Transportation Engineering - 1

Transportation Engineering – I

What is transportation?
Transportation means movement of mass and goods. This system comprise of a good network of road, railway and airway

Objective:

- The primary purpose is relating population to land use by moving purses and goods from one place to another.
- Transportation increase valuation of goods by contributing with time utility and place utility.
- It increase work opportunity.
- Transportation makes possible regional specialization both in producing of raw materials and finished goods.

The four major modes of transportation are:

→ Roadways or highways
→ Railways
→ Waterways
→ Airways

Road way type

- Geographical classification

i. Rural road
ii. Urban road

- Functional classification

i. Rural

→ National Highway
→ Regional Highway
→ Zila road
→ Upazila road
→ Union road
→ Village road

ii. Urban

→ Primary/Main/ Arterial road
→ Secondary road
→ Local Road

The geometric design of highways depends on several design factors. The important of these factors which control the geometric elements are:

→ Design speed
→ Topography
→ Traffic factors
→ Design hourly volume and capacity
→ Environmental and other factors.

Question: State the objectives of highway planning (34th BCS)

Solution:

The objectives of highway planning are:

- Planning a highway network for safe, efficient and fast movement of people and goods.
- Keeping the overall cost of construction and maintenance of the roads in the network to a minimum.
- Planning for future development and anticipated traffic needs for a specific design period.
- **Phasing road development programmes from considerations of utility and importance as also of financial resources.**

Question: What do you mean by highway alignment? Discuss the factors controlling the alignment of a highway. (34 & 35 th BCS)

Solution:

The position of the center line on the highway in the ground is called highway alignment. Simply it is direction through which the road will pass. There are two types of highway alignment.

- Horizontal Alignment
- Vertical Alignment

Factors controlling alignment of a highway

Obligatory Points: The control points governing highway alignment are called obligatory points. These points decide where the alignment should pass and where the alignment should not pass.

Type of Traffic: If the traffic is of vehicular type and for fast-moving vehicles, it is advised to keep the alignment as straight as possible with fewer curves. Separate lanes for fast-moving vehicles are recommended.

The volume of traffic: The volume of traffic and an increase in the traffic volume per year and peak traffic is analyzed and alignment is finalized by considering all previous data of traffic respectively.

Horizontal Curve and gradient: The Horizontal curve must be as flat as possible. The gradient should be kept as flat as possible to avoid the excessive rise and fall of the highway alignment.

Earthwork and backfilling: To avoid excessive cutting and filling, the alignment should be changed where found necessary.

Railway Crossing: Road alignment should cross a rail lane ideally at 90Degrees. For fast-moving lanes or national highways or expressways, it is advisable to construct the bridge over rail lane to avoid the traffic jams.

Sight Distance: To avoid accidents, minimum sight distance should always be available for the drivers. The alignment should not obstruct the visibility of drivers, especially during nights.

Proper Drainage: Proper water drainage is provided at the edges of the alignment to avoid water logging during monsoon.

Stability of Slopes: Special care is to be taken for road alignment in hilly areas, the problem with the hilly areas is landslides. The road should be aligned to the side of the hill which is stable. Excessive earthwork cutting and backfilling affect stability.

Economy: The initial cost, operating cost and maintenance cost should be minimum for the finalized alignment. Avoid High embankments and deep cutting to reduce the cost of construction.

Question: State the importance of geometric design of a highway. Briefly discuss the geometric design elements of a highway. (34th BCS)

Solution:

Geometric design of highways deals with the layout and dimensions of visible features of the highway such as horizontal and vertical alignments, sight distance, intersections etc. The geometrics of highway has to be designed to generate sufficiency in traffic operations with maximum safety at reasonable cost.

Geometric design of highways deals with the following elements:

→ Cross section elements.
→ Sight distance considerations.
→ The gradient.
→ Horizontal alignment details.
→ Vertical alignment details.
→ Intersection elements.

Question: Classify roads and highway according to Bangladesh classification system. (31th BCS)

Solution:

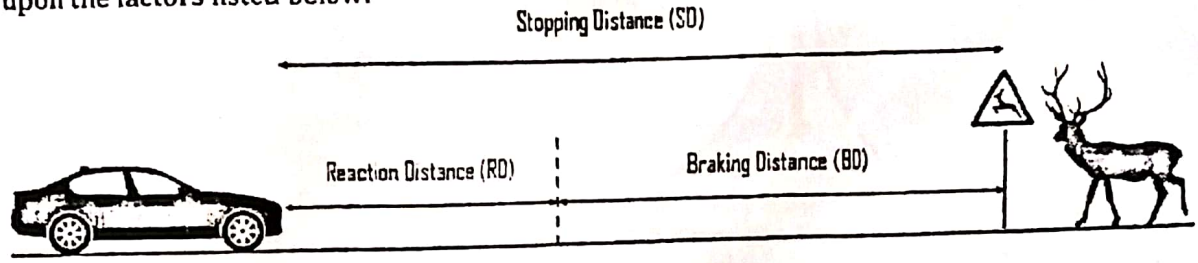
The road network of Bangladesh consists of national highways (designated by a number preceded by "N"), regional highways (R numbers), and zilla or district roads (Z numbers). The total length is nearly 21,000 km.

Road Class	Definition	Length (km)
National Highways	Highways connecting National capital with Divisional HQ's or sea ports or land ports or Asian Highway.	3,570
Regional Highways	Highways connecting District HQ's or main river or land ports or with each other not connected by National Highways.	4,323
Zila Roads	Roads connecting District HQ's with Upazilla HQ's or connecting one Upazilla HQ to another Upazilla HQ by a single main connection wth National/Regional Highway, through shortest distance/route.	13,678
Total		**21,571**

Source : Bangladesh Gazette, 6 November 2003 and Planning Commission, 2007

Stopping Sight Distance (SSD)

The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with obstruction. The absolute minimum sight distance is therefore equal to the stopping distance, which is also sometimes called non-passing sight distance. The distance within which a motor vehicle can be stopped depends upon the factors listed below:



- Total reaction time of the driver.
- Speed of vehicle.
- Efficiency of brakes.
- Frictional resistance between the road and the tyres and
- Gradient of the road, if any.

Total reaction time

Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied.

The total reaction time may be split up into two parts.

1. perception time
2. brake reaction time

The perception time is the time required for a driver to realise that brakes must applied. It is the time from the instant the object comes on the line of sight of the driver to the instant he realises that the vehicle needs to be stopped.

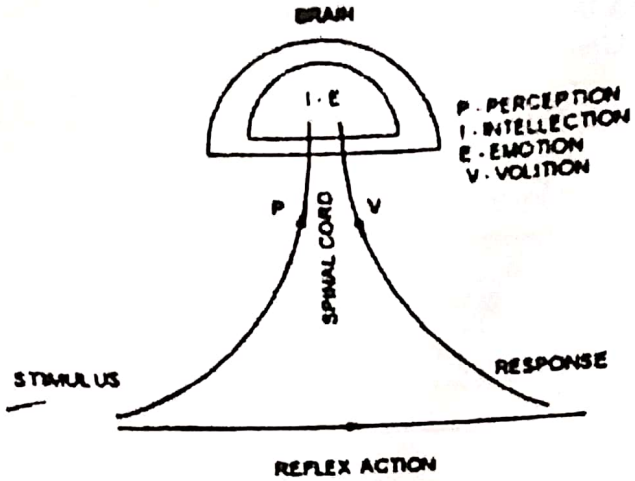
The brake reaction time also depends on several factors including the skill of the driver, the type of the problems and various other environmental factors. Often the total brake reaction time of the driver is taken together.

Question: What is PIEV theory? (BB AD – 2018)

Solution:

PIEV Theory: According to this theory the total reaction time of the driver is split into four pans.

→ Perception
→ Intellection
→ Emotion
→ Volition



Stopping distance

Stopping distance = lag distance + braking distance

$$SSD\ (m) = v\,t + \frac{v^2}{2\,g\,f} \qquad [When\ speed\ v\ is\ in\ 'm/s'\ unit]$$

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,f} \qquad [When\ speed\ V\ is\ in\ 'kmph'\ unit]$$

f = design coefficient of friction
= 0.4 to 0.35 depending on speed, from 30 to 80 kmph

g = acceleration due to gravity = 9.8 m/sec^2

Stopping distance at slopes

When there is an ascending gradient of say, + n% the component of gravity add to the braking action and hence the braking distance is decreased.

$$SSD\ (m) = v\,t + \frac{v^2}{2\,g\,(f \pm n\%)} \qquad [When\ speed\ v\ is\ in\ 'm/s'\ unit]$$

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,(f \pm n\%)} \qquad [When\ speed\ V\ is\ in\ 'kmph'\ unit]$$

Example: Calculate the safe stopping sight distance for design speed of 50 kmph for (a) two way traffic on a two lane road (b) two way traffic on a single lane road. (35th BCS)

Solution:

Assume coefficient of friction as 0.37 and reaction time for driver as 2.5 seconds.

Slopping distance, SSD = lag distance + braking distance

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,f} = 0.278 \times 50 \times 2.5 + \frac{50^2}{254 \times 0.37} = 61.35\ m$$

(*a*) Stopping sight distance when there are two lanes = 61.35 m

(*b*) SSD for two-way traffic with single lane = 2 x SSD = 2 x 61.35 = 122.27 m

Question: A car travelling at 50 mph on a highway observes a crash ahead of it. If the driver stopped the car 5 m in front of the crash, find the distance it has travelled. Perception time 2.5 sec. (DESCO – 2015)

Solution:

Assume, $f = 0.35$

$$V = 50 \text{ mph} = \frac{50 \times 1610}{3600} = 22.36 \text{ m/s}$$

$$SSD\ (m) = v\,t + \frac{v^2}{2\,g\,f} = 22.36 \times 2.5 + \frac{22.36^2}{2 \times 9.81 \times 0.35} = 128.7 \text{ m}$$

Question: Calculate the stopping sight distance for highway design speed is 50 mph. Assume, f = 0.42 and also required dated taken assume for standardization. (WRGCL – 2014, BPDB – 2015)

Solution:

Given, V = 50 mph = 80 kmph, f = 0.42, t = 2.5 sec

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,f} = 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.42} = 115.6 \text{ m}$$

Question: Calculate the safe stopping sight distance of a vehicle traveling at a speed of 80 km/hour on an upward gradient of 2%. Assume perception and brake reaction time t = 2.5 sec and coefficient of friction = 0.36. (40th BCS)

Solution:

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,(f \pm n\%)}$$

$$SSD\ (m) = 0.278 \times 80 \times 2.5 + \frac{80^2}{254\,(0.36 + 0.02)} = 121.90 \text{ m}$$

Question: Calculate the stopping sight distance for a highway for which the design speed is 50 mph. Assume f = 0.42 and also assume reasonable values for other data items involved in calculations. (WRGCL – 2014, BPDB – 2015, BWDB – 2013, LGD – 2018).

Solution:

Assume, $t = 2.5$ sec

$$V = 50 \text{ mph} = \frac{50 \times 1610}{3600} = 22.36 \text{ m/s}$$

$$SSD\ (m) = v\,t + \frac{v^2}{2\,g\,f} = 22.36 \times 2.5 + \frac{22.36^2}{2 \times 9.81 \times 0.42} = 116.63 \text{ m}$$

Question: Calculate the stopping sight distance on a highway at a descending gradient of 2% for a design speed of 80 kmph. Assume f = 0.35 and t = 2.5 sec.

Solution:

$$SSD\ (m) = 0.278\,V\,t + \frac{V^2}{254\,(f \pm n\%)} = 0.278 \times 80 \times 2.5 + \frac{80^2}{254\,(0.35 - 0.02)} = 132 \text{ m}$$

Question: Calculate the safe SSD for design speed of 45 kmph for two way traffic on a two lane road. Assume co-efficient of friction f = 0.38 and reaction time, t = 2.5 sec. (LGD – 2018)

Solution:

$$SSD\ (m) = 0.278\ V\ t + \frac{V^2}{254\ (f \pm n\%)} = 0.278 \times 45 \times 2.5 + \frac{45^2}{254\ (0.38 \pm 0)} = 52.26\ m$$

SSD (when V is in 'mi/h' & SSD in 'feet' unit)

$$\text{Breaking distance, } D_b = \frac{V^2}{30\ (f \pm G)} = \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

AASHTO represents the friction coefficient as a/g and recommends a deceleration rate of 11.2 ft/sec². Similarly it can be shown that the horizontal distance traveled in reducing the speed of a vehicle from V_1 to V_2 in mi/h during a braking maneuver is given by,

$$D_b = \frac{V_1^2 - V_2^2}{30\left(\frac{a}{g} \pm G\right)}$$

Stopping sight distance = lag distance + braking distance

$$SSD\ (\text{ft}) = 1.47\ V\ t + \frac{V_i^2 - V_f^2}{30\left(\frac{a}{g} \pm G\right)}$$

Question: একটি 5.1% grade রাস্তার SSD নির্ণয় করুন যখন এর গতিবেগ 30 mph. (HED – 2020)

Solution:

Assume, Reaction time, $t = 2.5$ sec

$$SSD = 1.47\ V\ t + \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$SSD = 1.47 \times 30 \times 2.5 + \frac{30^2}{30\ (0.35 + 0.051)} = 185.06\ \text{ft (If the gradient is positive)}$$

$$SSD = 1.47 \times 30 \times 2.5 + \frac{30^2}{30\ (0.35 - 0.051)} = 210.58\ \text{ft (If the gradient is negative)}$$

Question: A motorist traveling at 65 mi/h on an expressway intends to leave the expressway using an exit ramp with a maximum speed of 35 mi/h. At what point on the expressway should the motorist step on her brakes in order to reduce her speed to the maximum allowable on the ramp just before entering the ramp, if this section of the expressway has a downgrade of 3%?

Solution:

$$\text{Friction coefficient, } f = \frac{a}{g} = \frac{11.2}{32.2} = 0.35$$

$$\text{Breaking distance, } D_b = \frac{V_1^2 - V_2^2}{30\ (f - G)} = \frac{65^2 - 35^2}{30\ (0.35 - 0.03)} = 312.5\ \text{ft}$$

The brakes should be applied at least 312.5 ft from the ramp.

Question: A motorist travelling at 55 mi/h down grade 5% on a highway observes a crash ahead of him, involving an overturned truck that is completely blocking the road. If the motorist was able to stop his vehicle 30 ft from the overturned truck, what was his distance from the truck when he first observes the crash? Assume perception reaction time = 2.5 sec. (NHA – 2020)

Solution:

$$S = 1.47\,V\,t + \frac{V^2}{30\left(\frac{a}{g} - G\right)} = 1.47 \times 55 \times 2.5 + \frac{55^2}{30\,(0.35 - 0.05)} = 538.20 \text{ ft}$$

Distance of the motorist when he first observed the crash = 538.2 + 30 = 568.2 ft

Question: In an attempt to estimate the speed of a vehicle just before it hit a traffic signal pole, a traffic engineer measured the length of the skid marks made by the vehicle and performed trial runs at the site to obtain an estimate of the coefficient of friction. Determine the estimated unknown velocity if the following data were obtained.
Length of skid marks = 585 ft, 590 ft, 580 ft and 595 ft
Speed of trial run = 30 mi/h, Distance traveled during trial run = 300 ft
Examination of the vehicle just after the crash indicated that the speed of impact was 35 mi/h.

Solution:

$$\text{Average length of skid marks} = \frac{585 + 590 + 580 + 595}{4} = 587.5 \text{ ft}$$

This is assumed to be braking distance D_b

$$\text{Unknown velocity, } U_u = \left(\frac{D_b}{D_b} u_k^2 + u_1^2\right)^{1/2} = \left(\frac{587.5}{300} \times 900 + 1255\right)^{1/2} = 54.66 \text{ mi/h}$$

Question: What is stopping site distance? A car is travelling at 50 mph during perception and reaction time. Perception and reaction time is 2.5 sec and deceleration rate is 11.2 ft/sec². Determine the stopping site distance. (EGCB – 2020)

Solution:

The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with obstruction. The absolute minimum sight distance is therefore equal to the stopping distance, which is also sometimes called non-passing sight distance.

$$SSD = 1.47\,V\,t + \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$SSD = 1.47 \times 50 \times 2.5 + \frac{50^2}{30\,(0.35 \pm 0)} = 423.33 \text{ ft}$$

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$$SSD = 1.47\,V\,t + \frac{V^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$SSD = 1.47 \times 50 \times 2.5 + \frac{50^2}{30\,(0.35 \pm 0)} = 423.33 \text{ ft}$$

Question: A directional sign needed. Highway turn-off 85th percentile speed is 50 mph, vehicle turn at design speed is 25 mph, car travel at 50 mph during perception and reaction time, using perception and reaction time is 1.25 sec to read and understand the sign and decelerate or (breaking) at 0.3g. What is the minimum distance the direction sign should be placed in advance of the turn off? (BWDB – 2016)

Solution:

$$SSD = 1.47\,V\,t + \frac{V_i^2 - V_f^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$SSD = 1.47 \times 50 \times 1.25 + \frac{50^2 - 25^2}{30\left(\frac{0.3g}{g} \pm 0\right)} = 300.2 \text{ ft}$$

Question: A temporary diversion has been constructed on a highway of + 4% gradient due to major repairs that are being undertaken on a bridge. The maximum speed allowed on the diversion is 10 mi/h. determine the minimum distance from the diversion that a road sign should be located informing drivers of the temporary change on the highway. Maximum allowable speed on highway = 70 mi/h. Letter height of road sign = 4" and Perception-reaction time = 2.5 sec. Assume that a driver can read a road sign within his or her area of vision at a distance of 40 ft for each inch of letter height.

Solution:

$$SSD = 1.47\,V\,t + \frac{V_i^2 - V_f^2}{30\left(\frac{a}{g} + G\right)} = 1.47 \times 70 \times 2.5 + \frac{70^2 - 10^2}{30\,(0.35 + 0.04)} = 666.93 \text{ ft}$$

Readability = Letter height in inches x 40 feet/inch of letter height

= 4 inches x 40 feet/inch = 160 feet

The sign can be read at a distance of 160 feet.

Distance from the diversion the sign should be placed,

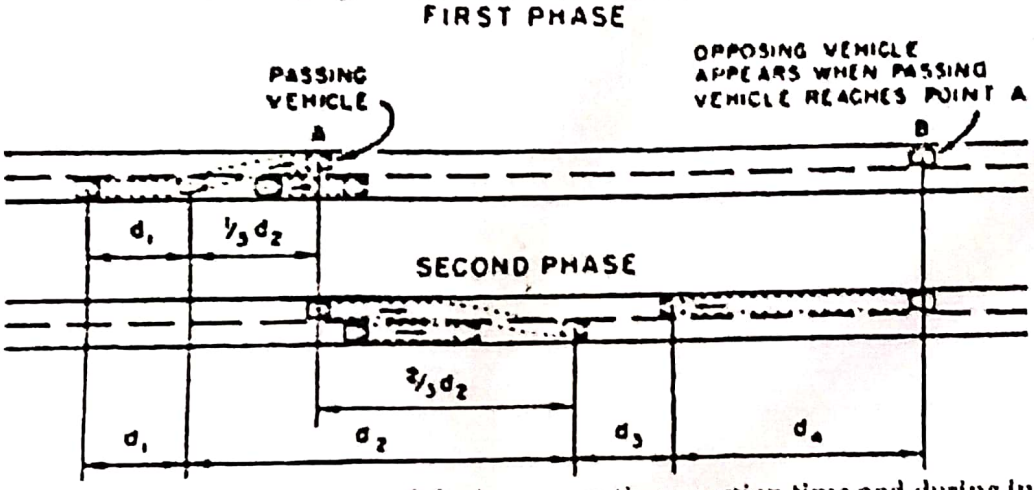
x = SSD – Readability distance = 666.93 – 160.00 = 506.93 feet

The sign should be placed approximately 510 feet prior to the diversion to alert drivers of the change on the highway.

Passing Sight Distance

The passing sight distance is the minimum sight distance required on a two-lane, two way highway that will permit a driver to complete a passing maneuver without colliding with an opposing vehicle and without cutting off the passed vehicle.

The minimum passing sight distance is the total of four components as shown in Figure.



Where, d_1 = distance traversed during perception-reaction time and during initial acceleration to the point where the passing vehicle just enters the left lane.

d_2 = Distance traveled during the time the passing vehicle is traveling in the left lane.

d_3 = Distance between the passing vehicle and the opposing vehicle at the end of the passing maneuver.

d_4 = Distance moved by the opposing vehicle during two thirds of the time the passing vehicle is in the left lane (usually taken to be 2/3 d_2)

$$d_1 = 1.47\, t_1 \left(u - m + \frac{a\, t_1}{2}\right)$$

The distance d_1 is obtained from the expression

u = average speed of passing vehicle (mi/h)

a = average acceleration rate (mi/h/sec)

t_1 = time for initial maneuver (sec)

m = difference in speeds of passing and impeder vehicles

The distance d_2 is obtained from

$$d_2 = 1.47\, u\, t_2$$

t_2 = time passing vehicle is traveling in left lane (sec)

u = average speed of passing vehicle (mi/h)

Question: Determine the minimum passing sight distance required for a two lane, two-way highway where average speed of passing vehicle is 51 mph, average speed of the passed vehicle is 41 mph, time of the preliminary delay for passing vehicle is 4 sec, average acceleration rate for passing vehicle is 1.43 mph, time passing vehicle occupies the opposite lane is 10 sec and safe clearance distance of 180 feet. (DTCA – 2018)

Solution:

Here, time for initial maneuver, $t_1 = 4$ sec

Time for passing vehicle is traveling in left lane, $t_2 = 10$ sec

Average acceleration rate (mi/h/sec), $a = 1.43$ mph

Average speed of passing vehicle (mi/h), $u = 51$ mph

Mean difference in speed of passing and impeder vehicles, $m = 51 - 41 = 10$ mph

Distance traveled during perception-reaction time,

$d_1 = 1.47\, t_1 \left(u - m + \frac{a\, t_1}{2}\right) = 1.47 \times 4 \left(51 - 10 + \frac{1.43 \times 4}{2}\right) = 257.89$ ft

Distance traveled while passing the vehicle, $d_2 = 1.47\, u\, t_2 = 1.47 \times 51 \times 10 = 749.7$ ft

Distance between the passing vehicle and opposite vehicle, $d_3 = 108$ ft

Distance moved by opposing vehicle, $d_4 = 0.67\, d_2 = 0.67 \times 749.7 = 499.8$ ft

Minimum sight distance $= d_1 + d_2 + d_3 + d_4 = 257.89 + 749.7 + 180 + 499.8 = 1687.39$ ft

Visual acuity

Visual acuity refers to how well a person can see. Normal vision is defined as the ability of a person to recognize a letter or an object of approximately 8.5 mm size from a distance of nearly 6 m. A person with normal vision is said to have 6/6 vision. A person with 6/9 vision has poorer than normal vision because he/she can read or recognize from a distance of 6 m what a normal person can read (or recognize) from a distance of 9 m. Alternatively, a person with 6/9 vision can read (or recognize) from a given distance letters (or objects) which are 9/6 (= 1.5) times bigger than those which a normal vision person can read (or recognize) from the same distance.

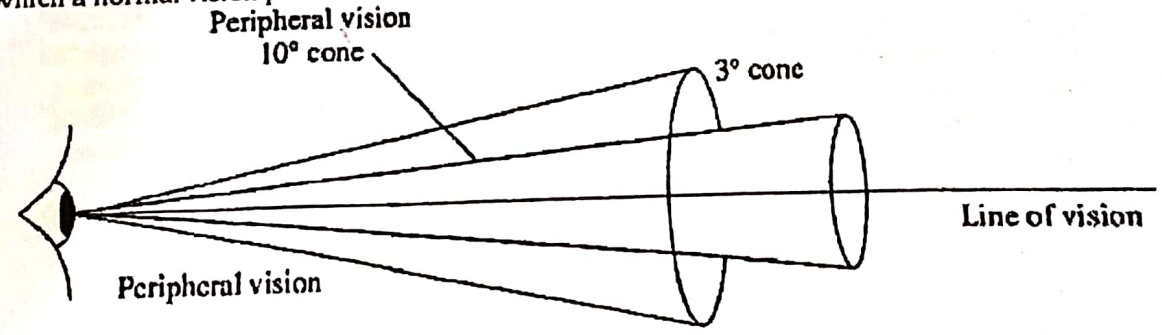


Diagram not to scale

Persons can see most clearly within a 3-degree cone. Sign should be placed within the 10-degree cone of vision of drivers. Information on field vision is important while deciding the placement of road signs.

Question: On a freeway a sharp horizontal curve exists. The speed limit on the curve is 40 kmph. The speed limit on the expressway is 75 kmph. A sign is to be posted, warning drivers of the impending curve and advising them to slow down to the speed limit. Determine the longitudinal placement of the sign and the letter size for the sign. Assume that the perception reaction time is 1.5 s, the coefficient of friction is 0.3, the road has 0% grade and a design driver has 6/9 vision. Also assume that the perception reaction time includes the time taken to read the sign.

Solution:

Let the letter height used be h mm. Hence the sign can be read by a 6/6 vision person from a distance of $(6h/8.5)$ m. Therefore, a 6/9 vision person can see the sign from

$$\frac{6}{9} \times \frac{6h}{8.5} = 0.377\,h \text{ m}$$

$$\text{Now, } SSD = V_i\,t + \frac{V_i^2 - V_f^2}{2g\,(f \pm G)}$$

$$SSD = 20.83 \times 1.5 + \frac{20.83^2 - 11.11^2}{2 \times 9.81\,(0.3 \pm 0)} = 84 \text{ ft}$$

Therefore, the total distance required between the point a which the sign becomes legible to the driver to the start of the curve should be 84 m. If x is the distance between the sign and the start of the curve, then

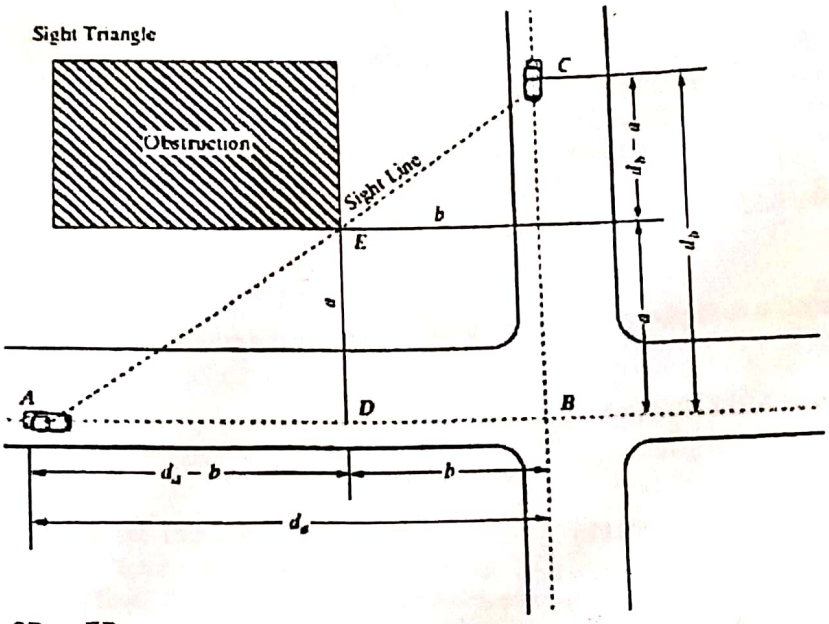
$$0.377h + x = 84$$

$$x = 84 - 0.377h$$

Generally, the letter heights on such roads are not less than 80 mm. Hnece, if 80 mm is used then the sign can be placed at a distance of 53.84 m (or 54 m) before the start of the curve.

Sight Distance at Intersections

The high crash potential at an intersection can be reduced by providing sight distances that allow drivers to have an unobstructed view of the entire intersection at a distance great enough to permit control of the vehicle. At signalized intersections, the unobstructed view may be limited to the area where the signals are located, but for unsignalized intersections, it is necessary to provide an adequate view of the crossroads or intersecting highways to reduce the potential of collision with crossing vehicles.



$$\frac{CB}{AB} = \frac{ED}{AD}$$

$$\frac{d_b}{d_a} = \frac{a}{d_a - b}$$

Question: A two-lane minor road intersects a two-lane major road at 90° forming a four-leg intersection with traffic on the minor road controlled by a yield sign. A building is located 125 ft from the centerline of the outside lane of the major road and 35 ft from the centerline of the nearest lane of the minor road. Determine the maximum speed that can be allowed on the minor road if the speed limit on the major road is 45 mi/h.

Solution:

Here, $a = 125$ ft and $b = 35$ ft

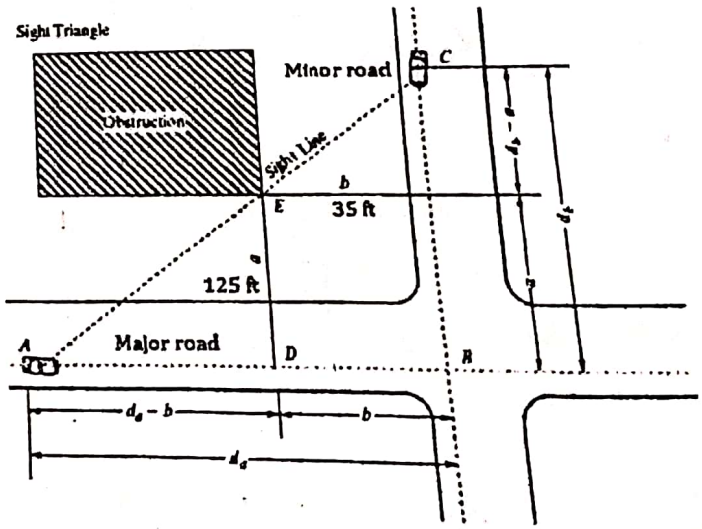
We know, $S = 1.47\,V\,t + \dfrac{V^2}{30\left(\frac{a}{g} \pm G\right)}$

$$d_a = 1.47 \times 45 \times 2.5 + \frac{45^2}{30 \times (0.35 \pm 0)}$$

$d_a = 358.23$ ft (major approach)

$$\frac{d_b}{d_a} = \frac{a}{d_a - b}$$

$$d_b = \frac{d_a \times a}{d_a - b}$$



$$d_b = \frac{358.23 \times 125}{358.23 - 35} = 138.53 \text{ ft}$$

Using d_b as stopping sight distance,

$$138.53 = 1.47 \times u_b \times 2.5 + \frac{u_b^2}{30 \times 0.35}$$

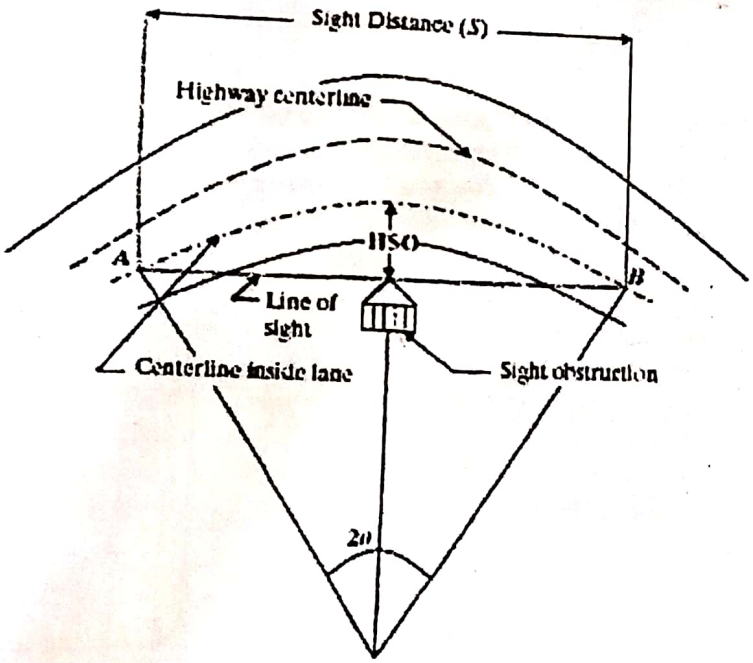
$$u_b = 23.45 \text{ mi/h}$$

Since speeds are typically posted in multiples of 5 mi/h, the posted speed on the minor road should be 20 mi/h.

