Transportation Engineering

Volume II

Part I
Railway Engineering

Chapter 1: Introduction and Historical Aspects

- One of the most important modes of transportation is the Railway. Successful implementation of the various phases of development and operation of a railway system constitutes 'Railway Engineering'.
- **Historical aspects**
  - Railways originated in England after George Stephenson built the first steam locomotive for hauling a train of coaches. The first train ran from Darlington to Stockton in 1825.
  - The first train in India ran from Bori Bunder in Mumbai (then Bombay) to Thane, a distance of 34 km, in 1853 during the British rule.

There has been steady growth of railways in India, especially after independence, through the successive five-year plans.

- The responsibility of all aspects of the construction, maintenance and operation of the railways is vested in the Central Government – the Ministry of Railways through the empowered Railway Board.
  - The Research, Design and Standards Organisation (RD & SO), Lucknow, is a premiere institution for research and standards in Railways.
  - There are presently 16 railway zones and several divisions for administrative convenience.
  - There are six production units for the manufacture of locomotives, coaches and wagons.

- The role of Railways in national development is significant on the economic, social and political fronts.

- In view of the inherent advantage of bulk transport over long distances, Railways play a special role of transport
- Indian railways is the largest public sector undertaking with over 66, 000 route kilometres and more than 13.1 lakh employees.
- Indian Railways successfully constructed challenging projects such as the Konkan Railway in the Western Ghats. The rail link in the Kashmir valley, which poses several technological challenges, is under construction.
- Recent developments for high speeds in advanced countries are the Tracked Air Cushion Vehicle (TACV) and MAGLEV (Magnetic Levitation).
- The most important objective of improvement and expansion of Railways is automation in operation and control of trains, abiding to safety norms.

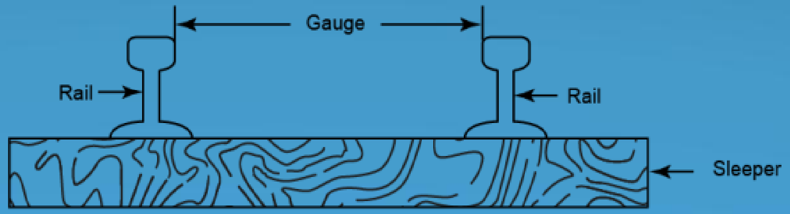
Chapter 2: Railway Planning, Alignment and Surveys

- Railway network planning needs an integrated approach; the basic principle of proceeding from the whole to the part has to be followed.
- Alignment of a new railway route needs the consideration of the purpose, compatibility with the master plan for the area, and the economic viability of the new route.
- The alignment involves horizontal alignment with curves at changes in direction and vertical alignment with vertical curves at places of changes of gradient. The choice of a good alignment leads to a route with ease of operation as well as economy.
- Governing criteria for a good alignment are obligatory points – geometric design standards which ensure safety and comfort, terrain characteristics, traffic requirements, appropriate crossings of major water bodies and finally economic considerations.

- Map study of the area, traffic survey, and engineering such as reconnaissance, preliminary and location surveys are essential; soil and electrification survey may be conducted, if required.
- Conventional methods of surveying involve the use of prismatic compass, Abney level and clinometer for preliminary surveys; precise level, theodolite and tacheometer are used for more accurate work such as location survey.
- Modern surveying methods involve the use of electronic distance measuring devices including total station, photogrammetry, remote sensing, GIS, GPS, and digital terrain modelling; these methods are justified only in the case of large projects.
- A detailed project report, along with detailed engineering drawings, has to be submitted to the competent authority for technical sanction and administrative approval.

Chapter 2: Railway Track and Its Components

- Railway track consists of two parallel rails, supported on cross-sleepers and embedded in ballast material, which is supported on a formation or soil subgrade. This is also called the ‘Permanent’ way in contrast to temporary tracks laid for transport of materials for construction.
- A sound pavement way is a prerequisite for safety; for this, it has to fulfil several requirements.
- ‘Gauge’ of a railway is defined as the horizontal distance between the inner or running faces of the rails.

