CMR
INSTITUTE OF
TECHNOLOGY

Improvement Test – November 2017

Solution

Sub:	HIGHWAY GEOMETRIC DESIGN						**Code:**	10 CV755
Date:	20/ 11 / 2017	Duration:	90 mins	Max Marks:	50	**Sem:** 7	**Branch:**	CIVIL

1. **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.

2. a) **Gradient:**

   Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. The positive gradient or the ascending gradient is denoted as +n and the negative gradient as−n.

Different types of grades are available and the recommended value of gradients for each type of terrain and type of gradient is given in table.

Ruling gradient, limiting gradient, exceptional gradient and minimum gradient are some types of gradients which 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 flatter terrain, it may be possible to provide flat 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.

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 metres 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%.

Critical length of the grade

The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, grad-ability of the truck, initial speed, final desirable minimum speed etc.

Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains require some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the 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.

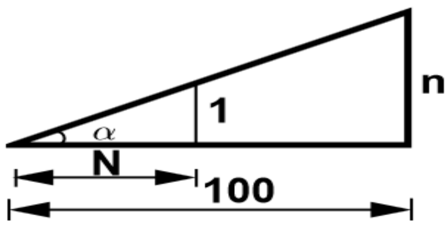

Figure 17:1: Representation of gradient

Table 17:1: IRC Specifications for gradients for different roads

Terrain	Ruling	Limitings	Exceptional
Plain/Rolling	3.3	5.0	6.7
Hilly	5.0	6.0	7.0
Steep	6.0	7.0	8.0

b) **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 a) **Valley Curve :**

A valley curve is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfil both comfort condition and head light sight distance requirements for a design speed of 80 kmph. Assume allowable rate of change of centrifugal acceleration $C = 0.6\ m/sec^3$.

Solution

Given design speed, V = 80 kmph, gradients $n_1 = -1/25$ and $n_2 = +1/30$

$$\text{Deviation angle, } N = -\frac{1}{25} - \frac{1}{30} = -\frac{11}{150}$$

$$V = 80 \text{ kmph}, v = 80/3.6 = 22.2 \text{ m/sec}$$

(b) Valley curve length, L for comfort condition

From Eq. 4.41,

$$L = 2\left[\frac{Nv^3}{C}\right]^{1/2} = 2\left[\frac{11}{150} \times \frac{22.2^3}{0.6}\right]^{1/2} = 73.1 \text{ m}$$

(c) Valley curve length for head light sight distance

Neglecting the ascending and descending gradients at the valley curve using Eq. 4.2 and assuming t = 2.5 secs. and f = 0.35, $SSD = v\,t + v^2/2gf = 22.2 \times 2.5 + (22.2^2/2 \times 9.8 \times 0.35) = 127.3$ m

Assuming L > SSD = 127.3 m and using Eq. 4.44,

$$L = \frac{NS^2}{(1.5 + 0.035S)} = \frac{11 \times 127.3^3}{150(1.5 + 0.035 \times 127.3)} = 199.5 \text{ m}$$

As this value of L is higher than the SSD of 127.3 m, the assumption is correct. The valley curve length based on head light sight distance being higher than that based on comfort condition, the design length of valley curve is 199.5 or say, 200 m.

b) **Summit curve problem:**

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

c) **Design elements**

The design elements include design speed, radius at entry, exit and the central island, weaving length and width, entry and exit widths. In addition the capacity of the rotary can also be determined by using some empirical formula. A typical rotary and the important design elements are shown in figure

