CMR INSTITUTE OF TECHNOLOGY

VTU Theory Examination – Jan 2018

Solution

Sub:	HIGHWAY GEOMETRIC DESIGN						**Code:**	10 CV755
Date:	02/ 01 / 2018	Duration:	90 mins	Max Marks:	50	**Sem:** 7	**Branch:**	CIVIL

1. A. **Factors affecting the geometric design are as follows.**

Design speed: Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc., a design speed is adopted for all the geometric design. Design speed is defined as the highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are conducive. Design speed is different from the legal speed limit which is the speed limit imposed to curb a common tendency of drivers to travel beyond an accepted safe speed. Design speed is also different from the desired speed which is the maximum speed at which a driver would travel when unconstrained by either track or local geometry.

Topography: It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain. Therefore, geometric design standards are different for different terrain to keep the cost of construction and time of construction under control. This is characterized by sharper curves and steeper gradients.

Traffic factors: It is of crucial importance in highway design, is the traffic data both current and future estimates. Traffic volume indicates the level of services (LOS) for which the highway is being planned and directly affects the geometric features such as width, alignment, grades etc., without traffic data it is very difficult to design any highway.

Design Hourly Volume and Capacity: The general unit for measuring traffic on highway is the Annual Average Daily Traffic volume, abbreviated as AADT. The traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to the highest value during the peak hour. It will be uneconomical to design the roadway facilities for the peak traffic flow. Therefore a reasonable value of traffic volume is decided for the design and this is called as Design Hourly Volume (DHV) which is determined from extensive traffic volume studies. The ratio of volume to capacity affects the level of service of the road. The geometric design is thus based on this design volume, capacity etc.

Environmental and other factors: The environmental factors like air pollution, noise pollution, landscaping, aesthetics and other global conditions should be given due considerations in the geometric design of roads.

b. **Passenger Car Unit (PCU):**

Different classes of vehicles such as cars, vans, buses, trucks, auto rickshaw, motor cycles, pedal cycles etc. are found to use the common roadway facilities without segregation.

The flow of traffic with unrestricted mixing of different vehicle classes forms the ‗Mixed Traffic Flow'. In a mixed traffic condition, the traffic flow characteristics are very much complex when compared to homogeneous traffic consisting of passenger cars only. It is very difficult to estimate the traffic volume and capacity of roadway facilities under mixed traffic flow. Hence the different vehicle classes are converted to one common standard vehicle unit.

It is common practice to consider the passenger car as the standard vehicle unit to convert the other vehicle classes and this unit is called Passenger Car Unit (or) PCU. Thus in a mixed traffic flow, traffic volume and capacity are generally expressed as pcu / hr (or) pcu / lane/ hr and traffic density as pcu / km length of lane.

Factors affecting PCU Values:

 Vehicles characteristics such as dimensions, power, speed, acceleration and braking characteristics.

 Transverse and longitudinal gaps (or) clearances between moving vehicles which depends upon speed, driver characteristics.

 Traffic stream characteristics such as composition of different vehicle classes, mean speed and speed distribution of mixed traffic stream, volume to capacity ratio etc.

 Roadway characteristics such as road geometrics includes gradient, curve etc., rural or urban road, presence of intersections and the types of intersections.

 Regulation and control of traffic such as speed limit, one-way traffic, presence of different traffic control devices etc. Environmental and climatic conditions.

PCU values suggested by IRC:

S. No	**Vehicle Type**	**PCU**
1.	Passenger Car, Pick up van or auto rickshaw	1
2.	Motor Cycle or scooter or cycle	0.5
3.	Agricultural tractor, Light Commercial Vehicle	1.5
4.	Truck or Bus	3
5.	Tractor-trailer , Agricultural Tractor- trailer	4.5
6.	Cycle- Rickshaw	2

7.	Hand Cart	3
8.	Horse Drawn Vehicle	4
9.	Bullock Cart Smaller bullock cart	6-8 6

2. A. **Camber:**

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain of rain water from road surface.

The objectives of providing camber are:

 Surface protection especially for gravel and bituminous roads

 Sub-grade protection by proper drainage

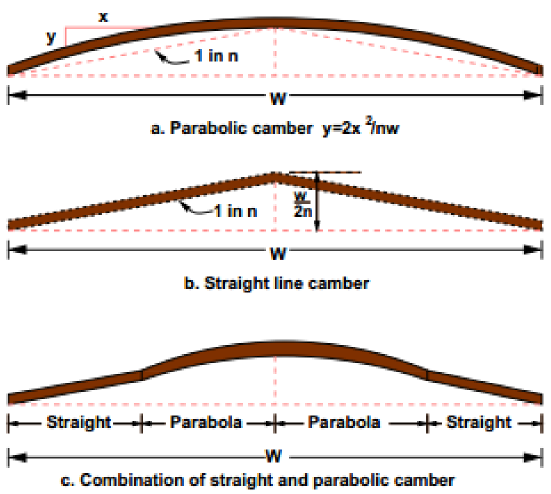
 Quick drying of pavement which in turn increases safety

Too steep slope is undesirable for it will erode the surface.