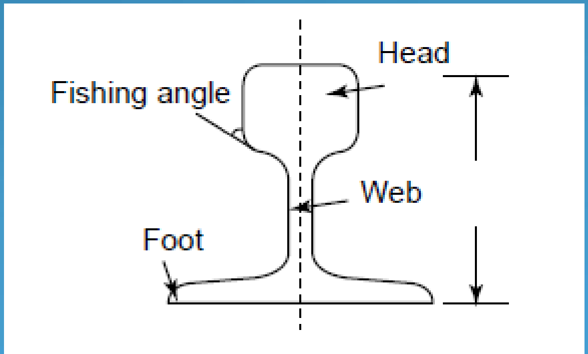


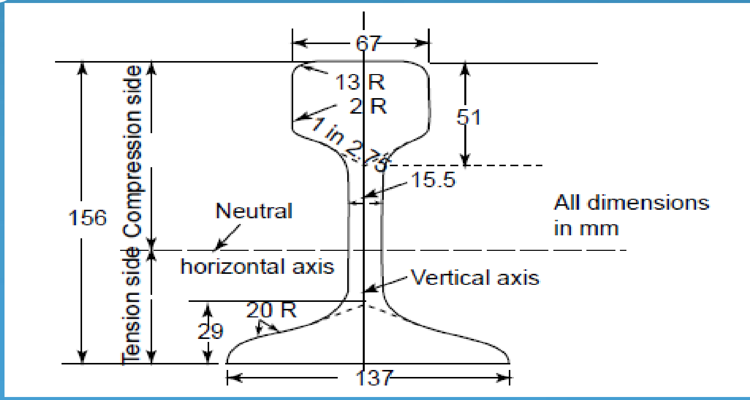
Gauge of a railway

There are three gauges on Indian Railways:
Broad Gauge (BG) – 1.676 m
Metre Gauge (MG) – 1.000 m
Narrow gauge (NG) – 0.762 and 0.610 m
The narrow gauge is used only for mountain railways.

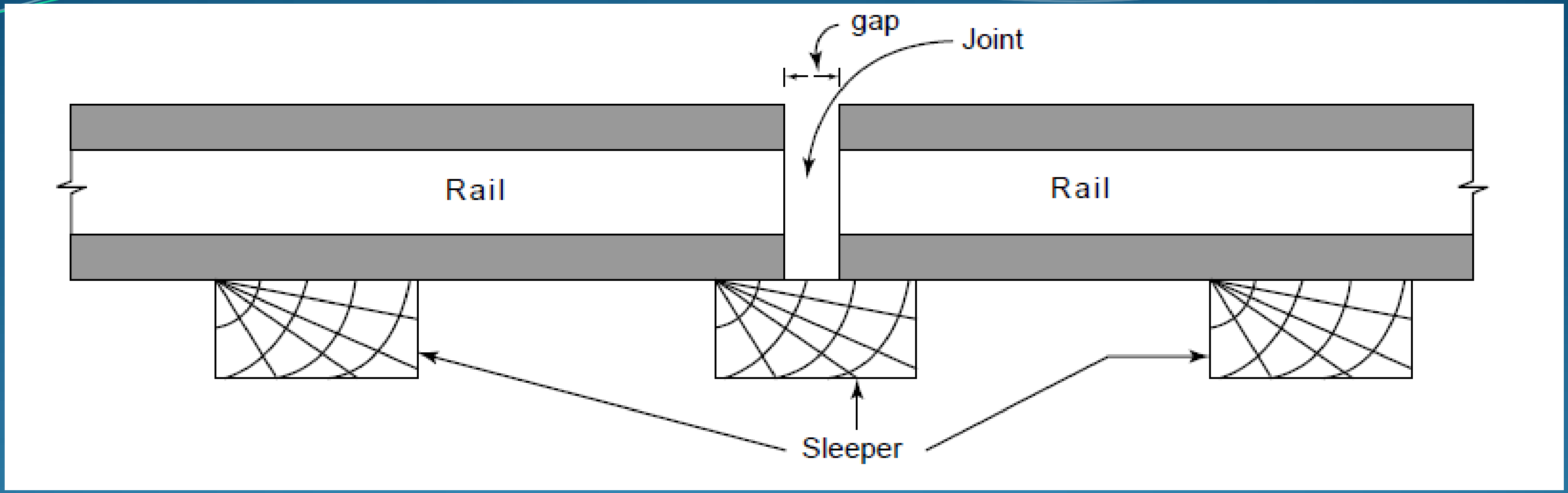
- Choice of gauge is based on economic, traffic and terrain considerations. For historical reasons, India has a multi-gauge system, which involves a lot of inconvenience in trans-shipment of passengers and goods. Hence, the Indian Railways have adopted a 'Uni-gauge' policy, which is being implemented in stages. As a result of this, over 90 per cent of the route kilometerage is on Broad Gauge now, and the remaining few Metre Gauge routes are expected to be completed soon.
- Railway routes are classified as Trunk routes, Main lines and Branch lines, based on their importance and traffic. Based on speed, they are classified as A, B, C, D, E, D spl and E spl on BG and Q, R, R1, R2, R3 and S on MG.

