Light reflection

White roads have good visibility at night, but caused glare during day time.

Black roads has no glare during day, but has poor visibility at night

Concrete roads has better visibility and less glare

It is necessary that the road surface should be visible at night and re ection of light is the factor that answers it.

Drainage

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain o 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 (Figure 12:1)

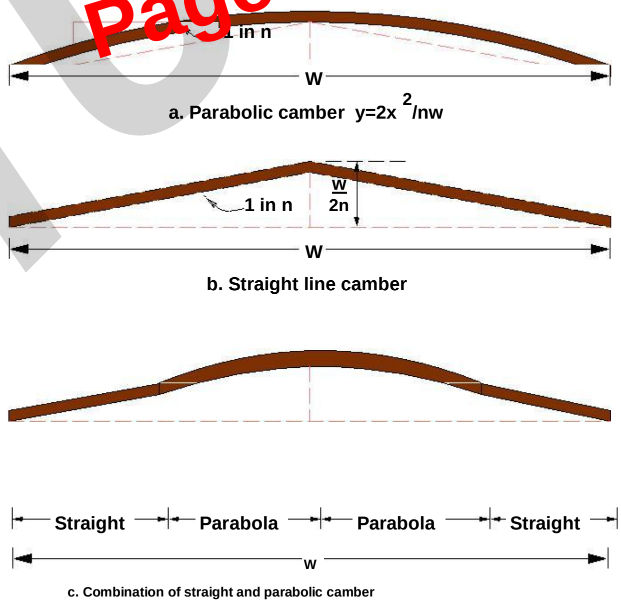


Figure 12:1: Different types of camber

Stopping sight distance

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 rst 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 at least 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 F l = f W l where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\frac{1}{2}mv^2 = \frac{1}{2}\frac{W v^2}{g}$$

$$f\,W\,l = \frac{W v^2}{2g}$$

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

$$SSD = vt + \frac{v^2}{2gf} \qquad (13.1)$$

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 coe cient of friction. The coe cient of friction f is given below for various design speed. When there is an

Table 13:1: Coe cient 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 W tan = W n=100. Equating kinetic energy and work done:

$$\left(f\,W + \frac{W\,n}{100}\right) l = \frac{W v^2}{2g}$$

$$l = \frac{v^2}{2g\left(f + \frac{n}{100}\right)}$$

Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation 13.2.

$$SSD = vt + \frac{v^2}{2g(f \quad 0{:}01n)} \qquad (13.2)$$

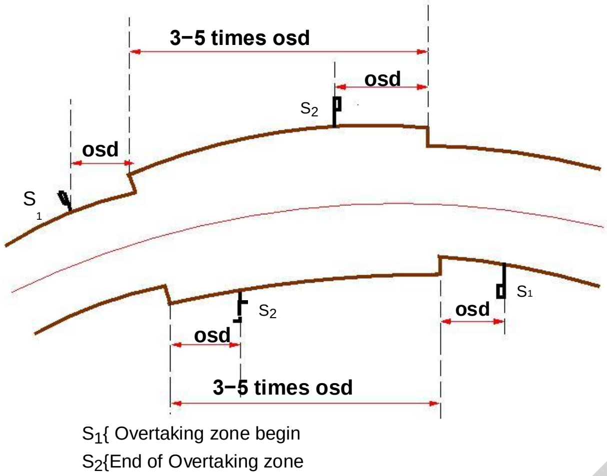


Figure 13:2: Overtaking zones

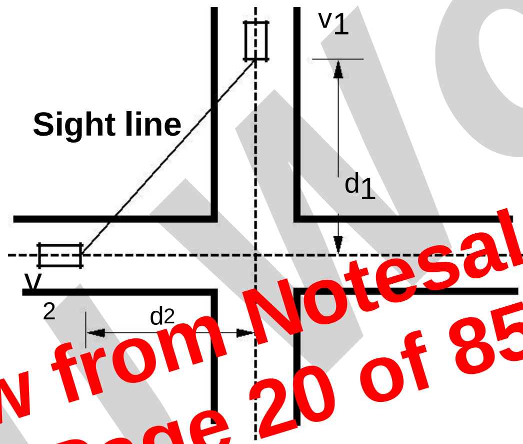


Figure 13:3: Sight distance at intersections

Sight distance at intersections

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. This is illustrated in the gure 13:3.

