# Transportation Engineering & Surveying

## Index


| Topics | Page |
|---|---|
| 1. introduction to the highway and Geometric design | 2 |
| 2. Traffic Studies on Flow, Speed & Volume | 23 |
| 3. Design of pavement | 36 |
| 4. Railway Engineering & airport & docks and harbour | 50 |
| 5. Principle of Surveying, Maps & Scale | 74 |
| 6. Chain Surveying & Levelling | 81 |
| 7. Traversing and Triangulation survey | 92 |
| 8. Miscellaneous- instruments, contouring, area and volume | 103 |

## introduction to the highway and Geometric design

### Cross-Sectional Elements

The features of the cross-section of the pavement influence the life of the pavement as well as the riding comfort and safety. Of these, pavement surface characteristics affect both of these. Camber, kerbs, and geometry of various cross-sectional elements are important aspects to be considered in this regard.

**Pavement Surface Characteristics**

- **Friction -** It affects the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.
    - Skidding happens when the path travelled along the road surface is more than the circumferential movement of the wheels due to friction.
    - Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road.

The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15. The former is useful in sight distance calculation and the latter in horizontal curve design

- **Unevenness**

It is always desirable to have an even surface, but it is seldom possible to have such a one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness affect the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tyres.

An unevenness index value less than 1500 mm/km is considered as good, a value less than 2500 mm/km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 kmph.

- **Light reflection**

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

• Black roads has no glare during day, but has poor visibility at night
• Concrete roads has better visibility and less glare

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

- **Drainage**

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

**Camber**

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rainwater from road surface. The objectives of providing camber are:

• Surface protection especially for gravel and bituminous roads
• Sub-grade protection by proper drainage
• Quick drying of pavement which in turn increases safety

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface.

Values suggested by IRC for various categories of pavement is given in Table

- **For Camber**

| Surface type | Heavy rain | Light rain |
|---|---|---|
| Concrete/Bituminous | 2 % | 1.7 % |
| Gravel/WBM | 3 % | 2.5 % |
| Earthen | 4 % | 3.0 % |

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

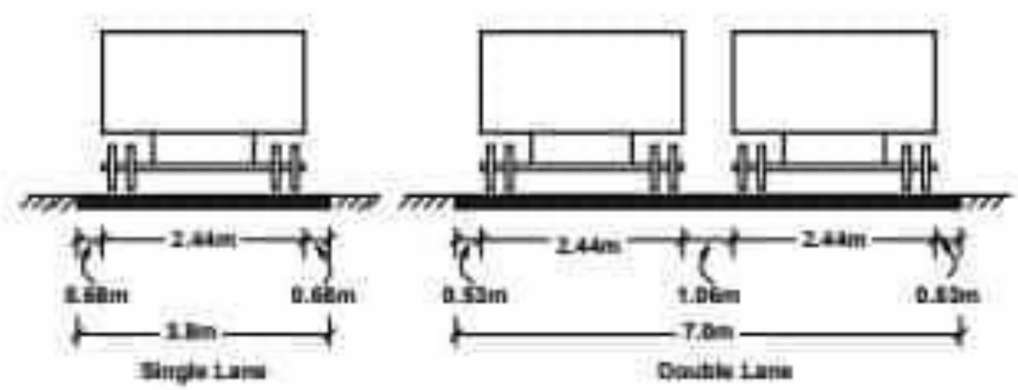
**Width of carriage way**

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This

This require minimum of lane width of 3.75 m for a single lane road. However, the side clearance required is about 0.53 m, on either side and 1.06 m in the center. Therefore, a
two lane road require minimum of 3.5 meter for each lane (Figure 12:2b).

IRC Specification for carriage way width

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




Lane width for single and two lane roads

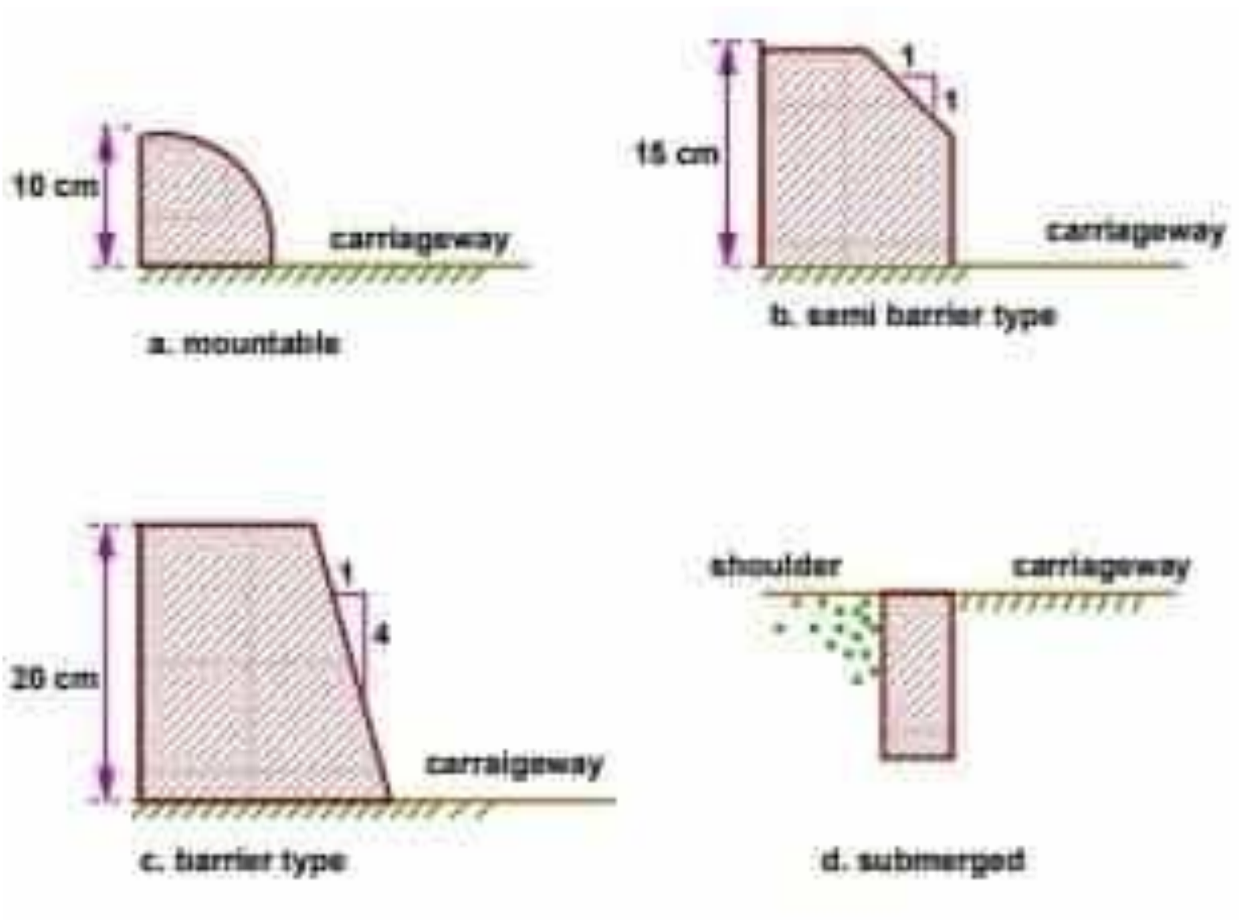
## Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types
of kerbs are:

• Low or mountable kerbs : This type of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.

• Semi-barrier type kerbs : When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.

• Barrier type kerbs : They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.




Different types of kerbs

- Submerged kerbs : They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.

**Road margins**

The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are given below:

- **Shoulders**

Shoulders are provided along the road edge and is intended for the accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses.

The shoulder width should be adequate for giving working space around a stopped vehicle. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane rural highways in India.

- **Parking lanes**

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving on the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking.

- **Bus-bays**

They should be at least 75 meters away from the intersection so that the traffic near the intersections is not affected by the bus-bay.

- **Service roads**

These roads are provided to avoid congestion in the expressways and also the speed of the traffic in those lanes is not reduced.

- **Footpath**

Footpaths are exclusive right of way to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. Minimum width is 1.5 meter and may be increased based on the traffic.

- **Guard rails**

Guard stones painted in alternate black and white are usually used. They also give better visibility of curves at night under headlights of vehicles.

**Width of formation**

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders. This does not include the extra land in formation/cutting.

Width of formation for various classed of roads

| Road classification | Roadway width in m | |
|---|---|---|
| | Plain and rolling terrain | Mountainous and steep terrain |
| NH/SH | 12 | 6.25-8.8 |
| MDR | 9 | 4.75 |
| ODR | 7.5-9.0 | 4.75 |
| VR | 7.5 | 4.0 |

**Right of way**

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development.

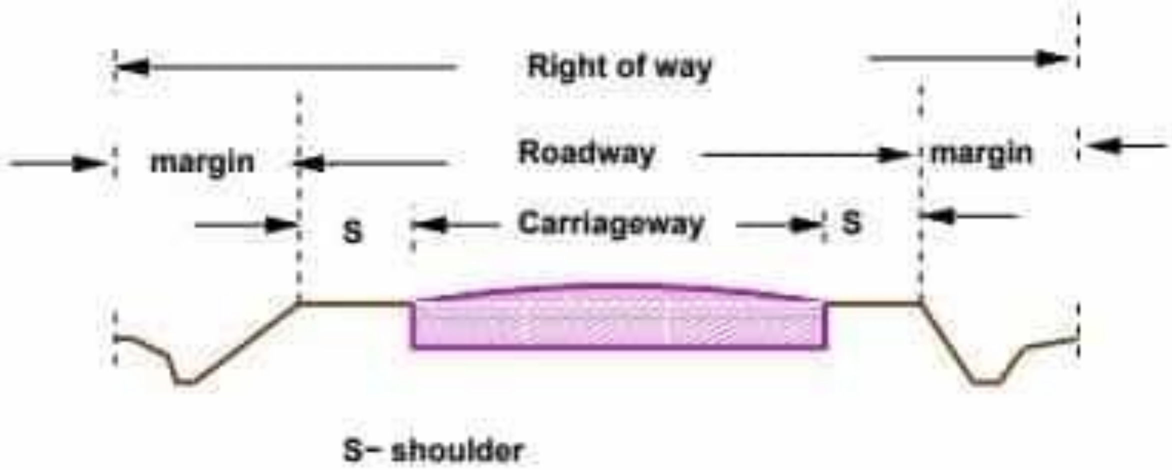
Building line represents a line on either side of the road, between which and the road no building activity is permitted at all. The right of way width is governed by:

Width of formation: It depends on the category of the highway and width of roadway and road margins.
• Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.
• Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
• Drainage system and their size which depends on rainfall, topography etc.
• Sight distance considerations : On curves etc. there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like

building structures etc.
• Reserve land for future widening: Some land has to be acquired in advance anticipating future developments like widening of the road.

Normal right of way for open areas

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




A typical Right of way (ROW)

### Sight Distances

**Stopping Sight Distance (SSD)**

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

The stopping distance of a vehicle is the sum of:

1. The distance traveled by the vehicle during the total reaction time known as lag distance and

2. The distance traveled by the vehicle after the application of the brakes, to a dead stop position which is known as the braking distance.

(i) lag distance = 0.278 Vt

Where, V = Speed in km/hr.

t = Reaction time in sec

(ii) Braking distance

$$= \frac{V^2}{254(f \pm S\%)}$$

f = Coefficient of friction

= 0.40 for v = 20 to 30 km/hr

= 0.35 for v = 100 km/hr

(iii) SSD = lag distance + braking distance

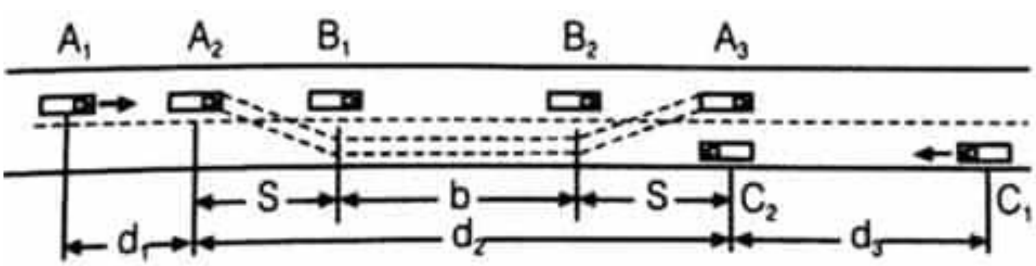
$$SSD = 0.278Vt + \frac{V^2}{254(f \pm S\%)}$$

Where, S% is gradient + ve sign for ascending gradient & -ve sign for descending gradient

SSD = Stopping sight distance in ‘m’.

**Overtaking Sight Distance (OSD)**

The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the minimum overtaking sight distance (OSD) or the safe passing sight distance available




Overtaking Manoeuvre

OSD = $d_1$+$d_2$+$d_3$

Where, O.S.D = Overtaking sight distance in ‘m’

d = Distance traveled by overtaking vehicle A during the reaction time t sec of the driver from position $A_1$ to $A_2$.

$d_1 = 0.278\ V_b t$

$d_2$ = Distance traveled by the vehicle A from $A_2$ to $A_3$ during the actual overtaking operation in time T sec.

$$d_2 = b + 2s \ and\ d_2 = 0.278 V_b T + \frac{1}{2} a T^2$$

where S = Minimum spacing between two vehicles.

$s = 0.2V_b+6$ here $V_b$ is in km/hr.

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

where, a = acceleration in m/s$^2$.

$$T = \sqrt{\frac{14.4s}{a}}$$

where a is in km/hr/sec.

$d_3=0.278V_C T$

Where,

$d_3$ = Distance traveled by oncoming vehicle C from $C_1$ to $C_2$ during the overtaking operation of A i.e., T sec.

$V_C$ = V = Speed of overtaking vehicle or design speed (km/hr)

If $V_b$ is not given then

$V_b$ = (V-16)km/hr

$V_b$ = (V-4.5)m/s

v = design speed in m/s.

**Overtaking Zone**

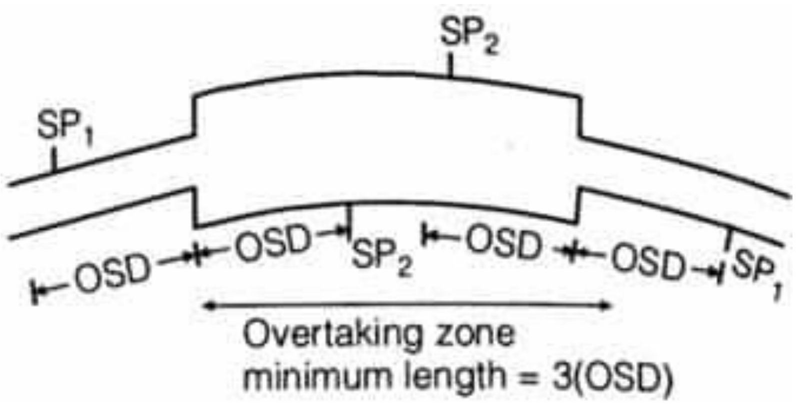
It is desirable to construct highways in such a way that the length of the road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance cannot be provided. In such zones were overtaking or passing is not safe or is not possible, sign posts should be installed indicating “No passing” or “Overtaking Prohibited” before such restricted zones start. But the overtaking opportunity for vehicles moving at design speed should be given at frequency intervals. These zones which are meant for overtaking are called overtaking zones.

O.S.D. = $d_1+d_2$

For one way traffic

O.S.D. = $d_1+d_2+d_3$

For two way traffic




Minimum length of overtaking zone = 3(OSD)

Desirable overtaking zone = 5(OSD)

## Horizontal Alignments

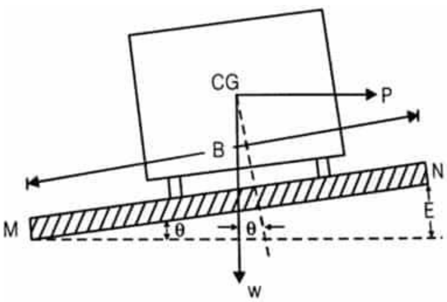
### Super Elevation (e)

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 or banking.

The superelevation 'e' is expressed as the ratio of the height of the outer edge with respect to the horizontal width.

$$(a)\quad e = \frac{NL}{ML} = \tan\theta$$

$$(b)\quad e + f = \frac{V^2}{127R}$$




Where V = Speed in km/hr

R = Radius in 'm'

F = Design value of lateral friction = 0.15

e = Rate of super elevation ~tanθ

- **Maximum Super Elevation ($e_{max}$)**

$$e_{max} = \begin{cases} 0.07 \rightarrow \text{For plain \& Rolling Terrain} \\ 0.10 \rightarrow \text{For Hilly Area} \\ 0.04 \rightarrow \text{For Urban roads with} \\ \qquad\quad \text{frequent intersections} \end{cases}$$

**Ruling Minimum Radius of the Curve ($R_{ruling}$)**

$$R_{ruling} = \frac{V^2}{127(e+f)}$$

Where, V = Ruling design speed in km/hr

e = Rate of super-elevation

f = Coefficient of friction ~0.15

**Extra Widening ($E_W$)**

The extra widening of pavement on horizontal curves is divided into two parts (i) Mechanical and (ii) Psychological widening.

$$E_W = W_m + W_p \rightarrow E_W = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

**Mechanical Widening ($W_m$):** The widening required to account for the off-tracking due to the rigidity of the wheelbase is called mechanical widening. ($W_m$).

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

**Psychological widening ($W_p$):** Extra width of the pavement is also provided for psychological reasons such as, to provide for greater maneuverability or steering at higher speeds, to allow for the extra space requirements for the overhangs of vehicles and to provide greater clearance for crossing and overtaking vehicles on the curves. Psychological widening is therefore important in pavements with more than one lane.

$$W_p = \frac{V}{9.5\sqrt{R}}$$

Where,

n = number of traffic lanes

l = length of wheelbase (m)

R = radius of the curve (m)

V = velocity (kmph)

**Transition Curve**

The Indian Roads Congress recommends the use of the spiral as a transition curve in the horizontal alignment of highways due to the following reasons:

The spiral curve satisfies the requirements of an ideal transition.

The geometric property of a spiral is such that the calculations and setting out the curve in the field is simple and easy.

**Length of Transition Curve (L)**

(i) According to the rate of change of radial/centrifugal acceleration

$$L = \frac{0.0215V^3}{CR}$$

Where

V = Speed of vehicle in (km/hr)

C = Allowable rate of change of centrifugal acceleration in m/sec$^3$

$$C = \frac{80}{75 + V}$$

R = Radius of the curve in ‘m’.

