1. Explain the design control and criteria which governs the design and highway.


Factors affecting 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.

**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.

**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.

**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.
2. Explain PCU value and factors affecting the PCU values. 

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.

Factors affecting PCU Values are as follows

- 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

3. Explain the objects of highway geometric design. List the various geometric elements to be considered in the highway design. (Dec 2010, Dec 2012)

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc. The features
normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection. The design of these features is to a great extend influenced by driver behavior and psychology, vehicle characteristics, track characteristics such as speed and volume.

The objective of geometric design is to provide maximum efficiency, in traffic operations with maximum safety at reasonable cost.

The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc.

Geometric design of highways deals with the following elements:
1. Cross-section elements
2. Sight distance considerations
3. Horizontal alignment details
4. Vertical alignment details
5. Intersection elements

4. Explain the important functional aspects of geometric design. (June July 2011)

The functional aspects of geometric design is as follows

1. To ensure the design of Cross-section elements - It includes cross slope, various widths of road
2. To design Sight distance considerations - It the visible land ahead of the driver at horizontal and vertical curves and at intersections for the safe movements of vehicles.
3. To ensure the design of Horizontal alignment - Horizontal curves are introduced to change the direction of road. It includes features like super elevation, radius of curve, transition curve.
4. To ensure the design of Vertical alignment - Its components like gradient, vertical curves (i.e., summit curve and valley curve) sight distance and design of length of curves.
5. To ensure the design of Intersection elements – Proper design of intersection is very much essential for the safe and efficient traffic movements. Its features like layout, capacity, etc.
UNIT2

1. List the important pavement surface characteristics and explain briefly:
   i) Friction and factors affecting friction;    ii) Pavement unevenness.


Friction

Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affects the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.

   - Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction
   - Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road

   Various factors that affect friction are:

   - Type of the pavement (like bituminous, concrete, or gravel),
   - Condition of the pavement (dry or wet, hot or cold, etc),
   - Condition of the tire (new or old), and
   - Speed and load of the vehicle

Unevenness

   It affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires. Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road. An unevenness index value less than 1500mm/km is considered as good, a value less than 2500 mm/km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 kmph.
2. Write note on the following and mention the IRC standards:
   i) Carriage way  ii) Right of way.  

   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 or single lane traffic is 0.68 m. This require minimum of lane width of 3.75 m for a single lane road (Figure 12:2a). However, the side clearance required is about 0.53 m, on either side and 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane (Figure 12:2b). The desirable carriage way width recommended by IRC is given in Table 12:2

   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 |

   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.

<table>
<thead>
<tr>
<th>Road classification</th>
<th>Roadway width in m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plain and rolling terrain</td>
</tr>
<tr>
<td>Open areas</td>
<td></td>
</tr>
<tr>
<td>NH/SH</td>
<td>45</td>
</tr>
<tr>
<td>MDR</td>
<td>25</td>
</tr>
<tr>
<td>ODR</td>
<td>15</td>
</tr>
<tr>
<td>VR</td>
<td>12</td>
</tr>
<tr>
<td>Built-up areas</td>
<td></td>
</tr>
<tr>
<td>NH/SH</td>
<td>30</td>
</tr>
<tr>
<td>MDR</td>
<td>20</td>
</tr>
<tr>
<td>ODR</td>
<td>15</td>
</tr>
<tr>
<td>VR</td>
<td>10</td>
</tr>
</tbody>
</table>
3. Draw the typical cross sections of the following roads indicating all the details:
   i)   NH - in cutting ii)   SH - in embankment.   (Dec 2010, 2012)

4. What is camber? What are the objectives of providing camber? When straight and
   parabolic cambers are preferred?   (June/july 2011)

Camber or cant is the cross slope provided to raise middle of the road surface in the
transverse direction to drain off 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. 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. The values suggested by IRC for various categories of pavement is given in Table 12:1 The common types of camber are parabolic, straight, or combination of them

   When a flat camber is required incase of rigid pavement then straight camber is preferred and when the movement of fast moving vehicles where the speed is more

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Heavy rain</th>
<th>Light rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete/Bituminous</td>
<td>2 %</td>
<td>1.7 %</td>
</tr>
<tr>
<td>Gravel/WBM</td>
<td>3 %</td>
<td>2.5 %</td>
</tr>
<tr>
<td>Earthen</td>
<td>4 %</td>
<td>3.0 %</td>
</tr>
</tbody>
</table>
5. What is right of way? State the factors influencing 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.

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Figure 12:1: Different types of camber
- 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.

6. Objectives of providing transition curves Dec 2010

7. Mention the various cross-sectional elements to be designed for a pavement and explain them briefly. June 2010

Geometric design of highways deals with the following elements:

1. Cross-section elements
2. Sight distance considerations
3. Horizontal alignment details
4. Vertical alignment details
5. Intersection elements

1. **Cross-section elements** - It includes cross slope, various widths of road (i.e., width of pavement, formation width and road land width), surface characteristics and features in the road margins.

2. **Sight distance considerations** - It the visible land ahead of the driver at horizontal and vertical curves and at intersections for the safe movements of vehicles.

3. **Horizontal alignment** - Horizontal curves are introduced to change the direction of road. It includes features like super elevation, radius of curve, transition curve, extra widening and setback distance.

4. **Vertical alignment** - Its components like gradient, vertical curves (i.e., summit curve and valley curve) sight distance and design of length of curves.

5. **Intersection elements** – Proper design of intersection is very much essential for the safe and efficient traffic movements. Its features like layout, capacity, etc.
8. Design the road hump as per IRC recommendations, with a neat sketch June 2010

These are round shaped elevated surface formed across roadways as physical devices to reduce the speed of the vehicles on minor or secondary or unimportant uncontrolled roads.