Design of sight distance at intersections may be used on three possible conditions:

Enabling approaching vehicle to change the speed

Enabling approaching vehicle to stop

Enabling stopped vehicle to cross a main road

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

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

where F_A and F_B is the fractional force at tyre A and B, R_A and R_B is the reaction at tyre A and B, f is the lateral coe cient of friction and W is the weight of the vehicle. This is counteracted by the centrifugal force (P), and equating:

$$P = fW \quad \text{or} \quad \frac{P}{W} = f$$

At equilibrium, when skidding takes place (from equation14.2)

$$\frac{P}{W} = f = \frac{v^2}{gR}$$

and for safety the following condition must satisfy:

$$f > \frac{v^2}{gR} \tag{14.4}$$

Equation 14.3 and 14.4 give the stable condition for design. If equation 14.3 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

Analysis of super-elevation

Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counteracting the e ect of centrifugal force. In order to nd out how much this raising should be, the following analysis may be done. The forces acting on a vehicle while taking a horizontal curve with superelevation is shown in gure 14:2.

Forces acting on a vehicle on horizontal curve of radius R m at a speed of v m/sec^2 are:

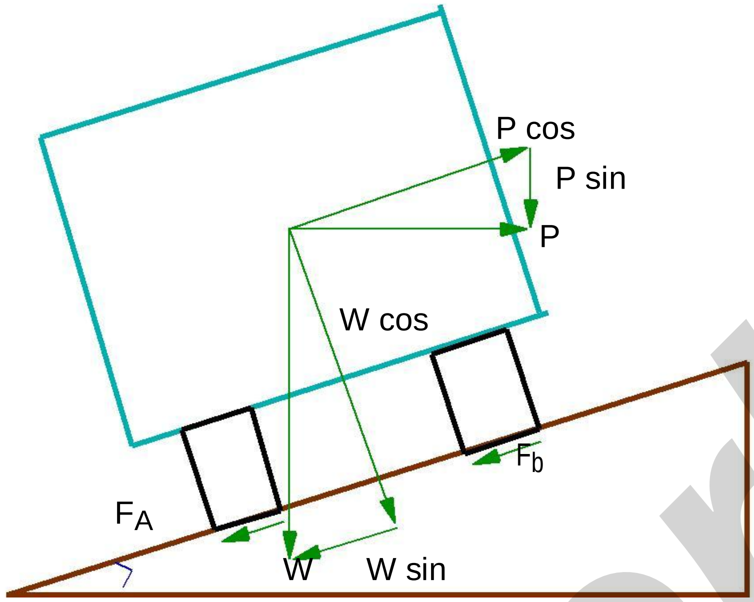


Figure 14:2: Analysis of super-elevation

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,

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

$$2.2.6 \quad W \sin + f (R_A + R_B)$$

$$2.2.7 \quad W \sin + f (W \cos + P \sin)$$

where W is the weight of the vehicle, P is the centrifugal force, f is the coe cient of friction, is the transverse slope due to superelevation. Dividing by W cos , we get:

$$\frac{P \cos}{W \cos} \quad 2.4 \frac{W \sin}{\cos} + f \frac{W \cos}{W \cos} + f \frac{P \sin}{W \cos}$$

$$\frac{P}{W} \quad 2.3.2 \quad \tan + f + f \frac{P}{W} \tan$$

$$\frac{P}{W} (1 \; f \tan) \quad 2.3.3 \quad \tan + f$$

$$\frac{P}{W} = \frac{\tan + f}{1 f \tan} \tag{14.5}$$

We have already derived an expression for P/W.By substituting this in equation 14.5, we get:

$$\frac{v^2}{gR} = \frac{\tan + f}{1 \quad f \tan} \tag{14.6}$$

Length of transition curve

The length of the transition curve should be determined as the maximum of the following three criteria: rate of change of centrifugal acceleration, rate of change of superelevation, and an empirical formula given by IRC.