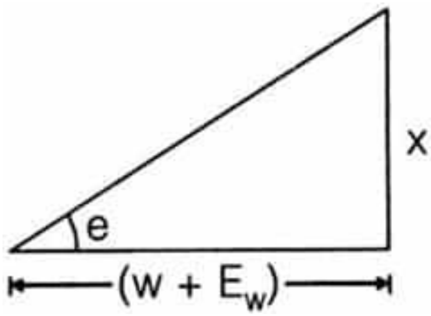
L = Length of the transition curve in ‘m’.

(ii) According to the rate of change of super-elevation

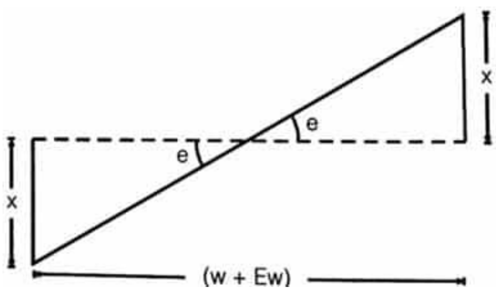
$$L = \begin{cases} 150X \rightarrow For\ plain\ \&\ Rolling\ Terrain \\ 100X \rightarrow For\ Built\ up\ Area \\ 60X \rightarrow For\ Hilly\ Area \end{cases}$$

Where, x = Raise of the outer line of the road.

X = (w + $E_w$)e if pavement is rotated about inner side.




$X = (w + E_w)\frac{e}{2}$ if the pavement is rotated about the centre line.




(iii) According to empirical formula (rate of change of curvature)

$$L = \frac{2.7V^2}{R} \text{ For Plain \& Rolling Terrain}$$
$$L = \frac{V^2}{R} \text{ For Hilly Area}$$

**Set Back Distance (m)**

The clearance distance or set back distance required from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance depends upon the following factors:

(i) Required sight distance (SSD)

(ii) Radius of the horizontal curve, (R)

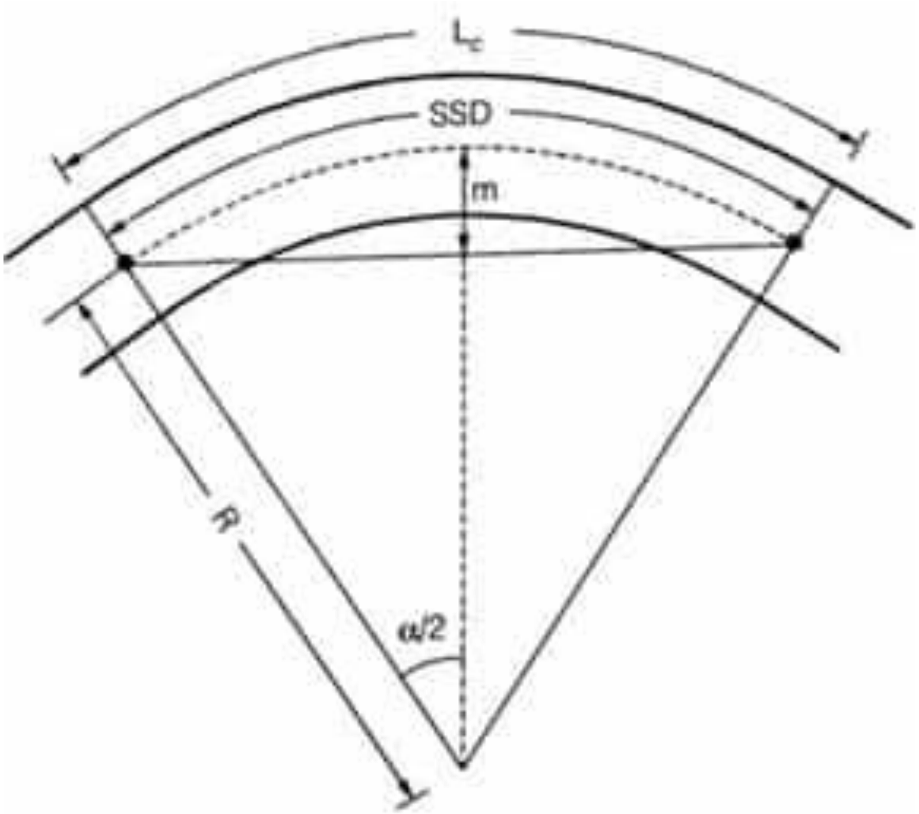
(iii) Length of the curve ($L_c$)

1. For single lane road

(a) when $L_C$ > SSD

$$m = R - R\cos\frac{\alpha}{2} \;\&\; \frac{\alpha}{2} = \frac{180s}{2\pi R}$$

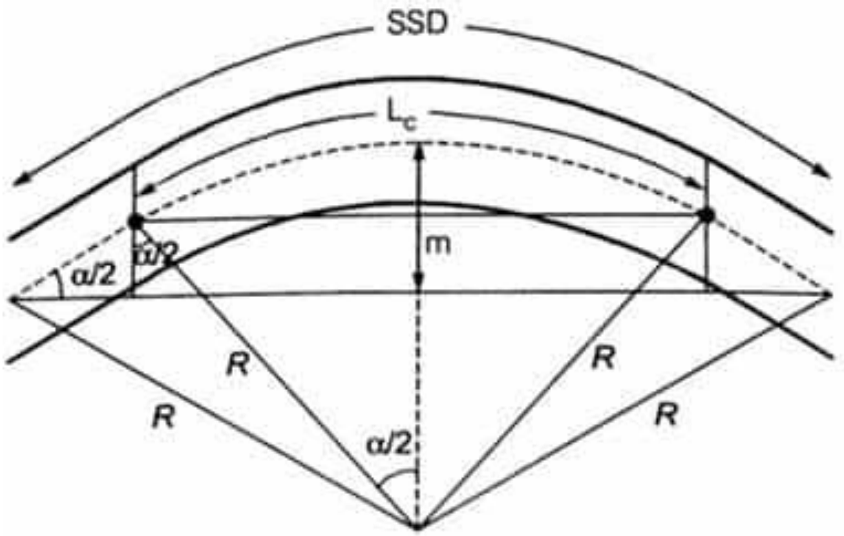
Where, $L_C$ = Length of curve & s = SSD




(b) When $L_C$ < SSD

$$m = R\left(1 - \cos\frac{\alpha}{2}\right) + \frac{S - L_C}{2}\sin\frac{\alpha}{2}$$

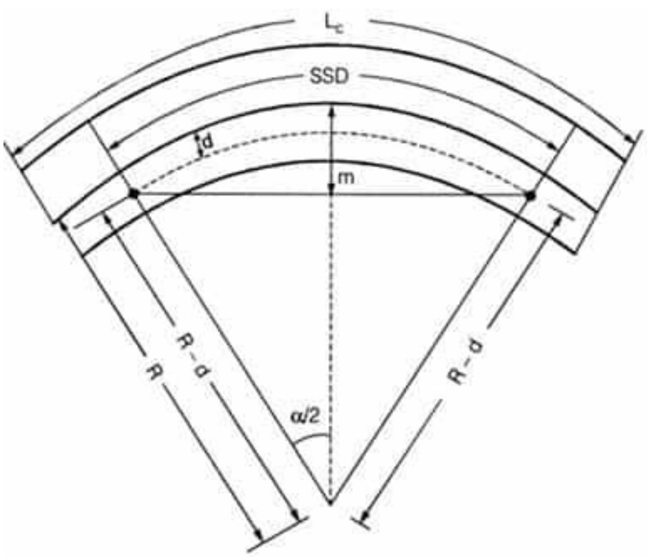
$$\& \quad \frac{\alpha}{2} = \frac{180L_C}{2\pi R}$$




2. For two lane road

(a) when **$L_C$ > SSD**

$$m = R - (R-d)\cos\frac{\alpha}{2} \; \& \frac{\alpha}{2} = \frac{180s}{2\pi(R-d)}$$

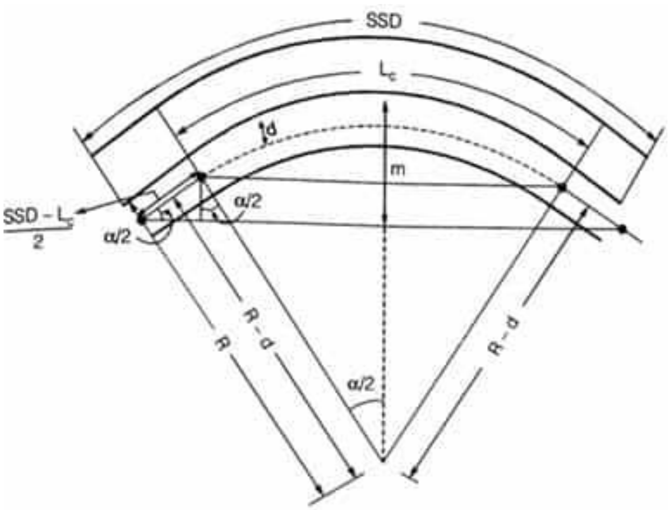



(b) when **$L_C$ < SSD**

$$m = R - (R-d)\cos\frac{\alpha}{2} + \left(\frac{S-L_C}{2}\right)\sin\frac{\alpha}{2}$$

&

$$\frac{\alpha}{2} = \frac{180L_C}{2\pi(R-d)}$$




**Grade Compensation**

Grade compensation

$$= \frac{30+R}{R}\%\ and$$

$$= \frac{75}{R}\%$$

The maximum value of the above two is taken as grade compensation.
But compensated grade can not be less than 4%

Where, R = Radius of curve in meter.

**Vertical Curve**

Due to changes in grade in the vertical alignment of the highway, it is necessary to introduce a vertical curve at the intersections of different grades to smoothen out the vertical profile and thus ease off the changes in gradients for the fast-moving vehicles.

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

(i) Summit curves or crest curves with convexity upwards

(ii) Valley or sag curves with concavity upwards.

- **Summit Curves (Crest Curve with Convexity Upward):** Summit curves with convexity upwards are formed in any one of the cases illustrated in fig. The deviation angles between the two interacting gradients is equal to the algebraic difference between them. Of all the cases, the deviation angle will be maximum then an ascending gradient meets with a descending gradient i.e., $N = n_1 - (-n_2) = (n_1 + n_2)$

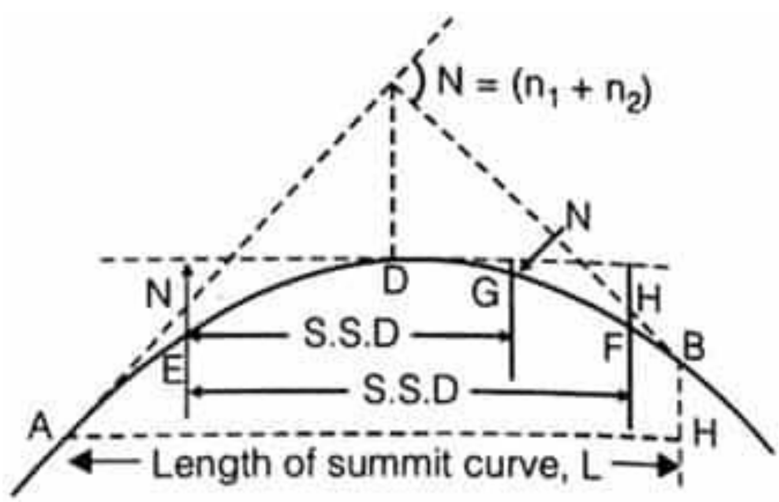
(i) Length of summit curve for SSD

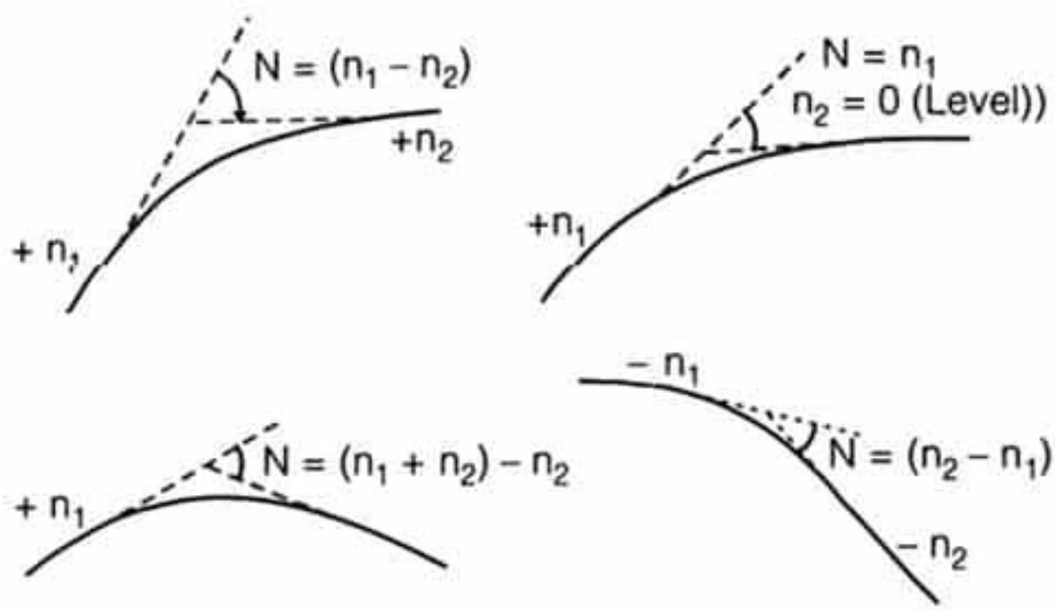
(a) when L > SSD

$$L = \frac{NS^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2}$$

$$\downarrow$$

$$L = \frac{NS^2}{4.4}$$






Where, L = Length of summit curve in meter

S = SSD (m)

N = Deviation angle

= Algebraic difference of grade

H = Height of eye level of the driver above roadway surface = 1.2 m

h = Height of subject above the pavement surface = 0.15 m

(b) When L < SSD

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N} \rightarrow L = 2S - \frac{4.4}{N}$$

(ii) Length of summit curve for safe overtaking sight distance (OSD) or intermediate sight distance (ISD)

(a) When L > OSD

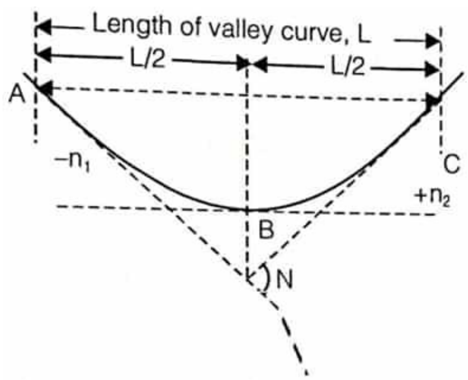
$$L = \frac{NS_0^2}{(\sqrt{2H} + \sqrt{2h})^2} \rightarrow L = \frac{NS_0^2}{9.6}$$

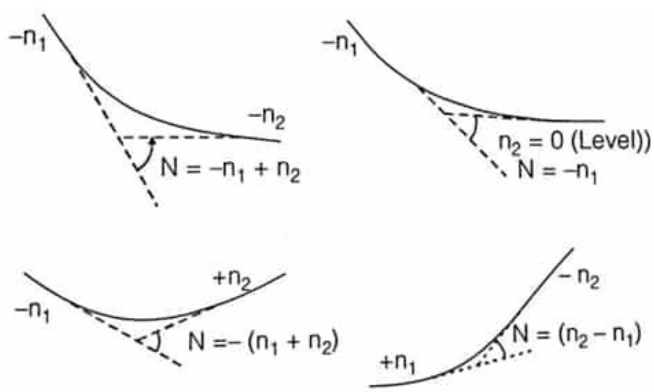
Where, $S_0$ = Overtaking or Intermediate sight distance

(b) When L < OSD

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N} \rightarrow L = 2S - \frac{9.6}{N}$$

- **Valley Curves (Sag Curve with Concavity Upward):** Valley curves or sag curves are formed in any one of the cases illustrated in fig. In all the cases the maximum possible deviation angle is obtained when a descending gradient meets with an ascending gradient.




(i) Length of valley curve as per comfort condition (transition curves are provided back to back).

$$L = 2\left[\frac{NV^3}{C}\right]^{1/2} \text{ if } C = 0.6\, m/s^3 \text{ then}$$

$$L = 0.38(NV^3)^{1/2}$$

(ii) Length of valley curve for head light sight distance (parabolic curve is provided).

(a) When L > SSD

$$L = \frac{NS^2}{2h_1 + 2s\tan\alpha} \rightarrow L = \frac{NS^2}{1.50 + 0.035s}$$

Where,

L = Total length of valley curve

S = SSD (m)

N = Deviation angle

α = Beam angle $\simeq$ 1°

$h_1$ = Avg. height of headlight = 0.75 m

(b) When L < SSD

$$L = 2S - \frac{(2h_1 + 2s\tan\alpha)}{N} \rightarrow L = 2S - \frac{(1.50 + 0.035S)}{N}$$

## Traffic Studies on Flow, Speed & Volume

### Traffic Engineering

Traffic engineering is that phase of engineering which deals with planning and geometric design of streets, highways, abutting lands, and with traffic operation thereon, as their use is related to the safe, convenient and economical transportation of persons and goods.

### Theoretical maximum capacity, (C)

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

where S = Minimum clear distance between two vehicles (m).

S = 0.2V + 6 where, v = Speed of vehicle in km/hr.

$$C = \frac{3600}{H_t}$$

C = Theoretical maximum capacity in vehicle/hour

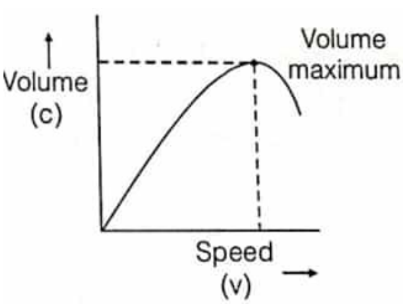
$H_t$ = Time headway in 'Sec'.

Where,

C = Traffic capacity or traffic volume in vehicle/hour

δ = Traffic density in vehicle/km

V = Traffic velocity in km/hr




**Passenger Car Unit**

The PCU may be considered as a measure of the relative space requirement of a vehicle class compared to that of passenger car under a specified set of roadway, traffic and other conditions.

$$PCU = \frac{\text{Capacity of roadway with passenger car only}}{\text{Capacity of roadway with a particular class vehicle only}}$$

**Accident Studies**

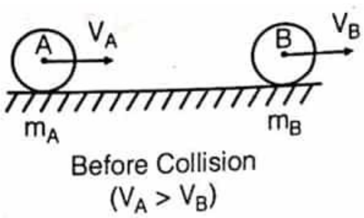
The problem of accident is very acute in highway transportation due to complex flow patterns of vehicular traffic presence of mixed traffic and pedestrians. Traffic accidents may involve property damages, personal injuries or even casualties.

