$

$$= \frac{0.07 \times 7.5}{2}$$

$$= 0.26 \text{ m}$$

Here, width of pavement (w) = 7.5 m

1 in N = 1 in 150

$$\therefore \quad L_t = \frac{EN}{2}$$

$$= 0.26 \times 150 = 39 \text{ m}$$

(c) By empirical formula,

$$L_t = \frac{2.7V^2}{R}$$

$$= \frac{2.7 \times 65^2}{200}$$

$$= 57.0375 \text{ m}$$

Adopt highest value of three,

$\therefore$ Length of transition curve (L_t) = 57.037 = 57 m

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

$$= \frac{57^2}{24 \times 200}$$

$$= 0.676 \text{ m}$$