1. Rate of change of centrifugal acceleration

At the tangent point, radius is in nity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. The rate of change of centrifugal acceleration should be adopted such that the design should not cause discomfort to the drivers. If c is the rate of change of centrifugal acceleration, it can be written as:

$$c = \frac{\frac{v^2}{R} - 0}{t};$$

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

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

Therefore, the length of the transition curve L_{S1} in m is

$$L_{s1} = \frac{v^3}{cR}; \qquad (16.1)$$

where c is the rate of change of centrifugal acceleration given by an empirical formula suggested by by IRC as below:

$$c = \frac{80}{75 + 3.6v}; \qquad (16.2)$$

subject to :

$$c_{min} = 0.5;$$

$$c_{max} = 0.8:$$

2. Rate of introduction of super-elevation

Raise (E) of the outer edge with respect to inner edge is given by $E = eB = e(W + W_e)$. The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve (typical range of N is 60-150). Therefore, the length of the transition curve L_{S2} is:

$$L_{S2} = N\,e(W + W_e) \qquad (16.3)$$

3. By empirical formula

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

$$L_{s3} = \frac{35v^2}{R} \qquad (16.4)$$

and for steep and hilly terrain is:

$$L_{s3} = \frac{12.96v^2}{R} \qquad (16.5)$$

and the shift s as:

$$s = \frac{L_S^2}{24R} \qquad (16.6)$$

The length of the transition curve L_S is the maximum of equations 16.1, 16.3 and 16.4or16.5, i.e.

$$L_S = \text{Max}: (L_{S1}; L_{S2}; L_{S3}) \qquad (16.7)$$

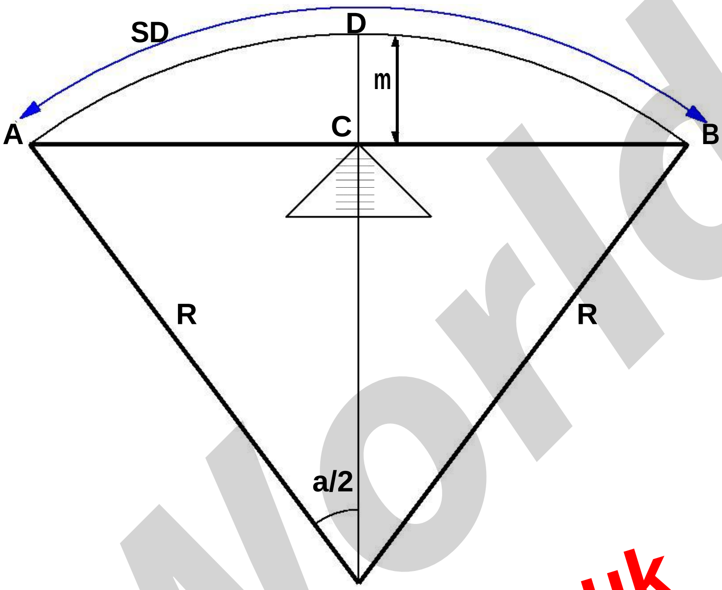


Figure 16:1: Set-back for single lane roads ($L_S < L_C$)