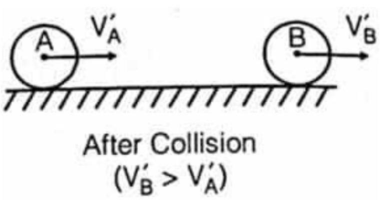
$$e = \frac{V_B' - V_A'}{V_A - V_B}$$

Where, e = Coefficient of restitution

$(V_B' - V_A') =$ Velocity of separation

$(V_A - V_B) =$ Velocity of approach.




$V_A$ = Velocity of vehicle 'A' of mass $m_A$ before collision.

$V_B$ = Velocity of vehicle 'B' of mass $m_B$ before collision.

$V_A' =$ Velocity of vehicle A after collision

$V_B' =$ Velocity of vehicle B after collision.

e = 1 for perfectly elastic collision.

e = 0 for perfectly inelastic collision or plastic collapse.

i.e., both vehicle move with same velocity after collision.

**Momentum Equation**

$$m_A v_A + m_B v_B = m_A v_A' + m_B v_B'$$

**Types of Collision**

Collision of moving vehicle with parked vehicle (assumption: collision is perfectly plastic)

$$(a)\ v_3 = \sqrt{2gfS_2}$$

$$(b)\ v_2 = \frac{(m_A + m_B)}{m_A}.v_3$$

$$(c)\ v_1 = \sqrt{v_2^2 + 2gfS_1}$$

Where, $v_1$ = Initial velocity of moving vehicle in km/hr.

$v_2$ = Velocity of moving vehicle after travelling distance '$s_1$' (in meter)

$v_3$ = Common velocity of moving & parked vehicle at the time of collision.

$s_2$ = Distance travelled by both vehicle till both vehicle comes in rest finally.

**Two Vehicle Approaching from Right Angle Collide at an Intersection**

$$(i)\ V_{A_3} = \sqrt{2gfS_{A_2}}$$

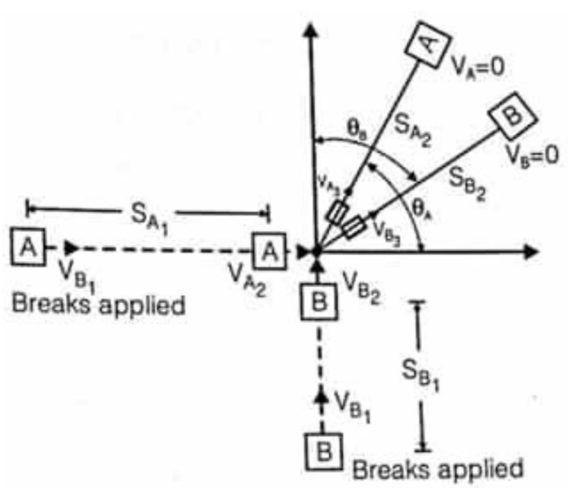
$$(ii)\ V_{B_3} = \sqrt{2gfS_{B_2}}$$

$$(iii)\ V_{A_2} = V_{A_3}\cos\theta_A + \frac{m_B}{m_A}.V_{B_3} = \sin\theta_B$$

$$(iv)\ V_{B_2} = \frac{m_A}{m_B}.V_{A_3}\sin\theta_A + V_{B_3}\cos\theta_B$$

$$(v)\ V_{A_1} = \sqrt{V_A^2 + 2gfS_{A_1}}$$

$$(vi)\ V_{B_1} = \sqrt{V_{B_2}^2 + 2gfS_{B_1}}$$




Where,

$S_{A_1}$ & $S_{B_1}$

are skid distance just before collision.

$S_{A_2}$ & $S_{B_2}$

are skid distance after collision.

$V_{A_3}$ & $V_{B_3}$

are speed of vehicle A & B respectively after the collision.

$V_{A_2}$ & $V_{B_2}$

are speed of vehicle A & B respectively after skidding a distance

$S_{A_1}$ & $S_{B_1}$.

$V_{A_1}$ & $V_{B_1}$

are speed of vehicle A & B respectively before skidding.

**Design Cycle Metho**

Trial Cycle Method

$$X_A = \frac{\eta_A}{15 \times 60} \times T \quad X_A = \frac{\eta_B}{15 \times 60} \times T$$

Where, $X_A$ = Number of vehicle accumulated in one cycle time on Road A.

$X_B$ = Number of vehicle accumulated in one cycle time on Road B.

T = Total cycle time in ‘sec’ (assumed)

$G_A = 2.5\ X_A\ \eta_A$ = Traffic count on road A in 15 minutes.

$G_B = 2.5\ X_B\ \eta_B$ = Traffic count on road B in 15 minutes.

$$T' = (G_A + A_A) + (G_B + A_B)$$

Where, T' = Total cycle time (Actual)

$A_A$ = Amber time on road A

$A_B$ = Amber time on road B

$G_A$ & $G_B$ are green time on road A & B respectively.

It T' = T then O.K. otherwise repeat the process.

**Approximate Method**

$$R_A = G_{AP} = \left(7 + \frac{W_A}{1.2}\right)$$

$$R_B = G_{BP} = \left(7 + \frac{W_B}{1.2}\right)$$

Whey, $R_A$ = Red time on road A

$R_B$ = Red time on road B

$G_{AP}$ = Green time on road A for pedestrians

$G_{BP}$ = Green time on road B for pedestrians

$W_A$ = Width of road A

$W_B$ = Width of road B

1.2 m/s = Speed of pedestrians $G_A = R_B - A_A$

$G_B = R_A - A_B$

Where, $G_A$ = Green time on road A

$G_B$ = Green time on road B

$A_A$ & $A_B$ are Amber time on road A & B respectively.

**Websters Method**

$$C_O = \frac{1.5L + 5}{1 - Y}$$

Where, $C_O$ = Optical cycle time

L = Total lost time

L = 2n+*R*

Where, n = number of phase

R = All red time

$$y = y_1 + y_2 \rightarrow y_2 = \frac{q_B}{S_B}$$

$$\downarrow$$

$$y_2 = \frac{q_A}{S_A}$$

Where, $q_A$ = Normal flow on road A

$q_B$ = Normal flow on road B

$S_A$ = Saturation flow on road A

$S_B$ = Saturation flow on road B

$$G_A = \frac{y_1}{y}(C_O - L) \quad G_B = \frac{y_2}{y}(C_O - L)$$

Where, $G_A$ & $G_B$ are green time on road A & B respectively.

**Annual Average Daily Traffic (AADT or ADT)**

$$AADT = \frac{Total\ yearly\ traffic}{365}$$

**Space Mean Speed ($V_s$)**

$$V_s = \frac{3.6.d.n}{\sum_{i=1}^{n} t_i}$$

Where, $V_s$ = Space mean speed in km/hr.

d = Length of road in meter

n = Number of individual vehicle observations

$t_i$ = Observed travel time (sec) for $i^{th}$ vehicle of travel distance ‘d’ meter.

**Time mean speed ($v_t$)**

$$V_t = \frac{\sum_{i=1}^{n} v_i}{n}$$

Where, $V_t$ = Time mean speed (km/hr)

$V_i$ = Observed instantaneous speed of $i^{th}$ vehicles (km/hr)

n = number of vehicles observed.

**Speed & delay study by floating car method**

Average journey time (t) in minute

$$\bar{t} = t_w - \frac{ny}{q},\ q = \frac{n_a + n_y}{t_a + t_w}$$

Where,

q = Flow of vehicles (volume per minutes) in one direction of the stream.

$n_a$ = Average number of vehicles counted in the direction of the stream when the test vehicle travel in the opposite direction.

$n_y$ = The average number of vehicles overtaking the test vehicle minus the number of vehicle overtaken when the test is in the direction of ‘q’.

$t_w$ = Average journey time when the test vehicle is travelling with the stream q.

$t_a$ = Average journey time, in minute when the test vehicle is running against the stream ‘q’.

**Relationship between speed, travel time, volume, density & capacity**

Travel time per unit length of road,

$$T_{(sec/km)} = \frac{3600}{V}$$

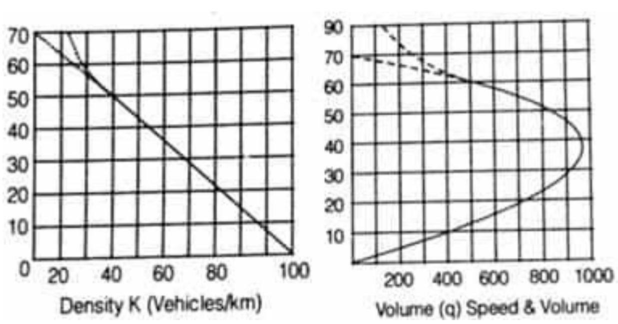
Where, V = Speed in km/hr

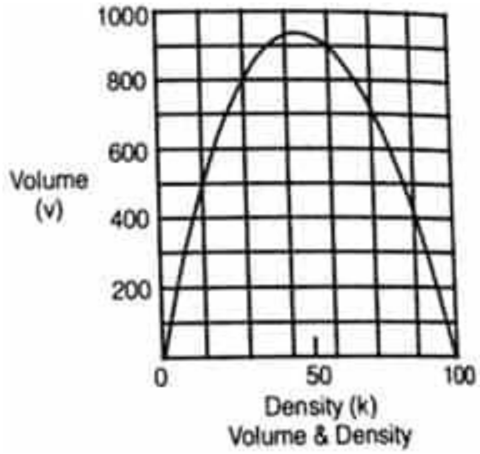
$q=kV_s$

Where, q = Average volume of vehicle passing a point during a specified period of time (vehicle per hour).

k = Average density or number of vehicle occupying a unit length of roadway at a give instant (vehicles/km).

$V_s$ = Space-mean speed of vehicles in a unit roadway length (km/hr)






**Capacity flow or maximum flow, ($q_{max}$)**

$$q_{\max} = \frac{V_{SF} . k_j}{4}$$

where, $V_{SF}$ = Free mean speed i.e., maximum speed at zero density.

$K_j$ = Jam density i.e., maximum density at zero speed

$$k_j = \frac{1000}{S}$$

Where, s = Spacing between vehicles.

**Rotary intersection**

A rotary intersection or traffic rotary is an enlarged road intersection where all converging vehicles are forced to move round a large central island in one direction (clockwise direction) before they can weave out of traffic flow into their respective directions radiating from the central island.

$$(i)\ V = 40\ km / hr \rightarrow For\ Rural\ Areas.$$
$$V = 30 km / hr \rightarrow For\ Urban\ Areas.$$

Radius of rotary, ($R$)

$$R = \frac{V^2}{127 f}$$

Where, V = Design speed of vehicle (km/hr)

f = Coefficient of friction may be taken as 0.43 & 0.47 for the speed of 40 & 30 km/hr respectively after allowing a factor of safety of 1.5.

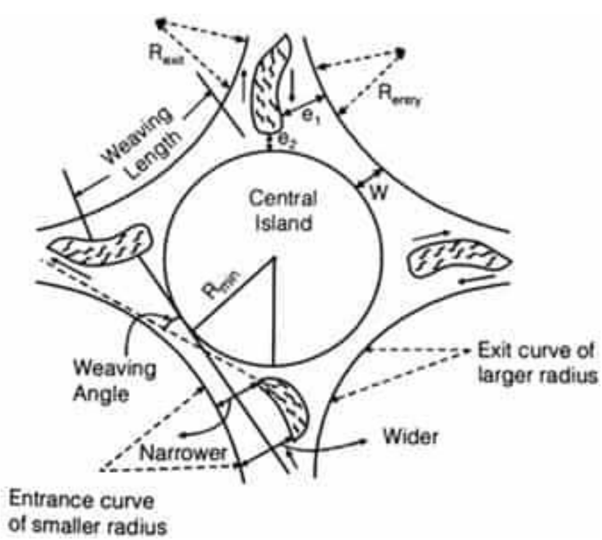
$(R_{min})_{Central\ Island} = 1.33\ (R)_{Entry\ curve}$.

$(R_{min})_{Central\ Island}$ = Minimum radius of central Island.

$(R_{min})_{Entry\ curve}$ = Radius of entry curve.

$$20m \le (R)_{entry\ curve} \le 35m \quad for\ v = 40\,km/hr.$$
$$15m \le (R)_{entry\ curve} \le 25m \quad for\ v = 30\,km/hr.$$

$$(iii)\ w = \left[\left(\frac{e_1 + e_2}{2}\right) + 3.5\right] metre$$




Where, w = Width of weaving section.

$e_1$ = Entry width,

$e_2$ = Width of non-weaving section.

Capacity of Rotary ($Q_P$)

$$Q_P = \frac{280w\left(1+\frac{e}{w}\right)\left(1-\frac{p}{3}\right)}{1+\frac{w}{L}}$$

Where, $Q_P$ = Practical capacity of weaving section of a rotary in PCU per hour.

w = Width of weaving section (6 to 18 m).

e = Average width of entry '$e_1$' & width of non-weaving section $e_2$ for the range e/w = 0.4 to

$$1.0 \sim \frac{e_1 + e_2}{2}.$$

L = Length of weaving section between the ends of channelizing islands in meter for the range of

$$\frac{w}{L} = 0.12 to 0.4.$$

p = Proportion of weaving traffic or weaving ratio.

$$(v)\ p = \frac{b+c}{a+b+c+d}\ 0.4 \le p \le 0.90$$

where, a = Left turning traffic moving along left extreme lane.

d = right turning moving along right extreme lane.

b = Crossing/weaving traffic turning towards right while entering the rotary.

c = Crossing/weaving traffic turning towards left while leaving the rotary.

**Parking Facilities**

**Number of spaces (N)**

$$(i)\ N = \frac{L}{6.6}$$

for parallel parking with equal spacing facing the same direction.

$$(ii)\ N = \frac{L}{6.75}$$

for parallel parking when two cars placed closely.

$$(iii)\ N = \frac{L - 0.85}{5.1}$$

for 30° angle parking

$$(iv)\ N = \frac{L - 2.0}{3.6}$$

for 45° angle parking

$$(v)\ N = \frac{L - 2}{2.9}$$

for 60° angle parking

$$(vi)\ N = \frac{L}{2.5}$$

for 90° angle parking

Out of various angles used in angle parking, 45 degree angle is considered the best from all considerations discussed above.

**Highway Lighting**

**Spacing between lighting units =**

$$\frac{\text{Lamp lumen} \times \text{Coefficient utilization} \times \text{Maintenance factor}}{\text{Average lux} \times \text{Width of road}}$$

**Trip Distribution**

$$T_{ij} = \frac{G_i A_j F_{ij}}{\sum_{j=1}^{n} A_j F_{ij}}$$

Where, $T_{ij}$ = Number of trips from zone I to zone j.

$G_i$ = Trips generated in zone i.

$A_i$ = Trips attracted to zone j.

$F_{ij}$ = Empirically derived 'Friction Factor' calculated on area wise basis.

$n$ = Number of zones in the urban area.

## Design of pavement

### Factors affecting Pavement Design

**Traffic and loading**

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

- **Contact pressure**: The tire pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in the analysis, a circular area is often considered.
- **Wheel load**: The next important factor is the wheel load which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affect the stress distribution and detection within 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.
- **Axle configuration**: The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.
- **Moving loads**: The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is

increased from 2 km/hr to 24 km/hr, the stresses and detection reduced by 40 percent.

- **Repetition of Loads**: 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. Therefore, modern design is based on the total number of standard axle load (usually 80 kN single axle).

**Material characterization**

The following material properties are important for both Flexible and rigid pavements.

- When pavements are considered as linear elastic, the elastic moduli and poisson ratio of subgrade and each component layer must be specified.
- If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided. However, many of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which requires the modulus of elasticity and Poisson's ratio only.

**Environmental factors**

Environmental factors affect the performance of pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation and they are discussed below:

- **Temperature**: The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed.

While in Flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition.

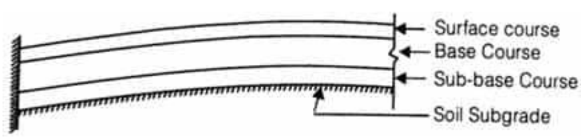
- **Precipitation**: The precipitation from rain and snow affects the quantity of surface water in filtrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc

**Flexible Pavement**

## Flexible Pavements

Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads.

A typical flexible pavement consists of four components: 1. soil subgrade 2. sub-base course 3. base course 4. surface course.




(i) **Stress Under Road Surface as per Boussineq's Equation,**

$$\sigma_z = q\left[1 - \cos^3 \alpha\right], \textit{ where } \cos\alpha = \frac{z}{\sqrt{a^2 + z^2}}$$

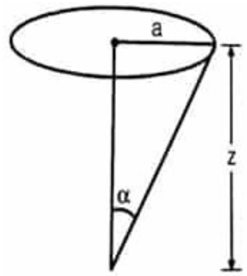
where,

$\sigma_z$ = vertical stress at depth z.

q = surface pressure.

z = depth at which $\sigma_z$ is computed.

a = radius loaded area.



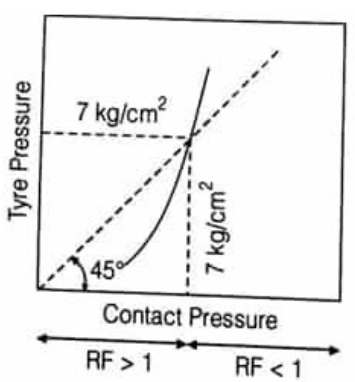

(ii) **As per IRC**

Maximum legal axle load = 8170 kg

Equivalent single wheel load = 4085 kg.

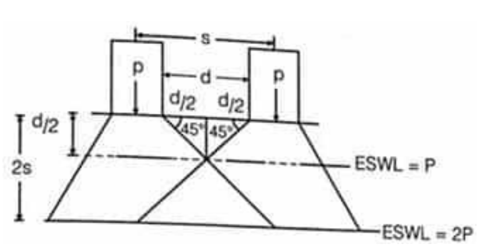
$$(iii)\ Contact\ pressure = \frac{\text{Load on wheel}}{\text{Contact area or area of imprint}}$$

$$(iv)\ Rigidity\ factor(R.F) = \frac{\text{Contact pressure}}{\text{Tyre pressure}}$$




(v) Equivalent Single Wheel Load (**ESWL**)

$$(ESWL)\ at\ \frac{d}{2}\ depth = P(ESWL)\ at\ 2s\ depth = 2P$$




**Methods of Flexible Pavement Design**

(i) **Group Index Method**

$G.I = 0.2a + 0.005ac + 0.01bd$

(ii) **C.B.R Method**

(a)

$$C.B.R\,values = \frac{\text{Load on soil sample}}{\text{Standard load}} \times 100$$

| Penetration | Standard load |
|---|---|
| 2.5 mm | 1370 kg |
| 5.0 mm | 2055 kg |

(b) **The thickness of Pavement, (T)**

$$T = \sqrt{P}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{1/2} or\, T = \left[\frac{1.75}{CBR} - \frac{A}{\pi}\right]^{1/2}$$

where, P = Wheel load in kg.