Curve Radii Based on Stopping Sight Distance

$$m = R\left[1 - cos\left(\frac{28.65\,S}{R}\right)\right]$$

Where m = the horizontal sightline offset, HSO (ft)
R = Radius of horizontal curve
S = Stopping sight distance
θ = One half central angle



Horizontal Curves with Sight-Distance Restrictions and Range of Lower Values for Stopping Sight Distances

Question: A horizontal curve with a radius of 800 ft connects the tangents of a two-lane highway that has a posted speed limit of 35 mi/h. If the highway curve is not superelevated, $e = 0$, determine the horizontal sightline offset (HSO) that a large billboard can be placed from the centerline of the inside lane of the curve, without reducing the required SSD. Perception-reaction time is 2.5 sec, and $f = 0.35$.

Solution

We know, $S = 1.47\,V\,t + \dfrac{V^2}{30\,(f \pm G)}$

$$\text{SSD} = 1.47 \times 35 \times 25 + \frac{35^2}{30 \times 0.35} = 245.29 \text{ ft}$$

$$m = R\left[1 - \cos\left(\frac{28.65\,S}{R}\right)\right] = R\left[1 - \cos\left(\frac{28.65 \times 245.29}{800}\right)\right] = 9.6 \text{ ft}$$

Question: The corner of a building is situated next to inner side of a two-lane horizontal curve with a radius of 50 m on a rural highway. Each lane is 3 m With 2 m shoulder. The corner is 0.8 m away from the shoulder. Is it safe to drive at a speed of 90 kmph on this curve? If not, how would you remedy the problem? Assume. Perception-reaction time = 2.5 sec and dedaration rate = 3.3 m/sec^2. (JB – 2017)

Solution

Here, $V = 90$ kmph $= 25$ m/s

Radius of inside lane, $R = 50 - \dfrac{3}{2} = 48.5$ m

Horizontal Sightline Offset $(HSO) = \dfrac{3}{2} + 2 + 0.8 = 4.3$ m

We know, $HSO = R\left[1 - \cos\left(\dfrac{28.65 \times SSD}{R}\right)\right]$

$$SSD, m = V\,t + \frac{V^2}{2\,a} = 25 \times 2.5 + \frac{25^2}{2 \times 3.3} = 157.197 \text{ m}$$

For safety, the available sight distance should be equal to SSD.

Therefore the building should be located at a distance, $= R\left[1 - \cos\left(\dfrac{28.65 \times SSD}{R}\right)\right]$

$$= 48.5\left[1 - \cos\left(\frac{28.65 \times 157.197}{48.5}\right)\right]$$

$= 50.92$ m $>$ 4.3 m (Available distance)

The building is not located at safe distance.

Question: A toll bridge carries 5000 vehicle/day. The current toll is 150 taka. When the toll is increased by 25 taka, traffic volume decreases by 500 vehicle/day. Determine the amount of toll that should be charged such that revenue is maximized.
(DTCA – 2018, BUET M.Sc – 2018, DMTCL – 2019)

Solution:

Let a = the toll increase in taka.

Assuming a linear relationship between traffic volume and cost, the expression for V is,

$$V = 5000 - \frac{a}{25} \times 500 = 5000 - 20\,a$$

The toll is, $T = 150 + a$

Revenue is the product of toll and volume:

$$R = V\,T = (5000 - 20\,a) \times (150 + a)$$
$$= 750{,}000 - 3000\,a + 5000\,a - 20\,a^2$$
$$= 750{,}000 + 2000\,a - 20\,a^2$$

For maximum value of a, compute the first derivative and set equal to zero:

$$\frac{dR}{dt} = 2000 - 40\,a = 0$$

$a = 50$ tk.

The new toll is current toll plus the toll increase.

Toll for maximum revenue = 150 + 50 = 200 tk.

The additional revenue, $AR = V_{max}\,T_{max} - V_{current}\,T_{current}$

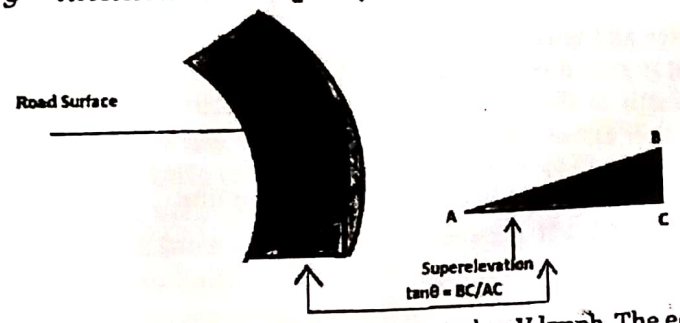
$$= (5000 - \frac{50}{25} \times 500) \times 200 - 5000 \times 150$$
$$= 800{,}000 - 750{,}000$$
$$= 50{,}000 \text{ tk.}$$

Superelevation

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge. This providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as superelevation or cant or banking.

$e + f = \frac{v^2}{g\,R}$

e = Rate of superelevation = tan θ
f = design value of lateral friction coefficient = 0.15
v = speed of the vehicle, m/sec
R = radius of the horizontal curve, m
g = Acceleration due to gravity = 9.8 m/sec²



If the speed of the vehicle is represented as V kmph. The equation may be written as follows;

$e + f = \frac{(0.278\,V)^2}{g\,R} = \frac{V^2}{127\,R}$

V = Speed in kmph; R = Radius

The maximum value of transverse skid resistance f for design purpose is standardised equal to 0.15 and Maximum superelevation is 7%.

Steps for superelevation design

Various steps in the design of superelevation in practice may be summarized as given below:

Step 1: The superelevation for 75 percent of design speed (v m/sec of V kmph) is calculated neglecting the friction

$e = \frac{(0.75\,v)^2}{g\,R}$ or $\frac{(0.75\,V)^2}{127\,R} = \frac{V^2}{225\,R}$

Step 2: If the calculated value of e is less than 7% or 0.07 the value so obtained is provided. If the value of e as per equation exceeds 0.07 then provide the maximum superelevation equal to 0.07 and proceed with steps 3 or 4.

Step 3: Check the coefficient of friction developed for the maximum value of e = 0.07 at the full value of design speed,

$$f = \frac{v^2}{g\,R} - 0.07$$

If the value of thus calculated is less than 0.15, the superelevation of 0.07 is safe for the design speed. If not, calculated the restricted speed as given in step 5.

Step 5: The allowable speed (v_a m/sec or V_a kmph) at the curve is calculated by considering the design coefficient of lateral friction and the maximum superelevation,

$$e + f = 0.07 + 0.15 = 0.22 = \frac{v_a^2}{g\,R} = \frac{V_a^2}{127\,R}$$

Calculate the allowable speed, $v_a = \sqrt{0.22\,g\,R} = \sqrt{2.156\,R}$ m/s

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

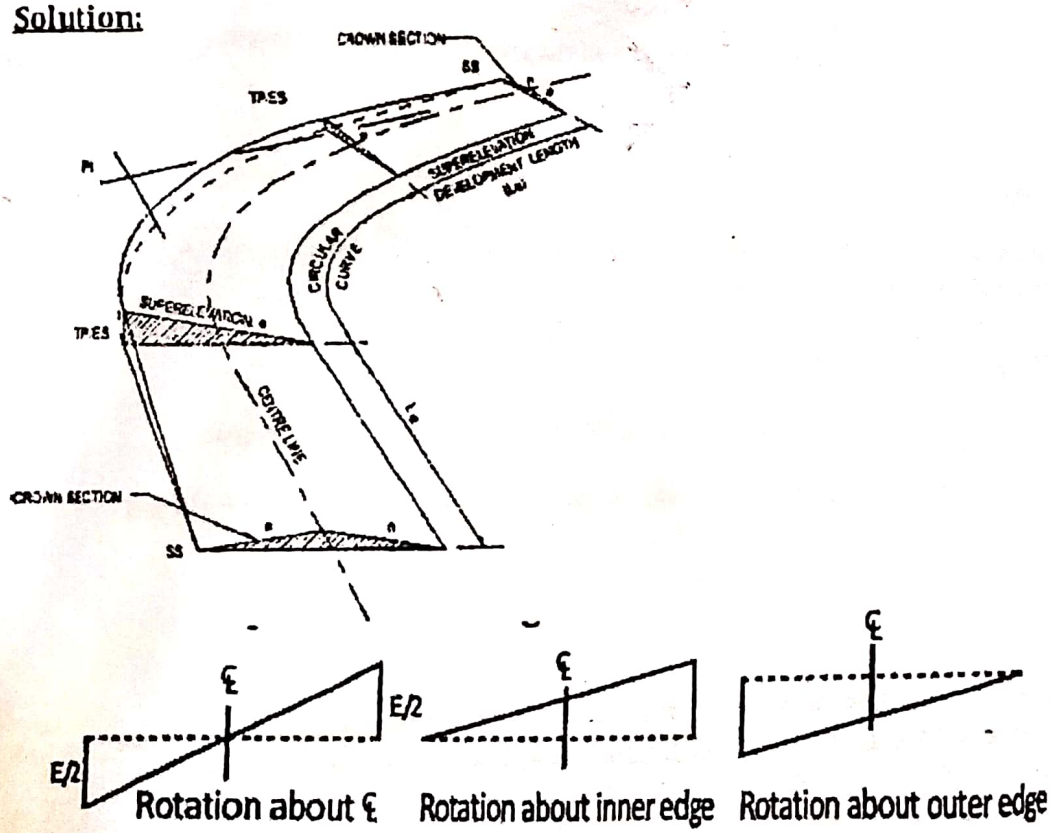
Question: Define super elevation. (ISTT – 2015)

Solution:

In order to counteract the effect of centrifugal force and to reduce the tendency of the Vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge. Thus providing a transverse slope throughout the length of the horizontal curve. This Transverse inclination to the pavement surface is known as super elevation or cant.

Question: Draw diagram for attaining super-elevation pavement rotating about centerline. (WASA – 2017, DTCA – 2018)

Solution:



Question: Why super elevation is provided? (EED – 2015, HED – 2017)

Solution:

Purpose of Providing Superelevation in Roads :

- The main aim of providing super elevation is to counteract the effect of centrifugal force acting on the moving vehicle.
- To prevent the damaging effect on the surface of the roads due to improper distribution of load on the roads.
- To help the fast-moving vehicles to pass through a curved path without overturning or skidding.
- To reduce the maintenance cost of the road on the curved portion.
- To ensure the smooth and safe movement of vehicles and passengers on the curved portion of the roads.

Question: Why are super elevation and extra widening provided at the curved portion of the roadway? (31th BCS)

Solution:

When a vehicle travels in a circular path or curved path, it is subjected to an outward force which makes a vehicle to overturn and skid due to Centrifugal force. To overcome this force and for safe travel of a vehicle, the outer edge of the road is raised above the inner edge. It reduces the effect of centrifugal force on the running wheels. If super elevation is not provided the entire centripetal force is produced by the friction between the vehicle's tires and the roadway, thus results in reducing the speed of a vehicle.

On a horizontal curve especially when there are not many very large radius, it is common to widen the pavement or carriageway slightly more than the normal width. This additional increase in the width of the pavement is termed as extra widening. The reasons of providing extra widening are given below:

1. Due to the rigidity of rear wheel base of the vehicle moving along the curve they don't trace the same path as taken by the front steering wheels. This is called off tracking. During this case, mechanical widening is required.
2. Due to the psychological tendency of drivers, drivers tend to take the outer lane for greater visibility and easy gradient at the beginning of the curves. So extra width is provided.
3. The extra width is provided to ensure safe and efficient overtaking operations.

Question: Design the rate of superelevation for a horizontal highway curve of radius 500 m and speed 100 kmph.

Solution:

For mixed traffic conditions, superelevation is given by equation,

$$e = \frac{V^2}{225\,R} = \frac{100^2}{225 \times 500} = 0.089$$

As the value is greater than the maximum superelevation of 0.07, the actual superelevation to be provided is restricted to 0.07. Check for coefficient of lateral friction developed for full speed,

$$f = \frac{V^2}{127\,R} - 0.07 = \frac{100^2}{127 \times 500} - 0.07 = 0.087$$

As the value is less than 0.15, the design is safe with a superelevation of 0.07.

Question: Determine the safe radius of circular curve for the following condition where the symbol contains their usual meaning V = 60 mph, e = 0.4 ft/10ft, f = 0.15 and g = 32.2 ft²/sec. (PGCL – 2014)

Solution:

$$V = 60 \text{ mph} = \frac{60 \times 5280}{3600} = 88 \text{ fps}$$

$$e + f = \frac{V^2}{g\,R}$$

$$R = \frac{V^2}{g\,(e+f)} = \frac{88^2}{32.2\,(0.04 + 0.15)} = 1265.77 \text{ ft}$$

Question: Radius = 300 ft, frictional factor is 0.02. Limited speed 30 km/hr. What is the angle of curve or banking of road? (NPCBL – 2017, RPGCL – 2017)

Solution:

$$R = 300 \text{ ft} = 91.46 \text{ m}, V = 30 \text{ kmph} = 30/3.6 = 8.33 \text{ m/s}$$

$$e + f = \frac{V^2}{g\,R}$$

$$\tan\theta = \frac{V^2}{g\,R} - f = \frac{8.33^2}{9.81 \times 91.46} - 0.02 = 0.0573$$

$$\theta = \tan^{-1}(0.0573) = 3.28^0$$

Question: If $e = 0.10$ and $f = 0.15$, design speed = 100 kmph, determine radius of curvature. (PGCB – 2017)

Solution:

$$e + f = \frac{V^2}{127\,R} \qquad (Where\ V\ is\ in\ km/hr)$$

$$R = \frac{V^2}{127\,(e+f)} = \frac{100^2}{127\,(0.1 + 0.15)} = 314.96 \text{ m}$$

Question: Radius of a horizontal circular curve is 100 m. The design speed is 50 kmph and design co-efficient of lateral friction is 0.15. Calculate super elevation required if full lateral friction is assumed to develop. (BB AD – 2018)

Solution:

We know, $e + f = \frac{V^2}{127\,R}$ $\qquad (Where\ V\ is\ in\ km/hr)$

$$e = \frac{50^2}{127 \times 100} - 0.15 = 0.047$$

Superelevation (when V is in 'mi/h' and R is in 'feet' unit)

$$R = \frac{V^2}{g\,(e + f_s)}$$

If g is taken as 32.2 ft/sec² and u is measured in mi/h, the minimum radius R is given in feet as

$$R = \frac{V^2}{15\,(e + f_s)}$$

Coefficient of Side Friction for Different Design Speeds

Design Speed (mi/h)	*Coefficients of Side Friction, f_s*
30	0.20
40	0.16
50	0.14
60	0.12
70	0.10

For highways located in rural areas with no snow or ice, a maximum superelevation rate of 0.10 generally is used. For highways located in areas with snow and ice, values ranging from 0.08 to 0.10 are used. For expressways in urban areas, a maximum superelevation rate of 0.08 is used.

Question: Determine the minimum radius of a horizontal curve required for a highway if the design speed is 60 mi/h. The superelevation rate is 0.04 and coefficient of friction is 0.12. (SGFCL – 2017)

Solution:

$$R = \frac{V^2}{15\,(e + f_s)} = \frac{60^2}{15\,(0.04 + 0.12)} = 1500 \text{ feet}$$

Question: An existing horizontal curve on a highway has a radius of 465 ft, which restricts the posted speed limit on this section of the road to only 61.5% of the design speed of the highway. If the curve is to be improved so that its posted speed will be the design speed of the highway, determine the minimum radius of the new curve. Assume that the rate of superelevation is 0.08 for both the existing curve and the new curve to be designed. (DSCC – 2019)

Solution:

Since the posted speed limit is not known, assume f_s is 0.16.

$$R = \frac{V^2}{15\,(e + f_s)}$$

$$465 = \frac{V^2}{15\,(0.08 + 0.16)}$$

$$V = 40.91 \text{ mi/h}$$

The posted speed limit is 40 mi/h, as speed limits are usually posted at intervals of 5 mi/h.
Check assumed f_s for 40 mi/h = 0.16.
Determine the design speed of the highway = 40/0.615 = 65.04 mi/h

Design speed = 65 mi/h.

Find the radius of the new curve,
[$f_s = 0.11$, interpolating between 60 mi/h ($f_s = 0.12$) and 70 mi/h ($f_s = 0.10$)]

$$R = \frac{65^2}{15\,(0.08 + f_s)} = \frac{65^2}{15\,(0.08 + 0.11)} = 1482.45 \text{ ft.}$$

Question: A horizontal curve is to be designed for a section of a highway having a design speed of 60 mi/h. (a) If the physical conditions restrict the radius of the curve to 500 ft, what value is required for the superelevation at this curve? (b) Is this a good design?

Solution:

(*a*) For 60 mi/h design speed, $f_s = 0.12$

$$R = \frac{V^2}{15\,(e + f_s)}$$

$$e = \frac{V^2}{15\,R} - f_s = \frac{60^2}{15 \times 500} - 0.12 = 0.36$$

(*b*) The superelevation for this curve would be 0.36.
Since $e = 0.36 > 0.10$ (allowable maximum superelevation)
This would NOT be a good design.

Question: The radius of a horizontal curve on an existing highway is 750 ft. The superelevation rate at the curve is 0.08, and the posted speed limit on the road is 65 mi/h. Is this a hazardous location? If so, why? What action will you recommend to correct the situation?

Solution:

(*a*) Determine superlevation required for the given speed and radius

$$R = \frac{V^2}{15\,(e + f_s)}$$

For speed of 65 mi/h, $f_s = 0.11$ (from the table)

$$e = \frac{V^2}{15\,R} - f_s = \frac{65^2}{15 \times 750} - 0.11 = 0.266$$

The superelevation that is required for a speed of 65 mi/h is much higher than the provided at the curve. The curve is therefore a hazardous location as. Also the superelevation of 0.266 is much higher than the maximum of 0.1 normally used.

(*b*) Corrective measures
Determine a maximum safe speed for a radius of 750 ft and e of 0.08 and post this speed at the curve.
Try a speed of 50 mi/h, $f_s = 0.14$

$$R = \frac{V^2}{15\,(e + f_s)}$$

$$V = \sqrt{15\,R\,(e + f_s)} = \sqrt{15 \times 750 \times (0.08 + 0.14)} = 49.8 \text{ mi/h}$$

A maximum safe speed of 50 mi/h should be posted at the curve.

Question: A section of highway has a superelevation of 0.05 and a curve with a radius of only 300 ft. What speed limit will you recommend at this section of the highway?

Solution:

Assume. $f_s = 0.15$

$$R = \frac{V^2}{15\,(e + f_s)}$$

$$300 = \frac{V^2}{15\,(0.05 + 0.15)}$$

$V = 30$ mi/h

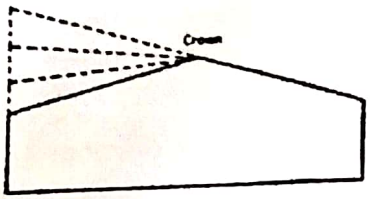
Question: Explain diagrammatically the method of attaining superelevation considering a crowned pavement revolved about the profile of the inside edge. (SGFL – 2021)

Solution:

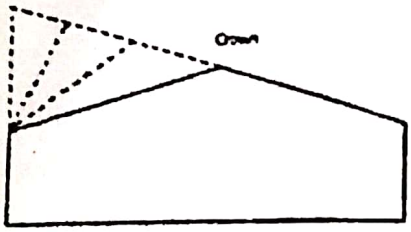
Superelevation is provided in the following two methods.
1. Elimination of the crown of the cambered section.
2. Rotation of pavement to attain full superelevation.

1. Elimination of the Crown of the Cambered Section

In this method, the outer half of the camber is gradually decreased. This may be done by two methods. In the first method, the outer half of the camber is rotated about the crown at the desired rate such that the surface falls on the same plane as the inner half.



In the second method, the crown is progressively shifted outwards. This method is not usually adopted.

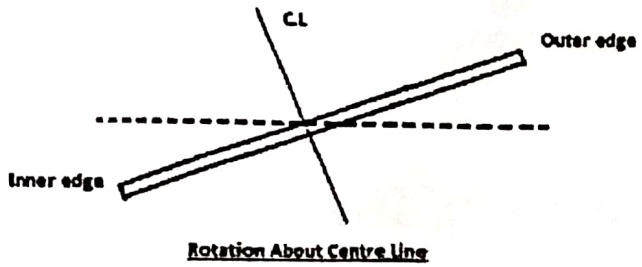


2. Rotation of Pavement to Attain Full Superelevation

In this stage, superelevation is gradually provided over the full width of the carriageway so that the required superelevation is available at the beginning of the circular curve. The different method employed for attaining the superelevation is as follows:

A. Revolving Pavement about the Center Line

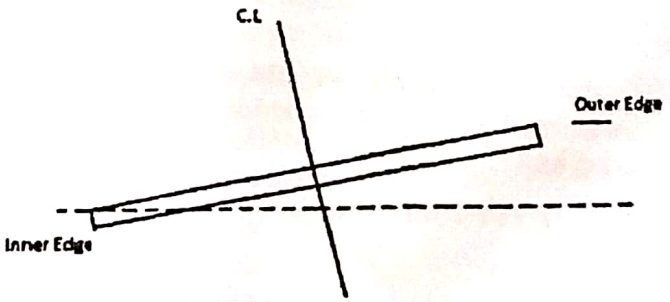
In this method the surface of the road is rotated about the center line of the carriageway, gradually lowering the inner edge and rising the upper edge. The level of the center line is kept constant. This method is widely used.



Rotation About Centre Line

B. Revolving Pavement about the Inner Edge

In this method, the surface of the road is rotated about the inner edge, raising the center and outer edge.



C. Revolving Pavement about the Outer Edge

In this method, the surface of the road is rotated about the outer edge depressing the center and inner edge.

Determining Spot Speed Sample Size

Minimum sample size,

$$N = \left(\frac{Z\,\sigma}{d}\right)^2$$

Where, Z = number of standard deviations corresponding to the required confidence
σ = Standard deviation (mi/h)
d = Limit of acceptable error in the average speed estimate (mi/h)

Constant Corresponding to Level of Confidence

Constant Corresponding to Level of Confidence

Confidence Level (%)	*Constant Z*
68.3	1.00
86.6	1.50
90.0	1.64
95.0	1.96
95.5	2.00
98.8	2.50
99.0	2.58
99.7	3.00

An engineer wishing to obtain the speed characteristics on a bypass around her city at a confidence level of 95%, and an acceptable limit of ± 1.0 mi/h collected a total of 130 spot speed samples and determined that the variance is 25 (mi/h)². Has the engineer met with all of the requirements of the study?

Question: As part of a class project, a group of students collected a total of 120 spot speed samples at a location and determined from this data that the standard variation of the speeds was ± 6 mi/h. If the project required that the confidence level be 95% and the limit of acceptable error was ± 1.5 mi/h. determine whether these students satisfied the project requirement. (BWDB – 2016)

Solution:

Where, $Z = 1.96$ (from Table), $\sigma = \pm 6, d = 1.5$

$$N = \left(\frac{Z\,\sigma}{d}\right)^2$$

$$N = \left(\frac{1.96 \times 6}{1.5}\right)^2 = 61.45$$

Therefore, the minimum number of spot speeds collected to satisfy the project requirement is 62. Since the students collected 120 samples, they satisfied the project requirements.

Question: An engineer wishing to obtain the speed characteristics on a bypass around her city at a confidence level of 95%, and an acceptable limit of ± 1.0 mi/h collected a total of 130 spot speed samples and determined that the variance is 25 $(mi/h)^2$. Has the engineer met with all of the requirements of the study? (DESCO – 2015, BWDB – 2016, BWDB – 2018, DPDC – 2019)

Solution:

$$N = \left(\frac{Z\,\sigma}{d}\right)^2 = \frac{Z^2 \times \sigma^2}{d^2}$$

$$= 1.962 \times \frac{25}{1^2} \quad [\text{For 95\% confidence level, } Z = 1.96]$$

$= 96.04 < 130$, the engineer met the requirement

Standard Deviation of Speeds

Which is a measure of the spread of the individual speeds. It is estimated as

$$S = \sqrt{\frac{\Sigma(u_j - \bar{u})^2}{N - 1}}$$

Where, S = standard deviation
$\bar{u}$ = Arithmetic mean
u_j = jth observation
N = Number of observations

The standard deviation of the differences in means is given as,

$$S_d = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

Where,
n_1 = sample size for study 1
n_2 = sample size for study 2
S_d = square root of the variance of the difference in means
S_1^2 = variance about the mean for study 1
S_2^2 = variance about the mean for study 2

Question: Speed data were collected at a section of highway during and after utility maintenance work. The speed characteristics are given as, and as shown below. Determine whether there was any significant difference between the average speeds at the 95% confidence level.

$\overline{u_1} = 35.3$ mi/h
$S_1 = 7.5$ mi/h
$n_1 = 250$

$\overline{u_2} = 38.7$ mi/h
$S_2 = 7.4$ mi/h
$n_2 = 280$

Solution:

$$S_d = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} = \sqrt{\frac{7.5^2}{250} + \frac{7.4^2}{280}} = 0.65$$

Difference in means = 38.78 - 35.5

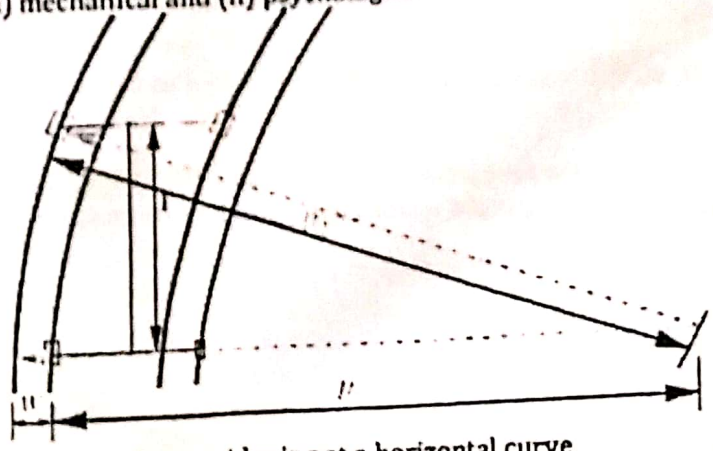
= 3.2 > 1.96 x 0.65

= 3.2 > 1.3 mi/h

It can be concluded that the difference in mean speeds is significant at the 95% confidence level.

Widening of Pavement on Horizontal Curves

The extra widening of pavement on horizontal curves is divided into two parts, (i) mechanical and (ii) psychological widening



Extra-widening at a horizontal curve

Mechanical widening: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure 15. This phenomenon is called off tracking, and has the effect of increasing the effective width of a road space required by the vehicle. Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles are using the road.

$$W_m = \frac{n\,l^2}{2\,R}$$

Here, R is the mean radius of the curve.

l = Length of wheel base, m.

n = Traffic lanes.

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.

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

Hence the total widening W_e, m required on a horizontal curve is given by:

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

$$W_e = \frac{n\,l^2}{2\,R} + \frac{V}{9.5\sqrt{R}}$$

Hence, n = number of traffic lanes
V = design speed, kmph
R = radius of horizontal curve, m
l = length of wheel base of longest vehicle, m. The value of l may normally be taken as 6.1 m or 6.0 m for commercial vehicles, if not known.

Example: Calculate the extra widening required for a pavement of within 7m on a horizontal curve of radius 250 m if the longest wheel base of vehicle expected on the road is 7.0 m. Design speed is 70 kmph.

Solution:

Here, $n = 2$ (two lanes for pavement width of 7.0 m)

$l = 7.0$; $R = 250$ m; $V = 70$ kmph

Extra widening required $W_e = W_m + W_{ps}$

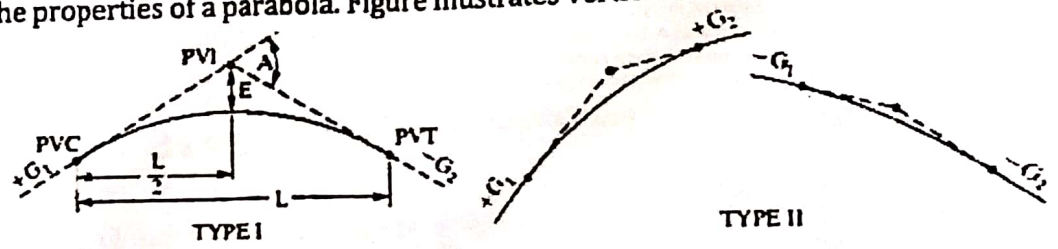
$$W_e = \frac{n\,l^2}{2\,R} + \frac{V}{9.5\sqrt{R}}$$

$$W_e = \frac{2 \times 7^2}{2 \times 250} + \frac{70}{9.5\sqrt{250}} = 0.196 + 0.466 = 0.662 \text{ m}$$

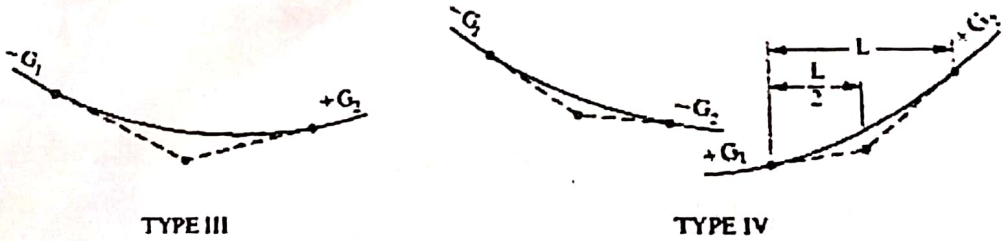
Vertical Alignment

The vertical alignment of a highway consists of straight sections known as grades, (or tangents) connected by vertical curves. The design of the vertical alignment therefore involves the selection of suitable grades for the tangent sections and the appropriate length of vertical curves. The topography of the area through which the road traverses has a significant impact on the design of the vertical alignment.

Vertical curves are used to provide a gradual change from one tangent grade to another so that vehicles may run smoothly as they traverse the highway. These curves are usually parabolic in shape. The expressions developed for minimum lengths of vertical curves are therefore based on the properties of a parabola. Figure illustrates vertical curves that are classified as crest or sag.



(a) Crest vertical curves



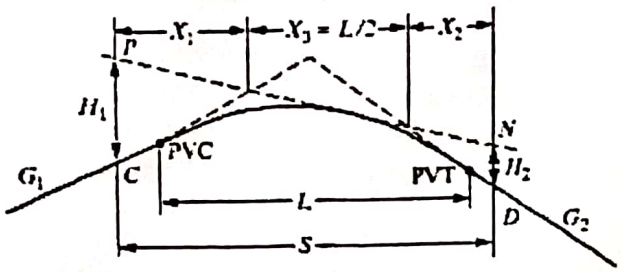
(b) Sag vertical curves

G_1, G_2 = grades of tangents (%)
A = algebraic difference
L = length of vertical curve
PVC = point of vertical curve
PVI = point of vertical intersection
PVT = point of vertical tangent

Figure: Types of Vertical Curves

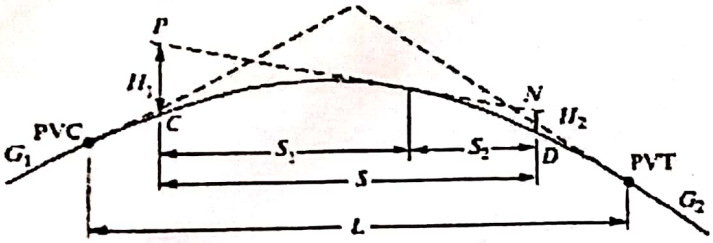
Length of Crest Vertical Curves

Provision of a minimum stopping sight distance (SSD) is the only criterion used for design of a crest vertical curve. There are two possible scenarios that could control the design length: (1) the SSD is greater than the length of the vertical curve, and (2) the SSD is less than the length of the vertical curve.