The road humps design may be carried out based upon the finding of field experiment. They are observed that the ratio of cross sectional area to width of the road hump is significant for controlling hump cross speed, this is given the equation.

\[ \frac{1}{V_{85}} = 0.0212 + 0.4072 (\frac{A}{W}) \]

Where \( V_{85} \) = Desired design 85\(^{th}\) percentile of the hump crossing speed

\( \frac{A}{W} \) = Area to width ratio.

UNIT 3

1. Draw a neat sketch of overtaking zone with all detail for overtaking and overtaken vehicles speeds are 80 kmph and 65 kmph. Take average rate of acceleration as 3.6 kmph/sec, single lane. (Dec 2011, June/july 2011, June 2010)

\[ \text{OSD} = d_1 + d_2 + d_3 \]

\[ d_1 = 0.028 \text{ vb} \times t \]
\[ = 0.28 \times 65 \times 2 \]
\[ = 36.4 \text{ m} \]

\[ s = 0.2 \text{ vb} + 6 \]
\[ = 0.2 \times 65 + 6 = 19 \text{ m} \]

\[ T = \text{sqrt} \ 14.4 \times \frac{S}{A} \]
\[ T = 8.7 \text{ secs} \]
\[ d_2 = 0.278 \times 65 \times 8.7 + 2 \times 19 \]
\[ d_2 = 195.20 \text{m} \]
\[ d_3 = 0.28 \times 80 \times 8.7 = 194.88 \text{m} \]

Therefore, OSD = \[ d_1 + d_2 + d_3 \]
\[ = 426.8 \text{m} \]

2. Calculate the SSD on a highway at a descending gradient of 2\% for a design speed of 80kmph. (Dec 2010, Dec 2012)

Soln

**Down grade of 2\%**

\[ SSD = vt + \frac{v^2}{2g(f \pm 0.01n)} \]
\[ = 22.22 \times 2.5 + \frac{22.22^2}{(2 \times 9.81 \times 0.35 - 0.01 \times 2)} \]
\[ = 131.8 \text{m} \]

3. Explain sight distance and factors causing restriction to sight distance. Give significance of SSD, ISD and OSD. (Dec 2011)

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 sides. 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.

Overtaking sight distance
The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction. The overtaking sight distance or passing sight distance is measured along the center line of the road over which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2 m above the road surface.

**Stopping sight distance**

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

3. **Derive an expression for calculating the overtaking sight distance on the highway, (June 2010, Dec 2011)**

The following notations is discribed as below

- $d_1$ the distance traveled by overtaking vehicle A during the reaction time $t = t_1 - t_0$
- $d_2$ the distance traveled by the vehicle during the actual overtaking operation $T = t_3 - t_1$
- $d_3$ is the distance traveled by on-coming vehicle C during the overtaking operation ($T$).

It is assumed that the vehicle A is forced to reduce its speed to $v_b$, the speed of the slow moving vehicle B and travels behind it during the reaction time $t$ of the driver. So $d_1$ is given by:

$$d_1 = v_b t$$

Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle A maintains the spacing $s$ before and after overtaking. The spacing $s$ in m is given by:

$$s = 0.7v_b + 6$$

Let $T$ be the duration of actual overtaking. The distance traveled by B during the overtaking operation is $2s + v_b T$. Also, during this time, vehicle A accelerated from initial velocity $v_b$ and overtaking is completed while reaching final velocity $v$. Hence the distance traveled is given by:
The distance traveled by the vehicle C moving at design speed \( v \text{ m/sec} \) during overtaking operation is given by:

\[
d_2 = v_b T + \frac{1}{2} a T^2
\]

\[
2s + v_b T = v_b T + \frac{1}{2} a T^2
\]

\[
2s = \frac{1}{2} a T^2
\]

\[
T = \sqrt{\frac{4s}{a}}
\]

\[
d_2 = 2s + v_b \sqrt{\frac{4s}{a}}
\]

The factors affecting sight distance is as follows:

- **Speed of the vehicle**
  
  The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

- **Efficiency of brakes**
  
  The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100\%, the vehicle will stop the moment the brakes are applied. But practically,
it is not possible to achieve 100% brake efficiency. Therefore it could be understood that sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.

**Frictional resistance between the tire and the road**

The frictional resistance between the tire and road plays an important role to bring the vehicle to stop. When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less. No separate provision for brake efficiency is provided while computing the sight distance. This is taken into account along with the factor of longitudinal Friction. IRC has specified the value of longitudinal friction in between 0.35 to 0.4.

**Gradient of the road**

Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in that case.

**Reaction time of the driver**

Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory. In practice, all these times are usually combined into a total perception- reaction time suitable for design purposes as well as for easy measurement. Many of the studies show that drivers require about 1.5 to 2 secs under normal conditions. However taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 secs.