CBR = California bearing ratio in percent

p = Tyre pressure in $kg/cm^2$

A = Area of contact in $cm^2$.

$A = \pi a^2$

a = Radius of contact area.

(c) **Number of a heavy vehicle per day for design (A),**

$A = P[1+r]^{(n+10)}$

where, A = No. of vehicles at the end of design period.

P = Number of heavy vehicles per day at least count.

r = Annual rate of increase of heavy vehicles

n = Number of years between the last count & the year of completion of construction.

(d) **CBR Method of pavement design by cumulative standard axle load,**

$$N_S = \frac{365A'[(1+r)^n - 1]}{r} \times F.D$$

where,

$N_s$ = Cumulative number of standard axle load

A' = Number of the commercial vehicle per day when construction is completed considering the number of lanes.

n = Design life of the pavement, taken as 10 to 15 years.

F = Vehicle damage factor.

D = Lane distribution factor

(iii) California Resistance Value Method

$$(a)\ T = \frac{k(TI)(90-R)}{C^{1/5}}$$

where, T = Total thickness of pavement, (cm)

k = Numerical constant = 0.166

T.I = Traffic Index

$T.I = 1.35(EWL)^{0.11}$

R = Stabilometer resistance value

C = Choesiometer value.

$$or\ T = \frac{0.22(EWL)^{0.11}(90 - R)}{C^{0.20}}$$

$$\frac{T_1}{T_2} = \left(\frac{C_2}{C_1}\right)^{1/5}$$

where, $T_1$ & $T_2$ are the thickness values of any two pavement layers & $C_1$ & $C_2$ are their corresponding Cohesiometer values.

(iv) **Triaxial Method**

(a) Thickness of pavement required for single layer, ($T_S$)

$$T_S = \sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}$$

where, $T_S$ = Thickness in cm

P = Wind load in kg

X = Traffic coefficient

Y = Rainfall coefficient

$E_S$ = Modulus of elasticity of subgrade soil ($kg/cm^2$)

a = Radius of contact area (cm)

Δ = Design deflection (0.25 cm)

(b) Thickness of Pavement Consist of Two layer system,

$$T_P = \left\{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2\right\}\left(\frac{E_S}{E_P}\right)^{1/3}$$

where, $E_P$ = Modulus of elasticity of pavement material

$$\frac{T_1}{T_2} = \left(\frac{E_S}{E_P}\right)^{1/3}$$

(v) MC Load Method

$$T = k.\log_{10}\left(\frac{P}{S}\right)$$

where, T = Required thickness of gravel base (cm)

P = Gross wheel load, (kg)

k = Base course constant.

(vi) Burmister Method (Layered System)

Displacement equations given by Burmister are,

$$(a)\ \Delta = 1.5\frac{Pa}{E_s}.F_2 \rightarrow for\ flexible\ plate$$

$$(b)\ \Delta = 1.18\frac{Pa}{E_s}.F_2 \rightarrow for\ flexible\ plate$$

$$\mu_s = \mu_p = 0.5$$

where, $\mu_s \;\&\; \mu_p$ are Poisons ratio for soil subgrade & pavement.

For single layer, $F_2 = 1$

P = Yielded pressure

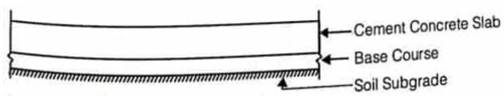
$E_S$ = Subgrade modulus

a = Radius of loaded area

For detailed schedule of **GATE Civil Engineering(CE) 2021 Champion Study Plan,** Click her

## Rigid Pavement

Rigid pavements are those which posses note worthy flexural strength or flexural rigidity. The stresses are not transferred from grain to grain to the lower layers as in the ease of flexible pavement layers. The rigid pavements are made of Portland cement concrete-either plain, reinforced or prestressed concrete. The plain cement concrete slabs are expected to take-up about 40 kg/cm$^2$ flexural stress.




(i) **Modulus of subgrade reaction (k),**

$$k = \frac{P}{\Delta}$$

where, k = Modulus of subgrade reaction (kg/cm$^2$/cm)

p = Pressure required for 'Δ' deflection (kg/cm$^2$)

Δ = Deflection(cm)

For 75 cm dia plate, Δ = 1.25 mm

(ii) **Radius of Relative Stiffness (l)**

$$l = \left\{ \frac{Eh^3}{12k(1-\mu^2)} \right\}^{1/4}$$

where, l = Radius of relative stiffness, cm

E = Modulus of elasticity of cement concrete (kg/cm$^2$)

μ = Poisson's ratio for concrete = 0.15

h = Slap thickness (cm)

k = Subgrade modulus or modulus of subgrade reaction (kg/cm$^3$)

(iii) **Equivalent Radius of Resisting Section (b)**

$$(a)\ b = \sqrt{1.6a^2 + h^2} - 0.675h$$

when a < 1.724 h

(b) b=a when a > 1.724h

where, a = Radius of contact area (cm)

h = Slab thickness (cm)

(iv) **Glodbeck's Formula for Stress due to Corner Load**

$$S_C = \frac{3P}{h^2}$$

where, $S_C$ = Stress due to corner load (kg/cm$^2$)

P = Corner load assumed as a concentrated point load, (kg)

h = Thickness of slab (cm).

(v) **Westergards Stress Equation**

(a) Stress at Interior Loading ($S_i$)

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

(b) Stress at Edge Loading ($S_e$)

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

(c) Stress at Corner Loading ($S_c$)

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

where, h = Slab thickness (cm)

P = Wheel load (kg)

a = Radius of contact area (cm)

l = Radius of relative stiffness (cm)

b = Radius at resisting section (cm).

(vi) **Warping Stresses**

(a) Stress at Interior Region

$$S_{t_i} = \frac{E\alpha T}{2}\left[\frac{C_X + \mu C_y}{1-\mu^2}\right]$$

where,

$(S_{t_i})$

Warping stress at interior region (kg/cm$^2$)

E = Modulus of elasticity of concrete, (kg/cm$^2$)

α = Coefficient of thermal expansion (/°c)

$C_X$ = Coefficient based on

$$\left(\frac{L_X}{l}\right)$$

in desired direction.

$C_y$ = Coefficient based on

$$\left(\frac{L_y}{l}\right)$$

in right angle to the above direction.

μ = Poissons's ratio ~ 0.15

| $L_X / l \, or \, L_y / l$ | $C_X \, or \, C_y$ |
|---|---|
| 4 | 0.6 |
| 8 | 1.1 |
| 12 | 1.02 |

$L_X$ & $L_y$ are the dimensions of the slab considering along X & y directions along the length & width of slab.

(b) Stress at Edge Region $(S_{t_e})$

$$S_{t_e} = \text{maximum}\begin{cases} \frac{E\alpha T}{2}.c_X \\ \frac{E\alpha T}{2}.c_y \end{cases}$$

(c) Stress Corner Region $(S_{t_c})$

$$S_{t_c} = \frac{E\alpha T}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

where, a = Radius of contact area

l = Radius of relative stiffness

(vii) **Frictional Stress ($S_f$)**

$$s_f = \frac{WLf}{2\times 10^4}$$

where, $S_F$ = Frictional stress (kg/cm$^2$)

W = Unit weight of concrete, (kg/cm$^3$)

f = Friction constant or coefficient of subgrade restraint

L = Slab length (m)

B = Slab width (m)

(viii) **Combination of Stresses**

1. Critical Combination During **Summer**

(a) Stress for edge/interior regions at Bottom = (+ load stress) + (warping stress of day time) – Frictional stress

(b) Stress for corner region at top = (+ load stress + warping stress at night)

2. Critical Combination During **Winter**

(a) Stress for edge/interior at bottom = (+ load stress + warping stress at day time + Frictional stress)

(b) Stress for corner at top = (load stress + warping stress at night)

**Design of Joints in Cement Concrete Pavements**

(i) **The spacing of expansion joints,** ($L_e$)

$$L_e = \frac{\delta'}{100\,\alpha(T_2 - T_1)}$$

Where, δ' = Maximum expansion in slab (cm)

$L_e$ = Spacing of expansion joint (m)

α = Coefficient of thermal expansion of concrete (/°c)

(ii) **The spacing of the contraction joint,** ($L_c$)

(a) When reinforcement is not provided

$$L_C = \frac{(2 \times 10^4) S_C}{w.f}$$

where, $L_c$ = Spacing of contraction joint (m)

$S_C$ = Allowable stress in tension in cement concrete.

f = Coefficient friction ∼ 1.5

w = Unit weight of cement concrete (kg/$m^3$).

(b) When reinforcement is provided

$$L_c = \frac{200 S_S A_S}{bgwf}$$

where, $S_S$ = Allowable tensile stress in steel (kg/$cm^2$)

≃ 1400kg/$cm^2$

$A_S$ = Total area of steel in $cm^2$.

(iii) Longitudinal Joints

$$A_s = \frac{bfhw}{100S_S}$$

where, $A_S$ = Area of steel required per meter length of joint ($cm^2$)

b = Distance between the joint & nearest free edge (m)

h = Thickness of the pavement (cm)

f = Coeff. of friction $\simeq$ 1.5

w = Unit wt. of concrete ($kg/cm^3$)

$S_s$ = Allowable working stress in tension for steel ($kg/cm^2$)

$$(b)\ L_t = \frac{d}{2}.\frac{S_s}{S_b}$$

where, $L_t$ = Length of tie bar

$S_S$ = Alloable stress in tension ($kg/cm^2$) $\simeq$ 1400

$S_b$ = Allowable bond stress in concrete ($kg/cm^2$)

= 24.6 $kg/cm^2$ for deformed bars

= 17.5 $kg/cm^2$ for plain tie bars

d = diameter of tie bar (cm).

**IRC recommendations for design of cement concrete pavements**

$A_d = P'[1+r]^{(n+20)}$

where, $A_d$ = Number of commercial vehicles per day (laden weight > 3 tonnes)

$P'$ = Number of commercial vehicles per day at last count.

JK Chrome
CHROME
JK Chrome | Employment Portal
Rated No.1 Job Application of India
Sarkari Naukri
Private Jobs
Employment News
Study Material
Notifications
JK Chrome
jk chrome
Contains ads
4.7 MB
Rated for 3+
Install
About this app
JK Chrome updates it's users with latest news & job updates from J&K.
News & Magazines
Rate this app
Tell others what you think
JOBS
NOTIFICATIONS
G.K
STUDY MATERIAL
GET IT ON
Google play
JK Chrome
jk chrome
Contains ads
Click here to DOWNLOAD
www.jkchrome.com | Email : contact@jkchrome.com

*r* = Annual rate of increase in traffic intensity.

*n* = Number of years between the last traffic count & the commissioning of new cement concrete pavement.

## Railway Engineering & airport & docks and harbour

1. **INTRODUCTION**

- Railway track is a combination of rails, fitted on sleepers and resting on ballast and subgrade.
- Essential function of railway track is to support and guide the vehicles that run over it.
- The conventional railway track consists of two rails located at fixed distance apart. The pressure exerted over by the rails is in turn transmitted to the formation with the help of sleepers and ballast.
- Railway track is also known as permanent way. In a permanent way, rails are joined in series by fish plates and bolts and then they are fixed to sleepers by different types of fastenings.
- The sleepers properly spaced, resting on ballast, are suitably packed and fixed with ballast.
- The layer of ballast rests on the prepared subgrade called as the formation.

1. **COMPONENTS OF RAIL SECTION**

### 2.1. Formation

The formation (also called subgrade level) is the ground surface prepared to support the track surface. It is the top layer of the extended subsoil. A subgrade protection layer applied to the formation is an integral part of track construction today.

**Formation protective layer:**

The fine-grained formation protective layer is applied on the formation, possibly on an additional layer of geosynthetics (geotextiles). It is also called "track bed layer", because it is intended to increase the load-bearing capacity of the soil and can be used for soil improvement with a lime-cement mixture.

### 2.2. Ballast

- Ballast is composed of hard rocks with sharp edges and a particle size of between 32 and 65 mm. It is broken in special ballast plants.
- It is important that the particles have sharp edges so that the ballast bed can provide a secure location in the ballast bed.
- The materials used are granite, diabase or basalt. Different materials are used from region to region.
- The quantity of ballast required per metre of track is 3.5 to 4 tonnes on average, which is slightly more than 2 $m^3$.
- After about 30 to 50 years, the ballast needs to be completely renewed.

**Ballast bed:**

- The ballast bed carries the track grid and ensures that it is retained in a stable position, but at the same time must be elastic and enables a certain amount of track deflection under load.
- In addition, the ballast bed must allow rain water to drain away effectively. Regular maintenance of the ballast bed (use of tamping machines, with selective hand tamping at certain points) ensures that it retains its properties.
- At longer time intervals, depending on load and ambient conditions, the ballast bed must be cleaned partially machines), or completely replaced.
- Inadequate maintenance reduces the carrying capacity of the track bed, leading to the introduction of speed restrictions and finally up to the destruction of the ballast.
- Some amount of elasticity will be generated by ballast. Minimum size ensures drainage conditions whereas maximum size ensures shear strength.

Depth of ballast =

Here, SS = spacing between sleepers

WS = Width of sleeper

DB = Depth of ballast

### 2.3. Sleepers:

The sleeper laid transverse to the direction of travel in general keeps both rails parallel to each other, distributes the load and ensures the correct track gauge.

**Types of Sleepers:**

- **General:** Typical forms are the classic wooden sleeper, the steel-reinforced concrete and steel sleeper, as well as the so-called Y-steel sleeper. With the so-called bi-block-sleeper two concrete elements are connected under the rails by steel rods. Sleepers lying under both rails along the direction of travel, which require additional tie rods or other elements to maintain the correct distance apart, are also designated as Long sleepers; they can also be concreted (type of ballast less track). Sleeper provides elasticity on the railway track.

**(i) Wooden sleeper:** Dog spikes were used for wooden sleeper.

Composite sleeper index is an index to check the suitability of a particular timber to be used as a sleeper.

Here, S: strength of timber

H: hardness of timber

**(ii) Steel sleeper:** Steel sleeper provides maximum rigidity to the rail movement

**(iii) Concrete sleeper:**Pandrol clip is used for concrete sleeper.

**Sleeper density:**

Number of sleeper used for one rail length are denoted by M + x, where M = length of rail in meter. Sleeper density for B.G. should lie between (M + 4) to (M + 7).

## 2.4. Rails

- There would be no railway without rails. There is a variety of different rail sections, some of which have limited use (e.g. crane rails).
- In principle, each rail is a rolled, long steel beam.
- The widest part is always the rail foot and above it there is the rail web and at the top of this there is the rail head. The rail foot is located next to the sleeper. Where appropriate, it is separated by an elastic rail pad.
- If rails are connected by bolted joints, holes are provided in the rail web and the rail ends are connected by steel bolts in the "fishplate surface", which connect the fishplates. Normally, rails are continuously welded today.
- In general usage, "rail" and "track" are often used as synonyms, but this is not correct. In general, the track is formed of two rails with sleepers and

ballast or slab track. In special cases such as the integration of narrow-gauge railways, the track can have three or even four rails. Routes with just one central, paved guide rail have been laid for rubber tyre vehicles similar to bus and coach lanes especially in French cities.

## 2.5. Fixtures & Fastenings:

- All those fittings which are required for connecting the rails end to end and for fixing the rails to the sleepers in a track are known as fixtures and fastenings.

They include -

1) Fish plates

2) Spikes

3) Bolts

4) Chairs

5) Keys

6) Blocks

7) Bearing plates

- The different functions of these fittings are:

1) To keep the rails in the proper positions.

2) Connection of rail to rail.

3) To set points and crossings properly

4) To allow for expansion and contraction of rails.

- The various types of fixtures and fastenings listed above are briefly described below:

**FISH PLATES:** These plates are used to maintain proper alignment of the rail line. They maintain the continuity of the rails and also allow expansion or contraction of rails caused due to temperature variations.

Generally these plates are made of mild steel and 20 mm in thickness.

They are 45.6 cm long and provided with 4 no. of 32 mm diameter holes at 11.4 centre to centre.

Indian railways generally adopt following two types of fish plates:-

1.Bone shaped fish plate

2.Increased depth fish plate

**SPIKES:** They are used to hold the rails to the wooden sleeper. A good spike should have following qualities:

1) It should have sufficient strength to hold the rail in position.

2) It should help in maintaining proper gauge.

3) It should be easy to fix and replace from the sleepers.

Indian Railways use following types of spikes:-

1. Dog spikes
2. Screw spikes
3. Round spikes
4. Standard spikes
5. Elastic spikes

**BOLTS:** They are used for connecting:

1) Fish plates to the rails at each rail joint.

2) Chairs or bearing plates to timber sleepers.

3) Sleepers to bridge girders, etc.

The different types of bolts used in Indian Railways are:

1. Hook bolts
2. Fish bolts
3. Fang bolts
4. Rag bolts

**CHAIRS:** They are used to hold the double headed and bull headed rails in required position. They are made of cast iron having two jaws and a rail seat. In order to fix the double headed or bull headed rail to a chair, the rail is placed between the two jaws of the chair.

**KEYS:** They are small tapered pieces of timber or steel to connect rails to chairs on metal sleepers.

Types of keys generally used are:

1) Timber keys

2) Metal keys

3) Stuart's keys

4) Morgan keys

**BLOCKS:** They are inserted in between the two rails running close to each other and bolted to maintain the required distance. They may touch either the webs or the finishing faces or both.

**BEARING PLATES**: They are the plates placed in between the flat footed rails and timber sleepers on a track. They serve as chairs for flat footed rails. They are made of cast iron, wrought iron or steel. Generally, they are of following types:

1.Flat bearing plates: Flat bearing plates are used at locations where rails are laid flat. Also they are used in turn out tracks under points and crossings.

2.Canted bearing plates: Canted Bearing plates are used on soft timber sleepers beneath outside rail on curves, on sleepers placed on either side of rail joints, bridges etc. where rails are laid at an inward tilt of 1 in 20.

1. **GAUGE DISTANCE**

It is the distance between inner faces of rails or running faces of rail section.