L = length of vertical curve (ft)
S = sight distance (ft)
H_1 = height of eye above roadway surface (ft)
H_2 = height of object above roadway surface (ft)
G_1 , G_2 = grades of tangents (%)
PVC = point of vertical curve
PVT = point of vertical tangent

Figure: Sight Distance on Crest Vertical Curve ($S > L$)



L = length of vertical curve (ft)
S = sight distance (ft)
H_1 = height of eye above roadway surface (ft)
H_2 = height of object above roadway surface (ft)
G_1 , G_2 = grades of tangents (%)
PVC = point of vertical curve
PVT = point of vertical tangent

Figure: Sight Distance on Crest Vertical Curve ($S < L$)

When the sight distance is greater than the length of the crest vertical curve,
The minimum length of the vertical curve

$$L_{min} = 2S - \frac{200\left(\sqrt{H_1} + \sqrt{H_2}\right)}{A} \quad (\text{for } S > L)$$

It had been the practice to assume that the height H_1 of the driver is 3.75 ft, and the height of the object is 0.5 ft. Due to the increasing number of compact automobiles on the nation's highways, the height of the driver's eye is now assumed to be 3.5 ft, and the object height, considered to be the tailight of a passenger car, is 2.0 ft. Under these assumptions, Eq. can be written as

$$L_{min} = 2S - \frac{2158}{A} \quad (\text{for } S > L)$$

When the sight distance is less than the length of the crest vertical curve, the minimum length of the vertical curve is

$$L_{min} = \frac{A\,S^2}{200\left(\sqrt{H_1} + \sqrt{H_2}\right)} \quad (\text{for } S < L)$$

Substituting 3.5 ft for H_1 and 2.0 ft for H_2, Eq. can be written as

$L_{min} = \frac{A\,S^2}{2158}$ (for $S < L$)

Question: A crest vertical curve is to be designed to join a +3% grade with a -2% grade at a section of a two-lane highway. Determine the minimum length of the curve if the design speed of the highway is 60 mi/h. $S < L$ and a perception-reaction time of 2.5 sec. The deceleration rate for braking (a) is 11.2 ft /sec². (SFGL – 2021)

Solution:

Since the grade changes constantly on a vertical curve, the worst-case value for G of 3% is used to determine the braking distance.

$$S = 1.47\,V\,t + \frac{V^2}{30\left(\frac{a}{g} - G\right)} = 1.47 \times 60 \times 2.5 + \frac{60^2}{30\left(\frac{11.2}{32.2} - 0.03\right)} = 598.1 \text{ ft}$$

The minimum length of the vertical curve,

$$A = +3 - (-2) = 5$$

$$L_{min} = \frac{A\,S^2}{2158} = \frac{5 \times 598.1^2}{2158} = 828.8 \text{ ft}$$

Question: An existing vertical curve on a highway joins a + 4.4% grade with a - 4.4% grade. If the length of the curve is 275 ft, what is the maximum safe speed on this curve? What speed should be posted if 5 mph increments are used? Assume a = 11.2 ft /sec2, perception-reaction time = 2.5 sec, and that $S < L$. (BUET M.Sc. –2013)

Solution:

Determine the SSD using the length of the curve

$$A = +4.4 - (-4.4) = 8.8$$

$$L_{min} = \frac{A\,S^2}{2158}$$

$$275 = \frac{8.8 \times S^2}{2158}$$

$$S = 259.69 \text{ ft}$$

Determine the maximum safe speed for this sight distance using the equation for SSD

$$259.69 = 1.47 \times 2.5 \times V + \frac{V^2}{30\left(\frac{11.2}{32.2} - 0.044\right)}$$

Which yields the quadratic equation

$$V^2 + 33.50\,V - 2367.02 = 0$$

Solving the equation, the maximum safe speed, $V = 34.7$ mi/h

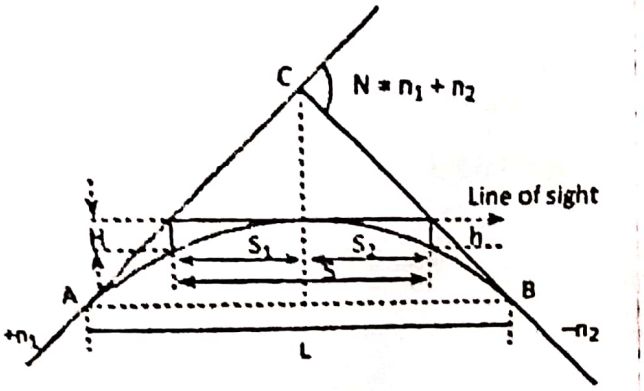
The maximum safe speed for an SSD of 259.69 ft is therefore 34.7 mi/h. If a speed limit is to be posted to satisfy this condition, a conservative value of 30 mi/h will be used.

Vertical Curves [MRS unit]

The vertical curves used in highway may be classified into two categories:

(a) Summit curves or crest curves with convexity upwards

(b) Valley or sag curves with concavity upwards



Length of summit curve for slopping sight distance (SSD)

(i) When L > SSD: The general equation for length L of the parabolic curve is given by:

$$L = \frac{N S^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

Here, L = length of summit curve, m

S = Stopping sight distance, (SSD), m

N = Deviation angle, equal to algebraic difference in grades, radians or tangent of the deviation angle.

H = Height of eye level of driver above roadway surface, m

h = height of subject above the pavement surface, m

The value of H, the height of driver's eye above roadway surface is taken as 1.2 m in. The height of object 'h' above the pavement surface for the purpose of safe stopping distance is taken as 0.15 m as per the IRC standard. Substituting these values in equation, the length of summit curve is obtained as:

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

(ii) When L< SSD: The general equation for the length of the parabolic summit curve, when it is less than the sight distance is given by:

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

Here the description for L, S, N, H and h are the same. By substituting the values of H = 1.2 m and h = 0.15 m the length of the curve is obtained as,

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

Length of summit curve for overtaking sight distance (OSD)

(i) When L > S: The same general is applicable in this case also. But in this case, the value of H and h both are taken equal to 1.2 m. Substituting h = H in the equation,

$$L = \frac{N S^2}{8 H}$$

The height of the eye level of the driver as well as the height of the approaching object are taken as 1.2 m. substituting the value of H, the height of eye level of driver above the pavement surface equal to 1.2 m.

$$L = \frac{N S^2}{9.6}$$

Here, L = the length of parabolic summit curve,
N = Deviation angle, radians or tangent of the deviation angle,
S = overtaking or intermediate sight distance. (OSD/ISD)

***(ii)* When L < S:** When L is less than OSD/ISD,

$$L = 2S - \frac{8H}{N}$$

Here again substituting the value of H as 1.2 m, the equation reduces to,

$$L = 2S - \frac{9.6}{N}$$

Question: A vertical summit curve is formed at the intersection of two gradients + 3 and − 5 percent. Design the length of summit curve to provide a stopping sight distance for a design speed of 80 kmph. Assume other data.

Solution:

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

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.

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

$$SSD = 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35} = 127.6$$

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

$$L = \frac{N S^2}{4.4} = \frac{0.08 \times 127.6^2}{4.4} = 296.03 \text{ m} > 128 \text{ m}$$

Therefore length of summit curve = 298 m

Question: An ascending gradient of 1 in 100 meets a descending gradient of 1 in 120. A summit curve is to be designed for a speed of 80 kmph so as to have an overtaking sight distance of 470 m.

Solution:

$$n_1 = +\frac{1}{100}, n_2 = -\frac{1}{120}$$

$$N = \frac{1}{100} - \left(-\frac{1}{120}\right) = \frac{11}{600}$$

If L > OSD, length of summit curve,

$$L = \frac{N S^2}{9.6} = \frac{11 \times 470^2}{600 \times 9.6} = 422 \text{ m}$$

As this value is less than OSD of 470 m, assume L less than OSD.

If L < OSD, length of summit curve,

$$L = 2S - \frac{9.6}{N} = 2 \times 470 - \frac{9.6 \times 600}{11} = 416.4 \text{ m} \approx 417 \text{ m}$$

This value is less than 470 m.

Therefore, the length of summit curve = 417 m.

TRAFFIC CHARATERISTIC

Vehicle characteristics:

- Static Characteristics:
  - Axle Load
  - Width
  - Length
  - Height
- Dynamic characteristics:
  - Speed: It effects
  - Acceleration / deceleration

Road user characteristics: Factors affecting road user's characteristics,

- Physical factor
- Mental factor
- Psychological factor

Question: A vehicle travelling at 40 kmph was stopped within 1.8 seconds after the application of the brakes. Determine the average skid resistance.

Solution:

Initial speed, $u = \frac{40}{3.6} = 11.11$ m/sec

$V = u + a\,t, a = \frac{u}{t} = \frac{11.11}{1.8} = 6.17$ m/sec^2

Force, $F = m\,a = W\,f = \frac{W\,a}{g}$

Average skid resistance, $f = \frac{a}{g} = \frac{6.17}{9.8} = 0.63$

Question: A vehicle moving at 40 kmph speed was stopped by applying the brake and the length of skid mark was 12.2 m. If the average skid resistance of the pavement is known to be 0.7, determine the brake efficiency of the test vehicle.

Solution:

Initial speed, $u = \frac{40}{3.6} = 11.11$ m/sec, $L = 12.2$ m, $f = 0.70$

Average skid resistance developed $f' = \frac{v^2}{2\,g\,L} = \frac{11.11^2}{2 \times 9.8 \times 12.2} = 0.516$

Brake efficiency, $\% = \frac{100\,f'}{f} = \frac{100 \times 0.516}{0.7} = 73.7\%$

Theoretical maximum capacity from space headway

Traffic volume per lane = Density per lane x Space mean speed

Traffic volume per lane (q) = $\frac{1}{\text{Space headway}}$ x Space mean speed

Theoretical maximum or basic capacity of a single lane may be made from the relation:

$$C = \frac{1000\,V}{S}$$

C = capacity of a single lane, vehicle per hour

V = speed, kmph

S = Average centre to centre spacing of vehicles, m

The minimum space gap Sg is given by: $S_g = v\,t = 0.278\,V\,t$, m

Where v and V are average speeds in m/sec and kmph

The minimum space headway S in a traffic stream is therefore equal to the minimum space gap plus average length of vehicle L in the stream,

$$S = S_g + L = 0.278\,V\,t + L$$

In a stream flow, as the driver of the following vehicle is quite alert, the average reaction time is found to be low; this value is often assumed to be 0.70 to 0.75 sec. If the value of reaction time has assumed as 0.7 sec. in the empirical relation for spacing, i.e. $S = (0.7\,v + L) = (0.2\,V + L)$, m

Theoretical maximum from time headway

$$\text{Volume} = \frac{1}{\text{Time headway}}$$

$$\text{Max theoretical capacity} = \frac{1}{\text{Minimum time headway (sec/veh)}}$$

$$\text{Max theoretical capacity} = \frac{3600}{\text{Minimum time headway in sec}} = \frac{3600}{H_t}$$

If the minimum time headway H_t is known, $q_{max} = \frac{3600}{H_t}$

Where q_{max} is the capacity in vehicles per hour and H_t is the minimum time headway in seconds.

Question: Estimate the theoretical capacity of a traffic lane with one way traffic flow at a stre speed of 40 kmph. Assume the average space gap between vehicles to follow the relation Sg = 0.2 V t where V is the stream speed in kmph, t is the average reaction time = 0.7 sec; assume avera length of vehicles = 5.0 m.

Solution:

$V = 40$ kmph; $t = 0.7$ sec; $L = 5.0$ m

$S = 0.278\,V\,t + L = 0.278 \times 40 \times 0.7 + 5 = 12.78$

Theoretical capacity, $C = \dfrac{1000\,V}{S} = \dfrac{1000 \times 40}{12.78} = 3130$ vehicles/hour/lane

Relationship between speed, Travel Time, Volume, Density and Capacity

$q = K\,V_s$

Where q = the average volume of vehicles passing a point during a specified period of time (vehicles per hour)

K = the average density or number of vehicles occupying a unit length of roadway at a given instant (vehicles/km)

V_s = space-mean speed of vehicles in a unit roadway length (kmph)

$$K\ (\text{vehicles/km}) = \frac{q\ (\text{vehicles/hour})}{V_s\ (\text{kmph})}$$

$$q_{max} = \frac{V_f\,K_j}{4}$$

Jam density (max density) space mean speed will be zero because vehicles will be in stand still conditions. When density zero there is no vehicle on road, the speed will be maximum called free mean speed. Relation between speed and density is,

We know, $V_s = V_f - \dfrac{V_f}{K_j}K$

We know, Traffic volume (q) = Space mean speed (V_s) x density (k)

$$q = V_f\,K - \frac{V_f}{K_j}K^2$$

To find density at maximum flow (volume)

$$\frac{dq}{dK} = 0$$

$$d\left[V_f\,K - \frac{V_f}{K_j}K^2\right] = 0$$

$$V_f - \frac{2\,V_f\,K}{K_j} = 0$$

$$K = \frac{K_j}{2}$$

Thus maximum flow (volume) will occur at density equal to half of jam density

- **To find speed at maximum flow (volume)**

$$\frac{dq}{dK} = 0$$

$$d\left[V_s K_j - \frac{K_j V_s^2}{V_f}\right] = 0$$

$$K_j - \frac{2 K_j V_s}{V_f} = 0$$

$$V_s = \frac{V_f}{2}$$

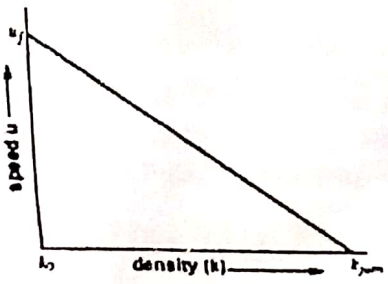
Thus for maximum volume speed should be half of free mean speed.

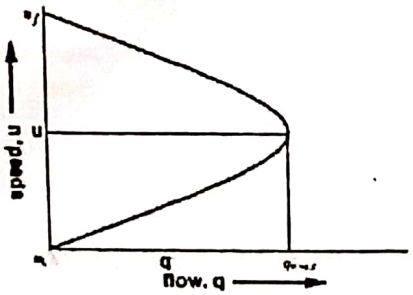
To find maximum flow

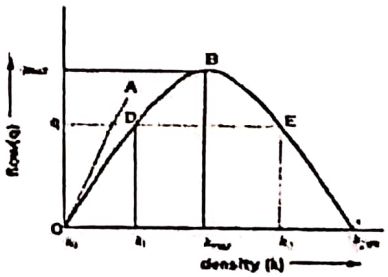
Maximum flow will occur at $K = \frac{K_j}{2}$

$$q = V_f K - \frac{V_f}{K_j} K^2$$

$$q_{max} = V_f \left(\frac{K_j}{2}\right) - \frac{V_f}{K_j}\left(\frac{K_j}{2}\right)^2 = \frac{V_f K_j}{2} - \frac{V_f K_j}{4} = \frac{V_f K_j}{4}$$







Example: The free mean speed on a roadway is found to be 80 kmph. Under stopped condition the average spacing between vehicles is 6.9 m. determine the capacity flow.

Solution:

Free mean speed $V_{sl} = 80$ kmph

Jam density $K_j = \frac{1000}{6.9} = 145$ vehicles/km (per lane)

Maximum flow $q_{max} = \frac{80 \times 145}{4} = 290$ vehicles/hour (per lane)

Question In speed density relationship $V_s = 65\left(1-\frac{K}{116}\right)$, determine the following condition.
(i) Flow density and flow speed (ii) free flow, jam density and capacity. (DESCO – 2015)

Solution:

We know $V_s = V_f\left(1-\frac{K}{K_j}\right)$

Considering V is in km/hour, from equation,
free flow V_f = 65 km/hour and jam density K_j = 116 vehicle/hour

For maximum value of q, $\frac{dq}{dK} = 0$

$\frac{dq}{dK} = 65 - 1.12\,K = 0$

K = 58.03 vehicle/km = flow density

Flow speed, $V_s = \frac{V_f}{2} = \frac{65}{2}$ = 32.5 km/hr

Capacity, $q = K\,V_s$ = 58.03 x 32.5 = 1885.97 vehicle/hour

Or

Considering V is in km/hour

$q = K\,V = K\left(1-\frac{K}{116}\right) = 65\,K - 0.56\,K^2$

$If\ q = 0, 65\,K - 0.56\,K^2 = 0$

$K\,(65 - 0.56\,K) = 0$

K = 0, 116.07 vehicle/km = jam density

For maximum value of q, $\frac{dq}{dK} = 0$

$\frac{dq}{dK} = 65 - 1.12\,K = 0$

K = 58.03 vehicle/km = density at maximum capacity

Maximum capacity, q_{max} = 65 x 58.03 – 0.56 x 58.03^2 = 1886.16 vehicle/hour

$At\ K = 0$, Maximum speed $V_s = 65\left(1-\frac{K}{116}\right)$ = 65 km/hour

Speed at maximum capacity $V_s = 65\left(1-\frac{58.03}{116}\right)$ = 32.48 km/hour

Question: What are the four steps of transportation planning? (BUET M.Sc.—2013)

The four stages transportation planning are given below,

- Trip Generation
- Trip Distribution
- Modal Split
- Traffic Assignment

Question: What is the theoretical relationship between speed, density and volume for a highway? (WASA – 2017, DTCA – 2018, BWDB – 2019, BCIC – 2019)

Solution:

Speed, flow and density are all related to each other. Under uninterrupted flow conditions, speed, density, and flow are all related by the following equation:

$q = K V_s$

Where, q = Flow (vehicles/hour)

V_s = Speed (miles/hour, kilometers/hour)

K = Density (vehicles/mile, vehicles/kilometer)

The relationship between these parameters of the flow may be derived as follows. Consider a short section of highway of length L in which N vehicles pass a point in the section during a time interval T, all the vehicles travelling in the same direction.

The volume flowing $Q = N / T$

$$\text{The density } D = \frac{\text{average no. of vehicles travelling over L}}{L}$$

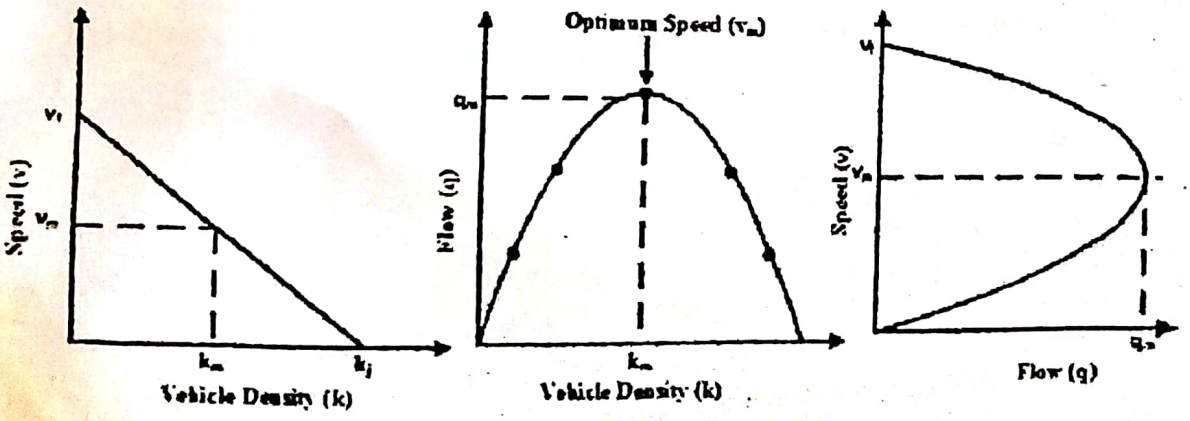
The average number of vehicles travelling over L is given by

$$\frac{\sum_{i=1}^{N} t_i}{T}$$

Where t is the time of travel of the i^{th} vehicle over the length L; then

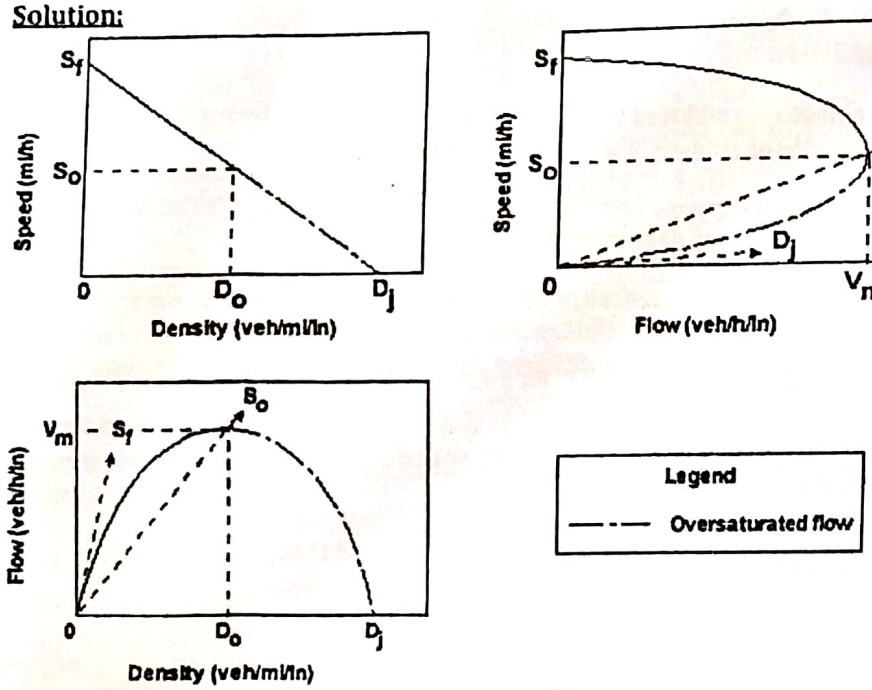
$$D = \frac{\sum_{i=1}^{N} t_i}{T} \Big/ L = \frac{\frac{N}{T}}{\frac{L}{\frac{1}{N}\sum_{i=1}^{N} t_i}}$$

$$\text{Density} = \frac{\text{Flow}}{\text{Space mean speed}}$$



Question: Draw flow density relation curve. Estimate the mean speed at point where the density is 175 vehicle/mile and flow is 10000 vehicle/hr. (EGCB – 2020)

Solution:



We know, $q = K\,V_s$

$V_s = q/K = 10000/175 = 57.14$ mile/hour

Question: Draw transportation & Land use flow diagram. (BUET M.Sc.–2011)

Solution:

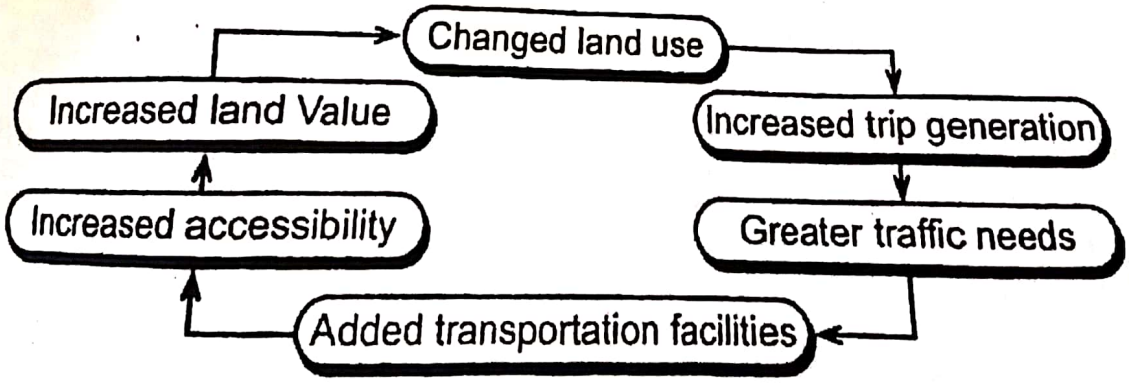


Figure: Transportation & Land use flow diagram

SPEED STUDY

Flow: Flow (q) is the equivalent hourly rate at which vehicles pass a point on a highway during a time period less than 1 hour. It can be determined by:

$$q = \frac{n \times 3600}{T} \text{ veh/h}$$

Where, n = the number of vehicles passing a point in the roadway in T sec
q = the equivalent hourly flow

Density: Density (k), sometimes referred to as concentration, is the number of vehicles traveling over a unit length of highway at an instant in time (veh/mi).

Speed: Speed (u) is the distance traveled by a vehicle during a unit of time. It can be expressed in miles per hour (mi/h), kilometers per hour (km/h).

Spot Speed: Spot speed is the instantaneous speed of a vehicle at a specified location. Spot speed can be used to design the geometry of road like horizontal and vertical curves, super elevation etc. Location and size of signs, design of signals, safe speed, and speed zone determination, require the spot speed data.

Average running speed: Running speed is the average speed maintained by a vehicle over a given course while the vehicle is in motion.

Time mean speed: Time mean speed (V_t) is the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time.

$$\text{Time mean speed, } V_t = \frac{\sum U}{N}$$

Where, n = number of vehicles passing a point in the highway
U = speed of the i^{th} vehicle (ft/sec)

Space mean speed: Space mean speed (V_s) is the harmonic mean of the speeds of vehicles passing a point on a highway during an interval of time.

$$\text{Space mean speed, } V_s = \frac{N}{\sum \frac{1}{U}}$$

Where, U = space mean speed (ft /sec)
n = number of vehicles

Time Headway: Time headway (h) is the difference between the time the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives at that same point. Time headway is usually expressed in seconds.

Space Headways: Space headway (d) is the distance between the front of a vehicle and the front of the following vehicle and is usually expressed in feet.

Question: Collect time required by 4 vehicles for travelling 1 km were 1.6, 1.2, 1.5 & 1.7 minute respectively. Find space and time mean speed. (PGCL – 2017)

Solution:

$$U_1 = \frac{1 \times 1000}{1.6 \times 60} = 10.416 \text{ m/s}$$

Similarly, $U_2 = 13.88$ m/s, $U_3 = 11.11$ m/s, $U_4 = 9.80$ m/s

$$\text{Time mean speed, } V_t = \frac{\sum U}{N} = \frac{10.416 + 13.88 + 11.11 + 9.80}{4} = 11.3 \text{ m/s}$$

$$\text{Space mean speed, } V_s = \frac{N}{\sum \frac{1}{U}} = \frac{4}{\frac{1}{10.416} + \frac{1}{13.88} + \frac{1}{11.11} + \frac{1}{9.80}} = 11.10 \text{ m/s}$$

Question: Find space and time mean speed for the values of 55, 60, 45, 95 and 60 mile/hr. (TGTDCL – 2018)

Solution:

$$\text{Time mean speed, } V_t = \frac{\sum U}{n} = \frac{55 + 60 + 45 + 95 + 60}{5} = 63 \text{ mile/hr.}$$

$$\text{Space mean speed, } V_s = \frac{n}{\sum \frac{1}{U}} = \frac{5}{\frac{1}{55} + \frac{1}{60} + \frac{1}{45} + \frac{1}{95} + \frac{1}{60}} = 59.34 \text{ mile/hr.}$$

Question: Find the Time mean speed and space mean speed from the following data.

Time (sec)	20	18	21	16	20	20
Distance (m)	300	300	300	300	300	300

(NPCBL – 2019, BCIC – 2019)

Solution:

$$U_1 = \frac{300}{20} = 15 \text{ m/s}$$

Similarly, $U_2 = 16.66$ m/s, $U_3 = 14.28$ m/s, $U_4 = 18.75$ m/s, $U_5 = 15$ m/s, $U_6 = 15$ m/s

$$\text{Time mean speed, } V_t = \frac{\sum U}{N} = \frac{15 + 16.66 + 14.28 + 18.75 + 15 + 15}{6} = 15.78 \text{ m/s}$$

$$\text{Space mean speed, } V_s = \frac{N}{\sum \frac{1}{U}} = \frac{6}{\frac{1}{15} + \frac{1}{16.66} + \frac{1}{14.28} + \frac{1}{18.75} + \frac{1}{15} + \frac{1}{15}} = 15.65 \text{ m/s}$$

Question: A new office building is expected to add 800 pedestrians per hour at its 15' sidewalk during the peak 10 minutes. The sidewalk already has a flow 1400 pedestrians during the peak period. Around 3' of the width of the sidewalk is used for light posts and other obstruction. Determine the new flow rate and maintain the unit measurement.
(PGCL – 2014, SGFCL – 2017, BIWTA – 2019)

Solution:

Sidewalk width = 15'

Effective walking width = 15' − 3' = 12'

Avg. flow rate, $q = \frac{v}{t\,W_t} = \frac{1400 + 800}{10 \times 12} = 18.33$ pedestrians /min/ft.

Question: Define the term " traffic volume". Explain the different methods for carrying out traffic volume studies. (34th BCS)

Solution:

Traffic volume is defined as the number of vehicles (or persons) that pass a point on a transportation facility during a specified time period, which is usually one hour. Traffic volume studies are conducted to determine the number, movements, and classifications of roadway vehicles at a given location. Two methods are available for conducting traffic volume counts: (1) manual and (2) automatic. Manual counts are typically used to gather data for determination of vehicle classification, turning movements, direction of travel, and vehicle occupancy.

Manual Count Method: Most applications of manual counts require small samples of data at any given location. Manual counts are rarely used when the effort and expense of automated equipment are not justified. Manual counts are necessary when automated equipment is not available. Manual counts are typically used for period of less than a day. Normal intervals for a manual count are 5, 10, or 15 minutes. Traffic counts during a rush hour of Monday morning and Friday evening rush hours shows exceptionally high volumes and is not normally used in analysis; therefore, counts are usually conducted on Tuesday, Wednesday, or Thursday.

Automatic Count Method: The automatic count method provides a means for gathering large amounts of traffic data. Automatic counts are usually taken in 1-hour interval for each 24-hour period. The counts extend for a week, month, or year. When the counts are recorded for each 24-hour time period, the peak flow period can be identified. Automatic counts are recorded using one of three methods: portable counters, permanent counters and videotape.

Average Daily Traffic (*ADT*) is defined as the average number of vehicles passing a specified point during a 24 hour period.

Annual average daily traffic (*AADT*) is defined as the total traffic volume of vehicle on a highway or road for the period of one year divided by 365 days. AADT is a useful and simple measurement of how busy a road is.

$$AADT = \frac{\text{Total traffic volume for 1 year}}{\text{365 days}}$$

Hourly Expansion Factors (*HEF*) are based on the average hourly distribution of the traffic flow for the 24 hour period over the extended time.

$$\therefore HEF = \frac{\text{Total volume for 24 hour period}}{\text{Volume for particular hour}}$$

DEF = Daily Expansion Factor

These factors are used to determine weekly volume from counts of 24hr duration.

$$\therefore DEF = \frac{\text{Average weekly volume}}{\text{Average volume for particular day}}$$

MEF = Monthly Expansion Factor

These factors are used to determine annual volume from counts of month duration.

$$\therefore MEF = \frac{\text{Average Annual Daily Traffic (AADT)}}{\text{ADT for particular month}}$$

Design Hour Volume (DHV): The DHV is a two-way traffic volume that is determined by multiplying the ADT by a percentage called the K-factor. Values for K typically range from 8 to 12% for urban facilities and 12 to 18% for rural facilities.

Design Hourly Volume $(DHV) = K \times AADT$

Directional design hour volume ($DDHV$): The directional design hour volume is the one-way volume in the predominant direction of travel in the design hour, expressed as a percentage of the two-way DHV. For rural and suburban roads, the directional distribution factor (D) ranges from 55 to 80 percent. A factor of approximately 50 percent is used for urban highways.

Directional design hour volume $(DDHV) = K \times D \times AADT$

K = Ratio of the two way design hourly volume to the two way AADT $= \frac{DHV}{AADT}$

D = Ratio of design hourly volume in major direction to the two way design hourly volume

Question: Define ADT and AADT. (37th BCS)

Solution:

Average Daily Traffic (ADT) is defined as the average number of vehicles passing a specified point during a 24 hour period.