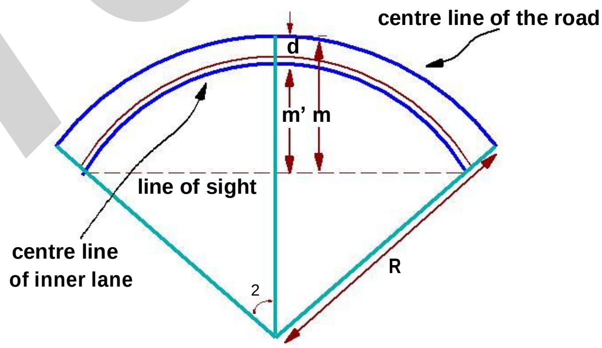


Figure 16:2: Set-back for multi-lane roads ($L_S < L_C$)

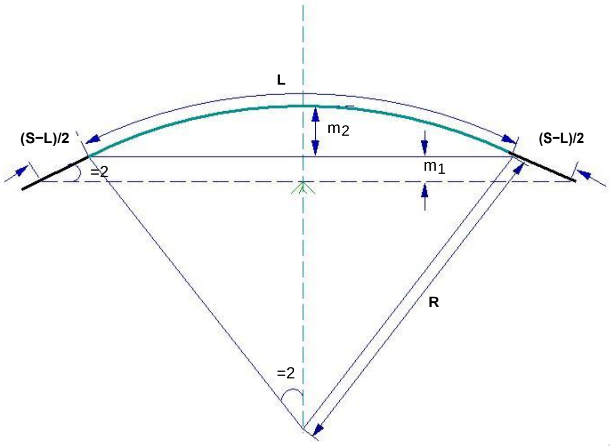


Figure 16:3: Set back for single lane roads ($L_S < L_C$)

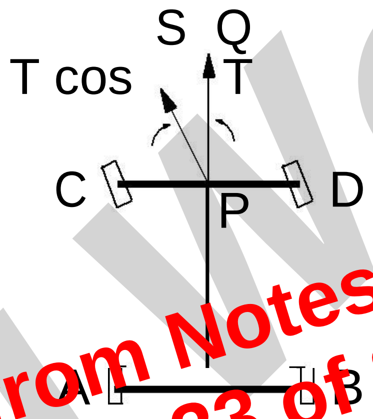


Figure 16:4: Curve resistance

Curve Resistance

When the vehicle negotiates a horizontal curve, the direction of rotation of the front and the r ear wheels are di erent. The front wheels are turned to move the vehicle along the curve, whereas the rear wheels seldom turn. This is illustrated in gure 16:4. The rear wheels exert a tractive force T in the PQ direction . The tractive force available on the front wheels is T cos in the PS direction as shown in the gure 16:4. This is less than the actual tractive force, T applied. Hence, the loss of tractive force for a vehicle to negotiate a horizontal curve is:

$$CR = TT \cos \tag{16.14}$$

Gradient

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 for designing the vertical curve. Before nalizing 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 di culty to climb and increase in the construction cost. More about gradients are discussed below.