**3.1. Type of Gauge:**

**(i) Broad Gauge:** 1.676 m

**(ii) Standard Gauge:** 1.435 m

**(iii) Meter Gauge:** 1.00 m

**(iv) Narrow Gauge:** 0.762 m

**(v) Feder Gauge:** 0.610 m

1. **CONING OF WHEELS**

The wheels are made cone shaped having different diameters at different cross sections. Diameter near flange is more than the diameter near other ends. The rails are also laid at a slope of lin20 (same slope of wheel face) this is called coning of wheels.

**Purpose of coning**

1.On a straight track: To keep the wheel assembly in central position to avoid derailment.
2. To reduce wear and tear of centrifugal force the wheel assembly in move in outward direction, so diameter on outer rail will increase. So the distance travelled on outer rail will become more as required. Due to difference of diameter on two rails, the trains will be moving on a circular track and distance travelled on two tracks will be adjusted as required.

2.Only some part of difference is adjusted due to coning. Remaining part is covered by slip or skid on the surface.
Due to cone shaped wheels, diameter of wheel is not same at each section.

3.On straight track, the wheel will always move in central position in such a way that diameter at contact point with rail is same on the two rails. If the train or axle of wheel tries to move in any direction, diameter of wheel on one rail will increase. So the axle will start moving on a circular track. Thus the wheel assembly will be automatically returned back in its central position.

1. **WELDING OF RAILS**

**Welding methods:**

- **Gas pressure welding**
- **Electric arc welding/Metal arc welding**
- **Flash butt welding**

- **Thermite welding**

1. **GEOMETRIC DESIGN OF RAILWAY TRACK**

**6.1. Maximum speed on a railway track:**

It is the minimum of,

(i) Speed decided by Railway board

(ii) Speed decided by Martin's formula

(iii) Speed calculated by super elevation formula

(iv) Speed calculated by length of transition curve formula

- Martin's formula : a) On a Transition Curve

1. For BG/MG

$V_{max}$= 4.35 √(R-67)

ii.For NG

$V_{max}$= 3.6 √(R-61)

1. b) On a Non- Transition Curve

$V_{max}$= 0.8 ($V_{max}$ of transition curve)

1. c) For High Speed Trains

$V_{max}$= 4.58 √(R)

**6.2. Radius of the curve**,

[For 1 chain length = 30 m]

**6.3. Super elevation:**

In the above figure, if Θ is the angle that the inclined plane makes with the horizontal line, then tan Θ = Super Elevation/ Gauge = e/G

Also, tan Θ = Centrifugal Force/ Weight = F/W

From these equations

e/G = F/W

e= F. (G/W)

e= (W/g). ($V^2$/R). (G/W) = G $V^2$ / gR

Where e is the equilibrium super elevation, G is the gauge, V is the velocity, g is the acceleration due to gravity, and R is the radius of the curve. In the metric system equilibrium super elevation is given by the formula

e= G $V^2$/ 127R

Where e is the super elevation 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.

**Equilibrium Super Elevation:**

Here G = gauge in 'meter'

V = velocity in km/h

R = radius in 'meter'

e = is in 'meter'

Different trains have different speed on the railway track and actual cant is provided for average speed and that is also called as equilibrium cant.

### 6.3.1.Permissible value of actual cant

| Gauge | Speed ≤ 120 km/h | Speed > 120 km/h |
|---|---|---|
| BG | 16.5 cm | 18.5 cm |
| MG | 10.0 cm | — |
| NG | 7.6 cm | — |

1. **CANT DEFICIENCY**

For high speed train cant requirement will be more than actual cant provided so the train will be forced to move on a lower value of cant. This deficiency of cant for high speed train movement is called cant deficiency.

$e_{theoretical} = e_{actual}$ + cant deficiency

### 7.1. Limits of cant deficiency

| **Cm** | **Speed ≤ 100 km/hr** | **Speed > 100 km/hr** |
|---|---|---|
| BG | 7.6 | 10 |
| MG | 5.1 | — |
| NG | 3.8 | — |

1. **VERTICAL CURVES**

### 8.1. Types of gradients

**(i) Ruling Gradient:** It is the maximum gradient that can be provided in the most general condition and that determines maximum load that a locomotive can carry on that particular section.

**(ii) Momentum gradient:** For a practical situation as shown in figure, gradient may be increased more than ruling gradient (with no stoppage)

**(iii) Pulling/helper/pusher gradient:** When gradient is greater than ruling gradient then extra locomotive is provided for that particular section.

Note: Greater gradient reduce the cutting cost

Minimum gradient at station yard: 1/100

Maximum gradient at station yard: 1/400

**8.2. Grade compensation:** If the gradient is provided on a curved location then gradient value is reduced to compensate curve resistance. Reduction in gradient for broad gauge is 0.04% per degree of the curve.

1. **TRANSITION CURVE**

It is required for

(i) Introduction the super elevation in a gradual manner within the length of transition curve in outer railway track.

(ii) Reducing the radius of the curve from infinite to some value

(iii) Curve should be perfectly tangential at joining points

(iv) If the centrifugal force is to be increased at a constant rate, centrifugal force must vary with time.

(v) The ideal condition for transition curve is:

(vi) Cubical parabola equation for transition curve:

h = in ‘m’

e = actual cant in ‘cm’

$V_{max}$ = in km/hr

CD = in cm

**Spiral and Deflection Angles:**

shift → because of transition curve, the path shifted w.r.t. circular curve

L = length of transition curve

1. **LEFT HAND TURNOUT**

It is an arrangement on railway track to direct the trains from one track to another track.

**(i) Tongue rail:** They are provided on sliding plate and each plate of tongue rail is connected by structure bars.

**(ii) Flare:** It is provided to guide the wheel such that range of wheel enter and leave the turnout smoothly.

**(iii) Heel Block**

- **Flangwayclearance :** It is the distance between adjacent faces of stock rail and tongue rail
- **Flange way depth:** It is the vertical distance from top of the rail surface to top of the heel block.
- **Heel divergence :**It is the distance between the running faces of stock rail and tongue rail

1. **CROSS OVER**

It is the combination of 2 turnouts with intermediate portion as straight portion or curved portion i.e., used to drive the trains from one track to another track.

From ΔABC,

from Δ CDE,

Also, we know

So total cross-over length

= 2GN + 2GN + DE

1. **HAULING EFFECT**

Maximum functional force that can be generated between rail surface and driving wheels.

Hauling capacity = $\mu WN$

Here, $\mu$ = functional co-efficient

W = load on each driving axle (in tonnes)

N = No. of pairs of driving wheel

1. **CREEP OF RAIL**

Longitudinal movement of rails w.r.t. sleeper is k/a creep of rails.

Dominating traffic theory (also called drag theory):

$P = AE \propto T$, here l = length of rail in one direction

T = temperature are valuation

∝ = thermal coefficient

= no. of sleeper required. {$R_o$: resistance offered by one single sleeper}

Length of rail in one direction = l = (n – 1) s

Here, s = spacing between two sleepers

1. **WIDENING OF GAUGE ON CURVES**

A vehicle normally assumes the central position on a straight track and the flanges of the wheels stay clear of the rails. The situation, however, changes on a curved track. As soon as the vehicle moves onto a curve, the flange of the outside wheel of the leading axle continues to travel in a straight line till it rubs against the rail. Due to the coning of wheels, the outside wheel travels a longer distance compared to the inner wheel. This, however, becomes impossible for the vehicle as a whole since the rigidity of the wheel base causes the trailing axle to occupy a different position. In an effort to make up for the difference in the distance travelled by the outer wheel and the inner wheel, the inside wheels slip backward and the outer wheels skid forward. A close study of the running of vehicles on curves indicates that the wear of flanges eases the passage of the vehicle round curves, as it has the effect of increasing the gauge. The widening of the gauge on a curve has, in fact, the same effect and tends to decrease the wear and tear on both the wheel and the track.

The widening of the gauge on curves can be calculated using the formula:

**Extra Width on curves=w = 13 $(B+L)^2/R$**

Where B is the wheel base of the vehicle in metres, R is the radius of the curve in metres,

$L = 0.02 (h^2 + D.h)^{0.5}$ is the lap of the flange in metres, h is the depth of flange below top of the rail, and D is the diameter of the wheel of the vehicle.

**Example:** The wheel base of a vehicle moving on a BG track is 6 m. The diameter of the wheels is 1524 mm and the flanges project 32 mm below the top of the rail. Determine the extra width of the gauge required if the radius of the curve is 168 m. Also indicate the extra width of gauge actually provided as per Indian Railways standards.

**Solution:**

(i) Lap of flange

Where h = 3.2 cm is the depth of the flange below the top of the rail and

D = 152.4 cm is the diameter of the wheel. Therefore,

(ii) Extra width of gauge (w)

(iii) As per Indian Railways standards, an extra width of 5 mm is provided for curves with a radius less than 400 in actual practice.

1. **NEGATIVE SUPER ELEVATION**

When the main line lies on a curve and has a turnout of contrary flexure leading to a branch line, the super elevation necessary for the average speed of trains running over the main line curve cannot be provided. In the figure below, AB, which is the outer rail of the main line curve, must be higher than CD. For the branch line, however, CF should be higher than AE or point C should be higher than point A. These two contradictory conditions cannot be met within one layout. In such cases, the branch line curve has a negative super elevation and, therefore, speeds on both tracks must be restricted, particularly on the branch line.

The provision of negative super elevation for the branch line and the reduction in speed over the main line can be calculated as follows:

(i)The equilibrium super elevation for the branch line curve is first calculated using the formula:

(ii) The equilibrium super elevation e is reduced by the permissible cant deficiency CD and the resultant super elevation to be provided is

x = e - CD

Where, x is the super elevation, e is the equilibrium super elevation, and CD is 75 mm for BG and 50 mm for MG. The value of Cd is generally higher than that of e, and, therefore, x is normally negative. The branch line thus has a negative super elevation of x.

(iii) The maximum permissible speed on the main line, which has a super elevation of x, is then calculated by adding the allowable cant deficiency (x + CD). The safe speed is also calculated and smaller of the two values is taken as the maximum permissible speed on the main line curve.

1. **RAILWAY MODERNISATION**

Railways are modernized with the objective of allowing heavier trains to run safely and economically at faster speeds, of improving productivity, and of providing better customer service to rail users. This consists of upgrading the track, use of better designed rolling stock, adopting a superior form of traction, better signalling and telecommunication arrangements, and using other modern techniques in the various operations of a railways system.

**A railway track is modernized by incorporating the following features in the track:**

(a) Use of heavier rail sections such as 52 kg/m and 60 kg/m and the use of wear-resistant rails for heavily used sections so as to increase the life of the rails.

(b) Use of curved switches of 1 in 16 and 1 in 20 type for smoother arrival at yards.

(c) Use of pre stressed concrete sleepers and elastic fastenings such as Pandrol clips to provide resilience to the track and ensure the smooth movement of trains at high speeds.

(d) Use of long welded rails and switch expansion joints to ensure a smooth and fast rail journey.

(e) Modernization of track maintenance methods to include mechanized maintenance, measured shovel packings, etc., in order to ensure better track geometry, to facilitate high speeds and smooth travel.

(f) Track monitoring using the Amsler car, portable accelerometer, Hallade track recorder, etc. to assess the standards of track maintenance and plan for better maintenance, if required.

**Other aspects of modernization of the railways generally include making the following provisions:**

(a) Use of better designed all-coiled, anti-telescope ICF coaches with better spring arrangements and better braking systems for safe and smoother rail travel.

(b) Provisions of universal couples to ensure uniformity in the coupling of the coaches.

(c) Introduction of diesel and electric traction in order to haul heavier loads at faster speeds.

(d) Introduction of modern signalling techniques to enable trains to move at high speeds without any risks.

(e) Setting up of a management information system for monitoring and moving freight traffic in order to avoid idle time and increase productivity.

(f) Computerization of the train reservation system to avoid human error and provide better customer service for reservation of berths.

(g) Use of computers and other modern management techniques to design and maintain railway assets more efficiently and economically, to ensure efficient human resource development (HRD), to increase productivity, and to provide better customer service.

1. **AIRPORT AND TUNNEL ENGINEERING**

1. **TUNNEL**

**1.1. Investigation**

**(i) Before planning:-**

(a) To determine relation between bed rock and top soil when exploration at the surface in form of knowing morphology, petrology, stratigraphy etc.

(b) Electrical resistivity methods are used to locate positions of work zone like faults and shear zones.

**(ii) At the time of planning :-**

(a) Investigations at the time of planning are made through drilling holes either by

Percussion

Rotary percussion

Rotary

**(iii) At the time of construction :-**

Information is achieved by driving either of the following.

Heading

driving drift

**1.2. Blasting :-**

**(i) Types of explosives :-**

(a) Straight dynamites

(b) Ammonia dynamites

(c) Ammonia gelatine

(d) Semi-gelatine

**(ii) Theory of blasting :-** Processes by which rock can be blasted

(a) Impact

(b) Abrasion

(c) Thermally induced spalling

(d) Fusion and vaporization

(e) Chemical reaction

**1.3. Shape and Size:-**

**(i) D-section :-** This section is suitable for sub-ways or navigation tunnels.

**(ii) Circular section :-** For tunnels which may have to withstand heavy internal or external radial pressure.

**(iii) Rectangular section:** Suitable in case of hard rocks.

**(iv) Egg shaped section:-** Used for carrying sewage because it gives self cleaning velocity.

**(v) Horse shoe form :-** Used for traffic purposes and as the floor of the tunnel is nearly flat, it gives working space to store material during construction

**1.4. Various types of Construction Technique**

(i) Cut and cover method

(ii) Bored tunnel method

(iii) Clay kicking method

(iv) Shaft method

(v) Box jacking meth d

(iv) Under water unnels.

1. **BRIDGES**

**2.1. Types of Bridges**

**(i) Arch Bridges :-**

(a) It is very strong and wide range of materials can be used.

(b) It is quiet expensive.

**(ii) Truss Bridges:-**

(a) It is frequently used as a draw bridge or as an overpass for railroad train.

(b) It is difficult to construct, high maintenance.

**(iii) Suspension Bridges:-**

(a) It has span distances up to 7000 feet,

(b) It allows large boats and heavy boat traffic to pass underneath.

(c) Expensive construction

**(iv) Cable Stayed Bridges:-**

(a) Not expensive and faster to build

## 2.2. Factors for Selection of Types of Bridges

(i) Geography (ii) Loading

(iii) Aesthetics (iv) Cost

## 2.3. Section Criteria for Bridge Site

(i) Topography (ii) Catchment area

(iii) Hydrology (iv) Geo-technical

(v) Seismology (vi) Navigation

(vii) Construction resources (viii) Traffic data

## 2.4. Types of Bridge Foundation

**(i) Spread or open foundation** is suitable for bridges of moderate height to be built on dry ground which is sufficiently firm to support the bridge structure.

**(ii) Raft foundation** is suitable when bed of water course consists of soft clay and silt.

**(iii) Grillage Foundation** is suitable for heavy load and located footing of piers where deep foundations are to be avoided.

**(iv) Inverted arch foundation** is suitable when depth of excavation for foundation is less. It is best suited where bearing capacity of soil is less.

**(v) Pile formation** is suitable when the soil is very soft and the hard strata are not available at reasonable depth.

**(vi) Well foundation** is suitable where good soil is available at about 3 to 4m below the bed level of the river the bed consist of sandy soil.

**(vii) Caisson foundation** is suitable when a hard is available near to the river bed but the depth of water is excessive and it is not economically possible to exclude water from a dry bed for sinking the wells to provide well foundation.

1. **AIRPORT**

## 3.1. Introduction:

Airports are classified by 2 organisations:

(i) ICAO: International Civil Aviation Organization.

(ii) FAA: Federal Aviation Agency.

ICAO classified airport into 2 categories-

(i) Based on basic runway length

A → longest runway

B → shortest runway

1. Equivalent Single Wheel Load of the aircraft.

**Important Points related to Wind- Rose Diagrams:**

(i) Length of runway requirements will be more if landing and take-off operation are performed along the wind direc ion.

(ii) Wind parameters (direction and intensity) are graphically represented by diagrams called as wind rose diagrams.

(iii) Wind parameters should be collected for a period of 3 years.

(iv) Normal component of the wind is called as cross-wind component & it may interrupt safe landing & take-off of the aircraft. For the smaller size of aircraft, max. Perm ssible limit is 15 km/hr & for bigger →25 km/hr of (due to more weight its h gher) of cross-wind component.

The % age of time during which in a year, the cross Wind component remains within the permissible limit is called as wind coverage.

## 3.2. Basic runway length requirements

1. Airport altitude is at MSL.
2. Temperature at airport is standard 15°c.
3. Runway is levelled in the longitudinal direction.

4. Aircraft is loaded through its full loading capacity. They themselves are worst cases. So no correction required for them.
5. Speed of wind should be zero on the runway.

Correction for elevation

ICAO recommends that the basic runway length should be increased by 7% per 300 m rise in elevation above MSL.

Correction for temperature

Std. Atmospheric temperature at rest altitude is calculated as

Local body temperature of a particular area is called as airport reference temperature & that is defined for hottest month of the year

$T_a \rightarrow$ monthly mean of avg. Daily temperature.

$T_m \rightarrow$ monthly mean of max. Daily temperature.

ICAO recommends that the basic runway length after corrected for elevation should be increased by 1% for every 1°c rise of art above the std. Atmospheric temperature at that elevation (air density).

If the total correction for elevation & temperature is less than or equal to 35% of basic runway length, no corrections are >35%, scientific analysis must be performed at site conditions again (economical).

Correction for gradient

[Only as per FAA].

After corrected runway length for elevation & temperature, runway length should be increased by 20% for every 1% of effective gradient.

**Example:** Basic runway length = 1620 m. [under std. Condition]

ART = 32.94°c

Elevation- of airport site = 270m.

If the runway is to be constructed with 0.2% eff. Gradient.

Calculate corrected runway length.

**Ans.** Correction for elevation→

Corrected runway length = 1620 + 102.06 = 1722.06 m.

(2) change in standard temperature→

= 15° – (0.0065 × change in el. Above MSL)

= 15° – (0.0065 × 270)

= 13. 24°c

ART = = 32.94°c (given)

ΔT °c = 32.94°c – 13.24°c

= 19.7°c

So, correction for temperature:

= 339.24 m.

Corrected runway length = 2061.3 m

1. Correction for gradient:

Corrected runway length

= 2143.75 m.

**Example:** Determine actual length of runway for them given parameter⇒ basic runway length = 1800 m.

El. Of airport site = 600 m, $\tau_a$ = 15°c, $\tau_m$ = 21.6°c,Eff grad = 0.6%

**Ans.**

Correction for elevation →

Corrected length = 1800 + 252

=

1. Temperature correction:

Std. Temperature

= 15° – (0.0065 × 600) = 11.1°c

So rise in ART = 17.2 – 11.1

(δt°C) = 6.1°c

So, correction =

= 125.172 m.