Factors affecting camber:

Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface and the amount of rainfall

The common types of camber are parabolic, straight, or combination of them.



b. (i) **Carriage way**

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This requires minimum of lane width of 3.75 m for a single lane road However, the side clearance required is about 0.53 m, on both side and 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane .The desirable carriage way width recommended by IRC is given in Table below.

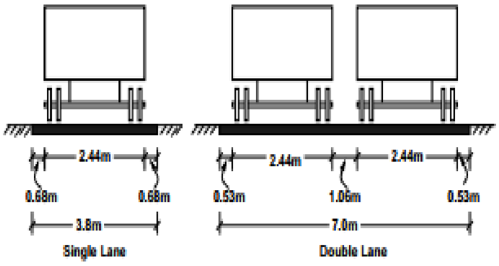


Table 12:2: IRC Specification for carriage way width

Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5

(ii) Right of way

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development. To prevent ribbon development along highways, control lines and building lines may be provided. Control line is a line which represents the nearest limits of future uncontrolled building activity in relation to a road. Building line represents a line on either side of the road; between which and the road no building activity is permitted at all.

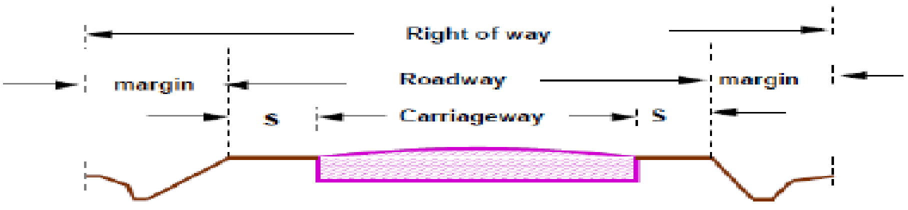
The right of way width is governed by:

- Width of formation: It depends on the category of the highway and width of roadway and road margins.
- Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.

- Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
- Drainage system and their size which depends on rainfall, topography etc.
- Sight distance considerations: On curves etc. there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like building structures etc.
- Reserve land for future widening: Some land has to be acquired in advance anticipating future developments like widening of the road.

Road classification	Roadway width in m	
	Plain and rolling terrain	Mountainous and steep terrain
Open areas		
NH/SH	45	24
MDR	25	18
ODR	15	15
VR	12	9
Built-up areas		
NH/SH	30	20
MDR	20	15
ODR	15	12
VR	10	9

The importance of reserved land is emphasized by the following. Extra width of land is available for the construction of roadside facilities. Land acquisition is not possible later, because the land may be occupied for various other purposes (buildings, business etc.) The normal ROW requirements for built up and open areas as specified by IRC is given in table above. A typical cross section of a ROW is given in figure below.



S– shoulder

3. A.

Restriction to sight distance :

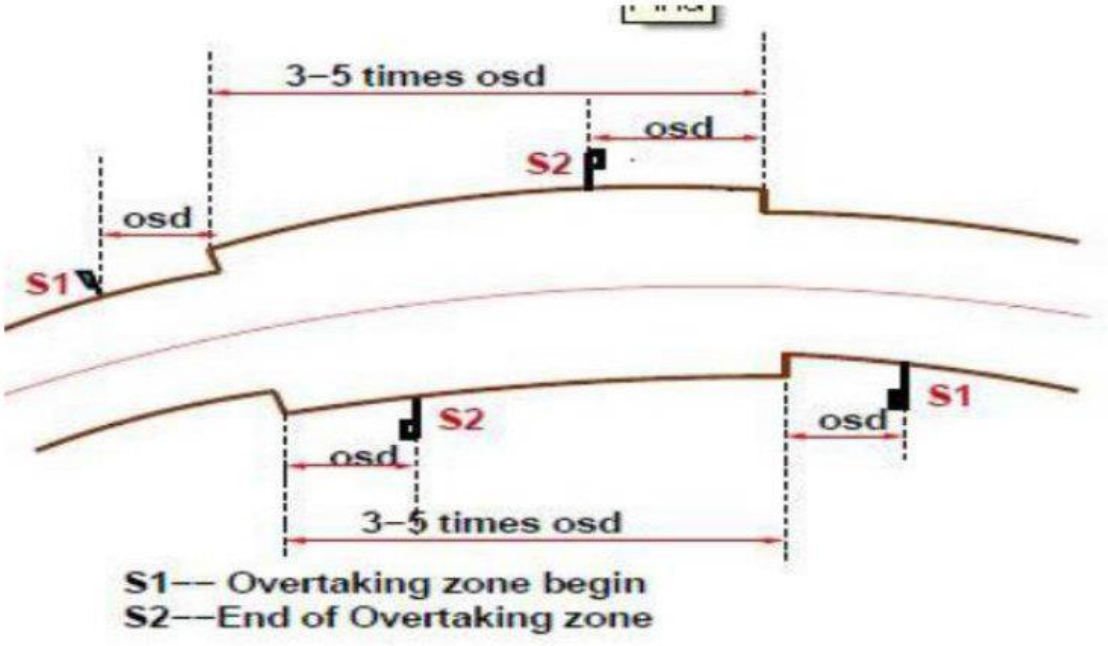
Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects. Three sight distance situations are considered for design:

- Stopping sight distance (SSD) or the absolute minimum sight distance
- Intermediate sight distance (ISD) is the defined as twice SSD
- Overtaking sight distance (OSD) for safe overtaking operation

Head light sight distance is the distance visible to a driver during night driving under the illumination of head light

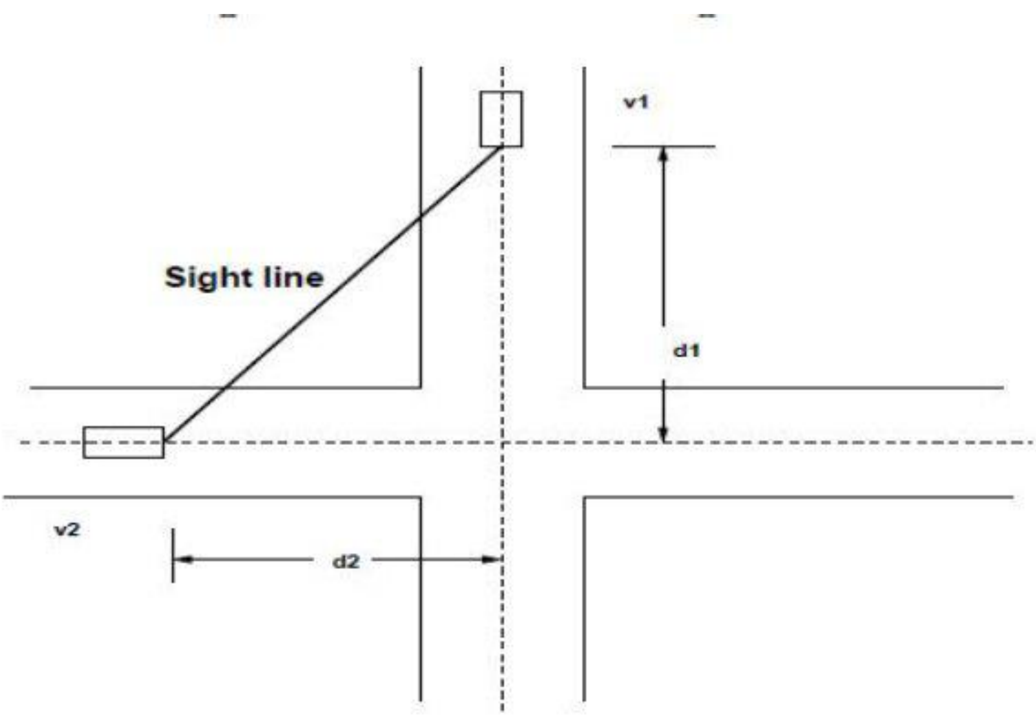
Safe sight distance to enter into an intersection.

Restriction due to overtaking of vehicles



It becomes very difficult for fast moving vehicles to overtake slow moving vehicles

Restriction due to intersection



Significance of SSD
At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either side. They should be able to perceive a hazard and

stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other.

B. OSD numerical

Speed of overtaking vehicle $V_A = V_C = 70$ kmph $= 19.4$ m/s

overtaken vehicle $V_B = 40$ kmph $= 11.1$ m/s

$a = 0.99 \text{ m/sec}^2$

It is a two way traffic road.