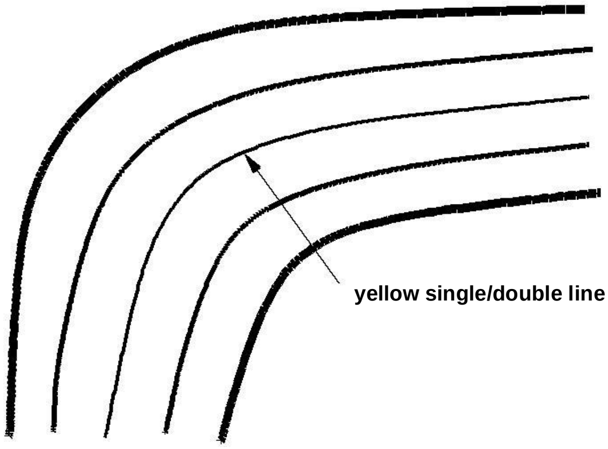


Figure 37:7: Barrier line marking for a four lane road

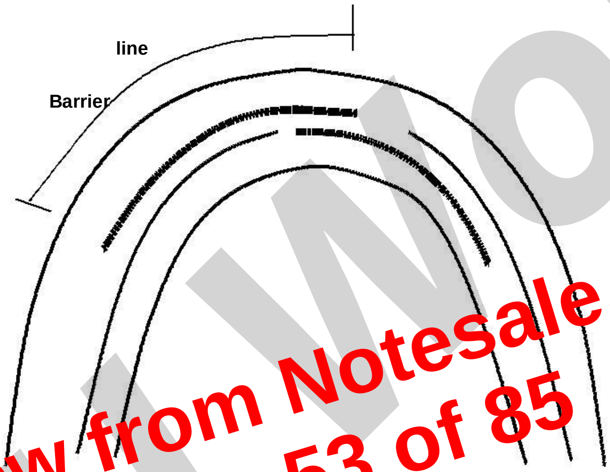


Figure 37:8: No passing zone marking at horizontal curves

opposing tra c. Some typical examples are shown in gure 37:7 and gure 37:8. In the latter case, the no passing zone is staggered for each direction.

Warning lines

Warning lines warn the drivers about the obstruction approaches. They are marked on horizontal and vertical curves where the visibility is greater than prohibitory criteria speci ed for no overtaking zones. They are broken lines with 6 m length and 3 m gap. A minimum of seven line segments should be provided. A typical example is shown in gure 37:9

Edge lines

Edge lines indicate edges of rural roads which have no kerbs to delineate the limits upto which the driver can safely venture. They should be at least 150 mm from the actual edge of the pavement. They are painted in yellow or white.

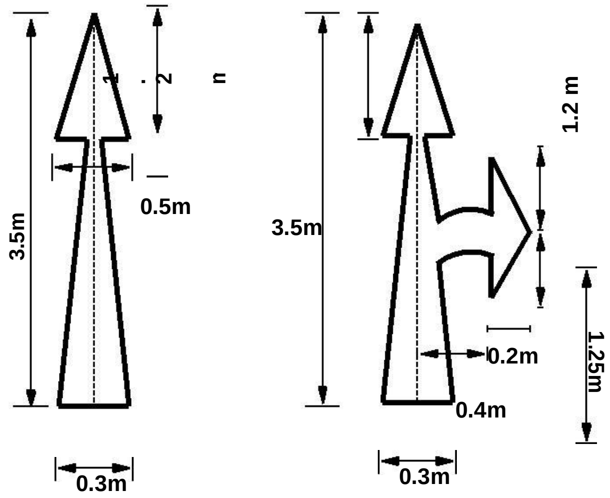


Figure 37:12: Directional arrow marking

the direction of tra c. These stripes shall be uniform and should not be less than 100 m wide so as to provide su cient visibility.

Objects adjacent to carriageway

Sometimes objects adjacent to the carriageway may pose some obstructions to the o w of tra c. Objects such as subway piers and abutments, culvert head walls etc. are some examples for such obstructions. They should be marked with alternate black and white stripes at a forward angle of 45 with respect to the direction of tra c. Poles close to the carriageway should be painted in alternate black and white up to a height of 1.25 m above the road level. Other objects such as guard stones, drums, guard rails etc. where chances of vehicles hitting them are only when vehicle runs o the carriageway should be painted in solid white. Kerbs of all islands located in the line of tra c ow shall be painted with either alternating black and white stripes of 500 mm wide or chequered black and white stripes of same width. The object marking for central pier and side walls of an underpass is illustrated in gure 37:13.

Word messages

Information to guide, regulate, or warn the road user may also be conveyed by inscription of word message on road surface. Characters for word messages are usually capital letters. The legends should be as brief as possible and shall not consist of more than three words for any message. Word messages require more and important time to read and comprehend than other road markings. Therefore, only few and important ones are usually adopted. Some of the examples of word messages are STOP, SLOW, SCHOOL, RIGHT TUN ONLY etc. The character of a road message is also elongated so that driver looking at the road surface at a low angle can also read them easily. The dimensioning of a typical alphabet is shown in gure 37:14.