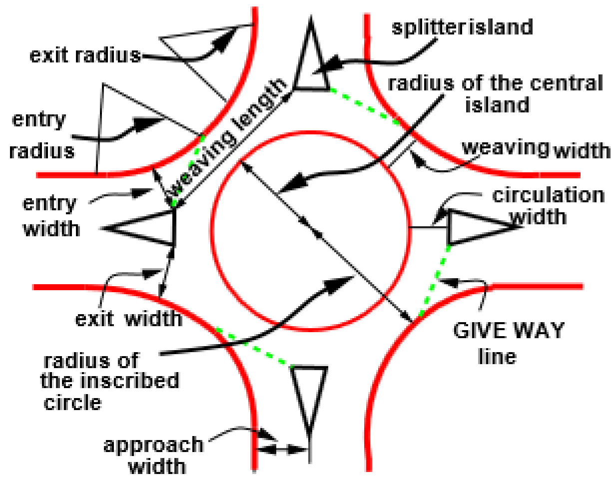

Figure 40:2: Design of a rotary

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,

$$W_{weaving} = \{(e_1+e_2)/2\} + 3.5m$$

where e_1 is the width of the carriageway at the entry and e_2 is the carriageway width at exit. Weaving length determines how smoothly the traffic can merge and diverge. It is decided based on many factors such as weaving width, proportion of weaving traffic to the non-weaving traffic etc. This can be best achieved by making the ratio of weaving length to the weaving width very high. A ratio of 4 is the minimum value suggested by IRC. Very large weaving length is also dangerous, as it may encourage over-speeding.

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.

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

Where, e=average entry & exit width i.e. $=(e_1+e_2)/2$

w= weaving width

l = weaving length

p = proportion of weaving traffic to the non-weaving traffic

The figure below 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.

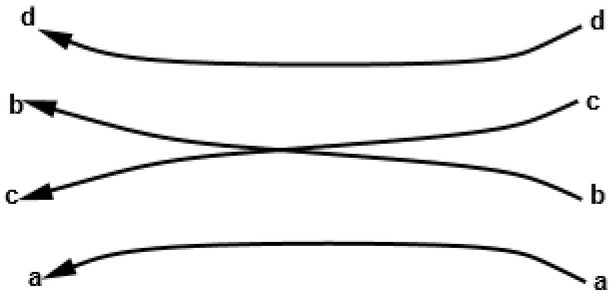

Figure 40:3: Weaving operation in a rotary

Therefore,

p = (b + c) / (a + b + c + d)

4 (a) Derive an expression for calculating the stopping sight distance for ascending gradient, descending gradient and level 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.

There is a term called *safe stopping distance* and is one of the important measures in traffic engineering. It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance atleast equal to the safe stopping distance should be provided. The stopping sight distance is the sum of lag distance and the braking distance. 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/sec^2. 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:

$$SSD = vt + \frac{v^2}{2gf} \tag{13.1}$$

where v is the design speed in m/sec^2, t is the reaction time in sec, g is the acceleration due to gravity and f is the coefficient of friction. The coefficient of friction f is given below for various design speed. When there is an

Table 13:1: Coefficient of longitudinal friction

Speed, kmph	<30	40	50	60	>80
f	0.40	0.38	0.37	0.36	0.35

ascending gradient of say $+n\%$, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the the braking force is equal to $W \sin\alpha \approx W \tan\alpha = Wn/100$. 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 13.2.

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)} \tag{13.2}$$

b)

Find SSD for a descending gradient of 2% for V=80kmph. [Ans: 132m].

Given: Gradient(n) = -2V = 80 Km/hr.

$$SD = vt + v^2/2g(f - n\%)$$

SSD on road with gradient = 132m.

c) In a road test for measuring skid resistance using skid resistance equipment, the timer indicating 5 seconds of brake application and the braking distance indicated by the colour spray was measured as 35 m before the vehicle was brought to stop. What is the average resistance of the pavement surface?

Using fundamental relations of motion for uniform acceleration/retardation

(i) $V = U + at$

Since $V = 0$, $u = (-at)$

(ii) $V^2 = u^2 + 2as$

$-u^2 = 2as$

$S = - u^2 / (2a)$

Substituting $u = (-at)$

$S = at^2 /2$

$a = 2s / t^2$

Braking distance L = s = 35m

Braking time t = 5seconds

Average skid resistance of the pavement $f = a/g$

$$= \frac{2s / t^2}{g}$$

$$= \frac{(2 * 35) / 5^2}{9.8}$$

$$= 0.285$$