Assume $t = 2$ seconds

Calculation of d_1:

$d_1 = 0.28 \times V_b \times t = 0.28 \times 40 \times 2 =$

$d_1 = 22.2$ m

Calculation of d_2:

$d_2 = b + 2s$

$b = 0.28 V_b \times T$

$S = 0.2 V_b + 6$

$S = 0.7 V_b + 6$

$S = 0.7 \times 11.1 + 6$

$= 13.8$ m

$T = \sqrt{\frac{14.4 S}{A}}$

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

$T = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47$ s

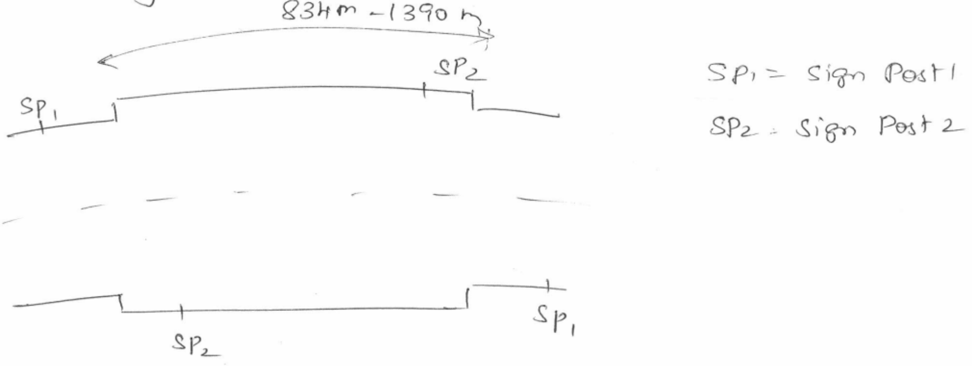
$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5$ m

$d_3 = V \cdot T = 19.4 \times 7.47 = 144.9$ m

(i) OSD $= d_1 + d_2 + d_3 = 278$ m

(ii) Overtaking Zone $= 3$ (OSD) $= 3 \times 278 = 834$ m

(iii) Overtaking Zone



4. **A. Mechanical widening and psychological widening**

Mechanical widening

The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure 4. This phenomenon is called off-tracking, and has the effect of increasing the effective width of a road space required by the vehicle. Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles are using the road. Trailer trucks also need extra carriageway, depending on the type of joint. In addition speeds higher than the design speed causes transverse skidding which requires additional width for safety purpose. The expression for extra width can be derived from the simple geometry of a vehicle at a horizontal curve as shown in figure 4. Let R_1 is the radius of the outer track line of the rear wheel, R_2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, then the mechanical widening W_m (refer figure 1) is derived below:

$$\begin{aligned} R_2^2 &= R_1^2 + l^2 \\ &= (R_2 - W_m)^2 + l^2 \\ &= R_2^2 - 2R_2W_m + W_m^2 + l^2 \\ 2R_2W_m - W_m^2 &= l^2 \end{aligned}$$

Therefore the widening needed for a single lane road is:

$$W_m = \frac{l^2}{2R_2 - W_m} \quad (1)$$

If the road has n lanes, the extra widening should be provided on each lane. Therefore, the extra widening of a road with n lanes is given by,

$$W_m = \frac{nl^2}{2R_2 - W_m} \quad (2)$$

Please note that for large radius, $R_2 \approx R$, which is the mean radius of the curve,then W_m is given by:

$$W_m = \frac{nl^2}{2R} \tag{3}$$

Psychological widening

Widening of pavements has to be done for some psychological reasons also. There is a tendency for the drivers to drive close to the edges of the pavement on curves. Some extra space is to be provided for more clearance for the crossing and overtaking operations on curves. IRC proposed an empirical relation for the psychological widening at horizontal curves W_{ps}:

$$W_{ps} = \frac{v}{2.64\sqrt{R}} \tag{4}$$

Therefore, the total widening needed at a horizontal curve W_e is:

$$\begin{aligned} W_e &= W_m + W_{ps} \\ &= \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} \end{aligned} \tag{5}$$

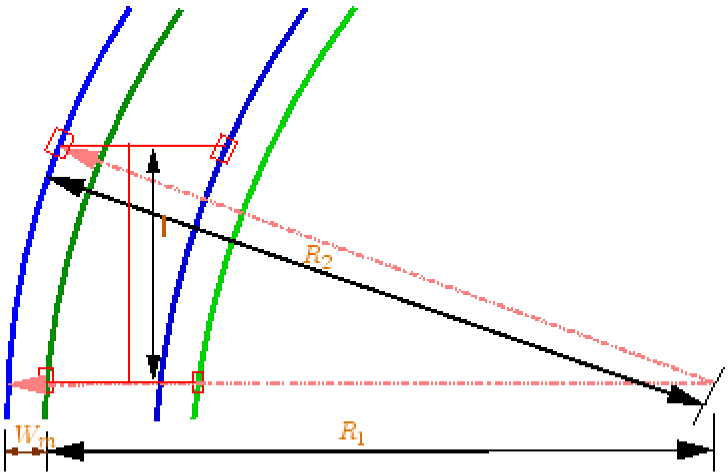


Figure 1: Extra-widening at a horizontal curve

B. Transition curve and its types

Transition curve is provided to change the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point)

There are five objectives for providing transition curve and are given below:

- To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
- To enable the driver turn the steering gradually for his own comfort and security,
- To provide gradual introduction of super elevation, and
- To provide gradual introduction of extra widening.
- To enhance the aesthetic appearance of the road.