Annual average daily traffic ($AADT$) is defined as the total traffic volume of vehicle on a highway or road for the period of one year divided by 365 days. AADT is a useful and simple measurement of how busy a road is.

$$AADT = \frac{\text{Total traffic volume for 1 year}}{\text{365 days}}$$

Table 4.5 Hourly Expansion Factors for a Rural Primary Road

Hour	Volume	HEF	Hour	Volume	HEF
6:00–7:00 a.m.	294	42.00	6:00–7:00 p.m.	743	16.62
7:00–8.00 a.m.	426	29.00	7:00–8:00 p.m.	706	17.49
8:00–9:00 a.m.	560	22.05	8:00–9:00 p.m.	606	20.38
9:00–10:00 a.m.	657	18.80	9:00–10:00 p.m.	489	25.26
10:00–11:00 a.m.	722	17.10	10:00–11:00 p.m.	396	31.19
11:00–12:00 p.m.	667	18.52	11:00–12:00 a.m.	360	34.31
12:00–1:00 p.m.	660	18.71	12:00–1:00 a.m.	241	51.24
1:00–2:00 p.m.	739	16.71	1:00–2:00 a.m.	150	82.33
2:00–3:00 p.m.	832	14.84	2:00–3:00 a.m.	100	123.50
3:00–4:00 p.m.	836	14.77	3:00–4:00 a.m.	90	137.22
4:00–5:00 p.m.	961	12.85	4:00–5:00 a.m.	86	143.60
5:00–6:00 p.m.	892	13.85	5:00–6:00 a.m.	137	90.14

Total daily volume = 12,350.

Table 4.6 Daily Expansion Factors for a Rural Primary Road

Day of Week	Volume	DEF
Sunday	7895	9.515
Monday	10,714	7.012
Tuesday	9722	7.727
Wednesday	11,413	6.582
Thursday	10,714	7.012
Friday	13,125	5.724
Saturday	11,539	6.510

Total weekly volume = 75,122.

Table 4.7 Monthly Expansion Factors for a Rural Primary Road

Month	ADT	MEF
January	1350	1.756
February	1200	1.975
March	1450	1.635
April	1600	1.481
May	1700	1.394
June	2500	0.948
July	4100	0.578
August	4550	0.521
September	3750	0.632
October	2500	0.948
November	2000	1.185
December	1750	1.354

Total yearly volume = 28,450.
Mean average daily volume = 2370.

Question: A traffic engineer urgently needs to determine the AADT on a rural primary road that has the volume distribution characteristics shown in Tables 4.5, 4.6, and 4.7. She collected the data shown below on a Tuesday during the month of May. Determine the AADT of the road.

Hour	Volume (Pcu)
7:00 - 8:00 a.m.	400
8:00 - 9:00 a.m.	535
9:00 - 10:00 a.m.	650
10:00 - 11:00 a.m.	710
11:00 - 12:00 a.m.	650

Solution:

Estimate 24 hour volume,

$$= \frac{400 \times HEF1 + 535 \times HEF2 + 650 \times HEF3 + 710 \times HEF4 + 650 \times HEF5}{5}$$

$$= \frac{400 \times 29 + 535 \times 22.05 + 650 \times 18.80 + 710 \times 17.10 + 650 \times 18.52}{5}$$

$= 11959$ pcu

Adjust the 24 – hr volume for Tuesday to an average volume for the week

Total 7 – day volume $= 11959 \times 7.727 = 92407.2$

Average 24 hour volume $= \frac{92407.2}{7} = 13701$ Pcu

Since the data were collected in May, MEF for May month $= 1.394$

Monthly expansion factor, $MEF = \frac{AADT}{ADT}$

$AADT = MEF \times ADT = 1.394 \times 13201 = 18402$ Pcu

Question: In a place number of vehicle passes per hour is shown in the table. If hourly expansion factor is 42 then find daily ADT? (PGCB – 2019)

Vehicle type	PCU factor	Flow (vehicle/hour)
Bus	3	41
Car, jeep	1	263
Micro, Taxi	0.5	55
NMT	0.5	48
Motorcycle	0.1	43

Solution:

Volume $= 41 \times 3 + 263 \times 1 + 55 \times 0.5 + 0.5 \times 48 + 0.1 \times 43 = 441.8$ vehicle/hour

Hourly expansion factor. $HEF = 42$

Average Daily Traffic = Volume for particular hr $\times HEF = 441.8 \times 42 = 18555.6$ vehicle/day

Question: A four lane two way road ADT is 4000 and commercial vehicle is 45%. Determine the number of vehicle in one way road.

Solution:

$$\text{Number of vehicle} = \frac{4000 \times 0.45}{2} = 900$$

Peak-hour factor (*PHF*): A measure of the variability of demand during the peak hour. It is the ratio of the volume during the peak hour to the maximum rate of flow during a given time period within the peak hour. For intersections, the time period used is 15 min, and the PHF is given as

$$\text{PHF} = \frac{\text{Volume during peak hour}}{4 \times \text{volume during peak 15 minute within peak hour}}$$

The PHF may be used in signal timing design to compensate for the possibility that peak arrival rates for short periods during the peak hour may be much higher than the average for the full hour. Design hourly volume (*DHV*) can then be obtained as

$$\text{DHV} = \frac{\text{Peak hour volume}}{\text{PHF}}$$

Question: The table below shows 15 minute volume counts during the peak hour on an approach of an intersection. Determine the PHF and the design hourly volume of the approach.

Time	volume
6:00 – 6:15 p.m.	375
6:15 – 6:30 p.m.	380
6:30 – 6:45 p.m.	412
6:45 – 7:00 p.m.	390

Solution:

Total volume during peak hour $= 375 + 380 + 412 + 390 = 1557$

Volume during peak 15 min $= 412$

$$\text{PHF} = \frac{\text{Volume during peak hour}}{4 \times \text{volume during peak 15 minute within peak hour}} = \frac{1557}{4 \times 412} = 0.945$$

$$\text{DHV} = \frac{\text{Peak hour volume}}{\text{PHF}} = \frac{1557}{0.945} = 1648$$

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Question: CBR value found of 10kms length as 3.8, 2.8, 3.2, 4.3 2.8, 4.7, 4.3, 3.9, 4.1 and 4.5%. Find the average CBR, standard deviation, CBR at 50% and 85% reliability. (BWDB – 2014, BPDB – 2016, CPGCBL – 2018)

Solution:

Average CBR, $\bar{x} = \frac{\sum x_i}{n} = 3.84$

Standard deviation, $S_d = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} = 0.687$

CBR at 50th reliability, $X_{50} = \bar{x} - Z S_d = 3.84 - 0 = 3.84$

CBR at 85th reliability, $X_{85} = \bar{x} - Z S_d = 3.84 - 1.04 \times 0.687 = 3$

Percentile	Z
99th	2.326
97.5th	1.96
95th	1.645
90th	1.282
75th	0.675
50th	0
85th	1.04

Question: CBR value found of 10 km length as 3.8, 2.8, 3.2, 4.3 2.8, 4.7, 4.3, 3.9, 4.1 and 4.5%. Find the average CBR, standard deviation, CBR at 50% and 90% reliability. (PGCB – 2018)

Solution:

Average CBR, $\bar{x} = \frac{\sum x_i}{n} = 3.84$

Standard deviation, $S_d = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} = 0.687$

CBR at 50th reliability, $X_{50} = \bar{x} - Z S_d = 3.84 - 0 = 3.84$

CBR at 85th reliability, $X_{85} = \bar{x} - Z S_d = 3.84 - 1.282 \times 0.687 = 2.96$

Percentile	Z
99th	2.326
97.5th	1.96
95th	1.645
90th	1.282
75th	0.675
50th	0
85th	1.04

Question: What are the different causes of traffic accidents? Explain various measures that may be taken to prevent accident? (40th BCS)

Solution:

Causes of traffic accidents

1. Over-speeding or driving in excess of prescribed speed limits.
2. Drunken driving or driving under the influence of drugs.
3. Use of mobile phones or ear phones while driving/crossing the road.
4. Violation of road signs, signals, traffic lights and road safety rules
5. Avoiding Safety Gears like Seat belts and Helmets
6. Insufficient driver knowledge
7. Bad Weather
8. Defective Automobiles

Measures that may be taken to prevent accident are given below:

Develop the right attitude about driving. Many teen auto accidents are a result of attitude and maturity, not skills or knowledge. Make a commitment to yourself to practice a responsible attitude about driving.

Always wear your safety belt. Get into the habit of wearing a safety belt whenever you are in a car, whether as a driver or a passenger - no exceptions.

Underage drinking and drug use is illegal. Even if you've consumed only one drink or smoked one joint, there is a chemical effect on your brain that can impair judgment and reaction time. Driving under the influence of alcohol, marijuana or other drugs can cost you your license - or your life.

Train for poor weather conditions. Even when you begin to feel confident driving on dry pavement, it's best to avoid driving in bad weather conditions unsupervised. Keep it simple at first, and get as much supervised practice driving in poor weather as you can before trying it on your own.

Cell phones are for emergency use only on the road. One of the worst habits anyone can get into is talking on a cell phone while driving. Keep a cell phone with you in the car for emergency situations only. If you have to use a cell phone, pull safely over to the side of the road.

Drive a safe vehicle. If you are thinking of getting your own car, look for one with high safety ratings. Avoid small cars, trucks or sport utility vehicles.

Drowsy Driving: Driving exhausted isn't talked about a lot, but is about as dangerous as driving under the influence. Most of the car accidents caused by drowsy driving occur at night.

Improper Turns: The reason that we have stop lights, turn signals, and lanes designated for moving either right or left as opposed to straight is to guide drivers. When drivers ignore these guides, car accidents are often the result. To prevent a car accident, always look for signs and obey the proper right-of-way before you make a turn.

Question: Write down some reasons why road accident occurs? (EED – 2019)

Solution:

Reasons for the traffic accidents:

1. Over-speeding or driving in excess of prescribed speed limits.
2. Drunken driving or driving under the influence of drugs.
3. Use of mobile phones or ear phones while driving/crossing the road.
4. Violation of road signs, signals, traffic lights and road safety rules
5. Avoiding Safety Gears like Seat belts and Helmets
6. Insufficient driver knowledge
7. Bad Weather
8. Defective Automobiles

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Analysis of Crash Data

The rate per million of entering vehicles (*RMEVs*) is the number of crashes per million vehicles entering the study location during the study period.

$$RMEV = \frac{A \times 1{,}000{,}000}{V}$$

Where, $RMEV$ = crash rate per million entering vehicles.
A = number of crashes, total or by type occurring in a single year at the location.
V = average daily traffic (ADT) x 365
This rate is often used as a measure of crash rates at intersections.

Question: The number of all crashes recorded at an intersection in a year was 23 and the average 24-hr volume entering from all approaches was 6500. Determine the crash rate per million entering vehicles (*RMEV*).

Solution:

$$RMEV = \frac{23 \times 1{,}000{,}000}{6500 \times 365} = 9.69 \text{ crashes/million entering vehicles.}$$

The **rate per 100 million vehicle miles** (***RMVM***) is the number of crashes per 100 million vehicle miles of travel. It is obtained from the expression:

$$RMEV = \frac{A \times 100{,}000{,}000}{VMT}$$

A = number of crashes, total or by type at the study location, during a given period
VMT = vehicle miles of travel during the given period
= ADT x number of days in study period x length of road
This rate is often used as a measure of crash rates on a stretch of highway with similar traffic and geometric characteristics.

Question: It is observed that 40 traffic crashes occurred on a 17.5 miles long section of highway in one year. The ADT on the section was 5000 vehicles.
(a) Determine the rate of total crashes per 100 million vehicle-miles.
(b) Determine the rate of fatal crashes per 100 million vehicles-miles, if 5% of the crashes involved fatalities. (DPDC – 2019)

Solution:

(a) $RMVM_T = \frac{40 \times 100{,}000{,}000}{17.5 \times 5000 \times 365} = 125.24$ crashes/100 million vehicle – miles

(b) $RMVM_F = 125.24 \times 0.05 = 6.26$ crashes/100 million vehicle – miles

Crash Reduction Capabilities of Countermeasures

Crash reduction capabilities are used to estimate the expected reduction that will occur during a given period as a result of implementing a proposed countermeasure. Crash reduction capabilities usually are expressed as crash reduction factors (CRFs) or crash modification factors (CMFs).

$$\text{Crashes prevented} = N \times CR \times \frac{\text{ADT after improvement}}{\text{ADT before improvement}}$$

Where, N = expected number of crashes if countermeasure is not implemented and if the traffic volume remains the same
CR = crash reduction factor for a specific countermeasure
ADT = average daily traffic

Question: The CRF for a specific type of countermeasure is 30 percent; the ADT before improvement is 7850 (average over three-year period) and the ADT after improvement = 9000. Over the three-year period before the improvement period, the number of specific types of crashes occurring per year are 12, 14, and 13. Use the following method to determine the expected reduction in number of crashes occurring after the implementation of the countermeasure.

Solution:

Average number of crashes/year = 13

$$\text{Crashes prevented} = N \times CR \times \frac{\text{ADT after improvement}}{\text{ADT before improvement}}$$

$$= \frac{13 \times 0.30 \times 9000}{7850} = 4.47 \text{ (4 crashes)}$$

Crash reduction factor

$$CR = CR_1 + (1 - CR_1)\,CR_2 + (1 - CR_1)\,(1 - CR_2)\,CR_3 + \ldots + (1 - CR_1)\ldots(1 - CR_{m-1})\,CR_m$$

CR = overall crash reduction factor for multiple mutually exclusive improvements at a single site
CR_i = crash reduction factor for a specific countermeasure i.
m = number of countermeasures at the site

Question: At a single location, three countermeasures with CRs of 40%, 28%, and 20% are proposed. Determine the overall CRF if all countermeasures are used.

Solution:

$CR_1 = 0.40$
$CR_2 = 0.28$
$CR_3 = 0.20$

$$CR = CR_1 + (1 - CR_1)\,CR_2 + (1 - CR_1)\,(1 - CR_2)\,CR_3$$

$$CR = 0.4 + (1 - 0.4)\,0.28 + (1 - 0.4)\,(1 - 0.28)\,0.2 = 0.66$$

Parking: Parking is one of the major problems that is created by the increasing road traffic. It is an impact of transport development. The availability of less space in urban areas has increased the demand for parking space especially in areas like Central business district.

Parking index: Parking index is also called occupancy or efficiency. It is defined as the ratio of number of bays occupied in a time duration to the total space available. It gives an aggregate measure of how effectively the parking space is utilized.

$$\text{Parking index} = \frac{\text{parking load}}{\text{parking capacity}} \times 100$$

On street parking

On street parking means the vehicles are parked on the sides of the street itself. This will be usually controlled by government agencies itself. Common types of on-street parking are as listed below. This classification is based on the angle in which the vehicles are parked with respect to the road alignment. As per IRC the standard dimensions of a car is taken as 5 x 2.5 meters and that for a truck is 3.75 x 7.5 meters.

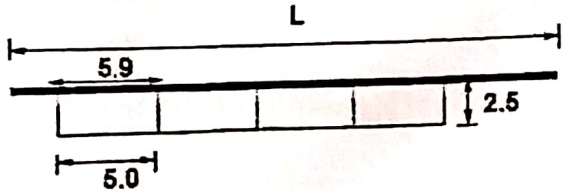


Illustration of parallel parking

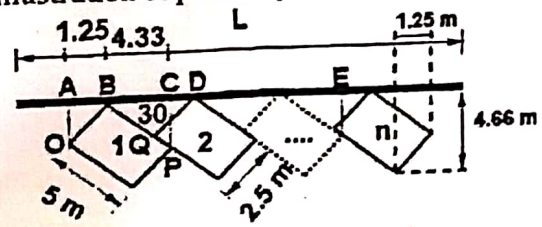


Illustration of 30⁰ parking

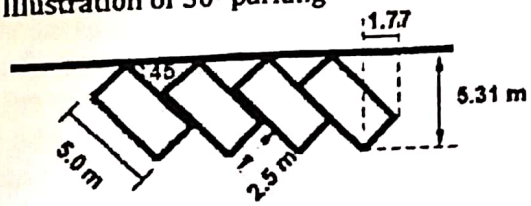


Illustration of 45⁰ parking

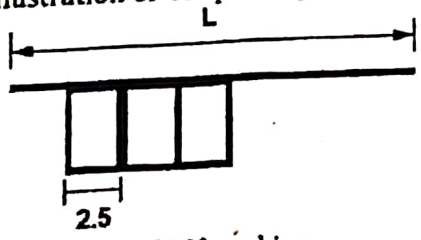


Illustration of 90⁰ parking

Off street parking

In many urban centres, some areas are exclusively allotted for parking which will be at some distance away from the main stream of traffic. Such a parking is referred to as off street parking. They may be operated by either public agencies or private firms. A typical layout of an off street parking is shown in figure.

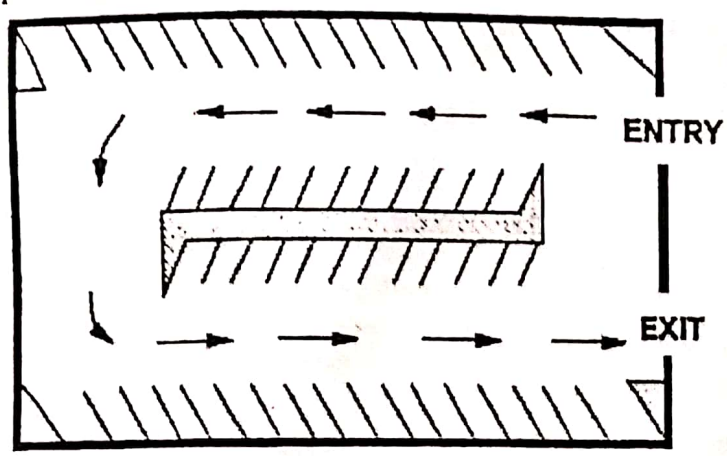


Illustration of off street parking

Question: Write the name of six equipment's for construction of highway. (BUET M. Sc. – 2013)

Solution:

The 6 equipment's for construction of highway are given below,

- Dump Truck
- Excavator
- Concrete mixer
- Bulldozer
- Front loader
- Road roller
- Truck crane

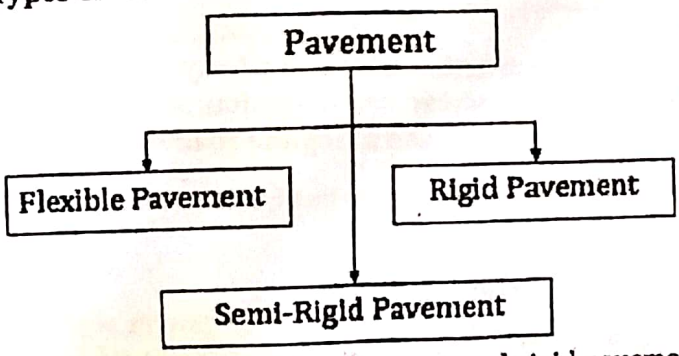
Transportation Engineering - II

Pavement: 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.

Requirements of a pavement: An ideal pavement should meet the following requirements:

- Sufficient 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 coefficient 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 traffic safety is not impaired by reducing visibility.
- Impervious surface, so that sub-grade soil is well protected.
- Long design life with low maintenance cost.

Types of Pavement



Question: Define flexible pavement and rigid pavement. (ISTT – 2015)

Solution:

A flexible pavement is one that is made up of one or more layers of materials, the highest quality material forming the top layer. Loads are transmitted through the layers, care being taken to ensure that the stresses in each layer are within the permissible values and the stress on the sub-grade is within its bearing. The flexible pavement layer transmits the vertical or compressive stresses to the lower layer by grain to grain transfers through the points of contact in the granular structure.

A rigid pavement depends upon the flexural strength or beam action of the slab for withstanding the wheel load. Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. The major contributor to the load- Rigid Pavement bearing capacity is the slab itself. The stresses are not transferred from grain to grain to the lower layer as in case of flexible pavement layers. Rigid pavement is laid in slabs with steel reinforcement. Rigid pavement is designed and analyzed by using the elastic theory.

Methods of pavement design

Various methods used for designing flexible pavement are:

- Asphalt institute method.
- AASHTO flexible pavement design method.
- Group index method (based on property of soil)
- California bearing ratio method.
- California resistance value method.
- Triaxial method.
- Burmister method.
- North Dakota cone test method.

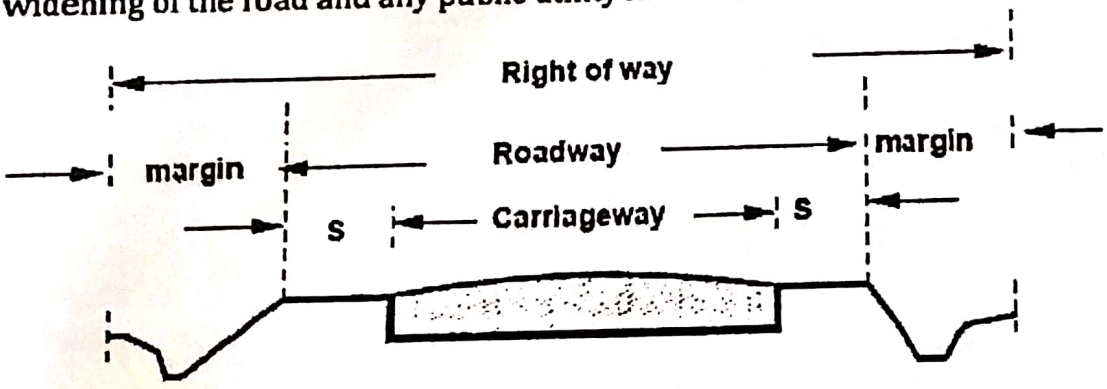
Various methods used for designing rigid pavement are:

- Portland cement association method.
- AASHTO rigid pavement design method.
- IRC method.

Question: What is the right of way? Sketch the right of way and its different parts.
(EED – 2015, ISTT – 2015)

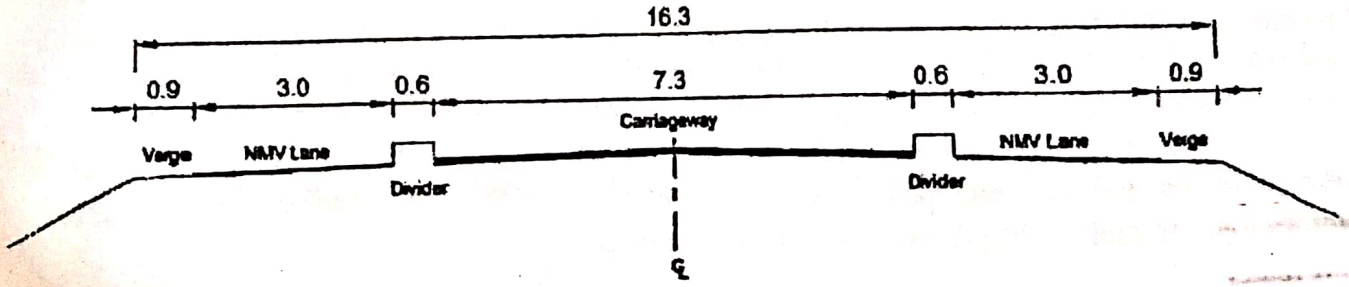
Solution:

The right of way is the total land area acquired for the construction of the roadway. Its width should be enough to accommodate all the elements of the roadway cross section, any future widening of the road and any public utility facilities that will be installed along the roadway.



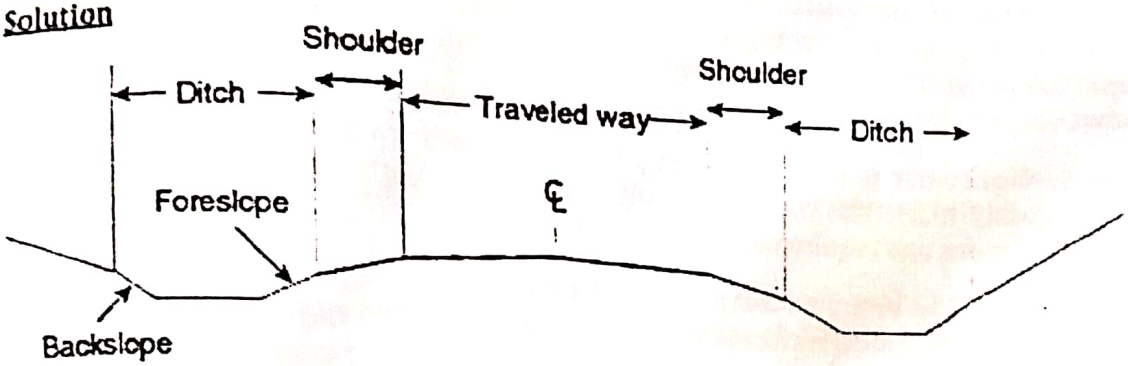
S– shoulder

Question: National Highway এর একটি Corss-section অঙ্কন করে এর বিভিন্ন অংশের নাম লিখুন।
(HED – 2017)

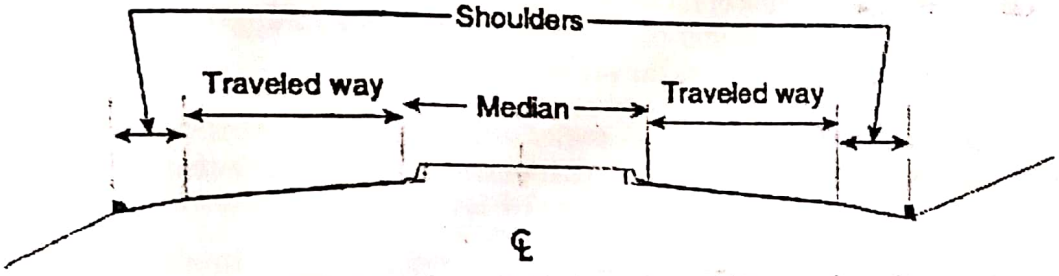


Question: Draw typical cross-sections of (a) a two-lane undivided roadway and (b) a two-lane divided roadway with raised median. (REB – 2018)

Solution



(a) A two-lane undivided roadway

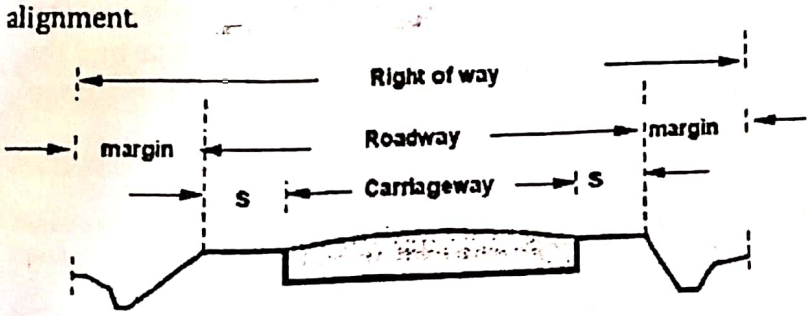


(b) A two-lane divided roadway with raised median.

Question: What is right of way? State the factors governing the land width of highway. (34th BCS)

Solution:

The right of way is the total land area acquired for the construction of the roadway. Its width should be enough to accommodate all the elements of the roadway cross section, any future widening of the road and any public utility facilities that will be installed along the roadway. RoW is the area of the road acquired for carriages way + other necessities + future extension, along its alignment.



S– shoulder

Factors governing the land width of highway

- Topography of the area
- Design speed
- Traffic loads
- Economy

Question: Write Course & coats used in different layers of Flexible pavement. (BUET M. Sc. – 2011)

Solution:

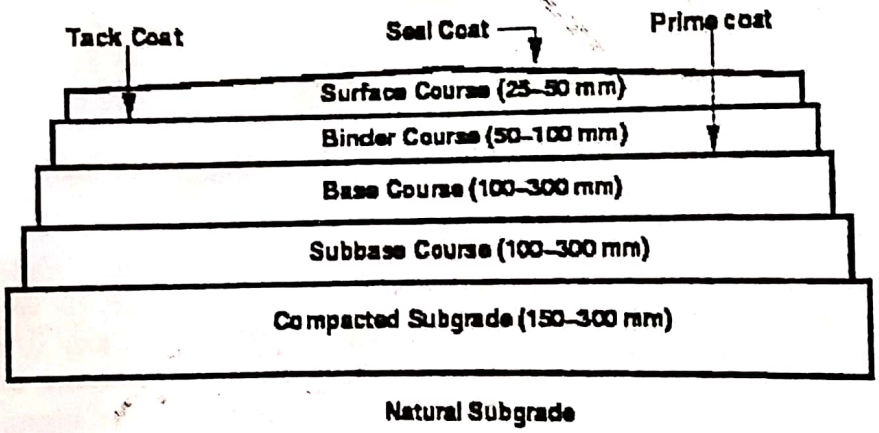
Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course: Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- To provide resistance against wear and tear due to traffic movements
- To provide smooth and dense riding surface to resist the pressure exerted by vehicle and to resist surface water infiltration.

Binder course: This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course. The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course.

Base course: The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage.



Sub-Base course: The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure.

- Act as a support for base and wearing course
- To improve drainage condition.
- To protect above layers from bad qualities from underlying soils.

Sub-grade: The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed.

- To receive the stress generation from the above layers
- To receive the materials of the above layers and act as a bedding layer.

Question: Write down the difference between Prime coat, tack coat and seal coat. (GTCL – 2016)

Solution:

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade.

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layers of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Question: Write short notes on application of seal coats, prime coats and tack coats in the construction of flexible pavement. (30th BCS)

Solution:

Prime Coat: Prime Coat is an application of bituminous materials to a previously untreated base or wearing surface. The bituminous material penetrates the surface and is generally completely absorbed. A prime coat serves several definite purposes.

- Promotes bond or adhesion between base and surface.
- Consolidate the surface to which new treatment is to be placed.
- Protect rise of capillary moisture into wearing surface.

Track Coat: Track Coat is single application of bituminous materials in an existing bituminous, Portland cement concrete brick or block surface or base for adhesion between existing surface and newly constructed bituminous surface.

Seal coat: Seal Coat is the application of bituminous materials at the top the wearing surface to seal the surface and make it water proof. Seal coats are applied as a final step in the constructions of many types of bituminous wearing surfaces, their primary purpose in the application being to water-proof or seal the surface.

Question: Write down the functions of base, subbase and surface course in flexible pavement. (31th BCS)

Solution:

Base course: The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage.

Sub-Base course: The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure.

- Act as a support for base and wearing course
- To improve drainage condition.
- To protect above layers from bad qualities from underlying soils.

Surface course: Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- To provide resistance against wear and tear due to traffic movements
- To provide smooth and dense riding surface to resist the pressure exerted by vehicle and to resist surface water infiltration.

Question: Write down the factors affecting pavement design. (RRI – 2015, GTCL 2016)

Solution:

There are so many factors which influencing the pavement design. The factors may be of loading, environment, materials used etc. Which are as follows.

- Wheel load
- Design life
- Traffic forecasting
- Axle configuration
- Shear Strength
- Contact pressure
- Vehicle speed
- Repetition of loads
- Sub-grade type
- Temperature
- Precipitation

Question: Draw the cross section with detailing of rigid and flexible pavement. (WRGCL – 2014, DPDC – 2014, RRI – 2015, BEPZA – 2016, BCIC – 2017, MPA – 2019, PGCB – 2020, DNCC – 2020)

Solution:

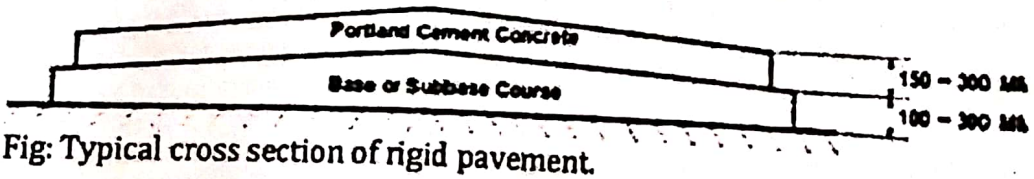


Fig: Typical cross section of rigid pavement.