Reaction time mainly depends upon PIEV theory

- Perception
- Intellection
- Emotion
• Voilation (final action)

6. Find the safe overtaking sight distance for a design speed of 96 kmph. Assume all the required data as per IRC (Dec 2010, Dec 2012)

Soln

\[
\text{OSD} = d1 + d2 + d3
\]

\[
d1 = 0.028 \times v_b \times t
\]

\[
= 0.28 \times 44 \times 2
\]

\[
= 44.8 \text{m}
\]

\[
s = 0.2v_b + 6
\]

\[
= 0.2 \times 80 + 6 = 22 \text{m}
\]

\[
T = \sqrt{14.4 \times S/A}
\]

\[
T = 11.3 \text{secs}
\]

\[
d2 = 0.278 \times 44 \times 11.13 + 2 \times 22
\]

\[
d2 = 297 \text{m}
\]

\[
d3 = 0.28 \times 93 \times 11.13 = 303.7 \text{m}
\]

therefore \( \text{OSD} = d1 + d2 + d3 \)

\[
= 646 \text{m}
\]

7. Derive the expression for SSD for ascending, descending gradient and level surface (June/july 2011)

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

**Level surface**

**Lag distance** is the distance the vehicle traveled during the reaction time \( t \) and is given by \( vt \),
where \( v \) is the velocity in m/sec².

**Braking distance** is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If \( F \) is the maximum frictional force developed and the braking distance is \( l \), then work done against friction in stopping the vehicle is

\[
Fl = fWl
\]

where \( W \) is the total weight of the vehicle. The kinetic energy at the design speed is

\[
\frac{1}{2}mv^2 = \frac{1}{2} \frac{Wv^2}{g} \]

\[
fWl = \frac{Wv^2}{2g}
\]

\[
l = \frac{v^2}{2gf}
\]

Therefore, the SSD = lag distance + braking distance and given by:

\[
SSD = vt + \frac{v^2}{2gf}
\]

**Ascending, descending gradient**

When there is an ascending gradient of \( +n\% \) the component of gravity adds to the braking action and hence the braking distance decreased. The component of gravity acting parallel to the surface which adds to the braking force is equal to \( W \sin \alpha = W \tan \alpha = Wn/100 \).

Equating kinetic energy and work done:

\[
\left( fW + \frac{Wn}{100} \right) l = \frac{Wv^2}{2g}
\]

\[
l = \frac{v^2}{2g \left( f + \frac{n}{100} \right)}
\]
Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation

\[ SSD = vt + \frac{v^2}{2g(f \pm 0.01n)} \]

UNIT 4
1. Derive necessary conditions for centrifugal ratio to avoid overturning and skidding of vehicle (Dec 2011, June/july 2011, Dec 2012, Dec 2010)

On a curved road, this force tends to cause the vehicle to overrun or to slide outward from the centre of road curvature. For proper design of the curve, an understanding of the forces acting on a vehicle taking a horizontal curve is necessary. Various forces acting on the vehicle is illustrated in the figure. They are the centrifugal force (P) acting outward, weight of the vehicle (W) acting downward, and the reaction of the ground on the wheels (RA and RB). The centrifugal force and the weight is assumed to be from the centre of gravity which is at h units above the ground. Let the wheelbase be assumed as b units.

The centrifugal force P in kg=m² is given by

\[ P = \frac{Wv^2}{gR} \]

where W is the weight of the vehicle in kg, v is the speed of the vehicle in m=sec, g is the acceleration due to gravity in m=sec² and R is the radius of the curve in m. The centrifugal ratio or the impact factor

\[ \frac{P}{W} \]

is given by:

\[ P = \frac{v^2}{WgR} \]
The centrifugal force has two effects: a tendency to overturn the vehicle about the outer wheels and a tendency for transverse skidding. Taking moments of the forces with respect to the other when the vehicle is just about to override is give as:

\[ \text{Ph} = \frac{Wb}{2} \]

At the equilibrium over turning is possible when

![Effect of horizontal curve](image)

The second tendency of the vehicle is for transverse skidding. i.e. When the centrifugal force \( P \) is greater than the maximum possible transverse skid resistance due to friction between the pavement surface and tire. The transverse skid resistance \( F \) is given by:

\[
F = FA + FB \\
= f(RA + RB) \\
= fW
\]

where \( FA \) and \( FB \) is the fractional force at tire A and B, \( RA \) and \( RB \) is the reaction at tire A and B, \( f \) is the lateral coefficient of friction and \( W \) is the weight of the vehicle. This is counteracted by the centrifugal force \( P \), and equating:
\[ P = fW \text{ or} \]
\[ P = i \]
At equilibrium, when skidding takes place (from equation 14.2)
\[ P = \frac{v^2}{WgR} \]
and for safety the following condition must satisfy:
\[ f > \frac{v^2}{gR} \]
If this equation is violated, the vehicle will overturn at the horizontal curve and if equation 14.4 is violated, the vehicle will skid at the horizontal curve.

2. Write a note on maximum and minimum super elevations Dec 2011

Superelevation is the rotation of the pavement on the approach to and through a horizontal curve. Superelevation is intended to assist the driver by counteracting the lateral acceleration produced by tracking the curve. Superelevation is expressed as a decimal, representing the ratio of the pavement slope to width ranging from 0 to 0.12 foot/feet. The adopted criteria allow for the use of maximum superelevation rates from 0.04 to 0.12. Maximum superelevation rates for design are established by policy by each State. Selection of a maximum superelevation rate is based on several variables, such as climate, terrain, highway location (urban vs. rural), and frequency of very slow-moving vehicles. For example, northern States that experience ice and snow conditions may establish lower maximums for superelevation than States that do not experience these conditions. Use of lower maximum superelevation rates by policy is intended to address the perceived problem created by vehicles sliding transversely when traveling at very low speeds when weather conditions are poor.

If maximum super levation is provided it becomes very difficult for slower moving vehicles to negotiate the curve if superelevation is more then there are
chances that vehicle may over top. hence minimum super elevation to be provided for safety of slower moving vehicles.