Types of transition curve:

Different types of transition curves are spiral or clothoid, cubic parabola, and Lemniscate. IRC recommends spiral as the transition curve because: 1. it fulfills the requirement of an ideal transition curve, that is; (a) rate of change or centrifugal acceleration is consistent (smooth) and (b) radius of the transition curve is ∞ at the straight edge and changes to R at the curve point ($Ls \propto 1\ R$) and calculation and field implementation is very easy.

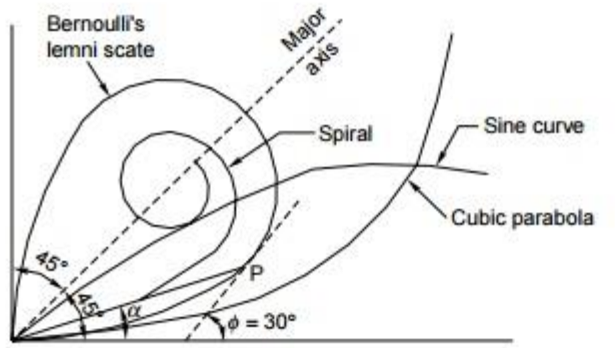


Fig. 13.11 Different types of transition curves

c**. Length of transition curve**

(a) As per allowable rate of centrifugal acceleration C

$C = 980 / (75+ V)) = 80 / (75+65) =0.57\ m/s^3$

$Ls = (0.0215\ V^3) / (CR) = 0.0215 * 65^3 / (0.57 * 220) = 47.1\ m$

(b) Length based on allowable rate of introduction of superelevation E

Superelevation rate $e = V^2 / 225R = 65^2 / (225 *220) = 0.085$

As this value is greater than the maximum allowable rate of 0.07, limit it to 0.7

Check for f

$f = V^2 / 127R = 0.15 – 0.07 = 0.08$.

As this value is less than the allowable limit of 0.15, it is safe.

Total width of the pavement at the curve , B = 7.5m

Total rise of outer edge of pavement w.r to centre line

$= E/ 2 = eB/2 = 0.07 *7.5 /2 = 0.26m$

Rate of introduction of superelevation , I in N = 1 in 150.
$Ls = EN/2 = 0.26*150 = 39m$
(C) Minimum length $Ls = 2.7v^2/ R = 2.7 * 65^2 / 220 = 51.9m$

Adopt the highest value of the three = 52m
Length of the shift $S = Ls^2/24R = 52^2/24*220 = 0.51m$

PART B

5. A. **Valley curve:**

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure 18:1 in any of the following four ways:

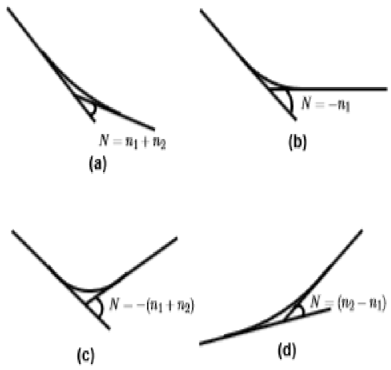


Figure 18:1: Types of valley curve

1. when a descending gradient meets another descending gradient [figure 18:1a].
2. when a descending gradient meets a flat gradient [figure 18:1b].
3. when a descending gradient meets an ascending gradient [figure 18:1c].
4. when an ascending gradient meets another ascending gradient [figure 18:1d].

B. **Length of the valley curve:**

The valley curve is made fully transitional by providing two similar transition curves of equal length The transitional curve is set out by a cubic parabola $y = bx^3$ where $b = 2N/3L^2$

The length of the valley transition curve is designed based on two criteria:

1. **comfort criteria**; that is allowable rate of change of centrifugal acceleration is limited to a comfortable level of about $0.6m/sec^3$.

2. **safety criteria**; that is the driver should have adequate headlight sight distance at any part of the country.