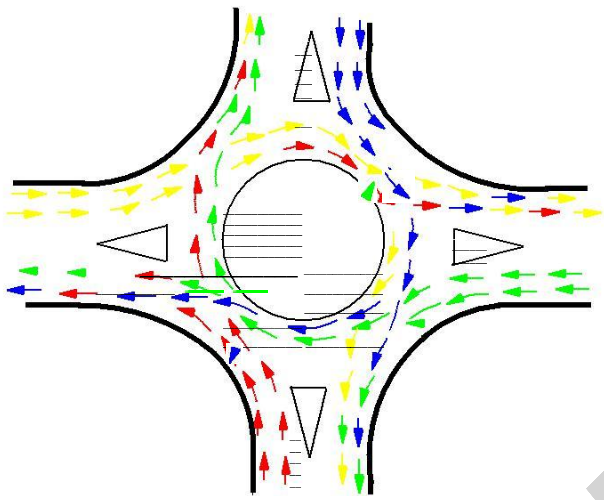


Figure 40:1: Trafficoperations in a rotary

Guidelines for the selection of rotaries

Because of the above limitation, rotaries are not suitable for every location. There are few guidelines that help in deciding the suitability of a rotary. They are listed below.

2.2.8 Rotaries are suitable when the trafficentering from all the four approaches are relatively equal.

2.2.9 A total volume of about 3000 vehicles per hour can be considered as the upper limiting case and a volume of 500 vehicles per hour is the lower limit.

2.2.10 A rotary is very bene cial when the proportion of the right-turn tra c is very high; typically if it is more than 30 percent.

2.2.11 Rotaries are suitable when there are more than four approaches or if there is no separate lanes available for right-turn tra c. Rotaries are ideally suited if the intersection geometry is complex.

Traffic operations in a rotary

As noted earlier, the tra c operations at a rotary are three; diverging, merging and weaving. All the other con icts are converted into these three less severe con icts.

2.5 **Diverging**: It is a tra c operation when the vehicles moving in one direction is separated into di erent streams according to their destinations.

2.6 **Merging**: Merging is the opposite of diverging. Merging is referred to as the process of joining the tra c coming from di erent approaches and going to a common destination into a single stream.

2.7 **Weaving**: Weaving is the combined movement of both merging and diverging movements in the same direction.

These movements are shown in gure 40:1. It can be observed that movements from each direction split into three; left, straight, and right turn.

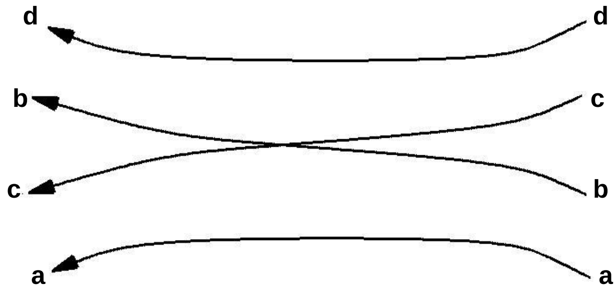


Figure 40:3: Weaving operation in a rotary

Width of the rotary

The entry width and exit width of the rotary is governed by the tra c 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,

$$w_{weaving} = \frac{e_1 + e_2}{2} + 3.5m \tag{40.1}$$

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 tra c can merge and diverge. It is decided based on many factors such as weaving width, proportion of weaving tra c to the non-weaving tra c 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 nd the capacity of the weaving section.

$$Q_w = \frac{280w[1 + \frac{e}{w}][1 - \frac{p}{3}]}{1 + \frac{w}{l}} \tag{40.2}$$

where e is the average entry and exit width, i.e, $\frac{(e_1 + e_2)}{2}$, w is the weaving width, l is the length of weaving, and p is the proportion of weaving tra c to the non-weaving tra c. Figure 40:3 shows four types of movements at a weaving section, a and d are the non-weaving tra c and b and c are the weaving tra c. Therefore,

$$p = \frac{b + c}{a + b + c + d} \tag{40.3}$$

This capacity formula is valid only if the following conditions are satis ed.