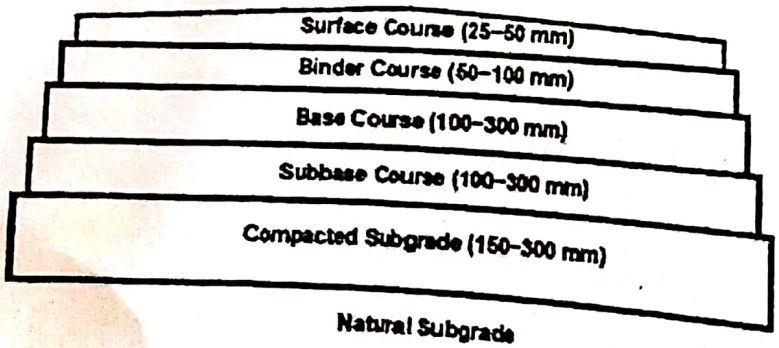


Fig: Typical cross section of flexible pavement

and generally
raded asphalt

Question: Draw typical load transmission curves for flexible & rigid pavement? (RAJUK – 2014)

Solution:

Question: Draw a flexible pavement and show the materials inside as well. (WASA – 2014, CPGCBL – 2015, BIFPCL – 2015, BCIC – 2016)

Solution:

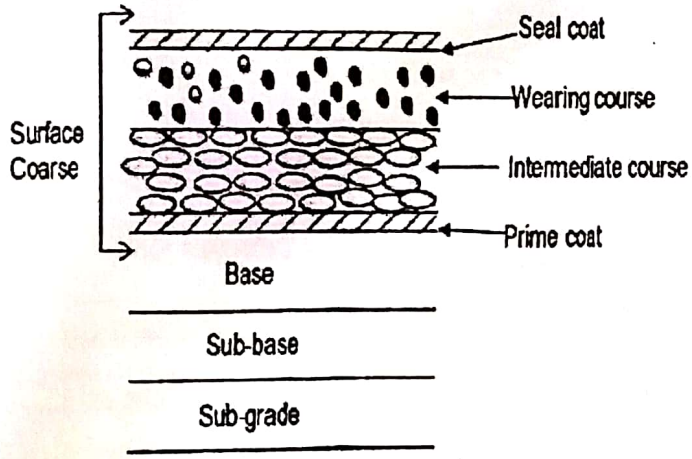
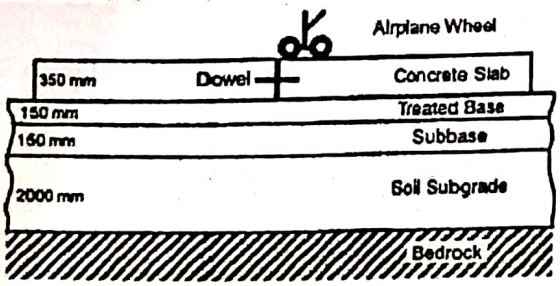


Fig: Flexible pavement with (details surface)

Question: Draw cross section of a rigid pavement.

Solution:



Question: Where rigid pavements are wanted?

Solution:

1. Where extra performance (due to stationary/slow loading condition, stopping & starting, impact) is needed,
- Junction
- Bus pull-out/bay
- Toll plaza
- Level crossing
- Runway threshold /turning area
- Taxiway
2. Road at Narrow (Lane by-lane) / Remote area (Roller accessibility problem)
3. Channelized/guided Traffic
4. Inundation / Submersible potential
5. Heavy duty pavements (Sea Port and Airport)

Question: Compare rigid pavement and flexible pavement. (36th BCS, EED – 2015, HED – 2017)

Solution:

Flexible pavement	Rigid pavement
Deformation in the sub grade is transferred to the upper layers.	Deformation in the sub grade is not transferred to subsequent layers.
Design is based on load distributing characteristics of the component layers.	Design is based on flexural strength or slab action.
Have low flexural strength.	Have high flexural strength.
Load is transferred by grain to grain contact.	No such phenomenon of grain to grain load transfer exists.
Have low completion cost but repairing cost is high.	Have low repairing cost but completion cost is high.
Have low life span.	Life span is more as compare to flexible.
Expansion joints are not needed.	Expansion joints are needed.
Strength of the road is highly dependent on the strength of the sub grade.	Strength of the road is less dependent on the strength of the sub grade.
Road can be used for traffic within 24 hours.	Road cannot be used until 14 days of curing.

Question: Write down the distress of flexible pavement and maintenance. (RRI – 2015)

Solution:

Different types of distress encountered in flexible pavements are as follow.

1. Fatigue Cracking (Alligator Cracking): Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue).

2. Longitudinal Cracking: Longitudinal cracks are long cracks that run parallel to the canter line of the roadway. These may be caused by frost heaving or joint failures or they may be load induced.

3. Transverse Cracking: Transverse cracks form at approximately right angles to the centerline of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced (over 20 feet apart). They usually begin as hairline or very narrow cracks and widen with age.

4. Block Cracking: Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction.

5. Edge cracking: Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture.

6. Rutting: Rutting is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement.

7. Potholes: Potholes are bowl-shaped holes similar to depressions. They are a progressive failure. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage.

8. De-lamination: De-lamination is a failure of an overlay due to a loss of bond between the overlay and the older pavement. Common causes of de-lamination include: wet or dirty surface during paving of the overlay, failure to use a tack coat, or poor compaction of the overlay.

Crack repairs are the proper and timely maintenance of cracks using sealing or filling techniques to extend pavement life. Crack repairs are very cost effective if done properly. The road user should be as per consideration only. If the nature of traffic changes due to unexpected growth of the area than it should be well maintained. There should not be any delay in maintenance. A crack repair program begins by determining if crack repairs are suitable for the type of distress.

- Sealing versus Filling
- Asphalt Resurfacing
- Rejuvenation
- Infrared Repair
- Fog Seal (PASS)
- Chip seal
- Self-Adhering Waterproofing Membranes
- Shallow Surface Repair (Pothole)

Question: Write down the distress of flexible pavement and maintenance. (50 BMA)

Solution:

Distress:

- Fatigue cracking (Alligator cracking)
- Longitudinal cracking
- Transverse cracking
- Block cracking
- Edge cracking
- Rutting
- Potholes
- De-Lamination

Maintenance:

- Sealing versus Filling
- Asphalt resurfacing
- Rejuvenation
- Infrared repair
- Fog seal (PASS)
- Chip seal
- Self-Adhering Waterproof Membranes
- Shallow Surface Repair (Pothole)

Question: What are the advantages and drawbacks of cement concrete road? (30th BCS)

Solution:

Advantages of Cement Concrete Road

1. Concrete roads have a long life.
2. They are quite durable and practically unaffected by weathering agencies.
3. They provide an excellent riding surface under all-weather condition.
4. They provide an impervious, dustless and sanitary surface.
5. No corrugations are developed in cement concrete roads.
6. They can be laid on any sub-grade.
7. They provide good visibility for traffic during night hours.
8. They are practically non-slippery and offer less tractive resistance.
9. Their load carrying capacity is more.
10. Their maintenance cost is very low.

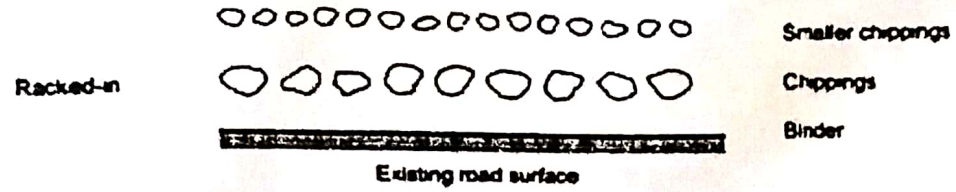
Disadvantages of Cement Concrete Road

1. The initial cost of construction is very high.
2. They require skilled supervision and labour for their construction.
3. They are liable to crack and warp due to temperature variations.
4. They become noisy under iron-tyred traffic.

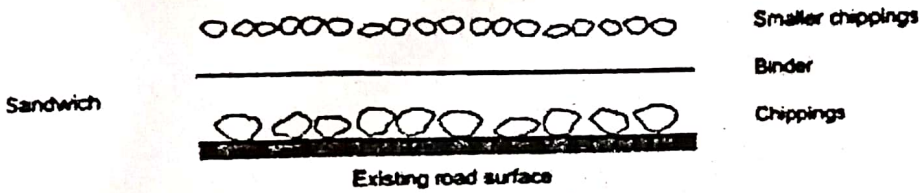
5. They are less resilient than bituminous or WBM roads.
6. They may cause glare due to reflected sunlight.
7. They cannot be opened to traffic shortly after construction.
8. It is very difficult to provide or repair underground pipes below cement concrete.

Question: Write down the definition of following: (i) Racked in surface dressing (ii) Sandwich surface dressing. (BWDB – 2016, NPCB – 2019, NHA – 2020)

Solution:



(i) Racked in surface dressing: One application of binder, one layer of chippings at about 90% of what would be used in a single dressing system followed by a second layer of smaller chippings. The smaller chippings lock the larger chippings in position producing a stable matrix. It is used where the traffic is partially heavy and fast and where the stresses are high.



(ii) Sandwich surface dressing: A layer of chippings only is applied before a single dressing. The system is used in situations in which the road surface condition is binder rich, usually just in the wheel-paths.

Question: Concrete pavement এবং bituminouspavement এর সুবিধা অসুবিধা লিখুন এবং LGED Catalogue অনুসারে Bituminous Surfacing এর জন্য নিচের উপাদান গুলোর তাপমাত্রা কত হবে তা উল্লেখ করুন
a) Bitumen b) Aggregate c) Mix of Bitumen and aggregate (LGED – 2019)

Solution:

Bituminous Road: Bitumen road consists of its surface with bituminous materials and biturnen is a sticky dark viscous liquid obtained from natural deposits.

Advantages:

1. Bitumen is very cost-effective material and that's why initial cost of bitumen road is less
2. Construction of bituminous road is time-efficient, Bitumen dries very fast and doesn't need to block the road for a long time.
3. Bitumen road has a smooth surface to ride
4. Gives less sound emission
5. Bituminous road is easy to repair, Repairing is time-efficient and easy.

Disadvantages

1. Bitumen road are less durable, pavement is more of maintenance than concrete. You need to reseal it every 3-5 year to prevent it from cracking.
2. Bitumen road have low tensile strength
3. Bitumen road will slick and soft in extreme weather and improper weather conditions.
4. To soils, bitumen with impurities can cause pollution
5. During extreme conditions of temperature, the cost of construction is high.

Concrete Pavement: Concrete pavement which is also called as rigid pavement is a concrete layer that is in contact with traffics directly and it is used for different purposes and applications.

Advantages:

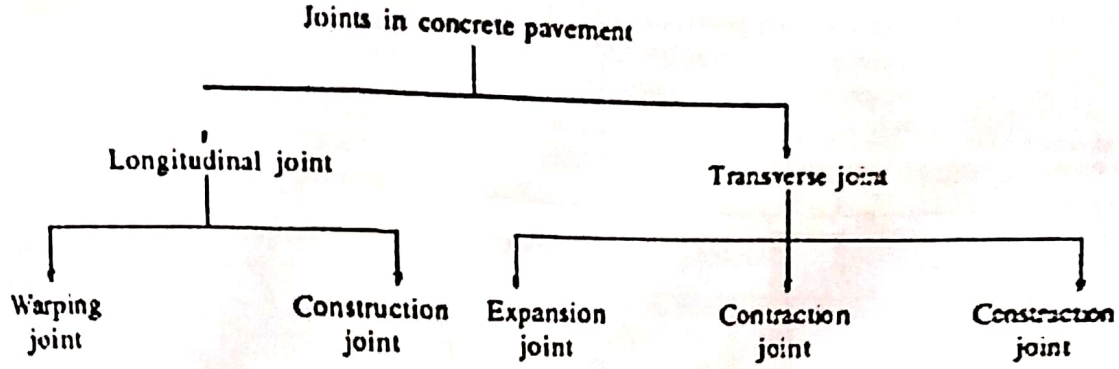
1. Concrete road has good longevity and no maintenance cost is required.
2. Concrete produces hard pavement.
3. It has good sustainability against truck loading.
4. Concrete has the ability to give protection against high temperature.
5. Provides impervious, dustless & sanitary surface.

Disadvantages

1. Initial cost of concrete pavement road is high.
2. Skilled supervision & labor are required during construction.
3. Less resilient than bituminous road.
4. Become noisy under iron-tyre traffic.
5. Required long time curing, thus can't be opened earlier.

Temperature Required

a) Bitumen 140 °C -155 °C
b) Aggregate 150 °C -170 °C
c) Mix of Bitumen and aggregate 140 °C -160 °C



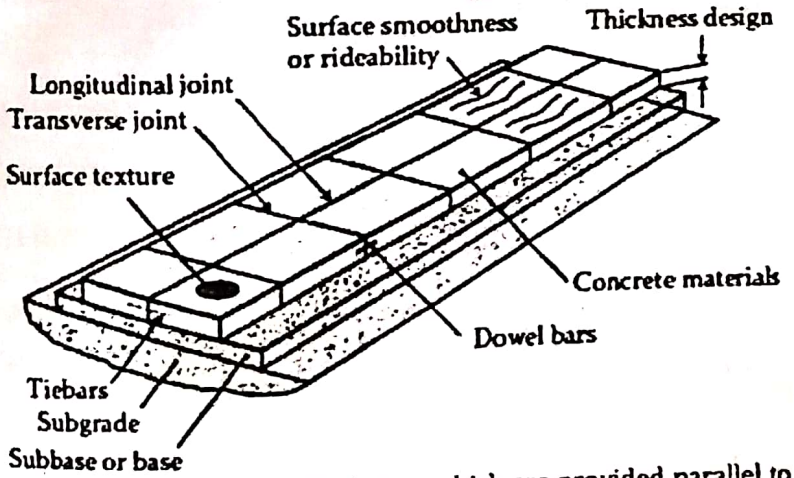
Question: Why joint used in rigid pavement? Type of joints? (BUET M.Sc.–2014)

Solution:

Joints in concrete pavements are provided due to following reasons:

- To permit expansion and contraction of concrete under the action of temperature and moisture content.
- To prevent irregular longitudinal cracks developed due to heavy wheel loads in continuous slab.
- To relieve warping and curling stresses due to temperature between top and bottom of pavement slab.
- To allow for break in construction at the end of the day's work.

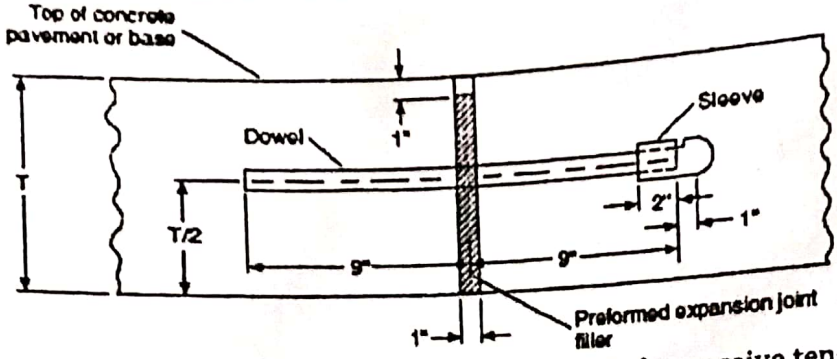
Types of Joints: Joints are broadly divided into two types:



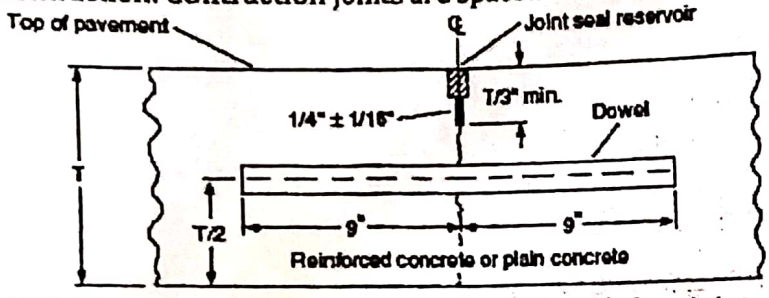
1. Longitudinal Joints: The joints which are provided parallel to the centre line of the pavement are called longitudinal joints. These joints are provided to prevent longitudinal cracking in the concrete pavements and are provided to pavements which have width over 4.5 m

2. Transverse Joints: The joints which are provided at right angles to the centre line of the pavement are called transverse joints. Transverse joints are further classified as:

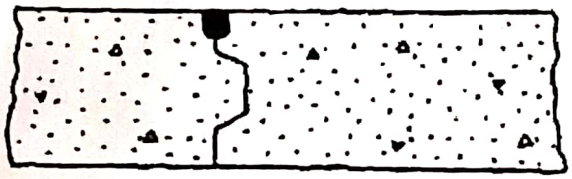
(i) Expansion joint: These joints are provided to allow for the expansion of the slab due rising in the slab temperature. Expansion joints must be constructed with clean break throughout the depth of the slab to permit expansion to take place. The clear distance across the joint is usually maintained at about ¾ inch.



(ii) Contraction joint: These joints are provided to receive tension developed in concrete due to contraction. Contraction joints are spaced closer than the expansion joints.

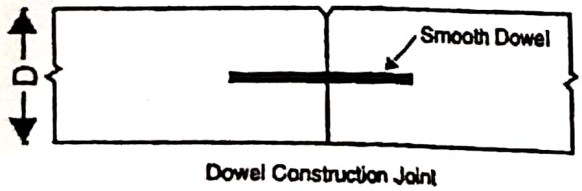


(iii) Warping joint: These are also called higher joints and are provided to relieve stresses included due to warping. Warping joints are used on highways to control cracking along the center line of the pavement.

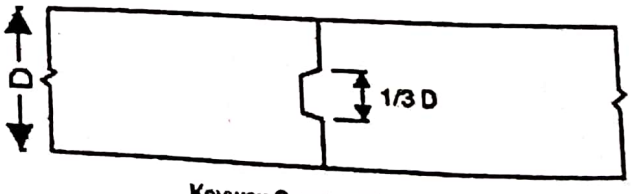


A warping joint (hinged)

(iv) Construction joint: These joints are provided when placing of concrete is suspended for more than 30 minutes. These are provided as transverse joints at the end of each day's work and contain dowel bars for transferring the load across the joint.



Dowel Construction Joint



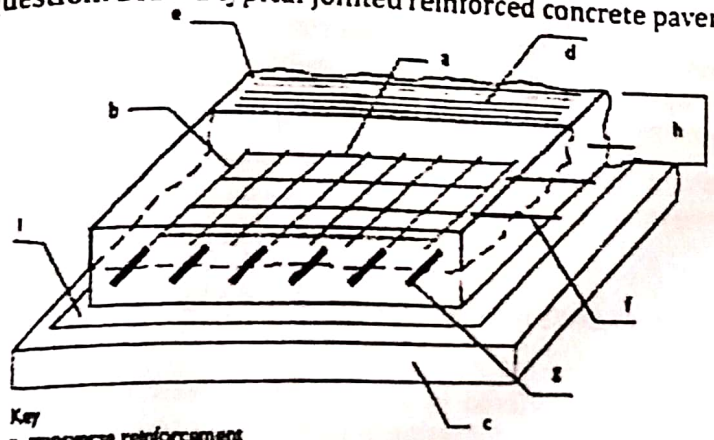
Keyway Construction Joint

Question: What is expansion joint in pavements and why it's provided? (DSCC – 2019)

Solution:

Expansion joints are placed in concrete to prevent expansive cracks formed due to temperature change. Concrete undergoes expansion due to high temperature when in a confined boundary which leads to cracks. Expansion joints permits thermal contraction and expansion without inducing stresses into the elements. Expansion joint absorb vibrations and permit soil movements due to earthquakes or ground settlement.

Question: Draw a typical jointed reinforced concrete pavement.



Key
a transverse reinforcement
b longitudinal reinforcement
c support platform
d trowelled border
e pavement surface finish
f tie bar (longitudinal joint)
g dowel bar (transverse joint)
h slab thickness
i de-bonding membrane

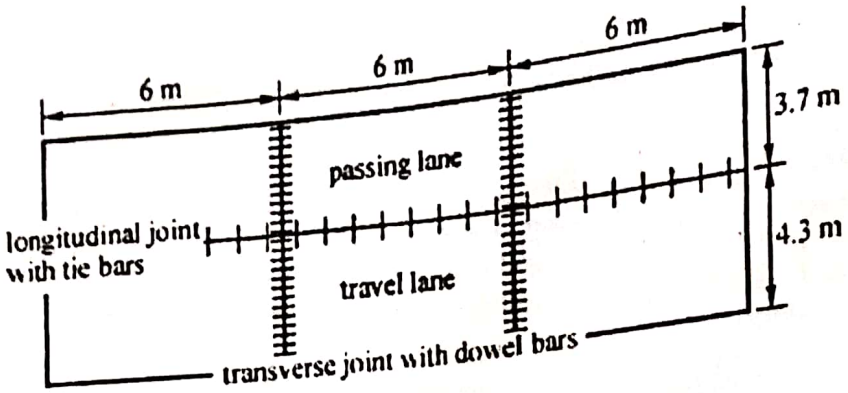
Figure: A typical JRC pavement.

Question: What is the difference between tie bars and dowel bars? (52 BMA)

Solution:

Tie bars: Tie bars are deformed rebar or connectors used for holding faces of rigid slabs in contact to maintain aggregate interlock. Tie bars are not load transferring device. For instance, tie bars are used in longitudinal joints in concrete pavement. Tie bars are smaller than dowel bars and spaced at grater intervals.

Dowel bars: Dowel bars are smooth round bars which mainly serve as load transfer device across concrete joints. They are placed across transverse joints of concrete pavement to allow movement to take place. Where movement is purposely designed for longitudinal joints, dowel bars can be adopted. Dowel bars spaced at close intervals to provide resistance to bending, shear and bearing of concrete. For highway work, dowel bars 1.25 inches in diameter, 2 feet long and spaced 1 foot on centers across the transverse joint are typical.



Modulus of sub-grade reaction

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection. Base on this assumption, Westergaard defined a modulus of sub-grade reaction K in kg/cm^3 given by

$$K = \frac{p}{\Delta}$$

Δ = displacement level taken as 0.125 cm

p = pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm.

Relative stiffness of slab to sub-grade

A certain degree of resistance to slab deflection is offered by the sub-grade. The sub-grade deformation is same as the slab deflection. Hence the slab deflection is direct measurement of the magnitude of the sub-grade pressure.

$$l = \sqrt[4]{\frac{E\,h^3}{12\,K\,(1-\mu^2)}}$$

l = Radius of relative stiffness in cm

E = modulus of elasticity of cement concrete in kg/cm^2 (3.0×10^5)

μ = Poisson's ratio of concrete = 0.15

h = slab thickness in cm

K = modulus of sub-grade reaction in kg/cm^3

Question: Compute the radius of relative stiffness of 15 cm thick cement concrete slab from the following data:

Modulus of elasticity of cement concrete = 210000 kg/cm^2

Poisson's ratio for concrete = 0.13

Modulus of subgrade reaction, K = 3 kg/cm^3

Solution:

Radius of relative stiffness, $l = \sqrt[4]{\frac{E\,h^3}{12\,K\,(1-\mu^2)}} = \sqrt[4]{\frac{210000 \times 15^3}{12 \times 3\,(1-0.15^2)}} = 67$ cm

Equivalent radius of resisting section

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard's gives a relation for equivalent radius of the resisting section in cm in the equation.

$$b = \begin{cases} \sqrt{1.6\,a^2 + h^2} - 0.675\,h & \text{if } a < 1.724\,h \\ a & \text{otherwise} \end{cases}$$

a = radius of the wheel load distribution in cm
h = slab thickness in cm.

Wheel load stresses - Westergaard's stress equation

The cement concrete slab is assumed to be homogeneous and to have uniform elastic properties with vertical sub-grade reaction being proportional to the deflection. Westergaard developed relationships for the stress at interior, edge and corner regions, denoted as σ_i, σ_e and σ_c in kg/cm² respectively and given by the equation.

$$\sigma_i = \frac{0.316\,P}{h^2}\left[4\,\log_{10}\left(\frac{l}{b}\right) + 1.069\right]$$

$$\sigma_e = \frac{0.572\,P}{h^2}\left[4\,\log_{10}\left(\frac{l}{b}\right) + 0.359\right]$$

$$\sigma_c = \frac{3\,P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

h = slab thickness in cm
P = wheel load in kg
a = radius of the wheel load distribution in cm
l = radius of the relative stiffness in cm
b = radius of the resisting section in cm

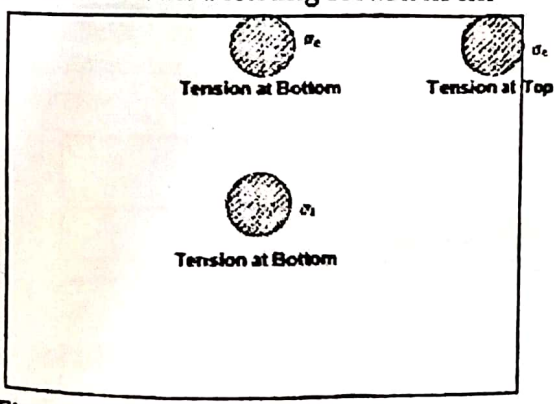
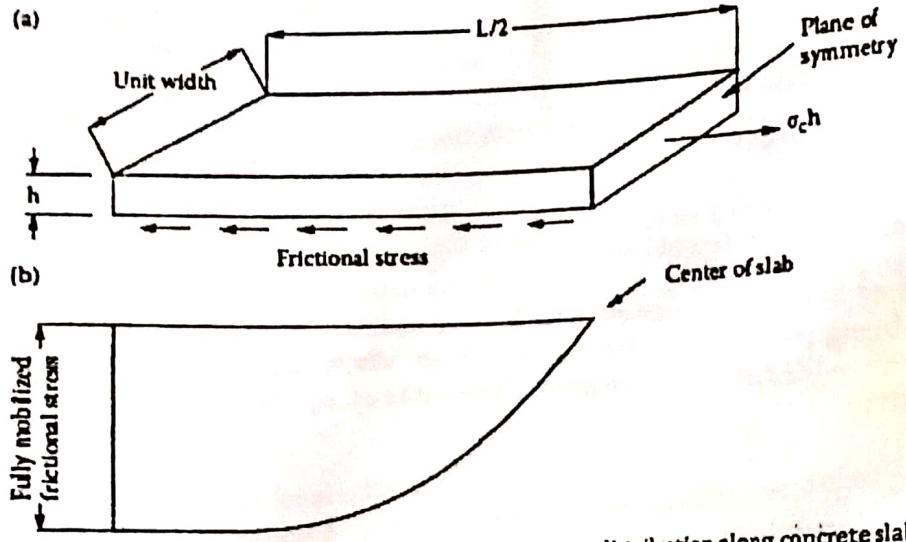


Figure: Critical stress locations

Stresses due to friction

Changes in temperature and moisture will create volume changes in concrete materials and will have significant effects on the concrete pavement slab. If a concrete slab, for example, is prevented from moving freely due to the friction between the slab and the supporting foundation, then

stresses will develop in the concrete, in the reinforcing steel if it is included, and in the tie bars across longitudinal joints and shoulders.



(a) Friction stress in concrete block and (b) friction stress distribution along concrete slab.

$$\sigma_c = \frac{\gamma_c L f_a}{2}$$

σ_c = concrete tensile strength in psi
γ_c = concrete unit weight in pci
L = length of the concrete slab in inch
f_a = average coefficient of friction between the slab and the subgrade.

In CGS unit

The frictional stress, $\sigma_f = \frac{W L f}{2 \times 10^4}$

σ_f = frictional stress in kg/cm^2

W = unit weight of concrete in kg/cm^3 (about 2400 kg/m^3)
f = coefficient of sub grade friction = 1.5
L = length of the slab in metres.

Tie bar steel design

Tie bars are placed along longitudinal joints to keep two adjacent concrete slabs tied together or across pavement slabs and concrete shoulders. Tie bars are also used to maintain load transfer across the joints. The amount of steel required is given by,

$$A_s = \frac{\gamma_c h L' f_a}{f_s}$$

A_s = area of steel required per unit length of slab
γ_c = unit weight of concrete
h = pavement thickness
L′ = distance from the longitudinal joint to the free edge where no tie bars are present
f_a = average coefficient of friction between the slab and the subgrade.

f_s = steel yield strength

Length of the bar, $L_T = 2\left(\frac{f_s A}{\varphi P}\right)$

L_T = length of the tie bar
f_s = steel yield strength
A = area of tie bar, $\pi d^2/4$
ϕ = bond strength between steel tie bar and concrete
P = tie bar perimeter, π d
The equation can be reduced to

The equation can be reduced to, $L_T = \frac{1}{2}\left(\frac{f_s d}{\varphi}\right)$

In CGS unit

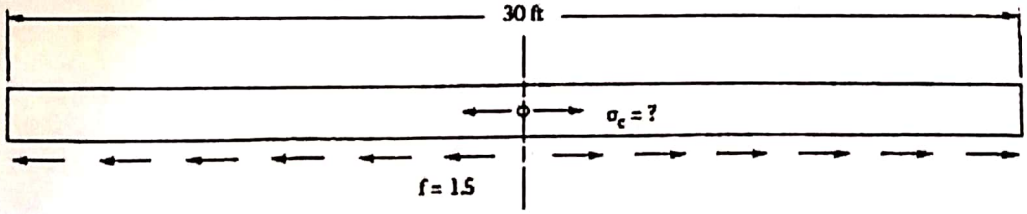
Area of steel required, $A_s = \frac{b\,h\,W\,f}{100\,S_s}$

A_s = area of steel required per meter
b = width of the pavement panel in m
h = depth of the pavement in cm,
W = unit weight of the concrete (assume 2400 kg/m^3),
f = coefficient of friction (assume 1.5)
S_s = allowable working tensile stress in steel (assume 1750 kg/cm^2).
Assume, 0.8 to 1.5 cm Ø bars for the design.

Length of the bar, $L_T = \frac{d\,S_s}{2\,S_b}$

d = diameter of the bar in cm
S_s = allowable tensile stress in kg/cm^2
S_b = allowable bond stress and can be assumed for plain and deformed bars respectively as 17.5 and 24.6 kg/cm^2.

Question: A concrete pavement slab as shown in Figure has a joint spacing of 30 ft (6.1 m) and a coefficient of friction equal to 1.5, the concrete unit weight γ_c = 150 pcf, and the concrete compressive strength is 3500 psi. Determine the stress developed in the concrete due to frictional forces.

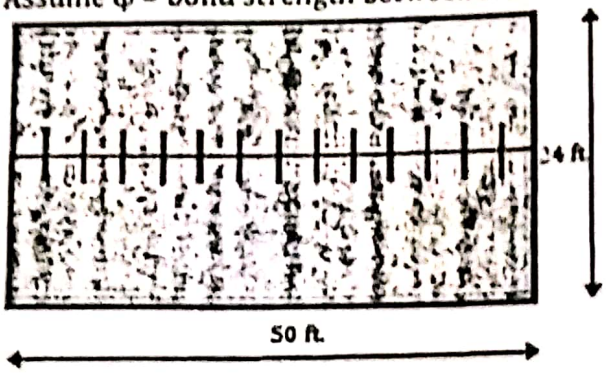


Solution:

Given the concrete unit weight γ_c = 150 pcf = 0.0868 pci
Joint spacing, L = 30 ft = 360 in.

$\sigma_c = \frac{\gamma_c L f_a}{2} = \frac{0.0868 \times 360 \times 1.5}{2} = 23.4$ psi (0.16 MPa)

Question: A two-lane concrete pavement is 9 inch thick, 50 ft long and 24 ft wide with a longitudinal joint in the center. (i) Determine the design of the tie bars. Use Billet steel with 40 ksi yield stress and an allowable stress of 27 ksi. The lane width L = 12 ft (144 in.), unit weight γ_c = 150 pcf = 0.0868 pci and coefficient of friction equal to 1.5 (ii) Determine the length of the tie bar. Assume ϕ = bond strength between steel tie bar and concrete = 350 psi.



Solution:

Area of steel required, $A_s = \frac{\gamma_c h L' f_a}{f_s} = \frac{0.0868 \times 9 \times 144 \times 1.5}{27000} = 0.00624 \text{ in}^2/\text{in}$

Using No. 4 bars with (0.5 in. diameter; area = 0.2 in^2)

The spacing of the tie bars = 0.2/0.00624 = 32 in.

Length of the bar, $L_T = \frac{1}{2}\left(\frac{f_s d}{\phi}\right) = 0.5 \times \frac{27000 \times 0.5}{350} = 19.3 \text{ in}$

For misalignment = 19.3 + 3 = 22.3 in = use 24 in length

Therefore, use no 4. Tie bars with 24 in. length and spaced 32 in. at the center.

Railway Engineering

Classification of Railway System

Intercity
→ Long distance.
→ Generally not very frequent.
→ Every 20/30 minutes to once a day.