- The track structure of rails and sleepers is supported on a cushion of ballast to absorb the impact loads from the trains, and transmit and distribute them to the subgrade soil such that the pressure does not exceed the safe bearing power.
- Rails are manufactured from special rail steel from the open-hearth furnace or by the Duplex process. The ultimate tensile strength should be at least 880 MPa.
- Although, historically speaking, different types of rail sections such as the double-headed and bull-headed ones were tried, the most popular section is the 'Flat-footed' type or the 'Vignole' Type (see image below). This is the standard section on Indian Railways – 52 kg/m or 90 lb/yd (90 R) sections for BG, and 75 R and 60 R sections for MG.

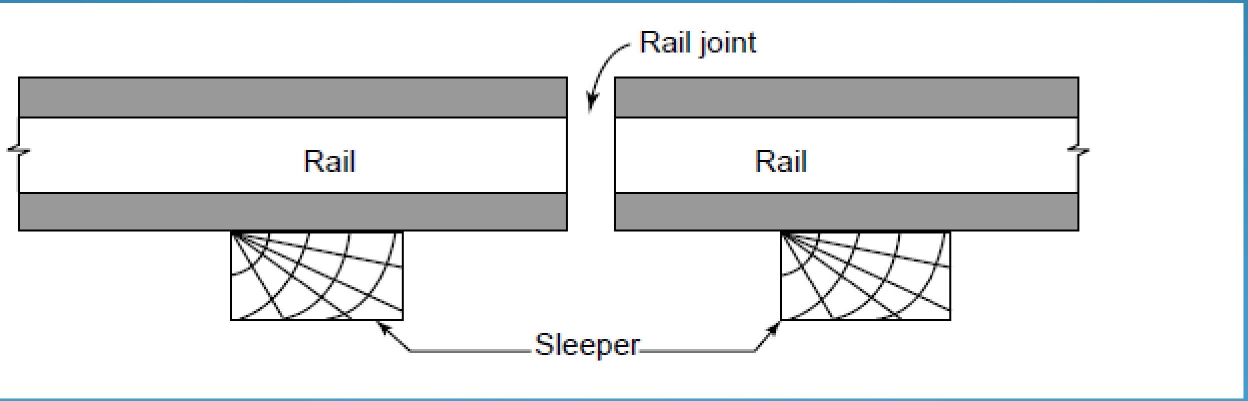




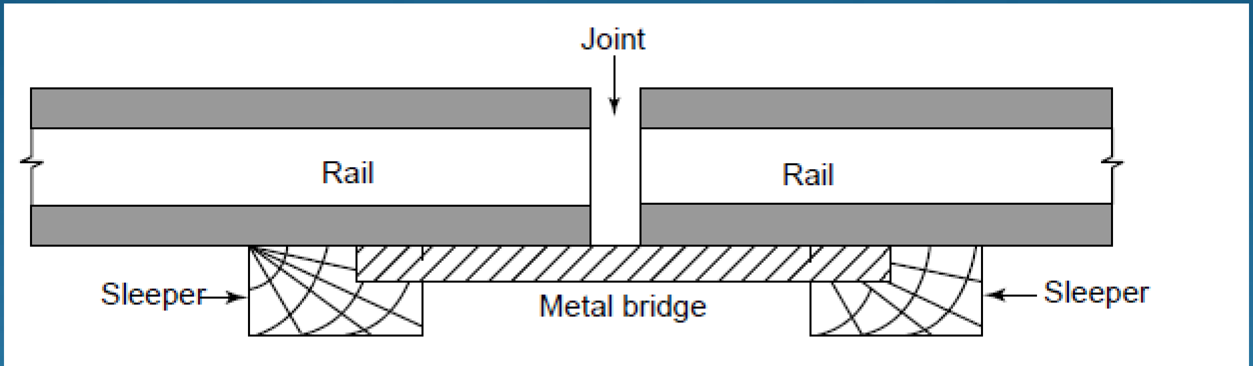
- The length of rails is governed by the convenience in manufacturing , transporting and handling, besides the expansion gap considerations at the ends. The standard length is 13 m for BG and 12 m for MG.
- Rigid joints: In view of the limitation on the length of a single rail, joints are inevitable for the rails. The fish-plated joint is the popular type adopted on the Indian railways.
- Since a joint is a weak point in the track, it has to be designed well. Three are three types of joints based on the positions of sleepers on either side of the joint:
  - Supported joint (supported on the sleeper)
  - Suspended joint (cantilevering from the sleepers at either end)
  - Bridge joint (supported by a bridge plate connected to the sleepers at either end).