3. **What are the objectives of providing extra widening of pavements on horizontal curves?**

   Derive an expression for the same. Dec 2010

**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, 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 travelling 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 proportions of vehicles are using the road. Trailor 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 Let R1 is the radius of the outer track line of the rear wheel, R2 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 Wm (is derive below):
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 $W_{ps}$

\[ R_2^2 = R_1^2 + l^2 \]
\[ = (R_2 - W_m)^2 + l^2 \]
\[ = R_2^2 - 2R_2W_m + W_m^2 + l^2 \]
\[ 2R_2W_m - W_m^2 = l^2 \]

Therefore the widening needed for a single lane road is:

\[ W_m = \frac{l^2}{2R_2 - W_m} \]

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,

\[ W_m = \frac{n l^2}{2R_2 - W_m} \]

**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 $W_{ps}$.
the objectives of providing extra widening of pavements on horizontal curves are as follows

- To counter the off tracking effect
- While two vehicles cross at horizontal curve there is a psychological tendency to maintain a greater clearance between vehicles than on the straight roads
- To provide greater visibility for drivers, to avoid the movement of drivers along the central path of the lane.

4. Design all the geometric features of a horizontal curve for a state highway passing through rolling terrain, assuming all the data as per IRC for a ruling minimum radius. Also, specify the minimum setback distance for a sight distance of 255 mts. Dec 2010

**Soln:**

Take $v = 80\text{kmph}$

$$R_{ruling} = \frac{v^2}{g(e + f)}$$

$$= 230\text{m}$$

**Super elevation:**

$$e = \frac{v^2}{225R} = 0.12 \text{ take } e \text{ value of } 0.07$$

**Extra widening:**
\[ \text{Transition curve} \]

1. The length of the transition curve \( L_{s1} \) in m is

\[ L_{s1} = \frac{u^2}{2R} + \frac{v}{2.64\sqrt{R}} = 0.65 \text{m} \]

\[ C = \frac{80}{75+V} = 0.52 \]

2. Rate of introduction of super-elevation

\[ L_{s2} = Ne \left( W + We \right) \\
= 150 \times 0.07 \times 7.66 \\
= 80.43 \text{m} \]

3. By empirical formula

IRC suggest the length of the transition curve is minimum for a plain and rolling terrain

\[ L_{s3} = \frac{2.7V^2}{R} \\
= 75.13 \text{m} \]

Adopt 91.9 m as transition curve length

5. While aligning a highway in a builtup area, it was necessary to provide a horizontal curve of radius 325 meter. Design the following geometric features:
   i) Super elevation
   ii) Extra widening of pavement
   iii) length of transition curve

Data available are design speed = 65 kmph, length of wheel base of largest truck = 6 m, pavement width = 10.5 m.

June/july 2011

Soln
\[ R_{\text{ruling}} = \frac{v^2}{g(e + f)} \]

\[ V = 95.29 \text{m/sec} \]

**Super elevation:**

\[ e = \frac{v^2}{225R} = 0.12 \text{ take } e \text{ value of } 0.07 \]

**Extra widening:**

\[ e = \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} = 0.55 \text{m} \]

**Transition curve**

1. The length of the transition curve \( L_s1 \) in m is

\[ L_{s1} = 0.0215v^3/CR = 124.4 \text{m} \]

\[ C = \frac{80}{75+V} = 0.46 \]

2. Rate of introduction of super-elevation

\[ L_{s2} = Ne(W + W_e) \]

\[ = 150 \times 0.07 \times 7.55 \]

\[ = 80 \text{m} \]

3. By empirical formula

IRC suggest the length of the transition curve is minimum for a plain and rolling terrain

\[ L_{s3} = 2.7V^2/R \]

\[ = 124.4 \text{m} \]

Adopt 124.4 m m as transition curve length
6. There is a horizontal highway curve of radius 400m and length 200m on this highway. Compute the set back distance required from the centre line on inner side of curve so as to provide for safe overtaking distance of 300m. The distance between the centerline of road and inner lane is 1.9 m. 

June/july 2011, Dec 2012

Soln

\[ S = 300m, \ L_c = 200m, \ R = 400m, \ d = 1.9m \]

\[
\begin{align*}
\alpha/2 &= 14.39 \\
\alpha &= 2 \times 14.39 = 28.78^\circ \\
m_1 &= (R - d) \cos(\alpha/2) \\
m_2 &= \frac{(S - L_c)}{2} \sin(\alpha/2)
\end{align*}
\]

\[
m = R - (R - d) \cos(\alpha/2) + \frac{(S - L_c)}{2} \sin(\alpha/2)
\]

\[= 14.4 + 12.4 = 26.8\]

7. A national highway passing through rolling terrain in heavy rainfall area has a horizontal curve of radius 500 m. Design the length of transition curve. Assume data suitably. 

June 2010, Dec 2012

Soln

\[
\begin{align*}
V &= 80 \text{ kmph} \\
W &= 7.0 \text{ m} \\
C &= \frac{80}{(75 + V)} = 0.52
\end{align*}
\]

Take N value as 150

1. The length of the transition curve Ls1 in m is
Super elevation:

\[ e = \frac{\nu^2}{225R} = 0.057 < 0.07 \]

Extra widening:

\[ L_s = \frac{n\nu^2}{2R} + \frac{\nu}{2.64\sqrt{R}} \]

\[ = 0.45 \text{m} \]

Total width B = 7.45 m

2. Rate of introduction of super-elevation

\[ L_s = Ne (W + We) \]

\[ = 150 \times 0.057 \times 7.45 \]

\[ = 63.7 \text{m} \]

3. By empirical formula

IRC suggest the length of the transition curve is minimum for a plain and rolling terrain

\[ L_s = 2.7\nu^2/R \]

\[ = 34.6 \text{ m} \]

Adopt 64.4 m as transition curve length

8 Derive expression for super elevation May/ June 2010
- P the centrifugal force acting horizontally out-wards through the center of gravity,
- W the weight of the vehicle acting down-wards through the center of gravity, and
- F the friction force between the wheels and the pavement, along the surface inward.