So corrected length

= 2052 + 125.172

Check=

1. Grad. Correction [FAA]

So final corrected length

= 2177.172 + 261. 26

= 2438.43 m

- In case of take-off elevation, temperature & gradient corrections are necessary.

In case of landing, only elevation correction is necessary.

**3.3. Turning radius at taxiway**

4) R> 120 m for Sub sonic jets.

**Example:** Evaluate taxiway radius for supersonic aircraft with

w = 35 m & tread of landing gear = 7.5 m.

Speed of aircraft = 50 km/hr

Ans. 1.

Let t = 22.5m,

So,

1. For supersonic = r ≥ 180 m

= max = 316.86 m

**3.4. Some Important elements of an Airport:**

Stop way is used in case of engine failure conditions.

Length of runway is decided on the basis of:

1. Normal landing case
2. Normal take off care
3. Engine failure case

Circling radius depends on

1. Type of aircraft
2. Weathering conditions & volume of aircrafts.

Aircraft movements will be more in case visual flight rules as compared to instrumental flight rules (which are applicable in bad weathering conditions.)

Size of hanger building is decided on basis of size of aircraft (length, width, height).

1. **DOCK, PORT AND HARBOUR**

**4.1. Some Important Definitions:**

- HARBOURS provide safe anchorage to ships in conditions of bad weather.
- PORTS are used for loading & unloading of passengers, cargo, etc.
- Every port is a harbour but reverse is not true.
- Docks which are used for ships to facilitate loading & unloading of passengers & cargo are known as Wet Docks.

- Docks which are used for serving & maintenance of ships are called as Dry Docks.
- WHARF → it is a type of fixed platform usually on file foundations where ships are loaded or unloaded.
- FENDER → Dock wall receives large amount of impact and to avoid this, cushions are provided permanently with dock walls & these are known as FENDERS. [In India, we use TYRES].
- DOLPHIN PILES → used to tie-up the ships.
- LITTORAL DRIFT → Sea waves are generated by prevailing winds & they move lighter particles of sand in suspension. This suspended sand is carried in a zig-zag manner & deposition of this sand is called LITTORAL DRIFT.
- Excavation below water surface is called as DREDGING.

## Principle of Surveying, Maps & Scale

### Fundamental Concepts of Surveying

### Introduction

**Surveying** is the process of determining the relative positions of different objects on the surface of the earth by measuring horizontal distances between them and preparing a map to any suitable scale. Measurements are taken in a horizontal plane.

### Reconnaissance:

• This is an exhaustive preliminary survey of the land to be surveyed. It may be either ground reconnaissance or aerial reconnaissance survey.
• Reconnaissance is made on arrival to site during which an overall picture or view of the area is obtained. The most suitable position of stations is selected, the purpose of the survey and the accuracy required will be drawn, and finally, the method of observation will be established.

### Objectives of reconnaissance

1. To ascertain the possibility of building or constructing route or track through the area.
2. To choose the best one or more routes and record on a map
3. To estimate probable cost and draft a report.

### Principle of working from whole to part

It is a fundamental rule to always work from the whole to the part. This implies a precise control surveying as the first consideration followed by subsidiary detail surveying.

• This surveying principle involves laying down an overall system of stations whose positions are fixed to a fairly high degree of accuracy as control, and then the survey of details between the control points may be added on the frame by less elaborate methods.
• Once the overall size has been determined, the smaller areas can be surveyed in the knowledge that they must (and will if care is taken) put into the confines of the main overall frame.
• Errors which may inevitably arise are then contained within the framework of the control points and can be adjusted to it.

**Types of Surveying**

On the basis of whether the curvature of the earth is taken into account or not, surveying can be divided into two main categories:

- **Plane Surveying**

Plane surveying is that type of surveying in which the mean surface of the earth is considered as a plane and the spheroidal shape is neglected.

All angles are considered to be plane angles. For small areas less than 250 km2 plane surveying can safely be used. For most engineering projects such as canal, railway, highway, building, pipeline, etc constructions, this type of surveying is used. It is worth noting that the difference between an arc distance of 18.5 km and the subtended chord lying in the earth's surface is 7mm. It is divided into three branches.

a. Cadastral surveying
b. Topographical surveying
c. Engineering surveying

- **Geodetic Surveying**

It is that branch of surveying, which takes into account the true shape of the earth (Ge-oid).

**Classification Of Surveying**

Surveying is classified based on various criteria including the instruments used, purpose, the area surveyed and the method used.

- **Classification on the Basis of Instruments Used**: Based on the instrument used; surveys can be classified into;
  - Chain tape surveys
  - Compass surveys
  - Plane table surveys
  - Theodolite surveys
- **Classification based on the surface and the area surveyed**

1) Land survey: Land surveys are done for objects on the surface of the earth. It can be subdivided into:
(a) Topographic survey: This is for depicting the (hills, valleys, mountains, rivers, etc) and manmade features (roads, houses, settlements…) on the surface of the earth.
(b) Cadastral survey is used to determining property boundaries including those of fields, houses, plots of land, etc.
(c) Engineering survey is used to acquire the requ red data for the planning, design and Execution of engineering projects like roads, bridges, canals, dams, railways, buildings,
etc.
(d) City surveys: The surveys involv ng the construction and development of towns including roads, drainage, water supply, sewage street network, etc. are generally
referred to as city survey.
(2) Marine or Hydrographic Survey: Those are surveys of large water bodies for navigation, tidal monitoring, the construction of harbors etc.
(3) Astronomical Survey: Ast onomical survey uses the observations of the heavenly bodies (sun, moon, stars etc.) to fix the absolute locations of places on the surface of the earth.

- **Classification Based on Instrument Used**

i. Chain/Tape Survey: This is the simple method of taking the linear measurement using a chain or tape with no angular measurements made.
ii. Compass Survey: Here horizontal angular measurements are made using the magnetic compass with the linear measurements made using the chain or tape.
iii. Plane table survey: This is a quick survey carried out in the field with the measurements and drawings made at the same time using a plane table.
iv. Leveling: This is the measurement and mapping of the relative heights of

points on the earth's surface showing them in maps, plane and charts as vertical sections or with conventional symbols.

Vi. Theodolite Survey: Theodolite survey takes vertical and horizontal angles in order to establish controls.

- **Classification on the basis of Purpose**

i) Engineering survey

ii) Control Survey: Control survey uses geodetic methods to establish widely spaced vertical and horizontal control points.

iii) Geological Survey: Geological survey is used to determine the structure and arrangement of rock strata. Generally, it enables to know the composition of the earth.

iv) Military or defence Survey is carried out to map places of military and strategic importance

iv) Archeological survey is carried out to discover and map ancient/relies of antiquity.

**Scales**

Scale is the fixed ratio that every distance on the plan bears with corresponding distance on the ground.

**Representative Fraction (RF)**

$$RF = \frac{\text{Map distance}}{\text{Ground distance}}$$

**(a) Plain scale:** Plain scale is one on which it is possible to measure two dimensions only such as units and lengths and diameters, miles and furlongs etc.

**(b) Diagonal scale:** On a diagonal scale it is possible to measure three dimensions such as meters, decimeters and centimetres; units tenth and hundreds; yards, feet and inches.

**(c) The Vernier:**

**(i) Direct vernier:** It is constructed (n-1) divisions of the main scale is equal to n division of the vernier.

In direct vernier, vernier scale moves in same direction of main scale.

$$Least\,count = \frac{s}{n}$$

where, s = value of one smallest division of main scale

n = number of division on the vernier

v = value of one smallest division of vernier

also nv = (n-1) s

**(ii) Retrograde vernier:** It is so constructed that (n + 1) division of main scale is equal to n division of vernier.

In retrograde vernier, vernier scale moves in opposite di ection of main scale.

$$Least\,count = \frac{s}{n}\ also\ nv = (n+1)s$$

**(d) Shrunk scale**

Shrunk scale = original scale x shrinkage factor

$$Shrinkage\ factor = \frac{\text{Shrunk length}}{\text{Actual length}}$$

| Type of purpose of survey | Scale | R.F. |
|---|---|---|
| (a) Topographic survey | | |
| 1. Building sites | 1 cm = 10 m or less | $\frac{1}{1000}$ *or less* |
| 2. Town planning schemes, reservoirs etc. | 1 cm = 50 m or 100 m | $\frac{1}{5000}$ *to* $\frac{1}{10000}$ |
| 3. Location surveys | 1 cm = 50 m or 200 m | $\frac{1}{5000}$ *to* $\frac{1}{20000}$ |
| 4. Small scale topographic maps | 1 cm = 0.25 km or 2.5 km | $\frac{1}{25000}$ *to* $\frac{1}{250000}$ |
| (b) Cadastral maps | 1 cm = 5 m or 0.5 km | $\frac{1}{500}$ *to* $\frac{1}{5000}$ |
| (c) Geographical maps | 1 cm = 5 km to 160 km | $\frac{1}{500000}$ *to* $\frac{1}{16000000}$ |
| (d) Longitudinal sections | | |
| 1. Horizontal scale | 1 cm = 10 m to 200 m | $\frac{1}{1000}$ *to* $\frac{1}{20000}$ |
| 2. Vertical scale | 1 cm = 1m to 2 m | $\frac{1}{100}$ *to* $\frac{1}{200}$ |
| (e) Cross-sections $\left(\begin{array}{c}\text{Both horizontal and}\\ \text{vertical scales equal}\end{array}\right)$ | 1 cm = 1m to 2 m | $\frac{1}{100}$ *to* $\frac{1}{200}$ |

**Error Due to Use of the Wrong Scale**

(a) **Correct length**

$$= \frac{\text{RF of wrong scale}}{\text{RF of correct scale}} \times Measured\ length$$

(b) Correct length

$$= \left(\frac{\text{RF of wrong scale}}{\text{RF of correct scale}}\right)^2 \times Calculated\ Area$$

**Error Due to Incorrect Length of Chain or Type**

(a) True length of the line, (l)

$$l = \left(\frac{L'}{L}\right) \times l'$$

Here, L = Designated length of tape/chain

L’ = Actual but wrong length of the chain or tape

l’ = Wrong measured length of the line

l = Actual true length of the line

**Case (a):** In case of Area

$$A = \left(\frac{L'}{L}\right)^2 . A'$$

where, A = True area

A’ = Wrong measured area

**Case (b):** In case of volume

$$V = \left(\frac{L'}{L}\right)^3 . V'$$

where, V = True volume

V’ = Wrong measured volume

**Most Probable Value**

$$E_s = \pm 0.6745 \sqrt{\frac{\sum V^2}{n-1}}$$

$$E_m = \frac{E_s}{\sqrt{n}}$$

Where, $E_s$ = Probable error of single observation

V = Difference between any single observation and the mean of the series

$E_m$ = Probable error of the mean

n = Number of Observation in the series

## Chain Surveying & Levelling

### Chain Surveying

- It is the simplest and oldest form of land surveying of an area using linear measurements only.
- It can be defined as the process of taking direct measurement, although not necessarily with a chain.

### Types of equipment used in Chain Surveying

These equipment's can be divided into three, namely

a. Those used for linear measurement. (**Chain, steel band, linear tape**)
b. Those used for slope angle measurement and for measuring right angle (**Eg. Abney level, clinometer, cross-staff, optical squares**)
c. Other items (**Ranging rods or poles, arrows, pegs etc.**)

**1. Chain**: This is an instrum nt used for measuring distance. There are four types of chains.

(i) **Metric chain**: In metric system the chains of **20m** and **30m** are commonly used. The chain is made with galvanized steel wire of 4mm diameter. Each meter is divided into 5 links of 20cm length. It is provided with brass handles on either ends. The tallies are fixed at every 5m length and small brass rings are provided at every meter length.

(ii) **Engineer's chain**: The Engineer's chain is **100ft** length and made of 100 links.

(iii) **Gunter chain**: It is 66 feet long and has 100 links. It is useful for measuring the distance in miles and areas in acres.

10 square Gunter chain = 1 acre = 4840 sq. yards.

(iv) **Revenue chain**: This chain is of 33ft length and is divided into 16 links.

**2. Tape**: The tapes are divided according to the materials used as following (i) Metallic tapes (ii) Steel tapes (iii) Invar tapes

(i) **Metallic tapes**: This tape is made with waterproof linen with brass, copper wires to avoid stretching. The tapes available in lengths 2, 5, 10, 20 and 30m

(ii) **Steel tapes**: This is most accurate tape for taking measurements. If carelessly handled it gets broken.

(iii) **Invar tapes**: If the measurements are to be made with the highest precision this tape is used. These are 6mm wide and available in lengths of 30, 50 and 100m.

**3. Ranging rods**: These are wooden or metal poles 2m or 3m long and having a diameter of 30mm. They are provided with iron shoes at the lower ends to facilitate easy driving in the ground. They are painted in bands alternatively in black and white or red and white. Ranging rods used for ranging a line.

**4. Offset rods**: This is mainly used to measure offsets of shorter lengths. It is usually 2m long.

**5. Cross staff**: Cross staff is an instrument used for setting perpendicular offsets. These are three types.
(i) Open cross staff: It consists of 4 metal arms at right angles to each other having eye vane at two adjacent ends and object vane at the other ends.
(ii) Adjustable cross staff: With this cross staff the object can be set at any angle.
(iii) French cross staff: This cross-staff is an octagonal brass tube with slits on its eight faces. With this cross staff we can set the object at an angle of 450 also.

**6. Optical Square**: This is an instrument used for setting out right angles to the chain lines and to find out the foot of the perpendicular on the chain line from an object. It works on the principle of reflection.

**7. Arrows**: These are used for marking the ends of a chain during the process of chaining. These are steel pins 400mm long and are pointed at one end.

**8. Plumb bob**: It is used to define the vertical line while measuring distance along slopes.

## General Procedure in making a Chain Survey

**1. Reconnaissance**: Walk over the area to be surveyed and note the general layout, the position of features and the shape of the area.
**2. Choice of Stations**: Decide upon the framework to be used and drive in the station pegs to mark the stations selected.
**3. Station Marking**: Station marks, where possible should be tied - into a permanent object so that they may be easily replaced if moved or easily found during the survey. In soft ground, wooden pegs may be used while rails may be used on roads or hard surfaces.
**4. Witnessing**: This consists of making a sketch of the immediate area around the station showing existing permanent features, the position of the stations and its description and designation. Measurements are then made from at least three surrounding features to the station point and recorded on the sketch. The aim of witnessing is to relocate a station again at much later date even by others after a long interval.
**5. Offsetting**:- Offsets are usually taken perpendicular to chain lines in order to dodge obstacles on the chain line.
**6.** Sketching the layout on the last page of the chain book, together with the date and the name of the surveyor, the longest line of the survey is usually taken as the baseline and is measured first.

### Linear Measurements

### Tape Corrections

**(a) Correction due to standardization or (correction due to absolute length)**

$$C_a = \left(\frac{C}{l}\right)L$$

where, $C_a$ = Correction for absolute length

L = Measured length of the line

l = Designated length of the tape

C = Correction per tape length

**(b) Correction due to temperature**

$C_T = L\alpha(T_m - T_0)$

where, $T_m$ = Temp. at the time of measurement

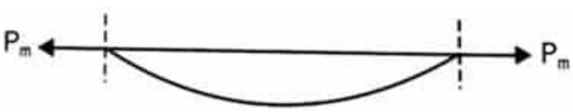
$T_0$ = Temp. at the time of standardization of the tape

$\alpha$ = Coefficient of thermal expansion

L = Measured length

**(c) Correction for pull or tension**

$$C_p = \frac{(P_m - P_0)L}{AE}$$




where, $C_p$ = correction for pull

$P_m$ = pull applied at the time of measurement

$P_0$ = Pull applied at the time of standardization

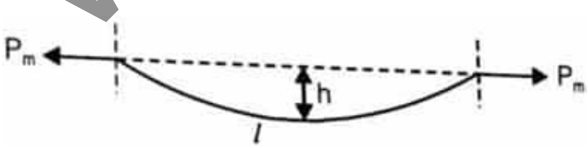
L = Measured length

A = Cross-sectional area

E = Young’s modulus of tape

**(d) Sag Correction**

$$C_{sag} = \frac{W^2 l}{24 P_m^2} \text{ (subtractive)}$$




where, $P_m$ = Pull applied, W = Total weight of tap = wl w = Weight per meter length, l = length of tape

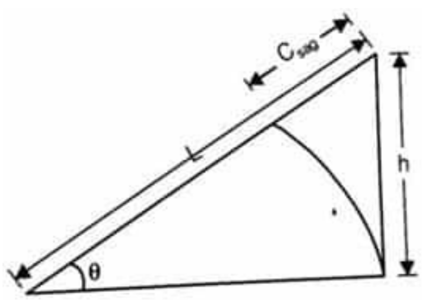
- **Case: Normal Tension**

At a particular value of pull (where $P_m > P_0$) pull correction and sag correction neutralize each other. This value is called normal tension.

$$\frac{(P_m - P_0)l}{AE} = \frac{W^2 l}{24P_m^2} \rightarrow P_m^2(P_m - P_0) = \frac{W^2 AE}{24}$$

**(e) Correction due to slope**

$$C_s = \frac{h^2}{2L}_{(substractive)}$$




where,

h = difference in elevation between the ends

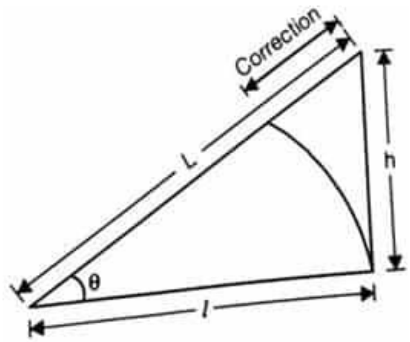
L = Inclined length measured

l = Horizontal leng h

$C_s$ = Correction due to sag

**(f) Correction due to the wrong alignment**

$$C_{al} = \frac{h^2}{2L}_{(substractive)}$$




where, L = length measured along wrong alignment

l = Correct length

h = Error in alignment

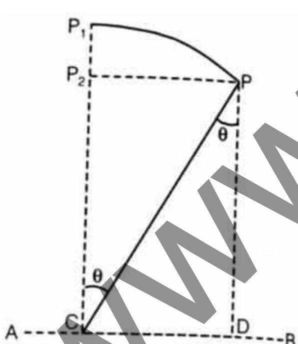
**Limiting Length of Offset**

**(a) Effect of error in laying out direction only**

$$l = \frac{S}{40 \sin\theta}$$

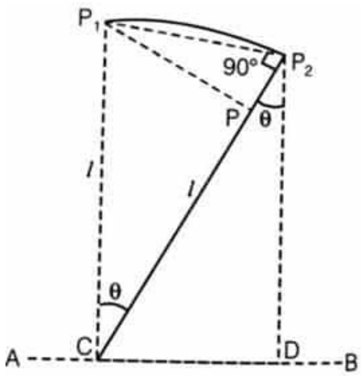
where, l = Limiting length of offset

S = Scale (1 cm = S meter)




**(b) Combined error in length and direction**

$$l = \frac{1}{\sin\theta}\sqrt{\left(\frac{S}{40}\right)^2 - X^2}$$




where,

X = error in length measurement.