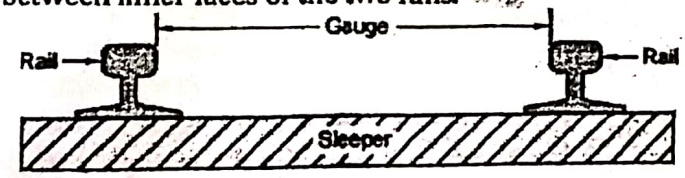
Urban
→ Short haul.
→ Frequent: Frequency as high as every 3 minutes.

Sub-urban
→ Suburb to main city. Mostly caters to commuting traffic.

Advantages of railway
→ High capacity
→ Lower operating cost
→ High speed
→ Fixed route and easier operation

Typical components
→ Rails
→ Sleepers (or ties)
→ Fasteners
→ Ballast
→ Subgrade

Rail Gauges: The gauge of a rail track is defined as the clear minimum perpendicular distance between inner faces of the two rails.



Types of Gauge

→ Broad gauge: 1.524m – 1.676m (5' 0" – 5' 6")
→ Standard gauge: 1.435m – 1.451m (4' 8.5" – 4' 9.125")
→ Meter gauge: 1m – 1.067m (3' 3.375" – 3' 6")
→ Narrow gauge: 0.610m – 0.762m (2' 0" – 2' 6")

Question: State the advantages of uniform gauge of a railway line. (37th BCS)

Solution:

The clear horizontal distance between the inner faces of the two rails forming a track is known as a railway gauge.

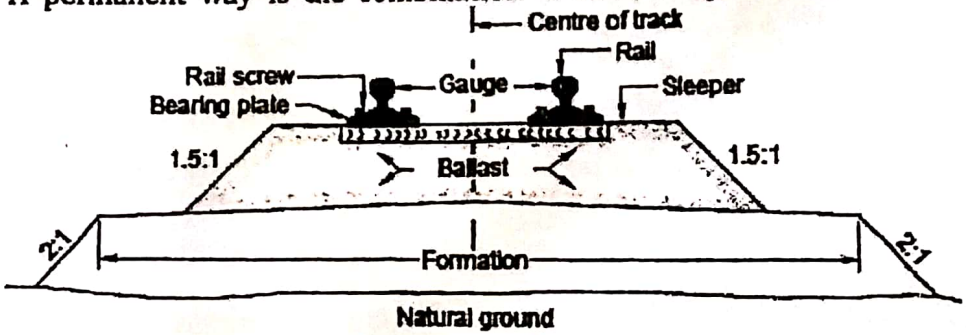
The use of a uniform gauge has the following advantages:
1. The delay cost and hardship in shifting passengers and goods from the vehicle of one gauge to the other are avoided.
2. Labour expenses of shifting are saved.
3. Breakage of goods due to shifting is avoided.
4. Possibility of thefts and misplacement during the shifting operation is eliminated.
5. Large sheds to store goods are not required.
6. Labour strikes etc. do not affect the service and operation of trains.
7. Wagons can be efficiently used on all the tracks if the gauge is uniform.
8. Locomotives can be effectively used on all the tracks if a uniform gauge is adopted.

Railway track: The track or permanent way is the railroad on which trains run. It consists of two parallel rails fastened to sleepers with a specified distance between them. The sleepers are embedded in a layer of ballast of specified thickness spread over level ground known as formation.

Question: What is permanent way? Draw a permanent way and show all the elements. (DMRTP – 2018, PGCB – 2019)

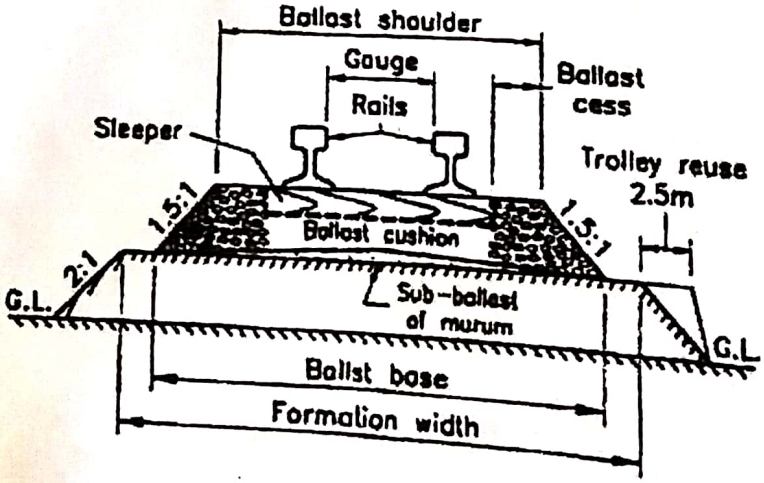
Solution:

A permanent way is the combination of rails, sleepers, ballasts, fixtures and fastenings, etc.



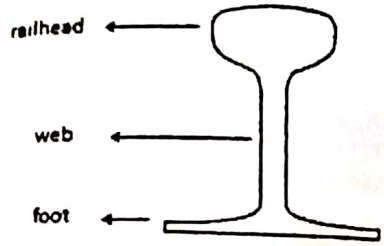
Question: Diagram of railway section with its different component. (BUET M. Sc.– 2017)

Solution:



of one gauge to

Rail: Rail is similar to steel girders. Rails are the members of the track laid in two parallel lines to provide an unchanging, continuous, and level surface for the movement of trains. To be able to withstand stresses, they are made of high-carbon steel.



The following is the thumb rule for defining the maximum axle load with relation to the rail section: Maximum axle load = 560 x sectional weight of rail in lbs per yard or kg per meter

Rails perform the following functions:

→ To provide continuous and level surface for movement of train.
→ Provide a pathway which is smooth and has very little friction.
→ Serve as a lateral guide for the running of wheels.
→ Transferring the load into formation through the sleepers and the ballast.

Sleepers: Sleepers are the transverse ties that are laid to support the rails. They have an important role in the track as they transmit the wheel load from the rails to the ballast.

Types of sleeper
→ Wooden
→ Steel
→ Concrete

Functions of sleepers:
→ Holding rails to correct gauge and alignment.
→ Giving a firm and even support to rails.
→ Absorb the blows and vibrations caused by moving loads
→ To maintain the alignment and gauge of the track correctly.
→ Transferring the load evenly from the rails to wider area of the ballast.
→ Providing lateral and longitudinal stability of permanent way.

Question: Write the advantages & disadvantages of wooden sleeper.

Solution:

Wooden sleepers have the following main advantages and disadvantages.

Advantages
→ Cheap and easy to manufacture
→ Absorbs shocks and bears a good capacity to dampen vibrations;
→ Easy handling without damage
→ Suitable for track-circuited sections
→ Suitable for areas with yielding formations
→ Alignment can be easily corrected

→ More suitable for modern methods of maintenance
→ Can be used with or without stone ballast
→ Can be used on bridges and ashpits also
→ Can be used for gauntleted track

Disadvantages

→ Lesser life due to wear, decay, and attack by vermin
→ Liable to mechanical wear due to beater packing
→ Difficult to maintain the gauge
→ Susceptible to fire hazards
→ Negligible scrap value

Question: Write the requirements of an ideal sleeper. Write the advantages of steel sleeper over wooden sleeper. (34th BCS)

Solution:

→ It should be economical.
→ They should be quite durable.
→ The weight of the sleepers should be moderate so that it can be handled easily.
→ It should be easy to handle so that gauge may be adjusted easily and maintained correctly.
→ They should be capable of resisting shocks and vibrations due to heavy moving loads.
→ The sleepers should have sufficient bearing area.
→ The bearing area of sleepers should be enough to resist crushing.
→ They should facilitate easy removal and replacement of ballast.
→ They should have high scrap value.

Steel sleepers has following advantages over wooden sleepers in railway track.

- The life of steel sleepers is more than wooden sleepers.
- The gauges can be easily maintained and adjusted
- These sleepers are light in weight and requires less fastenings.
- Lesser damage during handling & transportation.
- Manufacturing process is simple.
- Their scrap value more than the wooden sleepers
- Free from decay & attack by vermin.
- It is not susceptible to fire.

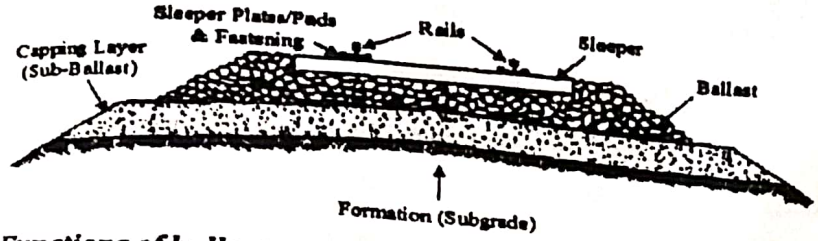
Ballast: Ballast is a layer of broken stone, gravel or any other granular material placed and packed below and around sleepers for distributing the load from the sleepers to the formation and for providing drainage.

Functions of ballast:

→ To provide a level and sound foundation for the sleepers to rest on.
→ To hold the sleepers in position during the passage of trains.
→ To transfer and distribute the load from sleepers to the large area of formation.
→ To provide necessary resistance to track for longitudinal and lateral stability.
→ To provide effective drainage to track and keep the sleepers in dry condition.

Question: Draw the cross section of ballast in railway. Write the function of ballast. (34th BCS)

Solution:



Functions of ballast:

- To provide a level and sound foundation for the sleepers to rest on.
- To hold the sleepers in position during the passage of trains.
- To transfer and distribute the load from sleepers to the large area of formation.
- To provide elasticity and resilience to track for getting proper riding comfort.
- To provide necessary resistance to track for longitudinal and lateral stability.
- To provide effective drainage to track and keep the sleepers in dry condition.

Question: Discuss the function and requirements of sleeper and ballast. (37th BCS)

Solution:

Functions of sleepers:

→ Holding rails to correct gauge and alignment.
→ Giving a firm and even support to rails.
→ Absorb the blows and vibrations caused by moving loads
→ To maintain the alignment and gauge of the track correctly.
→ Transferring the load evenly from the rails to wider area of the ballast.
→ Providing lateral and longitudinal stability of permanent way.

Requirements of railway sleepers are:

→ The initial as well as maintenance cost should be minimum.
→ The weight of the sleeper should be moderate so that it is convenient to handle.
→ The sleeper should have sufficient bearing area so that the ballast under it is not crushed.
→ The sleeper should be such that it is possible to maintain and adjust the gauge properly.
→ The design of the sleeper should be such that it is possible to have track circuiting.
→ The sleeper should have anti-sabotage and anti-theft features.
→ The sleeper should be capable of resisting vibrations and shocks caused by the passage of fast moving trains.

Functions of ballast:

→ To provide a level and sound foundation for the sleepers to rest on.
→ To hold the sleepers in position during the passage of trains.
→ To transfer and distribute the load from sleepers to the large area of formation.
→ To provide necessary resistance to track for longitudinal and lateral stability.
→ To provide effective drainage to track and keep the sleepers in dry condition.

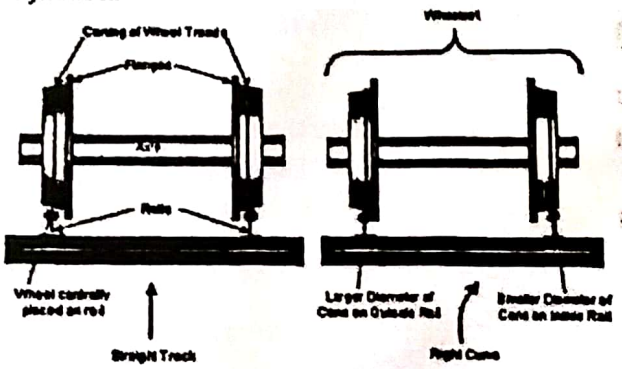
Ballast material should possess the following properties:

→ It should be tough and wear resistant.
→ It should be hard so that it does not get crushed under the moving loads.
→ It should be generally cubical with sharp edges.
→ It should be non-porous and should not absorb water.
→ It should resist both attrition and abrasion.
→ It should allow for good drainage of water.
→ It should be cheap and economical.

Question: What is coning of rails? Why coning of wheels is mainly done. (34th BCS)

Solution:

The Surface of wheels are made in cone shape at an inclination of 1 in 20, and the same slope is provided in the rails (see fig), this is known as coning of wheels. The diameter of wheel is different at different cross section of the wheel, when the train running on the straight track try to move in any direction, the diameter of the wheel increases over one rail and the wheel assembly is automatically forced to move back in its original central position due to difference of distances moved over two rails. Whereas on a curved track, due to centrifugal force the train is forced in outward direction, the diameter on outer track increases and the distance on two tracks are adjusted.



→ To keep the train in its central position of the rails, coning does not allow any sidewise movement on a straight track.
→ To allow the wheels to move different distances on a curved track and thereby reduce wear and tear.

Question: What are the purpose of signaling along a railway track? (DMRTP – 2018)

Solution:

- To provide safety to passengers, staff and railway track.
- To maintain a safe distance between the trains running on a same line.
- To provide protection against collision and derailment at conversing junctions.
- To give direction indications at divergent junctions.
- To increase the capacity of the track.
- To provide facilities for the efficient movement of train.

Question: Standard rail length of BG track is 12.80 m. If 45 kg rail is used in a particular BG track in Rajshahi, what is the total weight of each individual rail girder? What maximum axle load can be safely imposed on that track? (SGCL – 2017)

Solution:

Here, Number of rail = 1, Length of rail = 12.80 m, weight of rail per unit length = 45 kg

We know, Total weight of each individual rail girder,

= Number of rail x weight of rail per unit length x Length of rail

= 1 x 45 x 12.8 = 576 kg

According to IS, maximum axle load = 560 x sectional weight of rail in kg/m

= 560 x 45 = 25200 kg = 25.2 ton

Curves and superelevation: Curves are introduced on a railway track to bypass obstacles, to provide longer and easily traversed gradients, and to pass a railway line through obligatory or desirable locations. Horizontal curves are provided when a change in the direction of the track is required and vertical curves are provided at points where two gradients meet or where a gradient meets level ground. To provide a comfortable ride on a horizontal curve, the level of the outer rail is raised above the level of the inner rail. This is known as superelevation.

Radius or degree of a curve: A curve is defined either by its radius or by its degree. The degree of a curve (D) is the angle subtended at its centre by a 30.5-m or 100-ft chord.

The degree of curve, $D = \frac{1750}{R}$ (when R is in meters)

The degree of curve, $D = \frac{5730}{R}$ (when R is in feet)

Equilibrium Superelevation: To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the superelevation. A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the superelevation is enough to bring the resultant of the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve known as equilibrium superelevation.

$$e = \frac{G V^2}{g R}$$

Where e is the equilibrium superelevation, G is the gauge, V is the velocity, g is the acceleration due to gravity, and R is the radius of the curve.

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

Where e is the superelevation in millimetres, V is the speed in km/h, R is the radius of the curve in metres, and G is the dynamic gauge in millimetres, which is equal to the sum of the gauge and the width of the rail head in millimetres. This is equal to 1750 mm for BG tracks and 1058 mm for MG tracks.

Question: Define equilibrium cant. A curve of 5^0 is situated on a section of broad gauge. The maximum permissible speed in the section is 50 km/hr. Find out the amount of equilibrium cant. (35th BCS)

Solution:

To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the superelevation. A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the superelevation is enough to bring the resultant of the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve known as equilibrium superelevation.

Radius of curve, $R = \frac{1750}{D} = \frac{1750}{5} = 350$ m

$V = 50$ km/hr and $G = 1750$ mm

Superelevation for equilibrium speed, $e = \frac{G V^2}{127 R}$

$$e = \frac{1750 \times 50^2}{127 \times 350} = 98.42 \text{ mm}$$

Cant Deficiency: Cant deficiency occurs when a train travels around a curve at a speed higher than the equilibrium speed. Cant deficiency is the difference between the actual cant provided and equilibrium cant necessary for the maximum permissible speed on a curve. Cant deficiency should be as low as possible and is limited due to following reasons:

- Higher discomfort to passengers due to higher cant deficiency
- Higher cant deficiency results in higher unbalanced centrifugal force and hence extra pressure and lateral thrust on the outer rails, requiring strong track and more fastening for stability.
- Side wear and creep of outer rails of the track are more due to higher cant deficiency. Maximum values of cant deficiency as prescribed on Indian Railways on BG.

Question: A 7 degree curve branches off from a 4 degree main curve in an opposite direction in the layout of a B.G. yard. If the speed of the branch line is restricted to 30 km/hr, determine the speed restriction on the main line. Assume permissible cant deficiency 75 mm. (40th BCS)

Solution:

Radius of curve, $R = \frac{1750}{D} = \frac{1750}{7} = 250$ m

$V = 30$ km/hr and $G = 1750$ mm

Superelevation for branch line, $e = \frac{G V^2}{127 R}$

$$e = \frac{1750 \times 30^2}{127 \times 250} = 49.60 \text{ mm}$$

Negative superelevation $= 49.60 - 75 = -25.40$ mm

Maximum superelevation can be provided on the main line $= 75 + 25.40 = 100.4$ mm

Radius of curve, $R = \frac{1750}{D} = \frac{1750}{4} = 437.50$ m

Therefore, speed for main line, $e = \frac{G V^2}{127 R}$

$$V = \sqrt{\frac{127 R e}{G}} = \sqrt{\frac{127 \times 437.50 \times 100.4}{1750}} = 56.45 \text{ km/hr}$$

Question: What are the different points that has to be considered in selecting a railway stations? A curve of 6^0 is situated on a B.G. line and a train with a total weight of 1200 tons it passing over it. Calculate the curve resistance? (35th BCS)

Solution:

A railway station is defined as any place on a railway line where traffic is booked and dealt with. Following factors should be considered while site selection for railway station:

1. Drainage: The proposed railway station site should be on a fairly leveled ground and it should be well drained.

2. Water Supply: There should be plentiful supply for water at the site of station.

3. Future Allowances: There should be sufficient land available for the purpose of future extensions along both sides

4. Gradient: The site should be such that permissible maximum gradients can be obtained without much difficulty. The vehicles may start moving with wind which is very hazardous.

5. Location or Horizontal Alignment: The location of station yards should be such that it is neither located near a curve nor on a curve.

6. Vertical Alignment: The train should not be situated in a sag but it should be on a summit.

7. Accessibility: The station yards should be such that it is easily accessible from city or town. There should be well developed and efficient transportation system which leads the people and their goods to station with much ease.

8. Visibility: The environment around the site selected for a station should be such that their exists clear and improved visibility for the drivers of trains. There should be certain enough arrangements made which improvements made which improves the visibility of a station.

9. Facilities: The site selected for the station should be such that for the passengers of trains, machinery works, garages, workshops etc.

For broad gauge, curve resistance = 0.0004 x degree of curve x weight of train
= 0.0004 x 6 x 1200 = 2.89 MT

Function of railway station

→ To load or off load the goods or parcels.
→ To control the movement of trains.
→ To enable the train to cross each other in case of single line section.
→ To enable the faster trains to overtake the slower trains.
→ To enable the locomotives to take fuel water or coal.
→ To attach or detach coaches or wagons to the train.
→ To entrain or detrain the passengers.
→ To collect food and water for the passenger.
→ To provide facilities for change of engines and crew/staff.

Mass rapid transit (MRT): Grade separated and segregated heavy rail system.

Forms of MRT

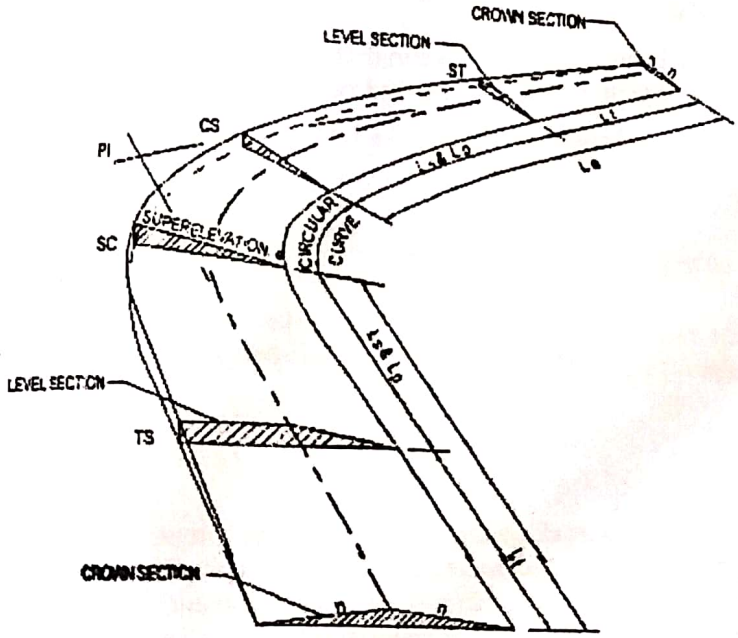
- Subway metro → under ground, most expensive to construct & run.
- At-grade metro → on ground, least expensive.
- Elevated metro → above ground or elevated.

Main advantages of MRT

→ Most reliable mode of transport.
→ Huge reidership potential (40,000 – 60,000 passenger/phpd)
→ It is very effective or strong congestion relieving tool.
→ Has enourmos potential to reduce over crowing at at-grade level.
→ Most importantly it is a demand responsive sustainable mode.

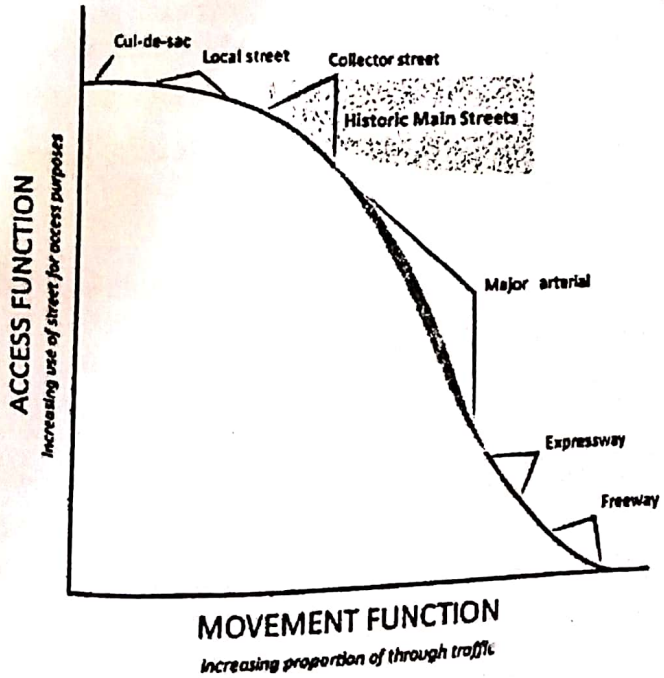
Question: Draw transition curve diagram of super elevation.
(BUET M. Sc. – 2017)

Solution:



Question: Draw Accessibility verses movement function diagram.
(PGCB – 2015, BUET M. Sc. – 2017, DTCA – 2018, BIWTA – 2019, DMTCL – 2019)

Solution:



Bus rapid transit (BRT): Bus rapid transit is a bus-based public transport system designed to improve capacity and reliability relative to a conventional bus system. Typically, a BRT system includes roadway that is dedicated to buses, and gives priority to buses at intersections where buses may interact with other traffic.

Question: Write down the six point of BRT Characteristics. (DSCC – 2019, TGTDCL – 2021)

Solution:

Bus Rapid Transit (BRT) is a high quality bus based transited system that delivers fast, comfortable and cost effective urban mobility through the provision of segregated right of way infrastructure. Six points of BRT system is given below,

- High capacity vehicles
- Dedicated lanes and alignment
- Quality stations
- Off-board fare collection
- Run buses very frequently
- In tunnels or subterranean structures
- Give buses their own lanes

Cycle Time and Number of Vehicles

Cycle time is the number of minutes needed to make a round trip on the route, including layover/recovery time. Cycle time is important for several reasons, including playing a part in the formula used for determining the number of vehicles needed to provide a given level of service on a route. Since cycle time equals the number of minutes needed to make a round trip, including the layover/recovery time, the scheduler determines the amount of time it takes to operate or "run" from one end of the route to the other and back, then adds layover/recovery time to yield the cycle time.

Layover/Recovery Time the time that transit vehicles should remain stationary at each terminal point. The layover/recovery time is used for resting, administrative purposes, and for maintaining proper headways.

Question: Distance of two compasses of a university is 5 km. Operation speed of bus is 30 kmph. Total time required for return whole distance is 10 min. What is the number of bus needed for 10 minute headway? (NPCBL – 2017)

Solution:

Assume, Layover time $= T_A = T_B = 2$ minute at either end of the route

Cycle time = Travel time + Layover time/Recovery time

$$\text{Cycle time} = \frac{2L}{V} + T_A + T_B = \frac{2 \times 5 \times 60}{30} + 2 + 2 = 24 \text{ minutes}$$

$$\text{Number of vehicle} = \frac{\text{Cycle time}}{\text{Headway}} = \frac{24}{10} = 2.4 = 3 \text{ unit}$$

m designed to
a BRT system
ctions where

Question: You have just designed a route that requires 65 minutes to travel round trip without any layover/recovery time at the route terminals. Your boss indicates that a layover/recovery period of at least 5% of the round trip time must be included at either end of the route. Adjust the cycle time to include the layover/recovery time and determine the number of vehicles that will be required to service this route if the required headway is 15 minutes

Solution:

Cycle time, C = Travel time + Layover time/Recovery time

$C = 65 + 65 \times (5\% + 5\%) = 71.5$ minutes

$$\text{Number of vehicle} = \frac{\text{Cycle time}}{\text{Headway}} = \frac{71.5}{15} = 4.76 = 5 \text{ vehicles}$$

Since the number of vehicles and the headway are set, we should solve for the new cycle time and determine what layover/recovery period is actually provided.

Cycle Time = Number of Vehicles x Headway
Cycle Time = 5 x 15 = 75 minutes

Since the actual travel time is 65 minutes and the total cycle time is 75 minutes, the total layover/recovery period for each bus is 10 minutes, or 5 minutes at each end. The layover/recovery period at each end is 7.69% of the travel time and the number of vehicles that are required is 5.

Traffic control device: Before a highway is opened to traffic, careful thought must be given to conveying to drivers clear and concise information concerning its proper and safe use. Such information is given primarily by traffic control devices (TCDs). They are of great help in regulating traffic by imparting message to the drivers about the need to stop, give way and limit their speeds.

Traffic control devices:

- Signs,
- Marking & Lighting,
- Signals.

Traffic Signs are mainly used to

- Inform drivers about the regulations,
- Adjust their lamp position, speed.
- Guide traffic flow.

Classification:

Mandatory Signs: They are meant to inform the road users of certain laws, regulations and prohibitions; the violation of these signs is a legal offense. Generally round.

Warning Signs: They are used to warn the hazardous conditions that exist or adjacent to the Roadway. The warning signs in the shape of equilateral triangle with one point upwards.

Question: Draw the following road signals a) No parking b) Roundabout c) No stopping d) Prohibited right turn (WASA – 2014)

Solution:

(a) No parking

(b) Roundabout

(c) No stopping

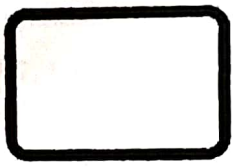
(b) Prohibited right turn

Question: The sign shape for (i) Mandatory sign (ii) Cautionary sign (iii) Information or Guide sign. (GTCL – 2016, TGTDCL – 2018)

Solution:

Circles
Mandatory

Triangles
warn



Rectangles
inform

Traffic Signal: Traffic signals are used to assign vehicular and pedestrian right-of-way. They are used to promote the orderly movement of vehicular and pedestrian traffic and to prevent excessive delay to traffic.

Types of Traffic Signal-

- Traffic control signals
- Pedestrian signal

Traffic control signals - They have three colored light glows facing each direction of traffic flow. RED light means to STOP, GREEN means to GO, YELLOW or AMBER means allows the CLEARANCE TIME.

Pedestrian Signals - They are meant to give the right way to pedestrian to cross a road during the "walk period" when the vehicular traffic shall be stopped by red or stop signal on the traffic signals of the road.

c) No stopping

Question: What are the advantages and disadvantages of traffic signals? (BCPCL – 2016, SGFCL – 2017)

Solution:

Advantages of traffic control signals on the road

- Provide for orderly movement of traffic;
- Increase traffic-handling capacity of an intersection;
- Reduce frequency and severity of certain types of crashes, especially right-angle collisions;
- They direct traffic on different routes without excessive congestion.
- They control the speed of vehicles on main as well as on secondary roads.
- Interrupt heavy traffic at intervals to permit other vehicles or pedestrians to cross.
- The provide economy over manual control at the intersection.

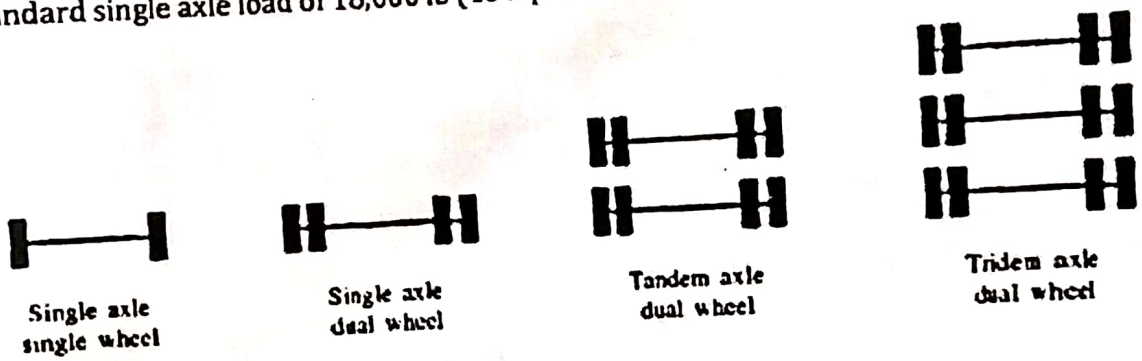
The disadvantage of traffic control signals on the road

- Traffic control signals may result in a re-entrant collision of vehicles;
- Excessive delay;
- Increased traffic congestion, air pollution and gasoline consumption;
- Disobedience of signals;
- Increased use of less-adequate streets to avoid traffic signals.

Wheel Load, Wheel Configuration, and Tyre Pressure

The weight of the vehicle is distributed among its axles, and the axles transmit the load to its wheels. Wheel load determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affect the stress distribution and deflection within a pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler. The concept of Equivalent Single Wheel Load (ESWL) is used to convert the equivalent effect due to dual wheels (or number of wheels with a given configuration) to a single wheel load. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth.

A vehicle can have a number of axles. A standard truck has two axles, namely the front and the rear. The weights of individual axle's arc called the axle load which may be assumed as approximately half the total weight of a standard truck. In practice, the weights of the rear and the front axles are not equal and they depend on the position of the load the vehicle carries. Generally for design purposes, it is the weight of the rear axle of a vehicle which is taken into account. A standard single axle load of 18,000 lb (18 kip or 80 KN) is assumed.



The ESWL is given by:

$$log_{10}\, ESWL = log_{10}\, P + \frac{0.301\, log_{10}\left(\frac{x}{d/2}\right)}{log_{10}\left(\frac{2S}{d/2}\right)}$$

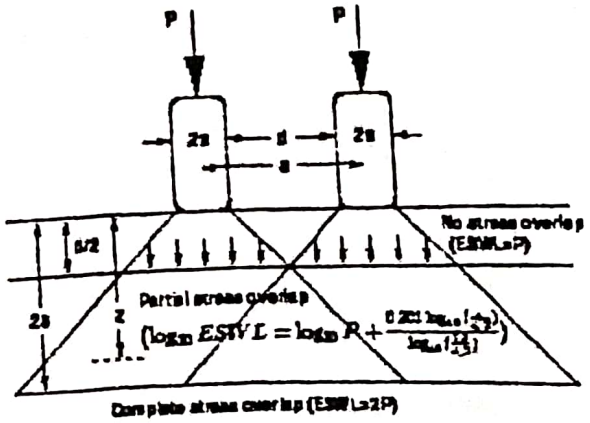


Figure: ESWL-Equal stress concept

Where P is the wheel load, S is the center to center distance between the two wheels, d is the clear distance between two wheels, and Z is the desired depth.

Types	In KN Unit	In Kip Unit
Single axle with single wheel	65	14.5
Single axle with dual wheel	80	18
Tandem axle with dual wheel	148	33
Tridem axle with dual wheel	224	50

Table: standard single axle load

The influence of traffic on pavement not only depend on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant.