Comfort criteria

The length of the valley curve based on the rate of change of centrifugal acceleration that will ensure comfort: Let c is the rate of change of acceleration, R the minimum radius of the curve, v is the design speed and t is the time, then c is given as:

$$\begin{aligned} c &= \frac{\frac{v^2}{R} - 0}{t} \\ &= \frac{\frac{v^2}{R} - 0}{\frac{L}{v}} \\ &= \frac{v^3}{LR} \\ L &= \frac{v^3}{cR} \end{aligned}$$

For a cubic parabola, the value of R for length Ls is given by:

$$R = \frac{L}{N}$$

$$\begin{aligned} L_s &= \frac{v^3}{\frac{cL_s}{N}} \\ L_s &= \sqrt[2]{\frac{Nv^3}{c}} \\ L &= 2\sqrt[2]{\frac{Nv^3}{c}} \end{aligned}$$

where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as 0.6m/sec^3.

c.

A vertical summit curve is formed at the intersection of two gradients, + 3.0 and – 5.0 percent. Design the length of summit curve to provide a stopping sight distance for a design speed of 80 kmph. Assume other data.

Solution

Given, design speed V = 80 kmph, gradients $n_1 = +3.0\ \%$ and $n_2 = -5.0\ \%$

(a) Determination of safe stopping sight distance, SSD

As there is ascending gradient on one side of the summit and descending gradient on the other side, the effect of gradients on the SSD is assumed to get compensated and hence ignored in the calculations.

$$SSD = 0.278Vt + \frac{V^2}{254f}$$

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

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

$$= 55.6 + 72.0 = 127.6, \text{ say } 128 \text{ m}$$

(b) Determination of length of summit curve

Deviation angle $N = 0.03 - (-0.05) = 0.08$

Assuming L > SSD, vde Eq. 4.35,

$$L = \frac{NS^2}{4.4} = \frac{0.08 \times 128^2}{4.4} = 297.9 \text{ m, say } 298 \text{ m}$$

This value of summit curve length L is greater than SSD of 128 m as per the assumption and therefore the calculated length may be accepted for design.

Length of summit curve, L = 298 m

6. a. **Grade separated intersections**:

It is an intersection layout which permits crossing manoeuvres at different levels. This design is the highest form of intersection treatment. It causes least delay and hazard to the crossing traffic and in general is much superior to intersection at grade from the traffic safety and efficient operation.

They are generally more expensive initially and are justified in the following conditions.

1. On high type facilities such as expressways, freeways and motorways
2. Certain at-grade intersections which have reached the maximum capacity and where it is not possible to improve the capacity further by retaining the at-grade junctions.
3. At certain locations which have a proven record of bad accident history when functioning as at-grade junctions.

4. At junctions where the traffic volume is heavy and the delays and loss caused justify economically the provision of grade-separation.
5. At certain specific topographical situations where it is logical to provide a grade-separated structure rather than an at-grade intersection, which may involve considerable earthwork or acquisition of land.

Advantages:

- Roads with grade separation generally allow traffic to move freely, with less interruptions, and at higher overall speeds; hence why speed limits are typically higher for grade-separated roads.
- In addition, less conflict between traffic movements reduces the chances for accidents.

Disadvantages:

- Grade-separated junctions are however large, and costly
- Their height can be obtrusive, and combined with the large traffic volumes that grade-separated roads attract, tend to make them unpopular to nearby landowners and residents
- Grade-separation is expensive, time-consuming and requires significant engineering effort compared to provision of an at-grade intersection