At equilibrium, by resolving the forces parallel to the surface of the pavement we get,
\[ P \cos \theta = W \sin \theta + FA + FB \]
\[ = W \sin \theta + f (RA + RB) \]
\[ = W \sin \theta + f (W \cos \theta + P \sin \theta) \]

where W is the weight of the vehicle, P is the centrifugal force, f is the coefficient of friction, f is the transverse slope due to super elevation. Dividing by W cos \( \theta \), we get:

\[
\frac{P \cos \theta}{W \cos \theta} = \frac{W \sin \theta}{W \cos \theta} + \frac{fW \cos \theta}{W \cos \theta} + \frac{fP \sin \theta}{W \cos \theta}
\]
\[
\frac{P}{W} = \tan \theta + f + f \frac{P}{W} \tan \theta
\]
\[
\frac{P}{W} (1 - f \tan \theta) = \tan \theta + f
\]
\[
\frac{P}{W} = \frac{\tan \theta + f}{1 - f \tan \theta}
\]

This is an exact expression for super elevation. But normally, \( f = 0.15 \) and \( \theta < 40^\circ \), if \( \tan \theta = 1 \)
UNIT 5

1. Explain the following with IRC specification:

Ruling gradient

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In atter terrain, it may be possible to provide at gradients, but in hilly terrain it is not economical and sometimes not possible also. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions. But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for the country as a whole. Hence IRC has recommended some values for ruling gradient for different types of terrain.

Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains requires some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions. A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory performance.
Limiting gradient

This gradient is adopted when the ruling gradient results in enormous increase in cost of construction. On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient. But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

Exceptional gradient

Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 meters at a stretch. In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient. At hairpin bends, the gradient is restricted to 2.5%.

<table>
<thead>
<tr>
<th>Terrain</th>
<th>Ruling</th>
<th>Limiting</th>
<th>Exceptional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain/Rolling</td>
<td>3.3</td>
<td>5.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Hilly</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Steep</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

2 A valley curve is formed by descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfill both comfort condition and head light sight distance requirements for a design speed of 80 kmph. Assume c = 0.6 m/sec.

Soln

Sight distance

\[
SSD = v^2t + \frac{y^2}{2gf} = 22.22^2 \times 2.5 + 22.22^2/2 \times 9.81 \times 0.35
\]

\[
= 127 m
\]

N = -0.058

Comfort condition
\[ Ls = \frac{NV^2}{C} \times 2 = 73.1m \]

Case 1: Length of valley curve greater than stopping sight distance \((L > S)\)

\[ L = \frac{NS^2}{1.5+0.035S} \]
\[ = 199.5m \]

Assumption is correct Length of valley curve is 200m

3. Define a gradient, explain in detail the different gradients adopted on a highway with specifications as per IRC Dec 2010

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. Before finalizing the gradients, the construction cost, vehicular operation cost and the practical problems in the site also has to be considered. Usually steep gradients are avoided as far as possible because of the difficulty to climb and increase in the construction cost. More about gradients are discussed below.

**Ruling gradient**

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In atter terrain, it may be possible to provide at gradients, but in hilly terrain it is not economical and sometimes not possible also. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions. But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for the country as a whole. Hence IRC has recommended some values for ruling gradient for different types of terrain.
Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains requires some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions. A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory Performance.

Limiting gradient

This gradient is adopted when the ruling gradient results in enormous increase in cost of construction. On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient. But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

Exceptional gradient

Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 meters at a stretch. In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient. At hairpin bends, the gradient is restricted to 2.5%.

4. Explain how the length of valley curve is designed. Dec 2010

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^3/L^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 0.6\(\text{m/sec}^3\).

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:

\[
L_s = \frac{v^3}{cR}
\]

For a cubic parabola, the value of \(R\) for length \(L_s\) is given by:

\[
R = \frac{L_s}{N}
\]

**Safety criteria**

Length of the valley curve for headlight distance may be determined for two conditions:

- length of the valley curve greater than stopping sight distance and
- Length of the valley curve less than the stopping sight distance.

**Case 1**: Length of valley curve greater than stopping sight distance (\(L > S\)) The total length of valley curve \(L\) is greater than the stopping sight distance SSD. The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve.
Case 2 Length of valley curve less than stopping sight distance (L < S)

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve. The case is shown in figure.

5. 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 SSD for a design speed of 80 kmph. Assume any other data as per IRC. Dec 2010, Dec 2012, June/july 2011
SSD = \( v \times t + \frac{v^2}{2gf} \) = 22.22*2.5 + 22.22^2/2*9.81*.35 

=127.44m

N = 0.08
L = 2S - 9.6/N = 297.9m > 127.44m

The length of summit curve is 298m

6. Design the length of valley curve to fulfill both comfort condition and head light sight distance requirements for a design speed of 80 kmph. Assume C = 0.6 m/s". Also, calculate the location of culvert from flatter grade formed by a descending grade 1 in n

Sight distance

SSD = \( v \times t + \frac{v^2}{2gf} \) = 22.22*2.5 + 22.22^2/2*9.81*.35 

= 127.4m

N= -.058

Comfort condition

\[ L_s = \frac{NV^3}{C} \] * 2 =65.13m

Case 1: Length of valley curve greater than stopping sight distance (L > S)

\[ L = \frac{NS^2}{2h_1 + 2S \tan \alpha} \]