Question: Find ESWL at depths of 5cm, 20cm and 40cm for a dual wheel carrying 2044 kg each. The center to center tyre spacing is 20cm and distance between the walls of the two tyres is 10cm.

Solution:

For desired depth z = 40 cm, which is twice the tyre spacing,
$ESWL = 2P = 2 \times 2044 = 4088\ KN$

For $z = 5$ cm, which is half the distance between the walls of the tyre,
$ESWL = P = 2044$ KN.

For z = 20 cm,

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}\left(\frac{x}{d/2}\right)}{\log_{10}\left(\frac{2S}{d/2}\right)}$$

$$\log_{10} ESWL = \log_{10} 2044 + \frac{0.301 \log_{10}\left(\frac{20}{10/2}\right)}{\log_{10}\left(\frac{2 \times 20}{10/2}\right)} = 3.511$$

Therefore, ESWL = antilog (3.511) = 3244.49 KN

Question: Determine ESAL for load repetition is 1.5 million and axle load is 120 KN. (WARPO – 2017)

Solution:

Load = 120 KN
Repetition = 1.5 million = 1.5×10^6

Equivalent axle load factor, $EALF = \left(\frac{\text{Axle load}}{\text{Standard axle load}}\right)^4 = \left(\frac{120}{80}\right)^4 = 5.0625$

ESAL = EALF x No. of repetition = $5.0625 \times 1.5 \times 10^6 = 7.59$ million

Question: A two way two lane road ADT is 4000. If the commercial vehicle is 45% and load 27 kip. Calculate the ESAL for commercial vehicle in one direction. (ERL – 2017, MPL – 2017, JOCL – 2018)

Solution:

Commercial vehicle in one direction $= \frac{4000 \times 45}{2 \times 100} = 900$

Equivalent axle load factor, $EALF = \left(\frac{\text{Axle load}}{\text{Standard axle load}}\right)^4 = \left(\frac{27}{18}\right)^4 = 5.0625$

Total $ESAL = 900 \times 5.0625 = 4556.25$

Question: Axle load of 27 kip and 36 kip are repeated 30 and 15 times respectively on pavement of 24 hours. What will be the Equivalent Single Axle Load (ESAL) in a year? (WASA – 2017)

Solution:

Assume, Standard axle load = 18 k (Single axle with dual wheel)

ESAL for 27 k load = EALF x No. of repetition $= \left(\frac{27}{18}\right)^4 \times 30 = 151.875$

ESAL for 36 k load = EALF x No. of repetition $= \left(\frac{36}{18}\right)^4 \times 30 = 240$

Total ESAL = 151.875 + 240 = 391.875 k

ESAL in a year = 391.875 x 365 = 143034.375 = 0.143 MSA

Question: A 36 kip axle load is repeated 1000 times a day. What will be the number of standard axles for this axle load in a year? (PGCB – 2019)

Solution:

Assume, Standard axle load = 18 k (Single axle with dual wheel)

ESAL for 36 k load = EALF x No. of repetition $= \left(\frac{36}{18}\right)^4 \times 1000 = 16000$

ESAL in a year = 16000 x 365 = 143034.375 = 5.84 MSA

Tyre contact pressure: The tyre contact pressure is the pressure exerted by the tyre on the ground. The tyre contact pressure could be more than, equal to, or less than the tyre pressure but generally it is assumed to be equal to the tyre pressure and uniform in distribution.

Question: Two closely separated wheels of load 20.5 KN each and tyre pressure 0.7 MPa are acting on a pavement section. If the two wheels are replaced by a single wheel with the same tyre pressure, calculate the radius of the tyre imprint (idealized as circle) of the single wheel. (BPDB - 2016)

Solution:

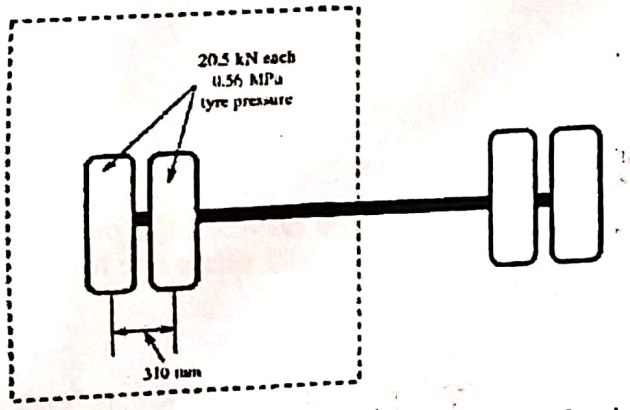
The total load acting on pavement is = 2 x 20.5 KN = 41 KN

Tyre pressure = 0.7 MPa

If the radius of the equivalent single wheel is r, then

$\pi r^2 (0.7 \times 10^6) = 41 \times 10^3$

$r = 0.136$ m



Question: Two close wheel imparted 20.5 KN load on each road. The applied pressure is 0.7 Mpa. If the two wheel is replaced by a single wheel of same property, then find out the imparted effective diameter on soil (by considering circular imparted effect) by the single wheel. (BPDB – 2016, CPGCBL – 2018)

Solution:

We know, $P = \frac{F}{A}$

$\frac{\pi D^2}{4} = \frac{F}{P} = \frac{2 \times 20.5 \times 10^3}{0.7 \times 10^6}$

$\therefore D = 0.273$ m

Question: The radius of a tyre imprint is approximated to a circle of 150 mm. What is the maximum loading duration on a particular point of pavement by a truck moving at a speed of 60 kmph? (RPGCL – 2017, GTCL – 2018)

Solution:

Duration is the time required to cross the diameter of the tyre imprint.

Therefore, the time required is $= \frac{2 \times 150}{\frac{60 \times 10^6}{3600}} = 0.018\ s$

Question: A plate load test is carried out on subgrade soil using a 300 mm radius rigid plate. A load of 5 tonnes resulted in a deflection of 1.2 mm. Determine the elastic modulus of the soil, if the poisson's ratio is 0.5.

Solution:

The pressure applied is $= \frac{5 \times 10^4}{\pi \times 300^2} = 0.176\ N/mm^2$

We know, $\delta = 1.18 \frac{p\,a}{E}$

$$1.2 = \frac{1.18 \times 0.176 \times 300}{E}$$

$$E = 52.16\ MPa$$

Skid resistance: The skid resistance force generated due to interaction between the pavement and locked tyre when the vehicle is moving. Skid number is defined as 100 times the frictional coefficient between the wheel tyre and the pavement surface.

Skid number = 100 x coefficient of friction

Question: A force of 25 KN is required to pull two locked wheels at a speed of 40 kmph, loaded with 50 KN of weight. Calculate the skid number.

Solution:

$$\text{Skid number} = 100 \times \frac{25}{50} = 50$$

Traffic Calculation: The design traffic in terms of the cumulative standard axle is obtained using the equation,

$$N = 365 \times A \times \frac{(1 + r)^n - 1}{r} \times VDF \times LDF$$

N = design traffic
A = Number of expected vehicle
r = growth rate
VDF = vehicle damage factor
LDF = lane distribution factor.

m. What is the
speed of 60

Question: The pavement will be a two-lane road with a single carriageway. The traffic expected is 500 commercial vehicles per day in both the directions with average vehicle damage factor of 1.9. The lane distribution factor is 0.75 and the assumed design life of the pavement is 12 years. Calculate the design traffic.

Solution:

The lane distribution factor, as per recommendation, is chosen as 0.75. Traffic growth factor is assumed as 7.5%. The value of cumulative standard axle repetitions is calculated,

$$N = 365 \times 500 \times \frac{(1 + 0.075)^{12} - 1}{0.075} \times 1.9 \times 0.75 = 4.79 \text{ msa}$$

Angularity number: The angularity of aggregates is the converse of roundness. In this case, oven-dried aggregates of appropriate size (passing through sieve size x and retained by sieve size y). The aggregates are filled in three layers in a metal cylinder of specified dimensions closed at one end. A tamping rod is used to apply 100 blows to each layer while filling, and the top surface is levelled. Tamping should be done carefully to avoid breaking of aggregates as otherwise they are adjudged unsuitable for angularity testing. The angularity number (AN) is determined as,

$$AN = 67 - \frac{W_a}{W_w G_a} \times 100$$

Where, W_a is the weight of the aggregate mass.
W_w is the weight of water occupying the mould
G_a is the specific gravity of the aggregates.

The number, 67, is a reference number which signifies the maximum attainable density level (100 minus voids) with spherical aggregates of the same size as that of the aggregates under test. The more angular the shape of the aggregates, the more will be voids, resulting in an increase in the angularity number. The aggregates suitable for bituminous pavement construction should generally be angular in shape for better interlocking.

Question: Calculate the angularity number for the aggregate sample from the following data relative density of the aggregate 2.8, mass of water required to fill the cylinder 2500 gm, mass of cylinder filled with compacted aggregate 5150 gm and mass of cylinder 1100 gm.
(PGCB – 2015, DNCC – 2016, BPDB – 2018)

Solution:

Here, W = Weight of aggregate = 5150 - 1100 = 4050 gm.

C = Weight of water to fill the cylinder = 2500 gm.

G_s = Specific gravity of the material = 2.8

We know, Angularity Number $= 67 - \frac{100\,W}{C\,G_s}$

$$= 67 - \frac{100 \times 4050}{2500 \times 2.8} = 9.14 = 9$$

Intersections: An intersection is an area, shared by two or more roads, whose main function is to provide for the change of route directions. Intersections vary in complexity from a simple intersection, which has only two roads crossing at a right angle to each other, to a more complex intersection, at which three or more roads cross within the same area. Intersections are classified into three general categories: grade-separated without ramps, grade-separated with ramps (commonly known as interchanges) and at-grade.

The purpose of the intersection design is primarily to modify the zone of conflict (by either removing it or reducing it to a large extent) with the twin objectives of improving the safety and efficiency (in terms of delay to vehicles) of the intersection.

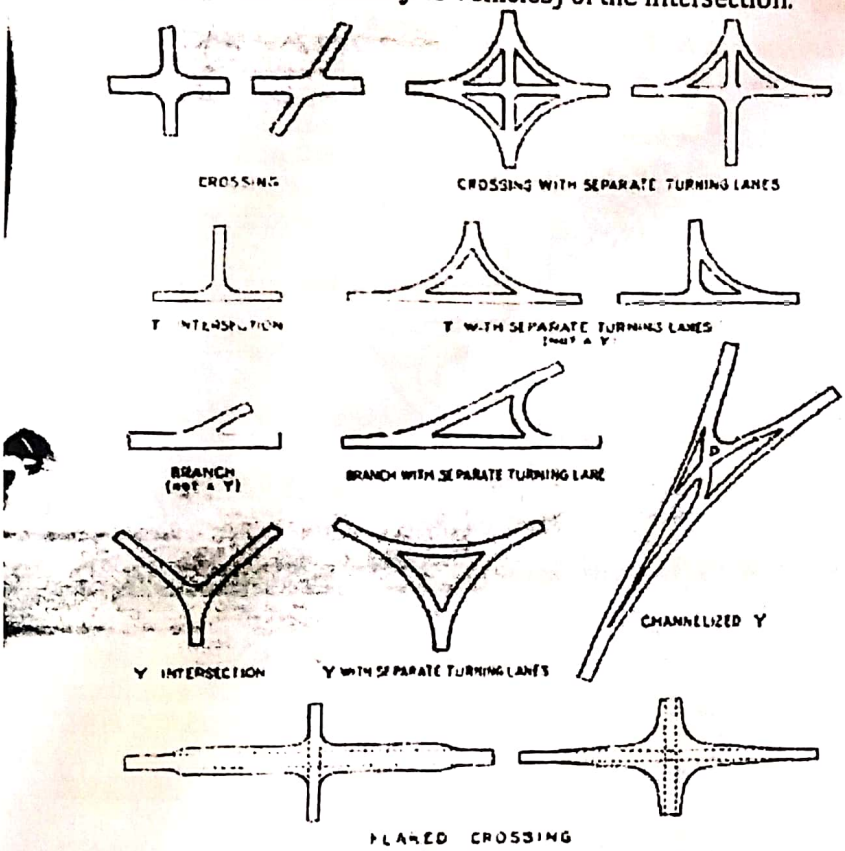


FIGURE 9-1 Types of intersections at grade. (Courtesy Federal Highway Administration.)

Interchanges: As stated earlier, interchanges are grade separated intersections (commonly referred to as flyovers in India) where the conflict in traffic flow is resolved by duplicating the intersecting space at various heights. Grade separated intersections obviously need to have roads which connect the intersecting roads. These connecting roads are called ramps.

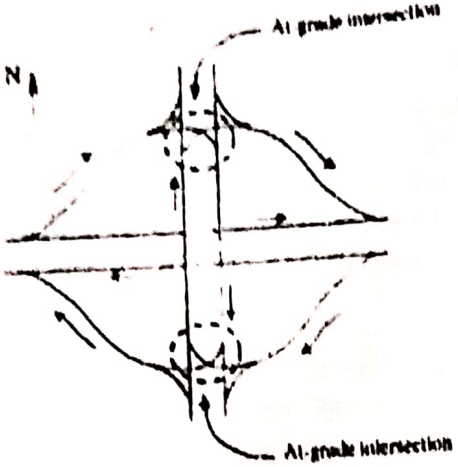


Figure Diamond interchange

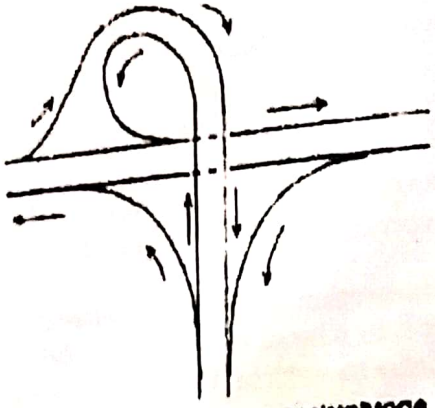


Figure Trumpet interchange.

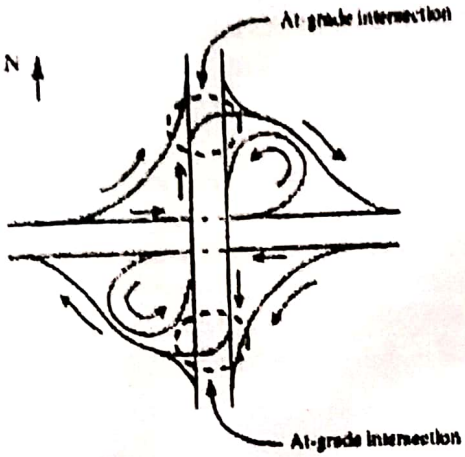


Figure Partial clover-leaf interchange.

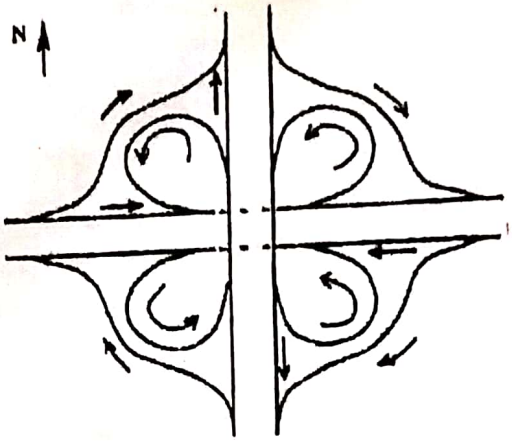
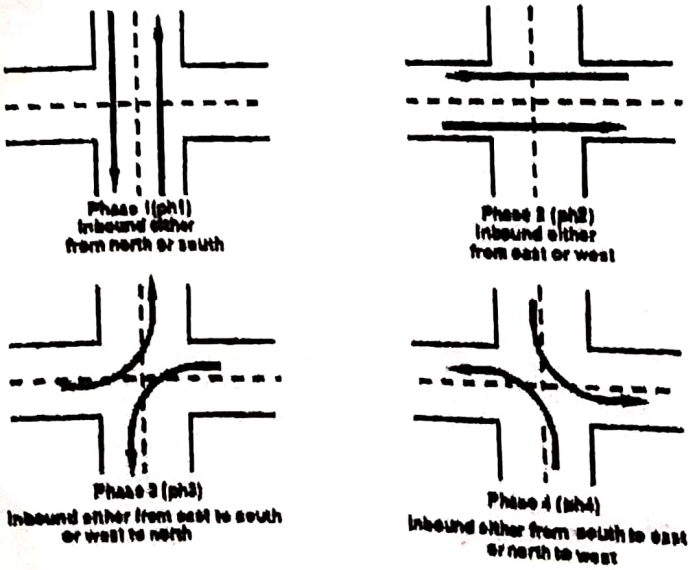


Figure Clover-leaf interchange.

Question: 4 leg intersection এর 4 phase signal এর জন্য traffic movement দেখান করুন। (HED – 2020)

Solution:



Yellow interval or Clearance Interval

Minimum clearance Interval, $t_{min} = \delta + \frac{W + L}{u_0} + \frac{u_0}{2a}$

If the effect of grade is added,

$$t_{min} = \delta + \frac{W + L}{u_0} + \frac{u_0}{2\,(a + Gg)}$$

δ = Perception reaction time (sec)
a = Constant rate of braking deceleration (ft/sec²)
G = Grade of the approach
g = Acceleration due to gravity (32.2 ft/sec²)

Safety considerations indicate the use of no less than 3 seconds of clearance interval. In this case, the clearance interval is set equal to the yellow indication

Question: Vehicles approaching an intersection with 60 km/h have to cross a 12 m street. If the average reaction time of a driver is 1.5 seconds, the deceleration rate is 3 m/sec² , the average length of a vehicle is 6 m, determine the clearance interval required. If the desired yellow interval is 4 seconds, should there be an all red indication?

Solution:

$u_0 = \frac{60 \times 1000}{3600} = 16.7$ m/sec

Minimum clearance Interval, $t_{min} = \delta + \frac{W + L}{u_0} + \frac{u_0}{2a}$

$t_{min} = 1.5 + \frac{12 + 6}{16.7} + \frac{16.7}{2 \times 3} = 5.4$ sec

Using a 4 second yellow, the remaining 1.4 seconds should be accommodated using an all red indication.

Question: Determine the minimum yellow interval at an intersection whose width is 40 ft if the maximum allowable speed on the approach roads is 30 mi/h. Assume average length of vehicle is 20 ft. (DNCC – 2020)

Solution:

We must first decide on a deceleration rate. AASHTO recommends a deceleration rate of 11.2 ft /sec². Assuming this value for a and taking d as 1.0 sec, we obtain

Minimum clearance Interval, $t_{min} = \delta + \frac{W + L}{u_0} + \frac{u_0}{2a}$

$$t_{min} = 1.0 + \frac{40 + 20}{30 \times 1.47} + \frac{30 \times 1.47}{2 \times 11.2}$$

In this case, a yellow period of 4.5 sec will be needed.

Lost Time: Traffic leaving the approach of an intersection at the beginning of the green indication is not discharged at full rate, since vehicles need to accelerate and drivers do not respond instantly to the change of signal indication. Similarly, at the beginning of the yellow interval vehicles will start decelerating and the discharge rate will drop. Assuming that there are enough vehicles in line to maintain a maximum constant discharge rate throughout the green interval, the times when the discharge rate drops is called lost time.

Lost time, $t_L = G_{ai} + y_i - g_{ei}$

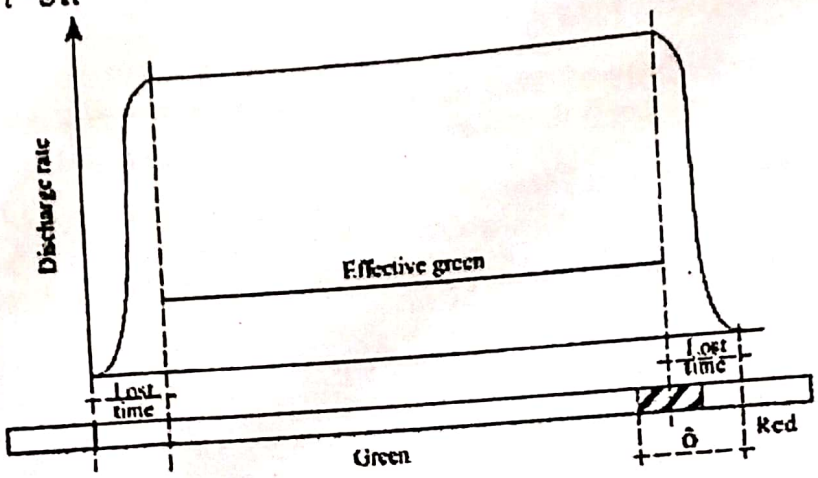


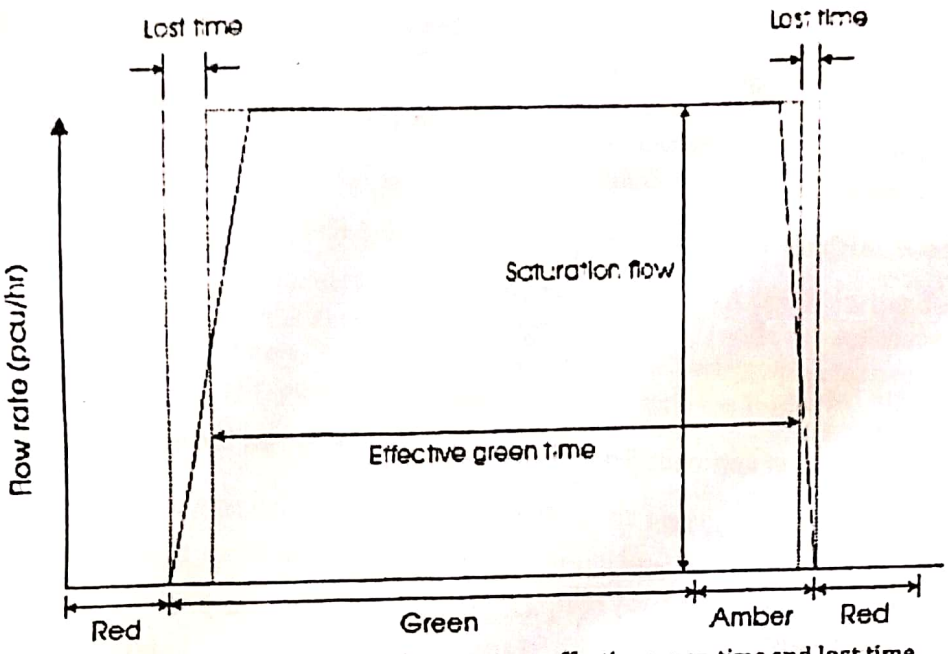
Figure: Lost time concept at signalized intersections

Effective green time

Effective green time is the actual time available for the vehicles to cross the intersection. It is the sum of actual green time (G_{ai}) plus the yellow minus the applicable lost times. This lost time is the sum of start-up lost time (l_1) and clearance lost time (l_2) denoted as t_L. If yellow time for phase i is Y_i thus effective green time for phase i can be written as,

$$g_{ei} = G_{ai} + y_i - l_i$$

Normally, the lost time is assumed to be taken as equal to 2 seconds, with the amber time set at 3 seconds. Effective green time is thus equal to actual green time plus 1 second.



Diagrammatic representation of actual green time, effective green time and lost time.

Lane capacity

The ratio of effective green time to the cycle length (g_{el}/C) is defined as green ratio. We know that saturation flow rate is the number of vehicles that can be moved in one lane in one hour assuming the signal to be green always. Then the capacity of a lane can be computed as,

$$C_i = S_i \frac{g_{ei}}{C}$$

Where C_i the capacity of lane in vehicle per hour, S_i is the saturation flow rate in vehicle per hour per lane, C is the cycle time in seconds.

Question: Let the cycle time of an intersection is 60 seconds. The green time for a phase is 27 seconds and the corresponding yellow time is 4 seconds. If the saturation headway is 2.4 seconds per vehicle, the startup lost time is 2 seconds per phase and the clearance lost time is 1 second/phase, find the capacity of the movement per lane?
(BWDB – 2018, BUET M.Sc – 2018, NHA – 2020)

Solution:

Total lost time, $l_i = 2 + 1 = 3$ seconds

Saturation flow rate, $S_i = \frac{3600}{h} = \frac{3600}{2.4} = 1500$ vehicle per hour

Effective green time, $g_{ei} = G_{ai} + y_i - l_i = 27 + 4 - 3 = 28$ seconds

Capacity of the green phase, $C_i = \frac{g_{ei}}{C} \times S_i = \frac{28}{60} \times 1500 = 700$ vehicle per hour per lane

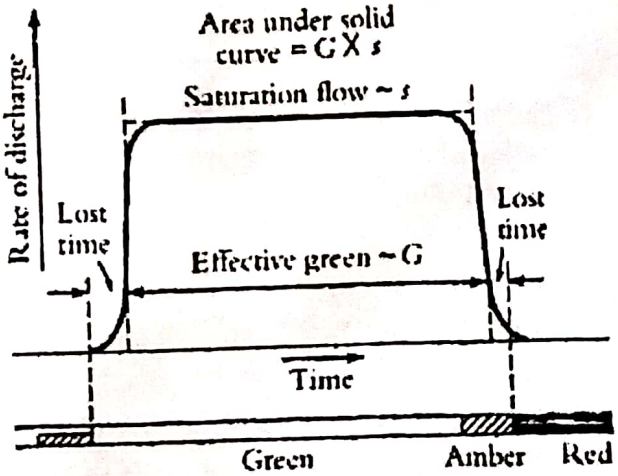
Cycle time

Cycle time is the time taken by a signal to complete one full cycle of iterations. i.e. one complete rotation through all signal indications. It is denoted by C.

Cycle length by Webster method,

$$C_0 = \frac{1.5\,L + 5}{1 - \sum_{i=1}^{\varphi_i} Y_i}$$

C_0 = optimum cycle length (sec)
L = total lost time per cycle (sec)
Y_i = maximum value of the ratios of approach flows to saturation flows for all lane groups using phase i (i.e. $\frac{q_{ij}}{s_j}$)
φ = number of phases
q_{ij} = flow on lane groups having the right of way during phase i
S_j = saturation flow on lane group j



Discharge of Vehicles at Various Times during a Green Phase

Total lost time, $L = \sum_{i=1}^{\varphi_i} l_i + R$

Where, R = Total all red time during the cycle

Total effective green time, $g_{te} = C_0 - L$

Effective green time for each phase, $g_{ei} = \frac{Y_i}{Y_1 + Y_1 + \ldots Y_\varphi} g_{te}$

Actual green time for each phase,

$G_{a1} = g_{e1} + l_1 - y_1$

$G_{a2} = g_{e2} + l_2 - y_2$

$G_{a\varphi} = g_{e\varphi} + l_\varphi - y_\varphi$

Question: Determine the total enter green time for two phase traffic having cycle time C = 66s; Green time for NS direction G_{NS} = 24s and for EW direction G_{EW} = 27s. (PGCL – 2017)

Solution:

Cycle time = $G_{NS} + G_{EW}$ + total inter green time

Total inter green time = Cycle time – $G_{NS} - G_{EW}$ = 66 – 24 – 27 = 15 sec

Question: The average normal flow of traffic on cross roads A and B during design period are 400 and 250 PCU per hour, the saturation flow values on these roads are estimated as 1250 and 1000 PCU per hour respectively. The all red time required for pedestrian crossing is 12 sec. Design two phase traffic signal with pedestrian crossing by Webster's method.

Solution:

Given, normal flow on roads A & B: $q_a = 400$ PCU/hr and $q_b = 250$ PCU/hr

Saturation flow, $S_a = 1250$ PCU/hr and $S_b = 1000$ PCU/hr

All red time, $R = 12$ sec & number of phase, $n = 2$

$$y_a = \frac{q_a}{S_a} = \frac{400}{1250} = 0.32 \text{ and } y_a = \frac{q_b}{S_b} = \frac{400}{1250} = 0.25$$

$$Y = y_a + y_b = 0.32 + 0.25 = 0.57$$

Total lost time, $L = 2n + R = 2 \times 2 + 12 = 16$ sec

Optimum cycle time, $C_0 = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 16 + 5}{1 - 0.57} = 67.4$ say 67.5 sec

$$G_a = \frac{y_a}{Y}(C_0 - L) = \frac{0.32}{0.57}(67.5 - 16) = 29$$

$$G_a = \frac{y_b}{Y}(C_0 - L) = \frac{0.25}{0.57}(67.5 - 16) = 29$$

Provide an all red time, R for pedestrian crossing = 12 sec

Providing Amber times of 2 sec each for clearance,

Total cycle time = 29 + 22.5 + 12 + 2 + 2 = 67.5 sec

Logit Models

An alternative approach used in transportation demand analysis is to consider the relative utility of each mode as a summation of each modal attribute. Then the choice of a mode is expressed as a probability distribution. For example, assume that the utility of each mode is

$$U_x = \sum_{i=1}^{n} a_i X_i$$

U_x = Utility of mode x
n = number of attributes
X_i = attribute value (time, cost and so forth)
a_i = coefficient value for attributes i (negative, since the values are disutilities)

If two modes, auto (A) and transit (T), are being considered, the probability of selecting the auto mode A can be written as

$$P_{(A)} = \frac{e^{UA}}{e^{UA} + e^{UT}}$$

Question: If utilities for auto, bus and walk are 0.47, -1.525 and -2.5 respectively. Determine their mode share probabilities using a basic logit model. (DTCA – 2018)

Solution:

$P_{Auto} = 0.47$
$P_{Bus} = -1.525$
$P_{Walk} = -2.5$

$$P_{Auto} = \frac{e^{U.auto}}{e^{U.auto} + e^{U.bus} + e^{U.walk}} = \frac{e^{0.47}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = \frac{1.599}{1.899} = 0.842$$

$$P_{Bus} = \frac{e^{U.bus}}{e^{U.auto} + e^{U.bus} + e^{U.walk}} = \frac{e^{-1.525}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = \frac{0.217}{1.899} = 0.114$$

$$P_{Walk} = \frac{e^{U.walk}}{e^{U.auto} + e^{U.bus} + e^{U.walk}} = \frac{e^{-2.5}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = \frac{0.0820}{1.899} = 0.043$$

Question: The utility functions for auto and transit are as follows.
Auto: $U_A = -0.46 - 0.35T_1 - 0.08T_2 - 0.005C$
Transit: $U_T = -0.07 - 0.05T_1 - 0.15T_2 - 0.005C$

Where
T_1 = total travel time (minutes)
T_2 = waiting time (minutes)
C = cost (cents)

The travel characteristics between two zones are as follows:

	Auto	Transit
T_1	20	30
T_2	8	6
C	320	100

Solution:

Use the logit model to determine the percent of travel in the zone by auto and transit.

$U_A = -0.46 - 0.35 \times 20 - 0.08 \times 8 - 0.005 \times 320 = -9.70$

$U_T = -0.07 - 0.05 \times 30 - 0.15 \times 6 - 0.005 \times 100 = -2.97$

$$P_A = \frac{e^{UA}}{e^{UA} + e^{UT}} = \frac{e^{-9.7}}{e^{-9.7} + e^{-2.97}} = 0.965$$

$$P_T = \frac{e^{UT}}{e^{UA} + e^{UT}} = \frac{e^{-2.97}}{e^{-9.7} + e^{-2.97}} = 0.034$$

CBR test: CBR test stands for California Bearing Ratio Test. This test was originally developed by the California Division of Highways prior to the World War II. The CBR test procedure is very popular in many countries for determining the subgrade strength of the soil, because of its simplicity and low cost for conducting the test. The test is arbitrary and the results give an empirical strength number which may not be directly related to fundamental properties governing the strength of soils such as cohesion, angle of internal friction, etc. For CBR test on the remoulded sample, soil is compacted in the CBR mould (inner diameter 150 mm) with optimum moisture content (determined from standard or modified proctor test). The material should pass through the 20 mm sieve. The larger size materials, if present, are replaced by an equal amount of material passing through the 20 mm sieve and retained by the 4.75 mm sieve.