b**. Channelized intersection**

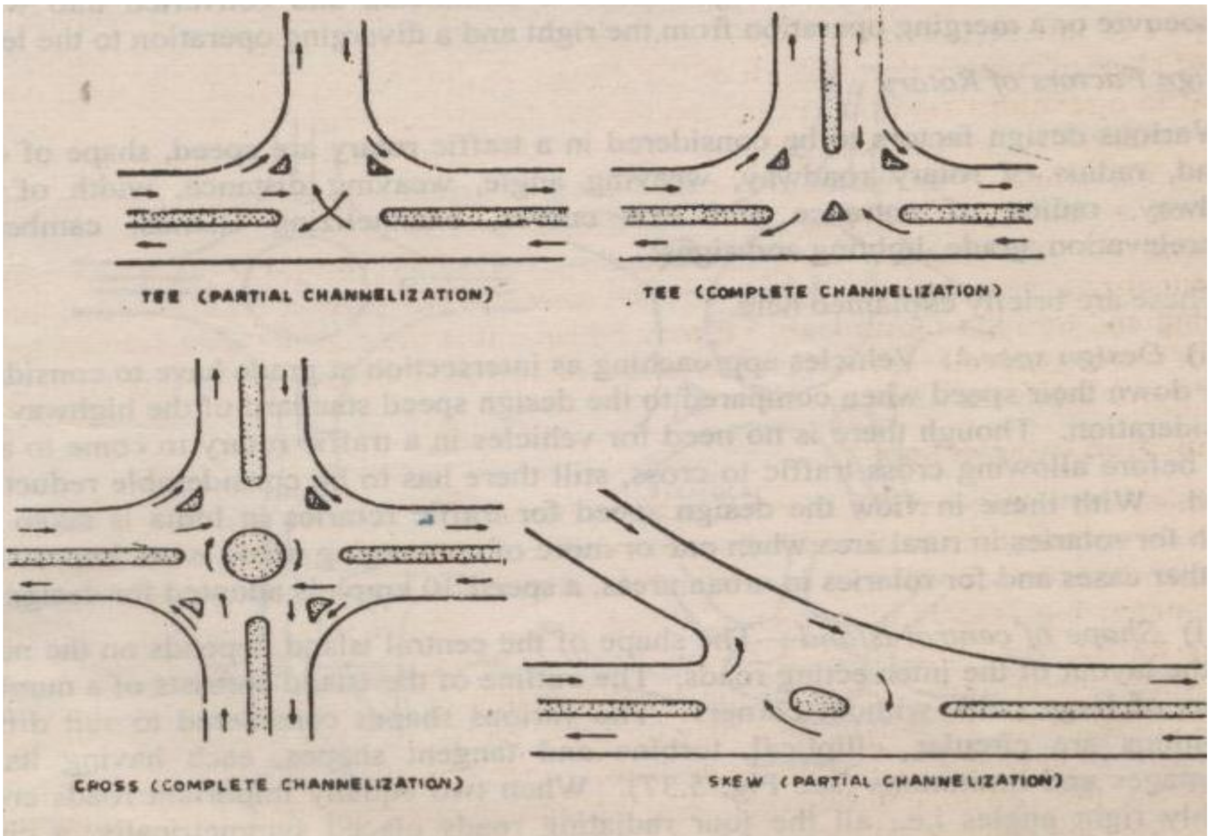


Fig. 5.35 Channelized Intersections

Advantages of channelized intersection

- Vehicles approaching an intersection are directed to definite paths by islands, marking etc. and this method of control is called channelization.
- Channelized intersection provides more safety and efficiency.
- It reduces the number of possible conflicts by reducing the area of conflicts available in the carriageway.
- If no channelizing is provided the driver will have less tendency to reduce the speed while entering the intersection from the carriageway.
- The presence of traffic islands, markings etc. forces the driver to reduce the speed and becomes more cautious while maneuvering the intersection.
- A channelizing island also serves as a refuge for pedestrians and makes pedestrian crossing safer.

Disadvantages of channelized intersection

- It requires more area for construction.
- It becomes very uneconomical in places were the traffic volume is low.

6. (A**) Rotary intersection**

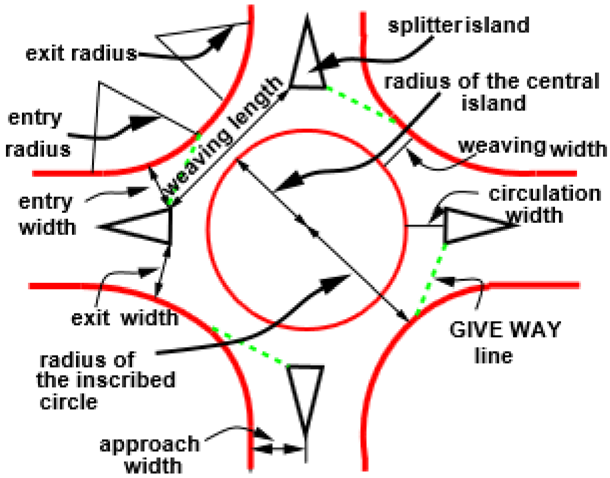
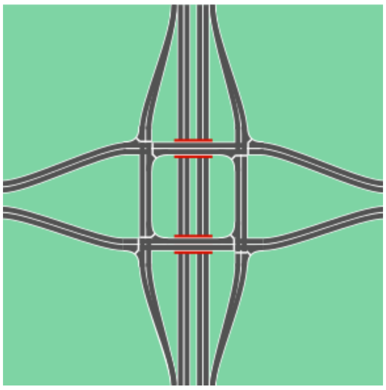


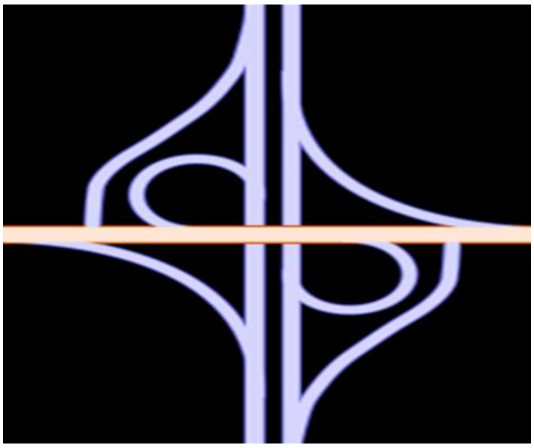
Figure 40:2: Design of a rotary

b. (i**) Diamond interchange**

Diamond interchange is a popular form of four-leg interchange found in the urban locations where major and minor roads crosses. The important feature of this interchange is that it can be designed even if the major road is relatively narrow.