Supported rail joint



Suspended rail joint



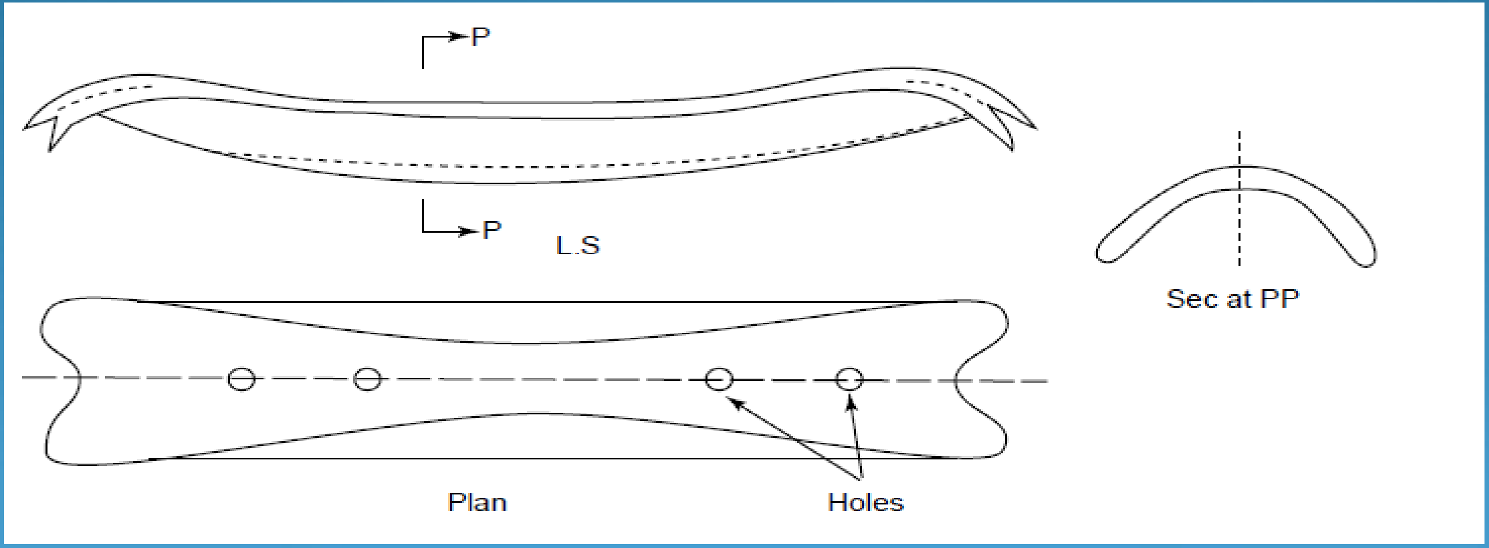
On horizontal curves, the joints are staggered instead of being square.

- Welding of rails: Besides being weak points in the track, rail joints cause discomfort to the passengers due to the jolts caused. In order to minimise the discomfort, as also to increase the structural strength of the track, welding of rails is adopted. Significant lengths of track are now being welded on Indian Railways.
  - Short-welded rails (SWR) – a few rail lengths
  - Long-welded rails (LWR) – a few km of track
  - Continuous welded rails (CWR) – several km of track. In case of LWRs, small portions at either end, which are free to expand, are known as 'breathing lengths'. Electric arc welding and flash-butt welding are commonly used on Indian Railways.