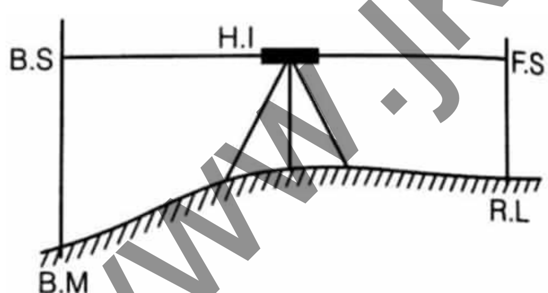
S = Scale (1 cm = S meter)

**Levelling**

**Definitions**

**(i) Reduced level:** The elevation of a point with respect to either Mean Sea Level (MSL) or with respect to a fixed point of known height is called reduced level.

**(ii) Benchmark:** Benchmark is the relatively permanent point of reference whose elevation with respect to some assumed datum is known. It is used either as a starting point for leveling or as a point upon which to close as a check.




**(iii) Back sight:** After setting up the instrument I$^{st}$ reading taken is called back sight. It is also known as plus sight.

**(iv) Foresight:** Last reading taken from an instrument station is called fore sight. It is also known as minus sight.

**(v) Intermediate sight:** All readings other than back sight and fore sight are intermediate sight.

**(vi) Height of instrument:** It is the Reduced Level (RL) of line of sight of the instrument set up at different stations.

*H.I = R.L + B.S*

*R.L = H.I – F.S*

**Arithmetic Check**

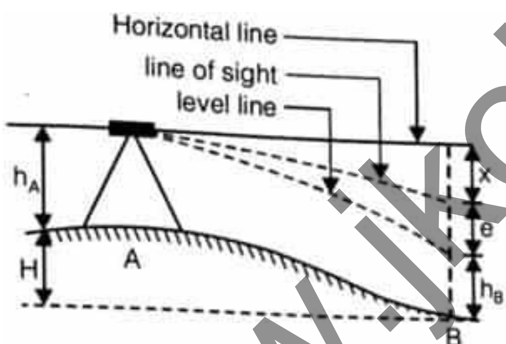
**(i) For rise and fall method**

*∑B.S - ∑F.S = ∑Rise - ∑Fall = Last R.L – First R.L*

**(ii) Height of instrument method**

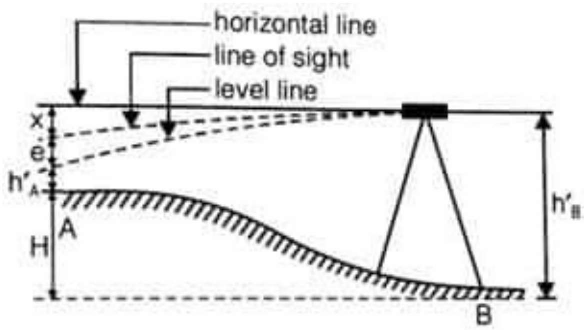
*∑ B.S - ∑ F.S = Last R.L – First R.L*

**Reciprocal Levelling**




Here, X = error due to inclined line of sight, and

e = error due to curvature and refraction




**When instrument is set up at A**

Reading on staff at A = $h_A$

Reading on staff at B = $h_B$

**When instrument is set up at B**

Reading on staff at A = $h'_A$

Reading on staff at B = $h'_B$

$h_A - h_B = h'_A - h'_B$ If instrument is correct.

$$H = \frac{(h_B - h_A) + (h'_B - h'_A)}{2}$$

Here 'H' is the true difference of R.L between A and B.

**True Readings**

| Instrument is at | Reading of A | Reading of B |
|---|---|---|
| A | $h_A$ | $h'_A - H$ |
| B | $h'_B - H$ | $h'_B$ |

**Curvature Correction ($C_C$)**

$$C_C = -\frac{d^2}{2R}$$

 www.jkchrome.com www.jkchrome.com

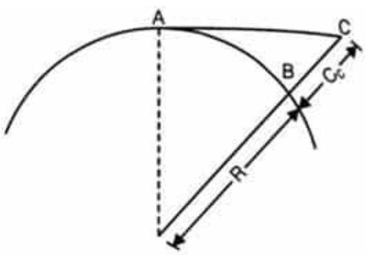
Here, d = horizontal distance between A and B

R = radius of earth

If R = 6370 km

Than $C_C = -0.07849d^2$

here '$C_C$' is in meter and 'd' is in kilometer




**Refraction Correction ($C_R$)**

$$C_R = +\frac{1}{7}C_C$$

$$C_R = +\frac{1}{7}\times\frac{d^2}{2R}$$

$$\downarrow \textit{If R is } 6370\,km$$

$$C_R = 0.01121d^2 \textit{ meter}$$

Here d is in kilometer.

**Combined Correction Due to Curvature and Refraction (C)**

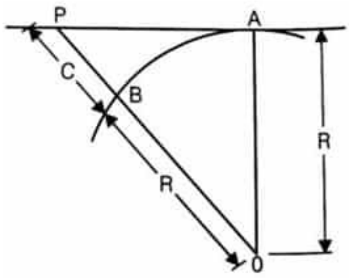
$$C = -\frac{6}{7}\times\frac{d^2}{2R} \textit{ If } R = 6370\,km$$

$C = -0.06728d^2$ meter Here d is in kilometer.

**Distance of Visible Horizon**

d = 3.8553√ckm

Here 'C' being in meters. (taking both curvature and refraction into accounts)




## Sensitiveness of Bubble Tube

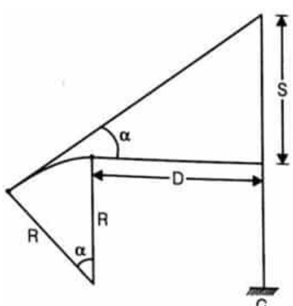
Sensitiveness of the bubble tube is defined as the angular value of one division of the bubble tube.

α' = sensitivity of the bubble tube

= angular value of one division

$$\alpha' = \frac{S}{nD} \times 206265 \text{ seconds}$$

$$\text{or } \alpha' = \frac{S}{nD \sin 1''} \text{ seconds}$$




Here, S = difference between two staff readings.

n = no. of divisions of bubble

$$\text{also, } \alpha' = \frac{l}{R} \text{ radian or } \alpha' = \frac{l}{R \sin 1''} \text{ seconds}$$

where, l = length of one division

R = radius of curvature of bubble tube.

## Contouring

**Contours:** Contour is an imaginary line joining points of equal elevation on earth surface.

**Contour interval:** Vertical distance between two contour is called contour internal.

**Some suitable value of contour intervals**

| Scale of map | Type of ground | Contour internal (meters) |
|---|---|---|
| Large | Flat | 0.2 to 0.5 |
| (1 cm ≅ 10 m or less) | Rolling | 0.5 to 1 |
| | Hilly | 1, 1.5 or 2 |
| Intermediate | Flat | 0.5, 1 or 1.5 |
| (1 cm = 10 m to 100 m) | Rolling | 1, 1.5 or 2 |
| | Hilly | 2, 2.5 or 3 |
| Small | Flat | 1, 2 or 3 |
| (1 cm = 100 m or more) | Rolling | 2 to 5 |
| | Hilly | 5 to 10 |
| | Mountainous | 10, 25 or 50 |

Contour internal for various purposes are suggested as:

| Purpose of survey | Scale | Interval (metres) |
|---|---|---|
| 1. Building sites | 1 cm = 10 m or less | 0.2 to 0.5 |
| 2. Town planning schemes, reservoirs etc. | 1 cm = 50 m to 100 m | 0.5 to 2 |
| 3. Location surveys | 1 cm = 50 m to 200 m | 2 to 3 |

$$\text{Contour interval} = \frac{25}{\text{No. of cm per km}} \text{(metres)}$$

$$\text{Contour interval} = \frac{50}{\text{No. of inches per mile}} \text{(feet)}$$

## Traversing and Triangulation survey

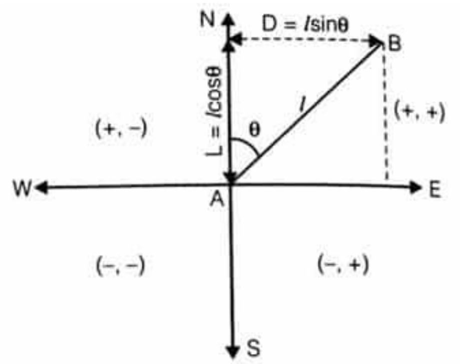
### Traverse Surveying

**Latitude and Departure**

The latitude and departure of the line AB of length l and reduced bearing θ are given by

L = $+l\cos\theta$

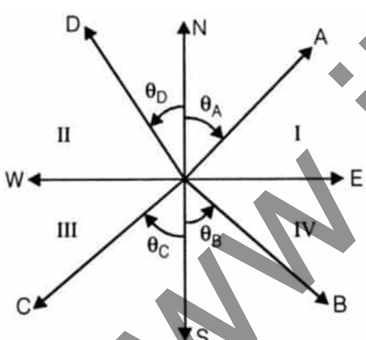
D = $l\sin\theta$




**Latitude:** Projection of a line on N-S direction is called latitude.

**Departure:** Projection of a line on E-W direction is called departure.

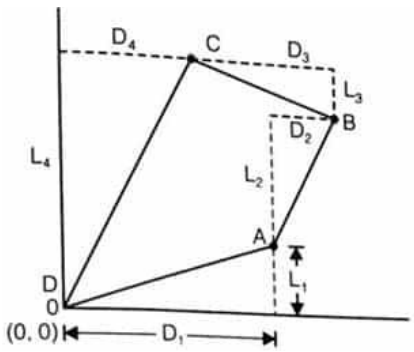
- **Latitude and departure in various quadrants**




| Line | Reduced Bearing | Quadrants | Latitude | Departure |
|---|---|---|---|---|
| OA | $N\theta_A E$ | I | $+l_1\cos\theta_A$ | $+l_1\sin\theta_A$ |
| OB | $S\theta_B E$ | IV | $-l_2\cos\theta_B$ | $+l_2\sin\theta_B$ |
| OC | $S\theta_C W$ | III | $-l_3\cos\theta_C$ | $-l_3\sin\theta_C$ |
| OD | $N\theta_D W$ | II | $+l_4\cos\theta_D$ | $-l_4\sin\theta_D$ |

Here, $l_1$, $l_2$, $l_3$ and $l_4$ are the length of line OA, OB, OC and OD respectively.

**Independent Coordinate**




**Closing Error**

If sum of latitude,

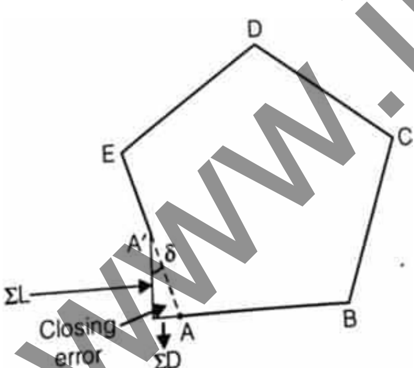
$\sum L \neq 0$

and sum of departure

$\sum D \neq 0$

then there is a closing error

Closing error,




$$e = AA'\sqrt{(\sum L)^2 + (\sum D)^2}$$

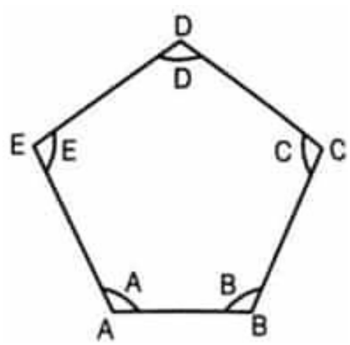
the direction of closing error (δ)

$$\delta = \tan^{-1}\left(\frac{\sum D}{\sum L}\right)$$

**Adjustment of Closing Error**

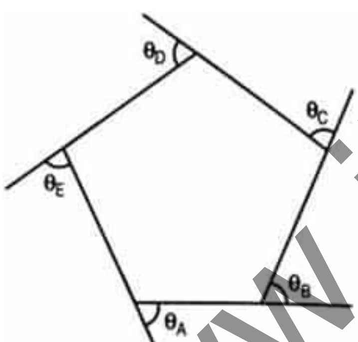
- Sum of all internal angles of a closed traverse = (2n-4) ×90°

where n = no. of sides




- Sum of all deflection angles = 360°

i.e. $\theta_A + \theta_B + \theta_C + \theta_D + \theta_E = 360°$




- Sum of latitude, ∑L=0

sum of departure, ∑D=0

**Balancing the Traverse**

**(a) Bowditch method**

Error in linear measurement ∝√l

Where *l* = length of a line

Error in angular measurement $\propto \frac{1}{\sqrt{l}}$

correction to a particular line

$$C_L = \left(\frac{l}{\sum l}\right) \times \sum L$$

$$C_D = \left(\frac{l}{\sum l}\right) \times \sum D$$

Here, l = length of a line,

$C_L$ = correction in latitude of a line

$\sum L$ = total error in latitude,

$C_D$ = correction in departure of a line

$\sum D$ = total error in departure

$\sum l$ = sum of length of all lines

**(b) Transit method**

Correction in the lat tude of all line,

$$C_L = \left(\frac{L}{L_T}\right) \times \sum L$$

Correction in the departure of all line,

$$C_D = \left(\frac{D}{D_T}\right) \times \sum D$$

Here, ∑L = Total error in latitude

$\sum D$ = total error in departure

L = latitude of a line

D = departure of a line

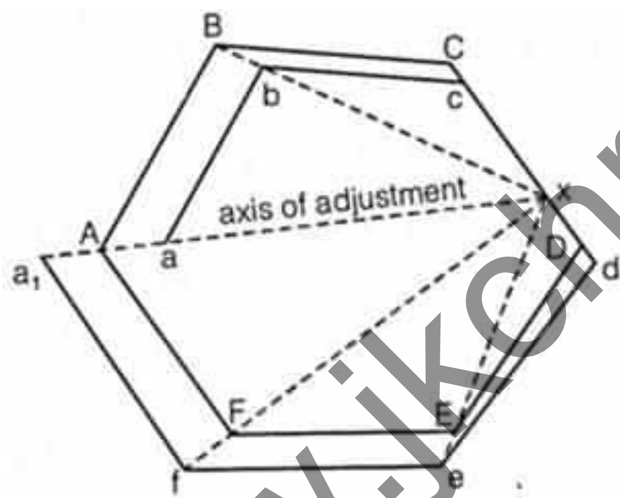
$L_T$ = sum of all latitude without considering sign

$D_T$ = Sum of all departure without considering sign.

**(c) Axis method**

Correction to any length

$$= \text{that length} \times \frac{\frac{1}{2}\text{Closing error}}{\text{Length of axis}}$$




$$\text{i.e. Correction of } a_{1f} \cdot \frac{\frac{1}{2}.a_a a}{aX}$$

**Triangulation**

**Definition**

The horizontal control in Geodetic survey is established either by triangulation or by precise traverse. In triangulation, the system consists of a number of interconnected triangles in which the length of only one line is called the base line and the angles of the triangle are measured very precisely.

| | | First order or 1° Triangulation | Second order or 2° Triangulation | Third order or 3° Triangulation |
|---|---|---|---|---|
| 1. | Average triangle closure → | < 1 seconds | 3 seconds | 6 seconds |
| 2. | Maximum triangle closure → | ≯ 3 seconds | 8 seconds | 12 seconds |
| 3. | Length of base line → | 5 to 15 kilometers | 1.5 to 5 km | 0.5 to 3 km |
| 4. | Length of the sides of triangles → | 30 to 150 kilometers | 8 to 65 km | 1.5 to 10 km |
| 5. | Actual error of base → | 1 in 300,000 | 1 in 150,000 | 1 in 750000 |
| 6. | Probable error of base → | 1 in 1000000 | 1 in 500,000 | 1 in 250,000 |
| 7. | Discrepancy between two measures of a section → | 10 mm $\sqrt{\text{kilometers}}$ | 20 mm$\sqrt{\text{km}}$ | 25 mm$\sqrt{\text{km}}$ |
| 8. | Probable error of computed distance → | 1 in 60000 to 1 in 250000 | 1 in 20000 to 1 in 50,000 | 1 in 5000 to 1 in 20,000 |
| 9. | Probable error in astronomic azimuth → | 0.5 seconds | 2.0 seconds | 5 seconds |

- **Criterion of strength of figure**

The strength of figure is a factor to be considered in establishing a triangulation system for which the computation can be maintained within a desired degree of precision.

The square of a probable error ($L^2$) that would occur in the sixth place of the logarithm of any side,

$$L^2 = \frac{4}{3} d^2 R$$

$$where, R = \frac{D-C}{D} \sum \left[ \delta_A^2 + \delta_A \delta_B + \delta_B^2 \right]$$

d = Probable error of an observed direction in seconds

D = Number of directions observed (forward and/or backward)

$\delta_A$ = Difference per second in the sixth place of a logarithms of the sine of the distance angle A of each triangle

$\delta_B$ = Same as $\delta_A$ but for the distance angle B

C = Number of angles and side conditions

C = (n' – s' + 1) + (n – 2s + 3)

n = Total number of lines

n' = Number of lines observed in both directions

s = Total number of stations

s' = Number of occupied stations

(n' – s' + 1) = Number of angle conditions

(n' – 2δ + 3) = Number of side conditions

**Signals and Towers**

- **A signal is a device erected to define the exact position of an observed station.**

**A.** Non Luminous Signals: Diameter of signal in cm = 1.3 D to 1.9 D Height of signal in cm = 13.3 D

where D = distance in km (Length of sight) for non-luminous signals

**B.** Luminous or Sun Signals Used when the length of sight distance > 30 Km

**Phase of Signals:** It is the error of bisection which arises, when the signal is partly in light and partly in shade.

- **Correction**

(i) when observation is made on the bright portion.