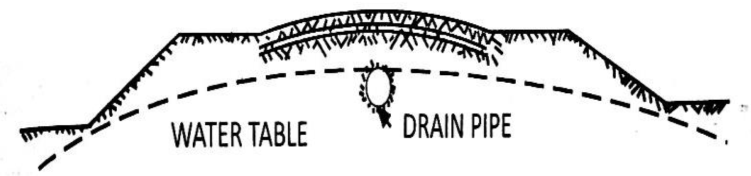
(ii) **Half cloverleaf interchange**

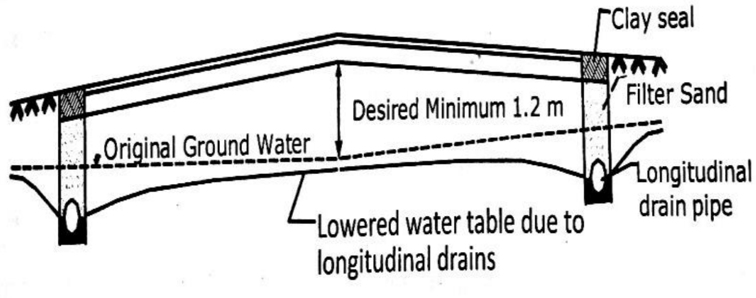


It is advantageous when a major road crosses a minor road (not more than 2 lanes)

7. (i) **Lowering of water table**

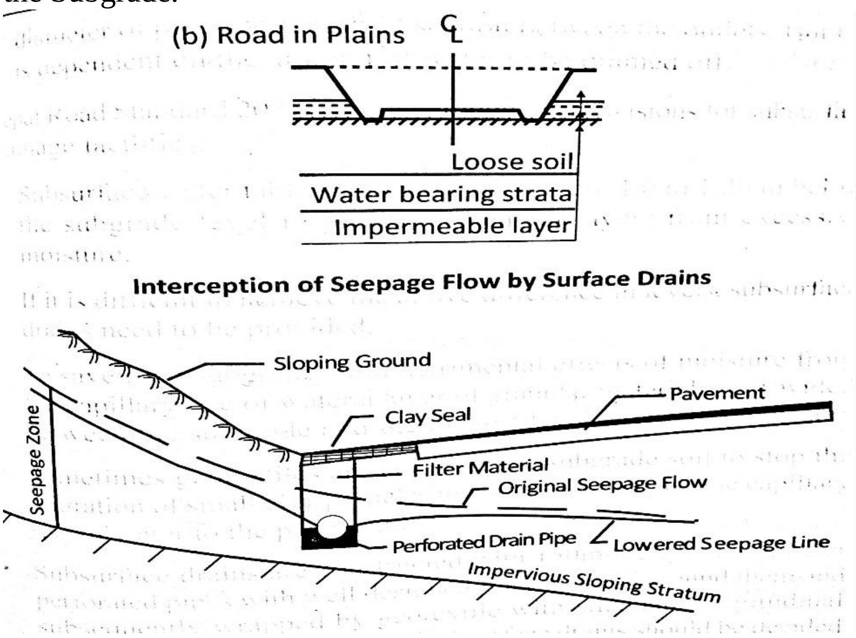
   The Highest level of water table should be fairly below the level of Subgrade, in order that the Subgrade and pavement layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 m the Subgrade. In places where water table is high (almost at ground level at times) the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 meter. When the formation is to be at or below the general ground level, it would be necessary to lower the water table





(ii) Control of seepage flow:

When the general ground as well as the impervious strata below are sloping, seepage flow is likely to exist. The Highest level of water table should be fairly below the level of Subgrade, in order that the Subgrade and pavement layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept at least 0.6 to 0.9 m the Subgrade.



(B) Cross section
The velocity of flow through the clay soil
V = 0.6m/sec
A = Q/V = 3 /0.6 = .5sqm
For trapezoidal c/s $1.5d^2 + d - 0.75 = 0$
Solving by quadratic equation for d
D= 0.45m
Taking free board as 0.15m now the total depth is 0.45+.15 = 0.60m
Slope: The slope is calculated using manning's formula
$V = 1/n * R^{2/3} * S^{1/2}$

Hydraulic radius R = area/ perimeter = 2.62m
By substituting the values slope S = 0.0553½
Therefore s = 0.0031 = 1/322.5