1. Weaving width at the rotary is in between 6 and 18 metres.

CHAPTER 5

HIGHWAY MATERIAL, CONSTRUCTION AND MAINTENANCE

Overview

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light re ecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are su ciently reduced, so that they will not exceed bearing capacity of the sub-grade. Two types of pavements are generally recognized as serving this purpose, namely exible pavements and rigid pavements. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements a ecting the riding quality.

Requirements of a pavement

An ideal pavement should meet the following requirements:

Su cient thickness to distribute the wheel load stresses to a safe value on the sub-grade

soil, Structurally strong to withstand all types of stresses imposed upon it,

Adequate coe cient of friction to prevent skidding of vehicles,

Smooth surface to provide comfort to road users even at high

speed, Produce least noise from moving vehicles,

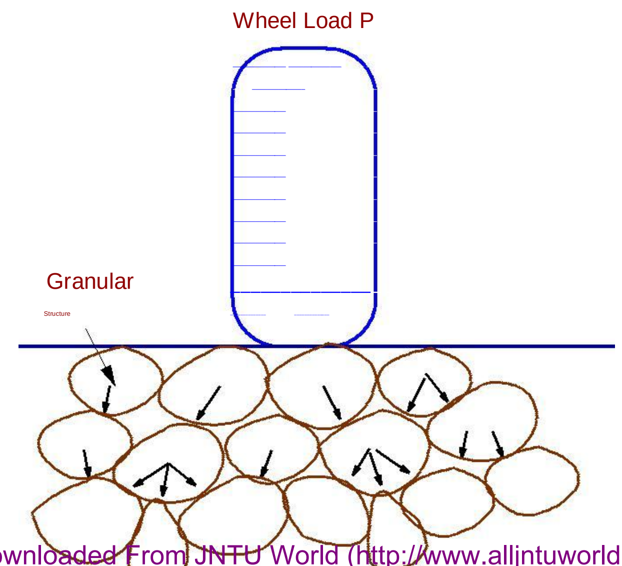
Dust proof surface so that tra c safety is not impaired by reducing visibility,

Impervious surface, so that sub-grade soil is well protected, and

Long design life with low maintenance cost.

Types of pavements

The pavements can be classi ed based on the structural performance into two, exible pavements and rigid pavements. In exible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The exible pavement, having less exural strength, acts like a exible sheet (e.g.



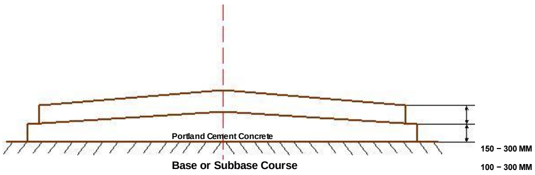


Figure 19:3: Typical Cross section of Rigid pavement

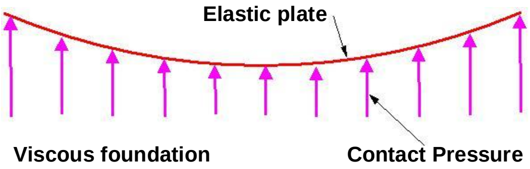


Figure 19:4: Elastic plate resting on Viscous foundation

Rigid pavements

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure 19:3. Compared to exible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure 19:4). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

Types of Rigid Pavements

Rigid pavements can be classified into four types:

1. Jointed plain concrete pavement (JPCP),
2. Jointed reinforced concrete pavement (JRCP),
3. Continuous reinforced concrete pavement (CRCP),

   and Pre-stressed concrete pavement (PCP).

Jointed Plain Concrete Pavement: are plain cement concrete pavements constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally has a joint spacing of 5 to 10m.

Jointed Reinforced Concrete Pavement: Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcement's help to keep the slab together even after cracks.