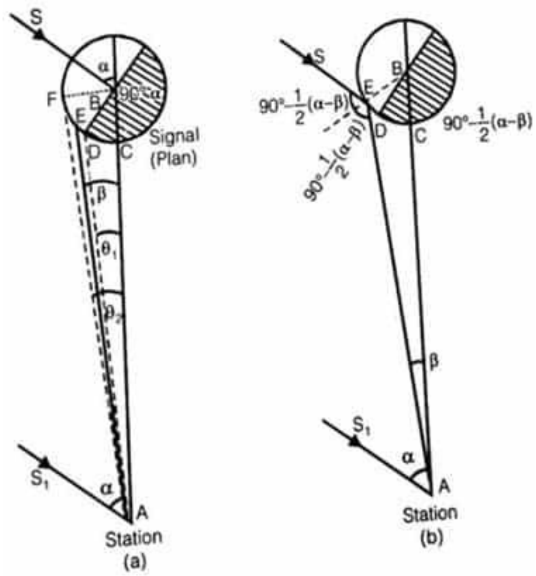
Phase correction

$$\beta = \frac{r\cos^2\frac{\alpha}{2}}{D} radians$$

*α* = Angle which the direction of sun makes with line of sight.

r = radius of the signal.

D = Distance of sight.




(ii) when the observation is made on the bright line:

$$\beta = \frac{r\cos\frac{\alpha}{2}}{D} \, radians$$

**Routine of Triangulation Survey**

The routine of triangulation survey generally consists of the following operations:

1. Reconnaissance
2. Erection of singles and towers
3. Measurement of base lines
4. Measurement of horizontal angles
5. Astronomical of horizontal angles
6. Computations

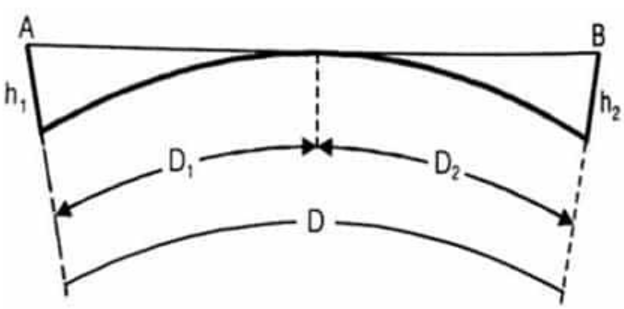
**Intervisibility and Height of Stations**

**(a) The distance between the stations:** If here is no obstruction due to intervening ground, the distance of the visible horizon from a station of known elevation above datum is given by where, h = height of the station above datum

D = distance to the visible horizon

R = mean radius of the earth

**Relative elevation of stations:** If there is no obstruction due to intervening ground, the formula $h = \frac{D^2}{2R}(1-2m)$ may be used to get the necessary elevation of a station at distance, so that it may be visible from another station of known elevation Let, $h_1$ = known elevation of station A above datum




$h_2$ = required elevation of B above datum

$D_1$ = distance from A to the point of tangency

$D_2$ = distance from B to the point of tangency

D = the known distance between A and B

then,

$$h_1 = 0.6728 D_1^2$$

$$D_1 = \sqrt{\frac{h_1}{0.0728}} = 3.8553\sqrt{h_1}$$

where $D_1$ is in km and $h_1$ is in meters, $D_2 = D - D_1$

$$h_2 = 0.06728 D_2^2 \; meters$$

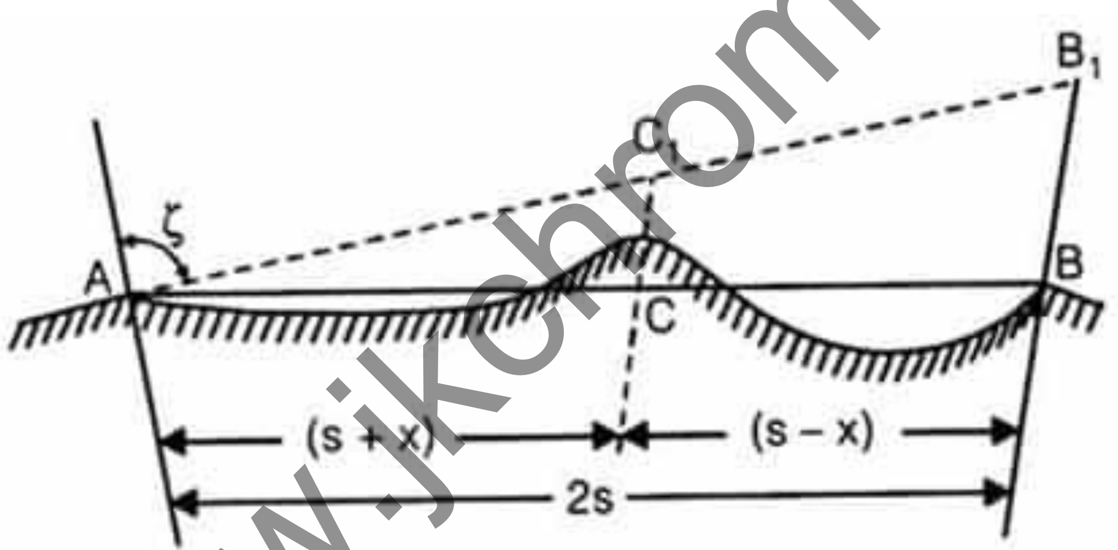
**(c) Profile of the intervening ground:** In the reconnaissance, the elevations and positions of peaks in the intervening ground between the proposed stations should be determined. A comparison of their elevations should be made to the elevation of the proposed line of sight to ascertain whether the line of sight is clear off the obstruction or not. The problem can be solved by using the principles discussed in the factors (1) and (2) above, or by solutions suggested by Captain G.T. McCaw. The former method will be clear from the worked out examples.

**Captain GT McCaw's Method**

Let, $h_1$ = height of station a above datum

$h_2$ = height of station B above datum

h = height of line of sight at the obstruction C




2s = distance between the two stations A and B

(s + x) = distance of obstruction C from A

(s – x) = distance of obstruction C from B

ζ = zenith distance from A to B

The height h of the line of sight at the obstruction is given by

$$h = \frac{1}{2}(h_2 + h_1) + \frac{1}{2}(h_2 - h_1)\frac{X}{s} - (s^2 - X^2)\operatorname{cosec}^2\zeta\left(\frac{1-2m}{2R}\right)$$

$\operatorname{cosec}^2\zeta = 1 + \frac{(h_2 - h_1)}{4s^2}$. The expression

$$\frac{1-2m}{2R} = 0.574$$

If X, s and R are substituted in miles, and $h_1$, $h_2$ and h are in feet.

And

$$\frac{1-2m}{2R} = 0.06728$$

If X, s and R are in km and $h_1$, $h_2$ and h are in meters.

## Miscellaneous- instruments, contouring, area and volume

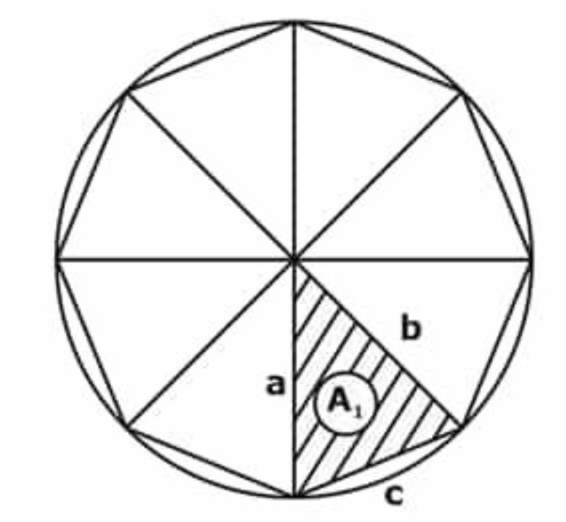
**AREA & VOLUME MEASUREMENTS :**

1. **AREA OF TRAVERSE**

The method of computation of area depends upon the shape of the boundary of the land and accuracy required. The area of the land is computed from its plan which may be enclosed by straight, irregular or combination of straight and irregular boundaries. When the boundaries are straight the area is determined by subdividing the plan into simple geometrical figures such as triangles, rectangles, trapezoids, etc. For irregular boundaries, they are replaced by short straight boundaries, and the area is computed using approximate methods or Planimeter when the boundaries are very irregular. Following are the methods of area computation

- **By Dividing into Number of Triangles**

Area is divided into number of triangles and area of each triangle is calculated. Total area will be equal to sum of areas of individual triangle.




If all three sides of the triangle are measured, the area is given by

$$\text{Area} = A_1 = \sqrt{s(s-a)(s-b)(s-c)}$$

Where,

s = half perimeter = $\frac{a+b+c}{2}$

and a, b and c are length of triangle.

If two sides and one included angle of triangle are measured, the area is given by

$$A_1 = \frac{1}{2} a \times b \times \sin C = \frac{1}{2} b \times c \times \sin A = \frac{1}{2} a \times c \times \sin B$$

Where,

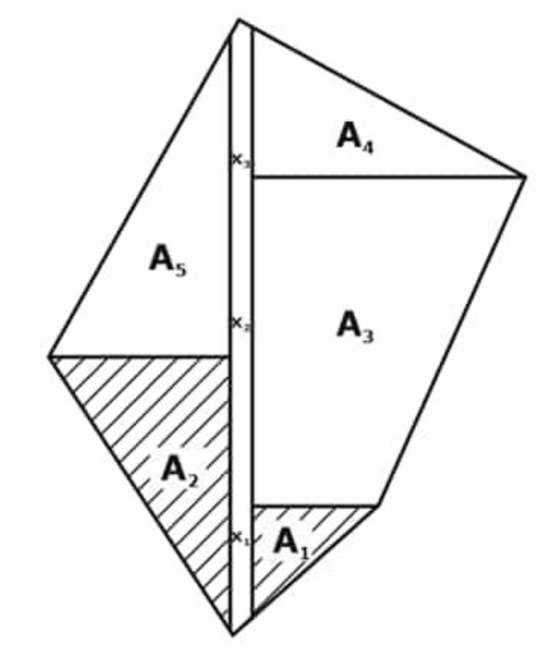
A, B and C are included angles opposite to sides a, b and c respectively.

Total area of land will be equal to

$$\text{Total area } (A_{total}) = A_1 + A_2 + A_3 + \text{------} + A_{n-1} + A_n$$

- **Irregular offset method**

When the shape of land is polygonal, the total area is sub divided into regular figures such as triangle and trapezoids by taking irregular offset from the base line of the area. Individual area of each regular shape is calculated and total area of the land is equal to sum of areas individual shapes.



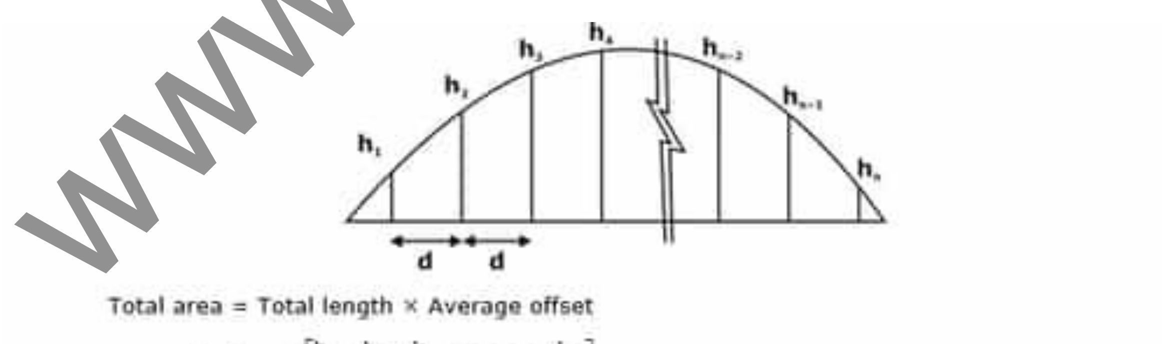

Total area ($A_{total}$) = $A_1 + A_2 + A_3 + ------ + A_{n-1} + A_n$

- **Regular offset method**

This method is suitable for narrow strip of land. The offsets are taken at regular interval from boundary to the base line. The area can be calculated by the following rules:

- **Average ordinate rule:**

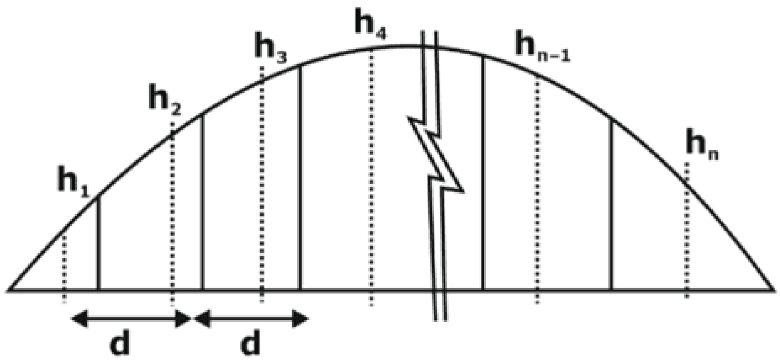
In this method, area of land is computed by taking average value of ordinate and multiplying it with the length of base line.




$$A_{total} = (n-1) \times d\left[\frac{h_1 + h_2 + h_3 - - - - - - + h_n}{n}\right]$$

- **Mid ordinate Rule:**

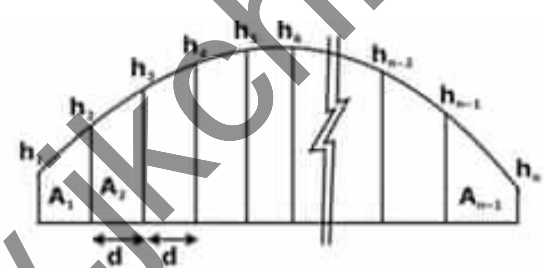
- In this method, the offsets are taken at the midpoint of the section of constant interval into which the chain line is divided.




$A_{total} = (h_1 + h_2 + \text{------} + h_n) \times d$

- **Trapezoidal rule:**

In trapezoidal rule, the area is divided into a number of trapezoids, boundaries being assumed to be straight between pairs of offsets. The area of each trapezoid is determined and added together to derive the whole area.




Area of 1st trapezoid $A_1 = d\left[\frac{h_2 + h_3}{2}\right]$

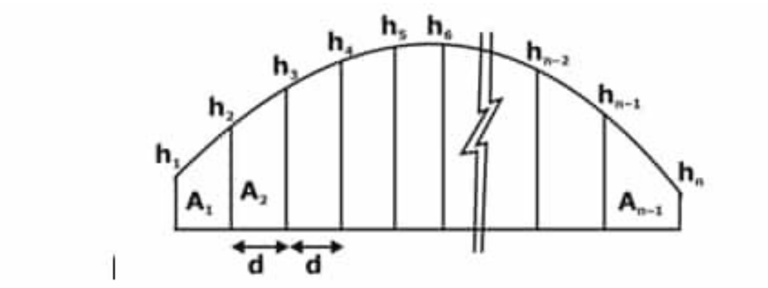
Area of last trapezoid $A_{n-1} = d\left[\frac{h_{n-1} + h_n}{2}\right]$

Total area $(A_{total}) = A_1 + A_2 + A_3 + \text{------} A_{n-1} + A_n$

$$\therefore A_{total} = d\left[\left(\frac{h_1 + h_n}{2}\right) + h_2 + h_3 + - - - - - + h_{n-1}\right]$$

- **Simpson's Rule / Prismoidal Rule:**

In Simpson's rule, the boundary line segment between the ordinates is assumed to be a parabola. The formula finds the area using three consecutive ordinates and two section at a time. Hence, even number of sections are required for this formula.




$$[A_1 + A_2] = \frac{d}{3}(h_1 + 4h_2 + h_3)$$

$$[A_3 + A_4] = \frac{d}{3}(h_3 + 4h_4 + h_5)$$

$$A_{n-2} + A_{n-1} = \frac{d}{3}(h_{n-2} + 4h_{n-1} + h_n)$$

Total area $(A_{total}) = (A_1 + A_2) + (A_3 + A_4) + \text{-------} + (A_{n-2} + A_{2n-1})$

$$\therefore A_{total} = \frac{d}{3}\left[(h_1 + h_n) + 4(h_2 + h_4 + ---) + 2(h_3 + h_5 + --)\right]$$

## VOLUME OF TRAVERSE

Earthwork operations involve the determination of volumes of material that is to be excavated or embanked in engineering project to bring the ground surface to a predetermined grade. Volumes can be determined via cross-sections, spot levels or contours. To determine volume from the standard cross section end-area rule or prismoidal rule which are analogous to the trapezoidal rule and Simpson's rule respectively can be used.

(i) **Trapezoidal rule (End Area Method):**

$$V_{total} = d\left[\left(\frac{A_1 + A_n}{2}\right) + A_2 + A_3 + --- + A_{n-1}\right]$$

(ii) **Simpson's rule/Prismoidal rule:**

$$V_{total} = \frac{d}{3}\left[(A_1 + A_n) + 4(A_2 + A_4 + ---) + 2(A_3 + A_5 + --)\right]$$

1. **INTRODUCTION**

Contour is the line joining points of equal or same elevation (RL).

A contour may be defined as an imaginary line passing through points of equal elevation on the earth surface.

A Contour line may also be defined as the intersection of a level surface with the surface of the earth.

Contour lines on a plan illustrate the topography of the ground.

Then the contours are drawn underwater, they are termed as *submarine contours, fathoms* or *bathymetric curves.*

1. **USE OF CONTOURS**

(a) Proper and precise location of engineering works such as roads, canals. etc.

(b) In location of. water supply. water distribution and t solve the problems of steam pollution.

(c) In planning and designing of dams, reservoirs aqueducts, transmission lines, etc.

(d) In selection of sites for new industria plants.

(e) Determining the intervisibility of stations.

(1) Determining the profile of the country along any direction.

(g) To estimate the quantity of cutting filling, and the capacity of reservoirs.

1. **CONTOUR INTERVAL**

Elevation differenc between two consecutive contours known as contour interval. It s always kept same for a map, so that difference features of area can be easily identified.

1. **HORIZONTAL EQUIVALENT**

Horizontal distance between two consecutive contour at any point called horizontal equivalent.

Generally for natural feature horizontal equivalent are irregular.

1. **SOME IMPORTANT POINT**

(i) If contours are parallel and horizontal equivalent between them are also constant then they represent uniform slope.

(ii) closely spaced contours represent steep slope and distant contour represent relatively mild slope

(iii) If contours are closed (loop), it represents either a hill or a pond/valley

(iv) Ridge line/valley line intersect contour at 90° angle

(v) Two contours of different elevations neither cross nor join each othe

Two exceptions, (a) vertical cliff (b) Overhang cliff

1. **RAVINE**

Ravine is a through like depression of the earth's surface, elongated in one direction with the bottom inclined towards one side

A ravine can be imagined as a depression washed out in-the ground by flowing water.

1. **VALLEY**

A valley is a broad ravine with a gentle sloping bottom.

The contours of a valley are n a shape of V

If the ground is low as compared to the surrounding land and the sides slope generally, it is called as a depression.

The contours are quite few and far apart.