= 157.97m
Assumption is correct Length of valley curve is 157.97m

Lowest pt of culvert lies at a distance
\[ X_0 = L \sqrt{n_1 \times 2N} \]
\[ X_0 = 6.47m \]

7. Explain the different cases of finding the length of summit curve for varying SSD and OSD

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. That is, a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road. Equation of the parabola is given by \( y = ax^2 \), where \( a = N \times 2L \), where \( N \) is the deviation angle and \( L \) is the length of the In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight Distance. Let \( L \) is the length

**Case a**: Length of summit curve greater than sight distance

The situation when the sight distance is less than the length of the curve
Case b: Length of summit curve less than sight distance

When stopping sight distance is considered the height of driver's eye above the road surface (\(h_1\)) is taken as 1.2 meters, and height of object above the pavement surface (\(h_2\)) is taken as 0.15 meters. If overtaking sight distance is considered, then the value of driver's eye height (\(h_1\)) and the height of the obstruction (\(h_2\)) are taken equal as 1.2 meters.

\[
S_1 + S_2 = \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}}
\]

\[
S^2 = \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2
\]

\[
S^2 = \frac{2L}{N} \left(\sqrt{h_1} + \sqrt{h_2}\right)^2
\]

\[
L = \frac{NS^2}{2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2}
\]

8 An ascending gradient of 1 in 100 and a descending gradient of 1 in 120 meet at a point. Design a summit curve for a speed of 80 kmph so as to have a OSD of 420 m.
SSD = \( \frac{v^2 + t^2}{2gf} \) = \( 22.22 \times 2.5 + \frac{22.22^2}{2} \times 9.81 \times 0.35 \)

= 127.44m

\( N = 0.018 \)

\( L = 2S - \frac{9.6}{N} = 422m < OSD \)

\( L < OSD \)

\( L = 2S - \frac{9.6}{N} = 2 \times 420 - 9.6 / 0.018 \)

= 306.67m

The length of summit curve is 306.67m

UNIT 6

1. Explain need of grade separated intersection and give advantages and disadvantages of grade separated and at grade intersection. Dec 2011, Dec 2010

Grade separated intersections are of two types. They are at-grade intersections and grade-separated intersections. In at-grade intersections, all roadways join or cross at the same vertical level. Grade separated intersections allows the traffic to cross at different vertical levels. Sometimes the topography itself may be helpful in constructing such intersections. Otherwise, the initial construction cost required will be very high. Therefore, they are usually constructed on high speed facilities like expressways, freeways etc. These type of intersection increases the road capacity because vehicles can flow with high speed and accident potential is also reduced due to vertical separation of traffic
Advantages

- Maximum facilities are given to the crossing traffic. As roads are separate which avoid accidents
- There is overall increase in comfort and convenience to the motorist and saving in travel time
- Stage constructions of additional ramps are possible after the grade separation structures between main roads are constructed.

Disadvantages

- It is very costly to provide complete grade separation and interchange facilities.
- In flat or plain terrain grade separation may introduce undesirable crests sags in the vertical alignment

2. What are the advantages and limitation of unchannelized and channelized intersection? Dec 2011, June/july 2011, Dec 2012

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

Advantages of unchannelized intersection

- It is efficient where the traffic volume is low
- Its design and construction is simple

Disadvantages of unchannelized intersection

- Vehicles approaching an intersection have no definite paths hence no of accidents will be more
- Unchannelized intersection provides more unsafe and inefficient when pedestrian traffic is more
- There is more number of possible and areas of conflicts available are more in carriageway.

3 What are the grade-separated intersections? Explain the situations at which grade separated intersections are justified. Dec 2010, Dec 2012

Grade-separated intersections are provided to separate the traffic in the vertical grade. But the traffic need not be those pertaining to road only. When a railway line crosses a road, then also grade separators are used. Different types of grade-separators are covers and interchange. Flyovers itself are subdivided into overpass and underpass. When two roads cross at a point, if the road having major traffic is elevated to a higher grade for further movement of traffic, then such structures are called overpass. Otherwise, if the major road is depressed to a lower level to
cross another by means of an under bridge or tunnel, it is called under-pass. Interchange is a system where traffic between two or more roadways flows at different levels in the grade separated junctions. Common types of interchange include trumpet interchange, diamond interchange, and cloverleaf interchange.

The following are the situations under which grade separation are preferred

- On high type facilities such as expressways, freeways and motorways.
- At certain locations which have a proven road of bad accidents history at grade junction.
- At junctions where the traffic volume is heavy and delays and loss caused justify economically the provision of grade separation.

4 Explain the principles governing the design of intersections. June/july 2011, Dec 2012
With neat sketches, explain the different types of grade intersections. Explain the advantages and limitations of Rotary intersection June 2010

The principles governing the design of intersections are as follows

- The no of intersection should be kept at minimum.
- The geometric layout should be so selected that hazardous movements of drivers are eliminated.
- The layout should follow the natural vehicles paths.
- Vehicles that are forced to wait in order to cross a traffic stream should be provided adequate space at the junction.