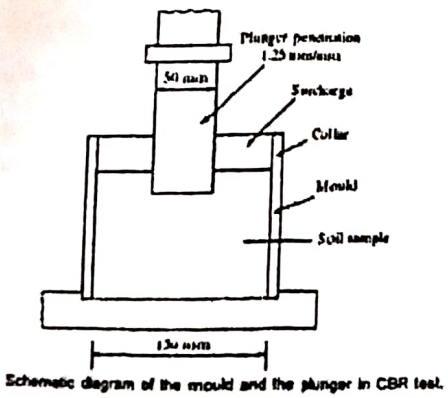
In the CBR test, a plunger of diameter 50 mm penetrates the mould of diameter 150 mm, at the rate of 1.25 mm/min where the soil sample is placed (see Figure 10.3). The load values corresponding to the penetration values of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10, and 12.5 mm are measured and plotted on a graph.

The standard aggregates are the aggregates from California on which the CBR test was actually evolved and the values of the pressure sustained by them are 70 kg/cm² and 105 kg/cm² for 2.5 mm and 5.0 mm penetration respectively. The CBR generally selected is at 2.5 mm penetration. If the CBR at 5 mm is greater than at 2.5 mm, the test should be repeated. If check test gives the similar values, then CBR at 5 mm is used.

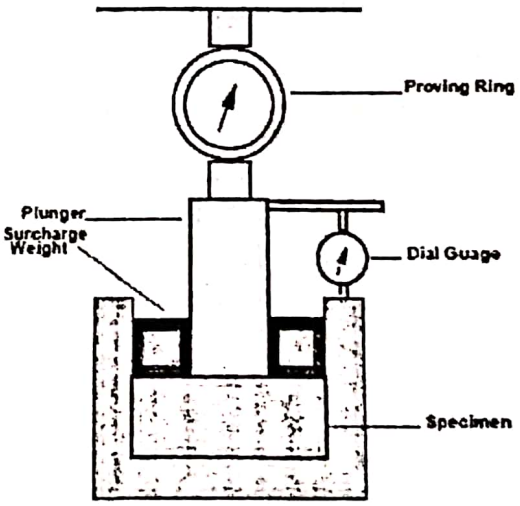
$$\text{CBR} = \frac{\text{pressure sustained by the specimen at 2.5 mm or 5 mm penetration}}{\text{pressure sustained by the standard aggregates}}$$

Standard load value

Penetration, mm	Standard loading, kg	Unit standard stress, kg/cm^2
2.5	1370	70
5.0	2055	105
7.5	2630	134



Schematic diagram of the mould and the plunger in CBR test.



Question: CBR test কেন গুরুত্বপূর্ণ ব্যাখ্যা করুন? Soaked এবং Un-soaked CBR এর পার্থক্য লিখুন।
(LGED – 2019)

Solution:

CBR test: The California Bearing Ratio or CBR test is performed to evaluate the strength of soil subgrades and base course materials. It's performed for materials used in highways, airport runways and other pavements.

Why CBR test is important: In roads, all vehicular loads are transferred to subgrade soil. CBR value gives an indication of the strength of subgrade soil. So, California Bearing Ratio or CBR property of soil is extremely important in road construction because this CBR value is an indication of whether or not the soil can bear such load & also helps in deciding the thickness of various pavements layers so that design is safe.

Soaked & Un-soaked CBR difference:

Un-Soaked CBR: When the CBR test is performed to evaluate the strength of subgrades materials under the condition of un-soaked sample or normal field conditions sample, that time the value of CBR is known as soaked CBR.

Soaked CBR: Pavement material is not always remains dry. Considering weakest condition, when it is in soaked condition after rainfall the Soaked CBR test is performed. When the CBR test is performed to evaluate the strength of subgrades materials under the condition of un-soaked sample, that time the value of CBR is known as soaked CBR.

Soaked CBR test	Un-soaked CBR test
CBR test in soaked condition.	CBR test in un-soaked condition.
Performed to simulate the worst conditions in the field.	Performed to simulate the normal conditions in the field.
Submerged in water for about 4 days (96 hours) before testing.	Water content is likely equal after the construction of the pavement.
CBR value will generally be lower for soaked soil.	CBR value will generally be higher for dry soil.

Question: CBR tests were conducted on specimen for a soil determine the CBR value of the soil if 100 division of load dial represents 210 kg load in celebrations chart to ring.

Penetration, mm	Dial reading
0	0
0.5	10
1	18
1.5	26
2	33
2.5	38
3	42
4	48
5	55

Load dial reading at 2.5 mm penetration is 38

$$\text{Load at 2.5 mm} = \frac{210}{100} \times 38 = 79.8 \text{ kg}$$

$$\text{Load at 5 mm} = \frac{210}{100} \times 55 = 115.5 \text{ kg}$$

$$\text{CBR at 2.5 mm} = \frac{79.8}{1370} \times 100 = 5.82\%$$

$$\text{CBR at 5 mm} = \frac{115.5}{2055} \times 100 = 5.62\%$$

So, selected CBR is 5.82%

Question: What is improved subgrade? Why it is provided in Bangladesh? (CPGCBL – 2015)

Solution:

When the subgrade material is not adequate to support the necessary loads, then additional work should be done to make the material suitable for the construction. Normally, subgrade material is improved by installing geotextiles. They are used to prevent mixing of soft or inadequate soil that might affect the structural capacity of the subgrade. Geotextiles must have specific mechanical and hydraulic properties to ensure they have the right characteristics for their intended use.

- Provide strength and support to the overlying pavement
- Provide drainage and frost protection
- Prevent settlements to pavement and slab on grade
- Be reusable if you decide to change your pavement surface

Question: Define and describe the design of concrete Mix and mention the different method of designing of concrete mixes. (RAJUK – 2016)

Solution:

Some of the commonly used mix design methods are,
- Marshal method
- Hubbard-filed method
- Hveem method
- Smith traxial method

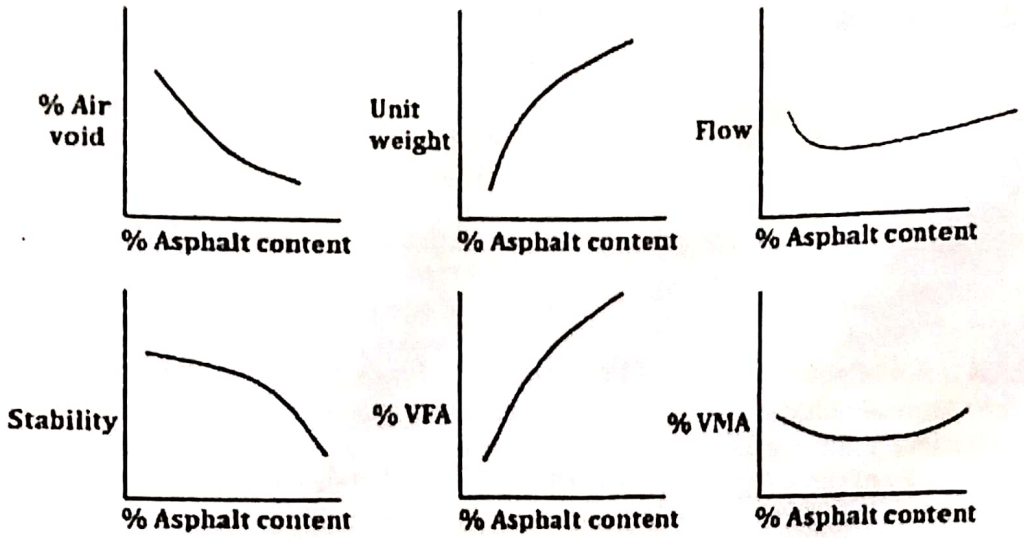
Question: What are the methods of grading asphalt? (PGCB – 2017)

Solution:

Four methods of grading of asphalt:
- Performance grading
- Penetration grading
- Viscosity grading
- Viscosity of aged residue grading

Question: Draw qualitative test property curves for hot mix design data by Marshall Method. (BUET M.Sc.-2013, 2014, WRGCL-2014, BWDB-2014, PGCB-2015, BPDB-2015, BCIC-2017, PGCB-2018, DTCA-2018, DMRTP-2018, BPDB-2018, DESCO-2019, SGFL-2020)

Solution:



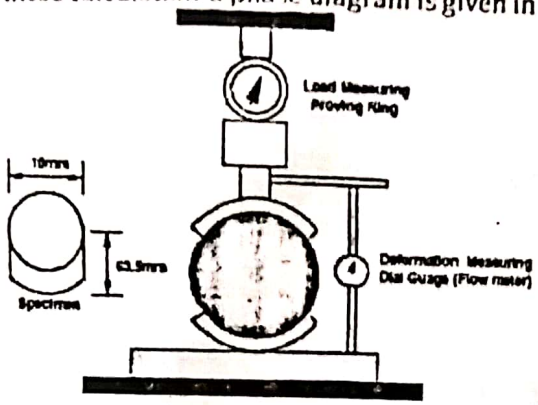
Mix design: Mix design is an economical blend & grading of aggregate and asphalt to obtain better stability and durability. The objective of dry mix design is to determine the amount of various sizes of mineral aggregates to use to get a mix of maximum density. The dry mix design involves three important steps, viz. selection of aggregates, aggregates gradation, and proportion of aggregates.

Objective: The objectives of asphalt paving mix design are to select and proportion materials to produce a mix that has,

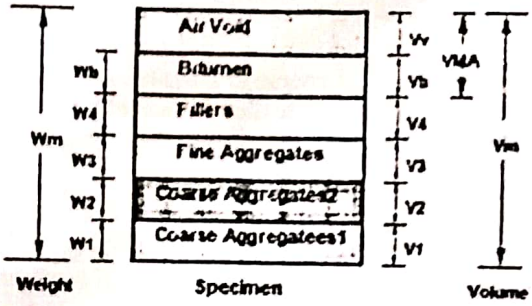
- Sufficient asphalt to ensure durable pavement.
- Sufficient mix stability to prevent distortion and displacement.
- Sufficient workability to ensure efficient placement.
- Sufficient voids on the total compacted mix to allow for a slight amount of additional compaction under traffic and a slight amount of asphalt expansion due to temperature increases without flushing, bleeding, and loss of stability.
- For surface mixes, proper aggregate texture and hardness to provide sufficient skid resistance in unfavorable weather conditions.

Marshall Mix design: The mix design (wet mix) determines the optimum bitumen content. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

Properties of the mix: The properties that are of interest include the theoretical specific gravity G_t, the bulk specific gravity of the mix G_m, percent air voids V_v, percent volume of bitumen V_b, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. To understand these calculation a phase diagram is given in Figure.



Marshall Test setup



Phase diagram of a bituminous mix

Theoretical specific gravity of the mix G_t

Theoretical specific gravity G_t is the specific gravity without considering air voids and is given by

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

Where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of fine aggregate, G_3 is the apparent specific gravity of filler and G_b is the apparent specific gravity of bitumen,

Bulk specific gravity of mix G_m

The bulk specific gravity or the actual specific gravity of the mix G_m is the specific gravity considering air voids and is found out by:

$$G_m = \frac{W_m}{W_m - W_w}$$

Where, W_m is the weight of mix in air, W_w is the weight of mix in water, Note that $W_m - W_w$ gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

Air voids percent V_v

Air voids V_v is the percent of air voids by volume in the specimen and is given by:

$$V_v = \frac{(G_t - G_m)\,100}{G_t}$$

Where, G_t is the theoretical specific gravity of the mix and G_m is the bulk or actual specific gravity of the mix given by equation.

Percent volume of bitumen V_b

The volume of bitumen V_b is the percent of volume of bitumen to the total volume and given by:

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_b}{G_m}}$$

Where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix. W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix given by equation.

Voids in mineral aggregate VMA

Voids in mineral aggregate VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen and is calculated from

$$VMA = V_v + V_b$$

Where, V_v is the percent air voids in the mix, given by equation and V_b is percent bitumen content in the mix, given by equation.

Voids filled with bitumen VFB

Voids filled with bitumen VFB is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

$$VFB = \frac{V_b \times 100}{VMA}$$

Where, V_b is percent bitumen content in the mix, given by equation and VMA is the percent voids in the mineral aggregate, given by equation.

Question: The specific gravities and weight proportions for aggregate and bitumen are as under for the preparation of Marshall Mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero, find V_v, V_b, VMA and VFB.

Item	A1	A2	A3	A4	B
Weight (gm.)	825	1200	325	150	100
Sp. Gr	2.63	2.51	2.46	2.43	1.05

Solution:

$$G_t = \frac{W_1 + W_2 + W_3 + W_4 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4} + \frac{W_b}{G_b}} = \frac{825 + 1200 + 325 + 150 + 100}{\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43} + \frac{100}{1.05}} = 2.406$$

$$G_m = \frac{W_m}{W_m - W_w} = \frac{1100}{475} = 2.316$$

$$V_v = \frac{(G_t - G_m)\,100}{G_t} = \frac{(2.406 - 2.316)\,100}{2.406} = 3.741\%$$

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_4 + W_b}{G_m}} = \frac{100}{1.05} \times \frac{2.316}{1600} = 8.483\%$$

$$VMA = V_v + V_b = 3.741 + 8.483 = 12.224\%$$

$$VFB = \frac{V_b \times 100}{VMA} = \frac{8.483 \times 100}{12.224} = 69.39\%$$

Question: The following materials with given masses are used to produce a batch of concrete. What is the volume of concrete if the air content is 3%? (Air content is the volume of air expressed as a percentage of the concrete volume) (BB AD – 2018)

Materials	Cement	Water	SSD (FA)	SSD (CA)
Mass (kg)	279	166	760	1044
SP. Gravity	3.15	1.00	2.60 (bulk SSD)	2.63 (bulk SSD)

Solution:

Material	Mass, kg	Specific gravity	Absolute density, kg/m³	Absolute volume, m³
Cement	279	3.15	3150	0.089
Water	166	1.00	1000	0.166
SSD, fine aggregate	760	2.60	2600	0.292
SSD, Coarse aggregate	1044	2.63	2630	0.397
			Total absolute volume =	0.944 m³

Volume of the concrete V_c is the summation of the absolute volume and the volume of the air V_a.

$V_c = 0.944 + V_a$

By definition of air content, $V_a = 0.03\,V_c$

So $V_c = 0.944 + 0.03\,V_c$

Therefore, $0.97\,V_c = 0.944$ and $V_c = 0.944/0.967 = 0.973$ m³

Question: Specific gravity of cement, CA & FA are 2.9, 2.67 & 2.6. Air content is 2%.
(*a*) Find the unit weight of CA.
(*b*) W/C ratio,
(*c*) unit weight of concrete
(*d*) If water is increased what will be the effect on compressive strength and workability.

Weight (kg)			
Water	Cement	CA	FA
187	397	-	636

(Combined Bank – 2020)

Solution:

(*a*) Volume of water, $V_w = \frac{W_w}{G_s \gamma_w} = \frac{187}{1 \times 1000} = 0.187 \text{ m}^3$

Volume of cement, $V_c = \frac{W_c}{G_s \gamma_w} = \frac{397}{2.9 \times 1000} = 0.136 \text{ m}^3$

Volume of FA, $V_{FA} = \frac{W_{FA}}{G_s \gamma_w} = \frac{636}{2.6 \times 1000} = 0.245 \text{ m}^3$

Volume of CA, $V_{CA} = 1 - (0.187 + 0.136 + 0.245 + 0.02) = 0.412 \text{ m}^3$

Weight of CA, $W_{CA} = V_{CA} G_s \gamma_w = 0.412 \times 2.67 \times 1000 = 1100.04 \text{ kg}$

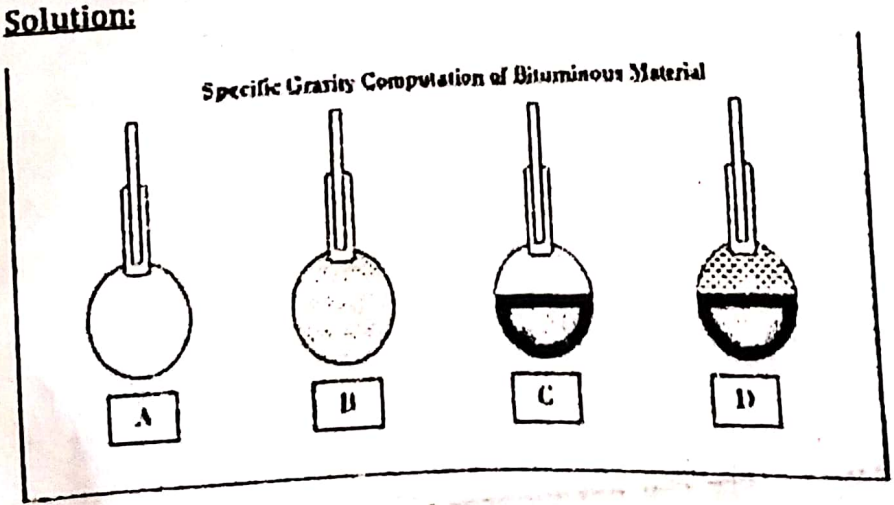
(*b*) Water cement ratio $= \frac{187}{397} = 0.47$

(*c*) Unit weight of concrete, $\gamma_c = \frac{W}{V} = \frac{187 + 397 + 636 + 1100.04}{0.187 + 0.136 + 0.245 + 0.412 + 0.02} = 2320.04 \text{ kg/m}^3$

(*d*) If water is increased the concrete compressive strength will decrease and workability will increase.

Question: Determine the specific gravity of a bituminous material from pycnometer test.
Mass of pycnometer = 30.48 gm.
Mass of pycnometer filled with water = 57.66 gm.
Mass of pycnometer filled ¾ part with bitumen = 57.68 gm. (BADC – 2020)

Solution:



Here, Mass of pycnometer, $A = 30.48$ gm.

Mass of pycnometer filled with water, $B = 57.66$ gm.

Mass of pycnometer filled ¾ part with bitumen, $C = 57.68$ gm.

D = Mass of pycnometer + ¾ part bitumen + ¼ part water

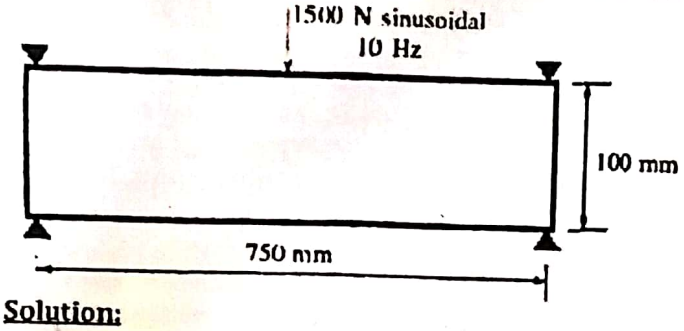
$D = 57.68 + 1/4\ (57.66 - 30.48) = 64.475$ gm

$$\text{Specific Gravity} = \frac{\text{Mass of bitumin with a definite volume}}{\text{Mass of water with same volume}} = \frac{C - A}{(B - A) - (D - C)}$$

$$= \frac{57.68 - 30.48}{(57.66 - 30.48) - (64.475 - 57.68)} = \frac{27.2}{27.18 - 6.795} = 1.33$$

$$\text{Alternatively, } G_s = \frac{\text{Mass of bitumin with a definite volume}}{\text{Mass of water with same volume}} = \frac{57.68 - 30.48}{\frac{3}{4}(57.66 - 30.48)} = 1.33$$

Question: In a fatigue test on bituminous mix, a single point sinusoidal load of 1500 N is applied with 10 Hz frequency to a specimen of size (100 x 100 x 750) mm³. A maximum deflection 1.3 mm was noted and the specimen was found to sustain 5.3×10^7 repetitions till occurrence of failure (constant strain). Calculate the stiffness modulus of the bituminous mix at the test temperature.



Solution:

$$\text{Moment of inertia, } I = \frac{100 \times 100^3}{12} = 8.333 \times 10^6 \text{ mm}^4$$

$$\text{Central deflection, } \delta = \frac{P L^3}{48 E I}$$

$$1.3 = \frac{1500 \times 750^3}{48 \times E \times 8.33 \times 10^6}$$

$E = 1216.8$ N/mm²

Stiffness modulus of the mix, $E = 1217$ MPa

Question: Compare between bitumen and tar as a binding material of flexible pavement. (30th BCS)

Solution:

Bitumen is a binding agent produced from petroleum. Bitumen is known for being strongly adhesive and resistant to damage from water and oil spills. This makes bitumen the ideal binder for asphalt because asphalt is commonly used as a surface for roads, car parks and driveways. Presently, roads are mostly constructed using Bitumen.

Tar is a black solid mass which is formed during destructive distillation of coal, peat, wood or other organic material. Tar is no longer used for road construction because of its carcinogenic effect and high temperature susceptibility. It has many uses as a waterproofing and sealing agent.

Question: What are the common requisite properties of aggregates in highway construction? (36th BCS)

Solution:

Common requisite properties of aggregates in highway construction are given below:

1. Strength: The aggregates to be used in road construction, particularly the aggregates used in the wearing course of the pavement should be sufficiently strong/ resistant to crushing to withstand the high stresses induced due to heavy traffic wheel loads.

2. Hardness :The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. Abrasive action may be increased due to the presence of abrasing material like sand between the tyres of vehicle and the aggregates exposed to the top surface. Thus, they should be hard enough to resist the wear due to abrasive action of traffic.

3. Toughness: Aggregates in the pavement are also subjected to impact due to moving wheel loads. The magnitude of impact increase with roughness of road and speed of vehicle. Severe impact is common when heavily loaded steel tyred vehicles move on WBM. The resistance to impact or toughness is thus another desirable property of aggregates.

4. Durability: The aggregates used in roads are subjected to physical and chemical actions of rains and ground water, the impurities in them and that of atmosphere. Thus it is desirable that the road stones used in the construction should be sound enough to withstand the weathering action. The property of aggregates to withstand the adverse actions of weather may be called soundness.

5. Shape of Aggregate: Road aggregates may be rounded, angular, flaky or elongated. Flaky and elongated particles have less strength than rounded and cubical particles. Thus, too flaky and too much elongated particles should be avoided.

6. Adhesion with bitumen: The aggregates in bituminous pavements should have less affinity with water when compared with bitumen, otherwise the bituminous coating on the aggregates will be stripped off in presence of water.

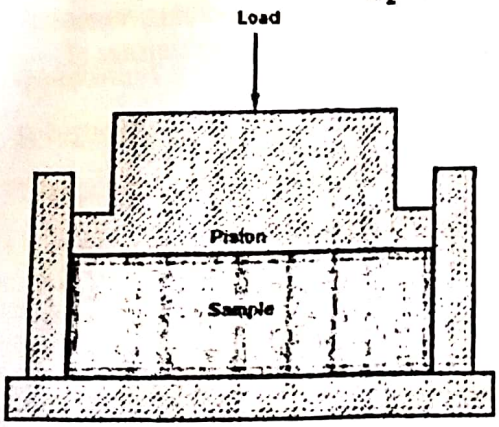
Test of Aggregate: Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements.

In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out:

- Crushing test
- Abrasion test
- Impact test
- Soundness test
- Shape test
- Specific gravity and water absorption test
- Bitumen adhesion test

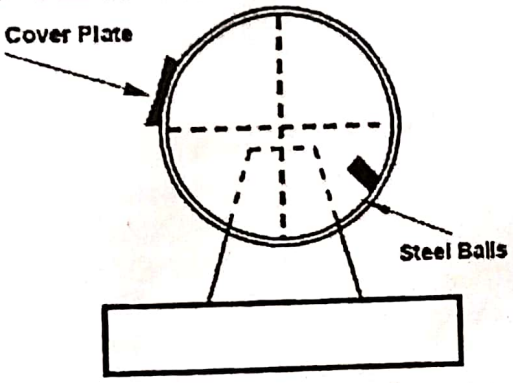
Crushing test: One of the model in which pavement material can fail is by crushing under compressive stress. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions (Figure 22:1). Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again. The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (W_2) is expressed as percentage of the weight of the total sample (W_1) which is the aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W_1}{W_2} \times 100$$



A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.

Abrasion test: Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge. Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated. An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinder along with the aggregates. The number of the abrasive spheres varies according to the grading of the sample. The quantity of aggregates to be used depends upon the gradation and usually ranges from 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates. After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value. A maximum value of 40 percent is allowed for WBM base course in Indian conditions. For bituminous concrete, a maximum value of 35 is specified.

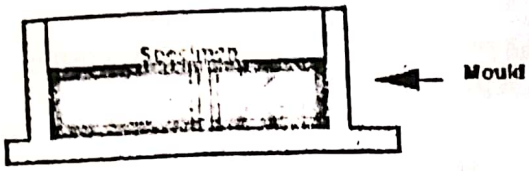


Impact test: The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal diameter 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 number of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as percentage of aggregates passing sieve (W_2) to the total weight of the sample (W_1).

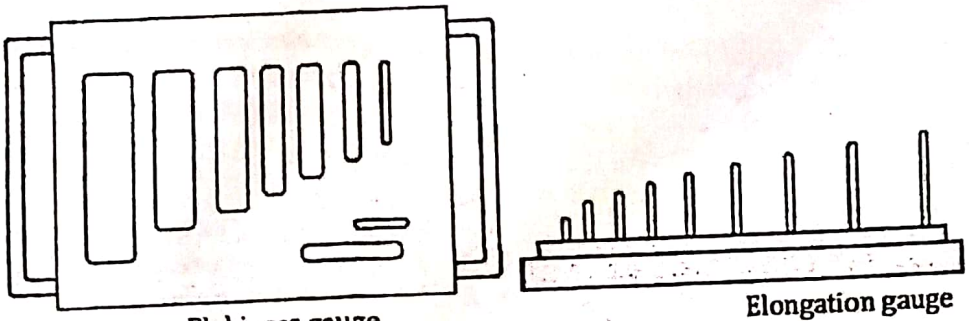
$$\text{Aggregate impact value} = \frac{W_1}{W_2} \times 100$$

Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent.

Soundness test: Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely. Aggregates of specified size are subjected to cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105 - 110°C to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.



Shape tests: The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes. The flakiness Index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm.



Flakiness gauge Elongation gauge

Bitumin: Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost. Bituminous materials consists of bitumen which is a black or dark coloured solid or viscous cementitious substances consists chiefly high molecular weight hydrocarbons derived from distillation of petroleum or natural asphalt, has adhesive properties, and is soluble in carbon disulphide. Tars are residues from the destructive distillation of organic substances such as coal, wood, or petroleum and are temperature sensitive than bitumen. Bitumen will be dissolved in petroleum oils where unlike tar.

Question: What are the test of bitumen?

Solution:

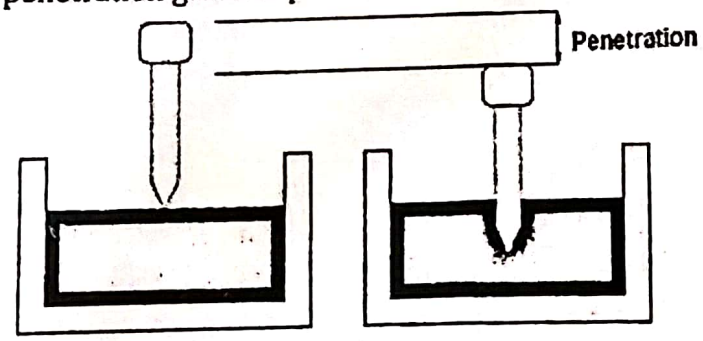
The following tests are usually conducted to evaluate different properties of bituminous materials.

- Penetration test
- Ductility test
- Softening point test
- Specific gravity test
- Viscosity test
- Flash and Fire point test
- Float test
- Water content test
- Loss on heating test

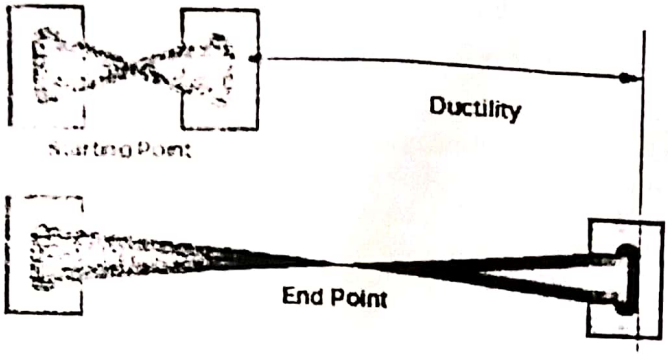
Tests on bitumen: There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

1. Penetration test
2. Ductility test
3. Softening point test
4. Specific gravity test
5. Viscosity test
6. Flash and Fire point test
7. Float test
8. Water content test
9. Loss on heating test

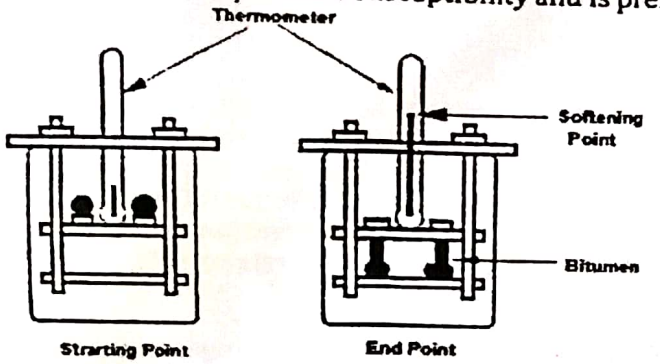
Penetration test: It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25° C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred.



Ductility test: Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27° C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc.



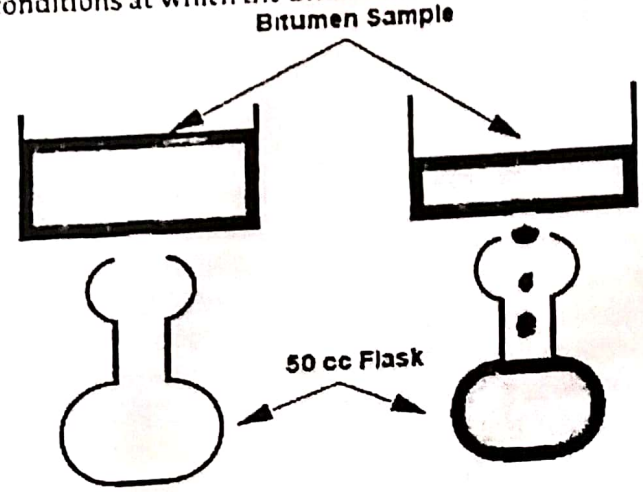
Softening point test: Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5° C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates.



Specific gravity test: In paving jobs, to classify a binder, density property is of great use. In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly influenced by its chemical composition. Increase in aromatic type mineral impurities cause an increase in specific gravity. The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27° C. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi-solid or solid state. The specific gravity of bitumen varies from 0.97 to 1.02.

Viscosity test: Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resist the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform _lm over aggregates, it will lubricate the aggregate particles. Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25° C or 10 mm orifice at 25 or 40° C.

Flash and fire point test: At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the ash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of ash under specified test conditions. The fire point is defined as the lowest temperature under Specified test conditions at which the bituminous material gets ignited and burns.

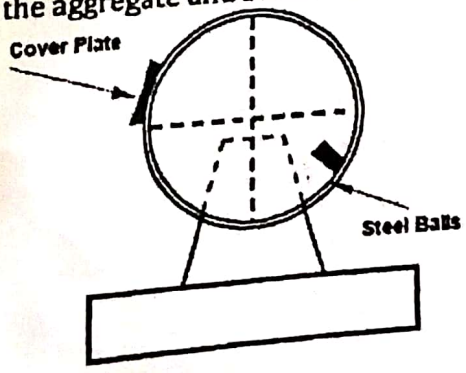


Float test: Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used. The apparatus consists of an aluminum oat and a brass collar filled with bitumen to be tested. The specimen in the mould is cooled to a temperature of 5°C and screwed in to oat. The total test assembly is floated in the water bath at 50°C and the time required for water to pass its way through the specimen plug is noted in seconds and is expressed as the float value.

Question: Why is Los Angeles abrasion test performed? Write down the laboratory procedure briefly. (31th BCS)

Solution:

Los angeles abrasion test: Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.



Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated. An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinder along with the aggregates. The number of the abrasive spheres varies according to the grading of the sample. The quantity of aggregates to be used depends upon the gradation and usually ranges from 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates. After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value. A maximum value of 40 percent is allowed for WBM base course in Indian conditions. For bituminous concrete, a maximum value of 35 is specified.