- Defects in rails: Several types of defects occur in the rails during operation:
  - Rail-wear
  - End-batter
  - Corrugations (cause 'roaring rails' with unpleasant sound)
  - Kinks
  - Corrosion
  - Rail creep (due to continuous pounding by wheel loads, causing flow of metal). Adjustment of creep may be done by pulling back the rails; anti-creep devices such as creep anchors tend to minimise rail creep.

Certain criteria for rail wear (such as 6% loss of weight) are adopted to indicate the need for rail renewal.

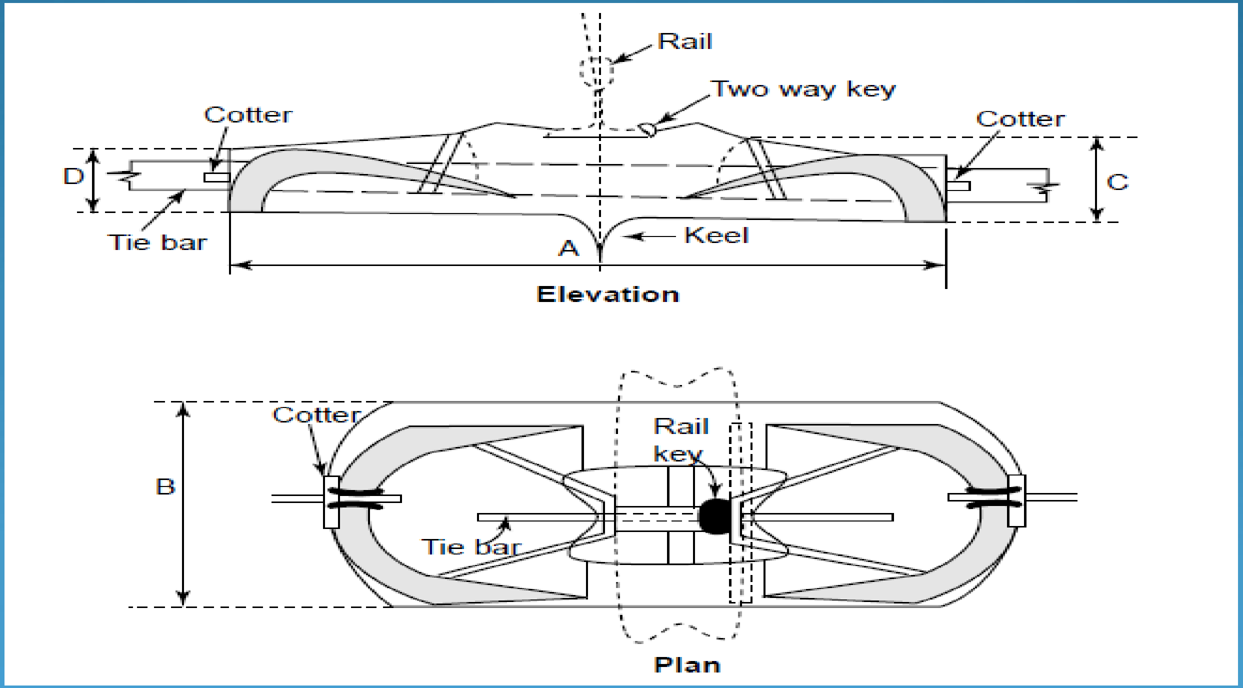
- The main function of sleepers is to provide proper support to the rails and elastically reduce the impact of the dynamic wheel load and transmit them to the ballast bed in which they are embedded.
- Types of Sleepers:
  - Timber or wooden sleepers (need seasoning and chemical treatment to increase the durability)
  - Steel-trough type sleepers