1. **Trumpet interchange:** Trumpet interchange is a popular form of three leg interchange. If one of the legs of the interchange meets a highway at some angle but does not cross it, then the interchange is called trumpet interchange. A typical layout of trumpet interchange is shown in figure

2. **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. A typical layout of diamond interchange is shown in figure

3. **Clover leaf interchange:** It is also a four leg interchange and is used when two highways of high volume and speed intersect each other with considerable turning movements. The main advantage of cloverleaf intersection is that it provides complete separation of traffic. In addition, high speed at intersections can be achieved. However, the disadvantage is that large area of land is required. Therefore, cloverleaf interchanges are provided mainly in rural areas. A typical layout of this type of interchange is shown in figure
5. Explain the important steps followed while designing rotary intersection along with relevant formulae employed

The important steps followed in designing the rotary intersection is as follows

**Design speed**

All the vehicles are required to reduce their speed at a rotary. Therefore, the design speed of a rotary will be much lower than the roads leading to it. Although it is possible to design roundabout without much speed reduction, the geometry may lead to very large size incurring huge cost of construction. The normal practice is to keep the design speed as 30 and 40 kmph for urban and rural areas respectively.

**Entry, exit and island radius**

The radius at the entry depends on various factors like design speed, super-elevation, and coefficient of friction. The entry to the rotary is not straight, but a small curvature is introduced. This will force the driver to reduce the speed. The entry radius of about 20 and 25 metres is ideal for an urban and rural design respectively. The exit radius should be higher than the entry radius and the radius of the rotary island so that the vehicles will discharge from the rotary at a higher rate. A general practice is to keep the exit radius as 1.5 to 2 times the entry radius. However, if
pedestrian movement is higher at the exit approach, then the exit radius could be set as same as that of the entry radius. The radius of the central island is governed by the design speed, and the radius of the entry curve. The radius of the central island, in practice, is given a slightly higher radius so that the movement of the traffic already in the rotary will have priority. The radius of the central island which is about 1.3 times that of the entry curve is adequate for all practical purposes.

**Width of the rotary**

The entry width and exit width of the rotary is governed by the traffic entering and leaving the intersection and the width of the approaching road. The width of the carriageway at entry and exit will be lower than the width of the carriageway at the approaches to enable reduction of speed. IRC suggests that a two lane road of 7 m width should be kept as 7 m for urban roads and 6.5 m for rural roads. Further, a three lane road of 10.5 m is to be reduced to 7 m and 7.5 m respectively for urban and rural roads. The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus weaving width is given as,

\[ w_{weaving} = \left(\frac{e_1 + e_2}{2}\right) + 3.5m \]

**Capacity**

The capacity of rotary is determined by the capacity of each weaving section. Transportation road research lab (TRL) proposed the following empirical formula to find the capacity of the weaving section.

\[ Q_w = \frac{280w[1 + \frac{e}{w}][1 - \frac{e}{3}]}{1 + \frac{w}{l}} \]

where e is the average entry and exit width, i.e, \((e_1+e_2)\) w is the weaving width, l is the length
of weaving, and \( p \) is the proportion of weaving traffic to the non-weaving traffic. Figure shows four types of movements at a weaving section, \( a \) and \( d \) are the non-weaving traffic and \( b \) and \( c \) are the weaving traffic. Therefore,

\[
p = \frac{b + c}{a + b + c + d}
\]

This capacity formula is valid only if the following conditions are satisfied.
1. Weaving width at the rotary is in between 6 and 18 metres.
2. The ratio of average width of the carriage way at entry and exit to the weaving width is in the range of 0.4 to 1.
3. The ratio of weaving width to weaving length of the roundabout is in between 0.12 and 0.4.

UNIT 7

1 Explain the cloverleaf interchange with its merits and demerits Dec 2011

Clover leaf interchange: It is also a four leg interchange and is used when two highways of high volume and speed intersect each other.
Advantages

- Only one structure is required
- Left turning traffic has a direct path
- It is very simple to use and does not confuse the drivers

Disadvantages

- Relatively large area is required
- The carriageway area required is also higher than a rotary interchange
- Weaving movements are involved, some them on the roadway of the structure and some underneath the structure
- The U turn are long and operationally difficult

2. List the advantages and disadvantages of a rotary intersection Dec 2010, June/july 2011

The key advantages of the rotary intersection are listed below:

1. Traffic flow is regulated to only one direction of movement, thus eliminating severe conflicts between crossing movements.
2. All the vehicles entering the rotary are gently forced to reduce the speed and continue to move at slower speed. Thus, more of the vehicles need to be stopped.
3. Because of lower speed of negotiation and elimination of severe conflicts, accidents and their severity are much less in rotaries.
4. Rotaries are self governing and do not need practically any control by police or traffic signals.
5. They are ideally suited for moderate traffic, especially with irregular geometry, or Intersections with more than three or four approaches.

Although rotaries offer some distinct advantages, there are few specific limitations for rotaries Which are listed below.
1. All the vehicles are forced to slow down and negotiate the intersection. Therefore the Cumulative delay will be much higher than channelized intersection.

2. Even when there is relatively low traffic, the vehicles are forced to reduce their speed.

3. Rotaries require large area of relatively at land making them costly at urban areas.

4. Since the vehicles are not stopping, and the vehicles accelerate at rotary exits, they are not suitable when there are high pedestrian movements.