A schematic view of steel trough sleeper

- Cast iron sleepers
  - Pot type
  - Plate type
  - Box type

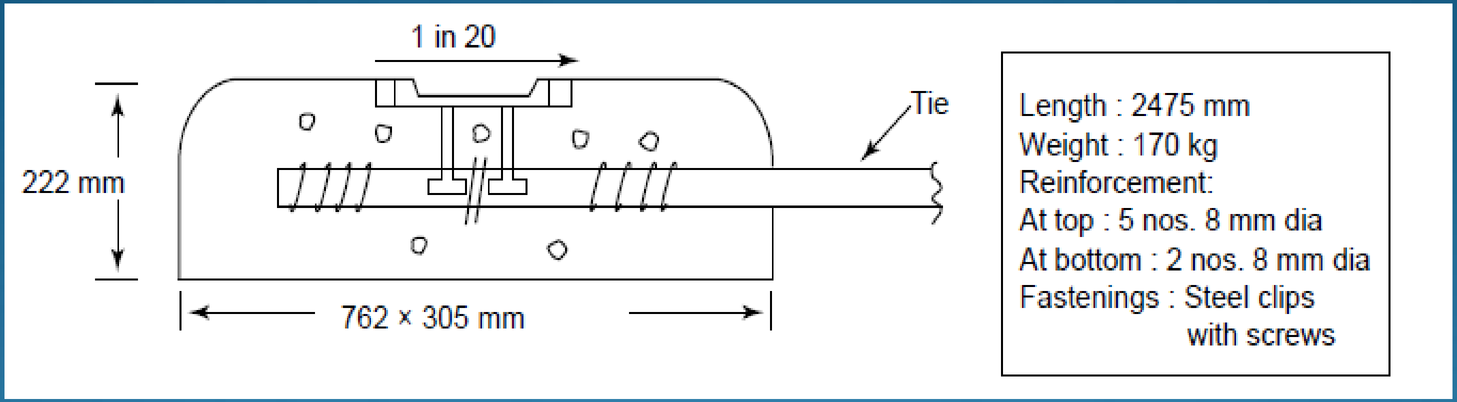
  CST-9 type is the latest



CST-9 sleeper

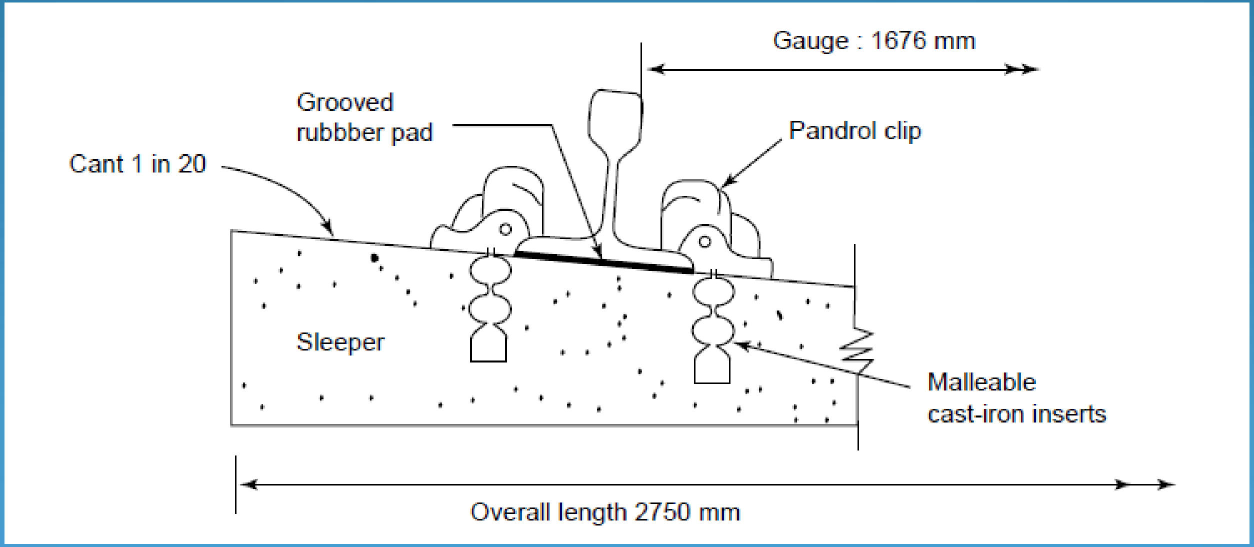
- Concrete sleepers

  RC sleepers – Block-and-tie type are stronger due to weight and flexural strength