3. Design the rotary for the data given below, with suitable assumptions. The highways intersect at right angles and have a carriage way width of 15 mts. Also draw the diagram of the rotary designed.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Left turning</th>
<th>Straight ahead</th>
<th>Right turning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
<td>1 2 3</td>
<td>1 2 3</td>
</tr>
<tr>
<td>N</td>
<td>200 50 100</td>
<td>250 100 150</td>
<td>150 50 80</td>
</tr>
<tr>
<td>E</td>
<td>180 60 80</td>
<td>220 50 120</td>
<td>200 40 120</td>
</tr>
<tr>
<td>W</td>
<td>220 50 120</td>
<td>180 60 100</td>
<td>250 60 100</td>
</tr>
<tr>
<td>S</td>
<td>250 80 100</td>
<td>150 50 90</td>
<td>160 70 90</td>
</tr>
</tbody>
</table>

Soln

```
1210 1408
```

```
1262
1260
```

```
1331 1544
```

```
1262
```

```
1260
```
Soln

\[
E_1 + E_2 / 2 + 3.5
\]

\[= 13.54m\]

\[p = \frac{b + c}{a + b + c + d}\]

\[= 0.72\]

\[Q_w = \frac{280w[1 + \frac{w}{e}][1 - \frac{e}{3}]}{1 + \frac{w}{l}}\]

\[= 288*13.5*1.74*0.76/12.45\]

\[= 4000\text{PCU/hr}\]

This is higher than the traffic flow 2746\text{PCU/hr}

Clover leaf intersection.

It is also a four leg interchange and is used when two highways of high volume and speed intersect each other with considerable turning movements. The main advantage of cloverleaf intersection is that it provides complete separation of traffic. In addition, high speed at intersections can be achieved. However, the disadvantage is that large area of land is required. Therefore, cloverleaf interchanges are provided mainly in rural areas. A typical layout of this type of interchange is shown in figure.
Half clover leaf

A partial cloverleaf interchange is a modification of a cloverleaf interchange. This interchange was developed by the Ontario Ministry of Transportation[citation needed] as a replacement for the cloverleaf on 400-Series Highways, removing the dangerous weaving patterns and allowing for more acceleration and deceleration space on the freeway.

The design has been well received, and has since become one of the most popular freeway-to-arterial interchange designs in North America. It has also been used occasionally in some European countries, such as Germany, the Netherlands, and the United Kingdom.

UNIT 8
1. Explain the significance of highway drainage. Dec 2011, Dec 2012

An increase in moisture content causes decrease in strength or stability of a soil mass the variation in soil strength with moisture content also depends on the soil type and the mode of stress application. Highway drainage is important because of the following reasons:-

- Excess moisture in soil subgrade causes considerable lowering of its stability the pavement is likely to fail due to Subgrade fail.
- Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.
- In some clayey soils variation in moisture content causes considerable variation in flume of Subgrade. This sometimes contributes to pavement failure.
- One of the most important causes of pavement failure by the formation of waves and A corrugation in flexible pavements is due to poor drainage.
- Sustained contact of water with bituminous pavements causes failures due to stripping of Bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.
- TIE- prime cause of failures in rigid pavements by mud pumping is due to the presence of Water in fine Subgrade soil.
- Excess water on shoulders and pavement edge causes considerable damage.
- Excess moisture causes increase in weight and thus increase in stress and simultaneous reduction in strength of the soil mass. This is one of the main reasons of failure of earth slopes and embankment foundations

2. Explain how the subsurface drainage is provided to lower the water table and control seepage flow Dec 2011 June/july 2011

**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 atleast 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.
Control of capillary rise

A layer of granular material of suitable thickness is provided during the construction of embankment between the Subgrade and the highest level of subsurface water table. another method of providing capillary cutoff is by inserting an impermeable bituminous layer in place of granular blanket

Control of seepages flow

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 atleast 0.6 to 0.9 m the Subgrade

3. Explain the design procedure of filter material used in subsurface drain. Dec 2011

The procedure to design the filler materials is as follows

- On a gain size distribution chart plot the grain size distribution curve for a foundation soil.
- Find the value of D15 size of foundation material & plot a point of particle size 5D15 of foundation to represent the lower limit of D15 size of the filler. This is fulfill the permeability condition

\[
\frac{(D15 \text{ of filter})}{D15 \text{ of Foundation}} > 5
\]

- To fulfill the condition to prevent piping

\[
\frac{(D15 \text{ of filter})}{D85 \text{ of Foundation}} < 5
\]

4. What are the requirements of a good highway drainage system June/July 2011

The requirements of good highway drainage system is as follows
The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to Subgrade.

- The surface water from the adjoining land should be prevented from entering the roadway.
- The side drain should have sufficient capacity and longitudinal slope to carry away all the surface water collected.
- Flow of surface water across the road and shoulders and along slopes should not cause formation of cress ruts or erosion.
- Seepage and other sources of underground water should be drained off by the subsurface drainage system.
- Highest level of ground water table should be kept well below the level of Subgrade, preferably by at least 1.2 m.
- In waterlogged areas special precautions should be taken, specially if detrimental salts are present or if flooding is likely to occur.

5. The maximum quantity of water expected in one of the open longitudinal drains on clayey soil is 0.9 m$^3$/sec. Design the cross section and longitudinal slope of a trapezoidal drain assuming the bottom width of section to be 1.0 m and cross slope to be IV to 1.5 H. The allowable velocity of flow in the drain is 1.2 m/sec and Manning's roughness co-efficient is 0.02 June/july 2011, Dec 2012

**Soln:**

Cross section

The velocity of flow through the clay soil $V = 1.2$m/sec

$$A = \frac{Q}{V}$$

$$0.9/1.2 = .75\text{sqm}$$

For trapezoidal c/s $1.5d^2 + d - 0.75 = 0$
Solving by quadratic equation for d

D= 0.45m taking free board as .15m now the total depth is 0.45+.15 = 0.60m

Slope:

The slope is calculated using manning’s formula

\[ V = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \]

Hydraulic radius \( R = \frac{\text{area}}{\text{perimeter}} = 2.62 \text{m} \)

By substituting the values slope \( S = 0.0553^{\frac{1}{2}} \)

Therefore \( s = 0.0031 = 1/322.5 \)