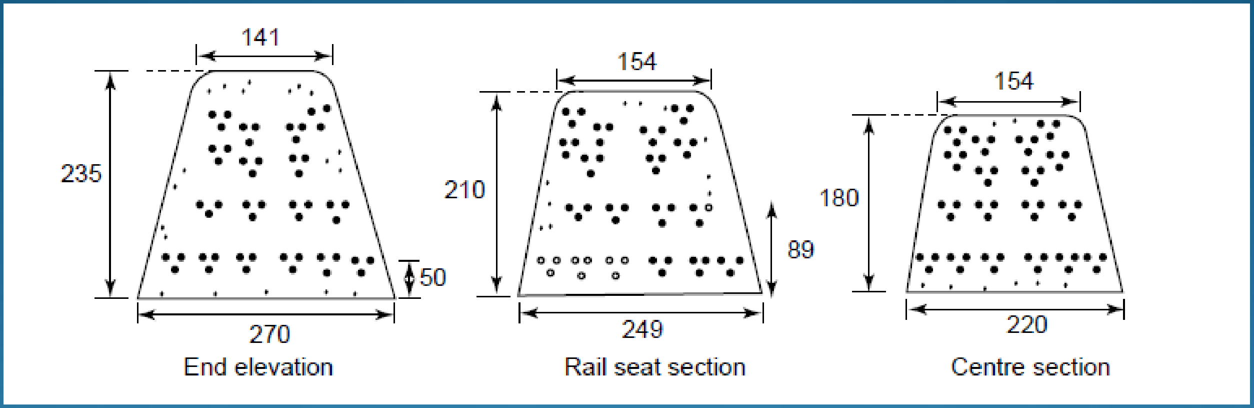


RC sleeper – block-and-tie type

- Pre-stressed concrete sleepers: Pre-cast pre-tensioned type is popular



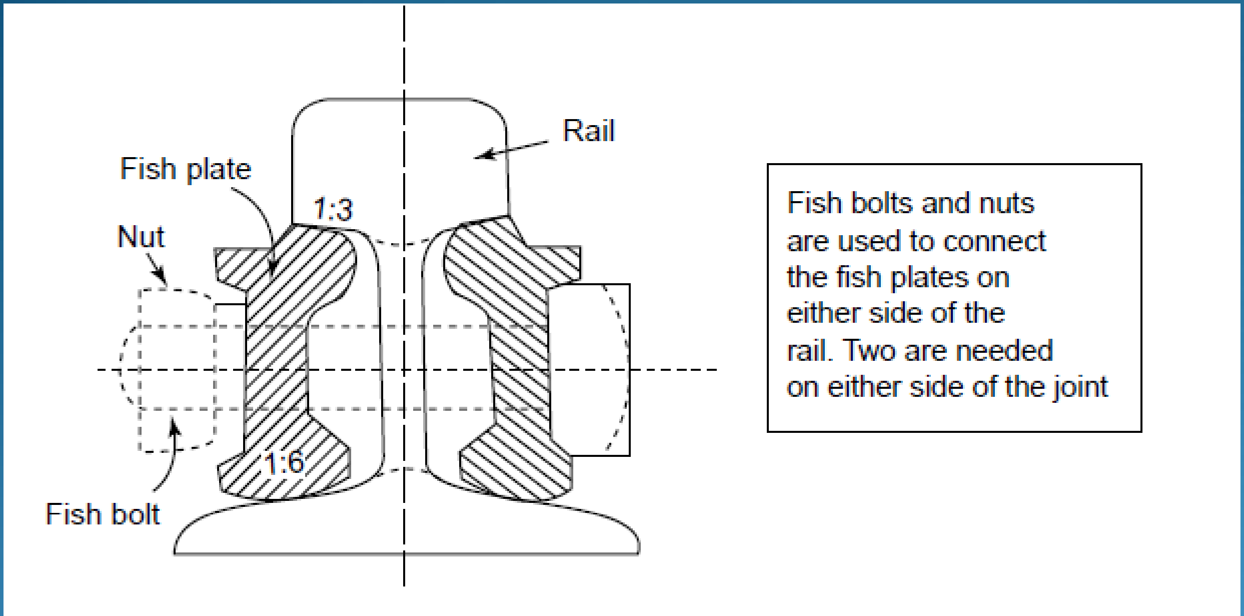
Mono-block pre-stressed concrete sleeper



Important dimensions of typical section of PSC sleeper

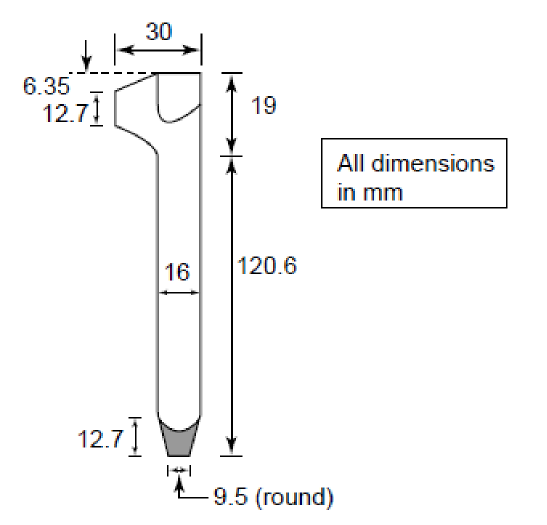
- Sleeper density' is expressed as (N + *x*) where N is the number of metres in rail length; thus (N + 4) on BG track means (13 + 4) or 17 sleepers per rail length.
  - The greater the sleeper density, the more the strength and stability of the track
  - This may also be expressed as the number of sleepers per kilometre length of track.
  - The spacing of sleepers need not be uniform; it is usually less than normal at special locations such as rail joints, horizontal curves and points and crossings

- Rail fastenings and track fittings are required to connect rail to rail, rail to sleepers, and other such purposes:
  - Fish plates



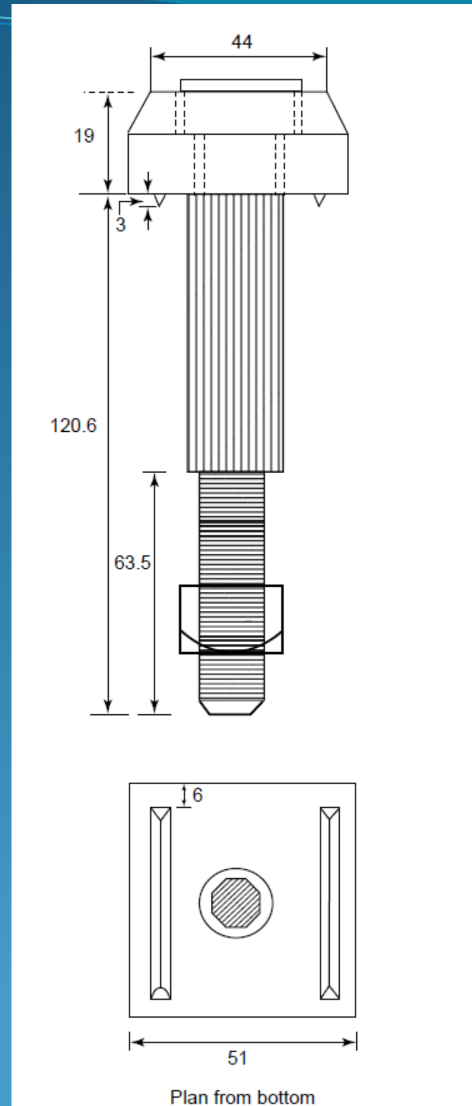
Fish plates and fish bolts

  - Spikes



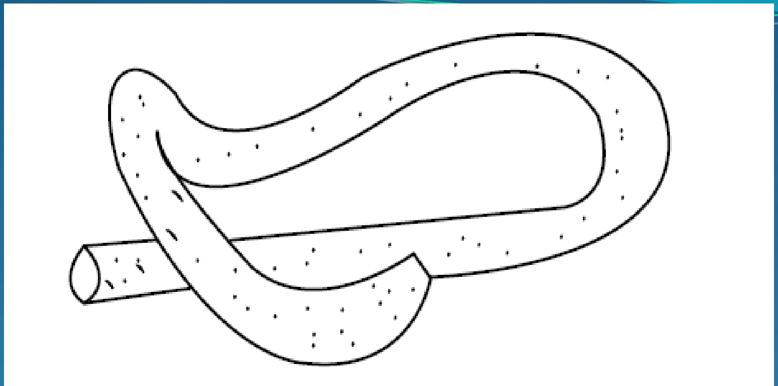
Dog spike

- Bolts
- Jaws and keys
- Chairs



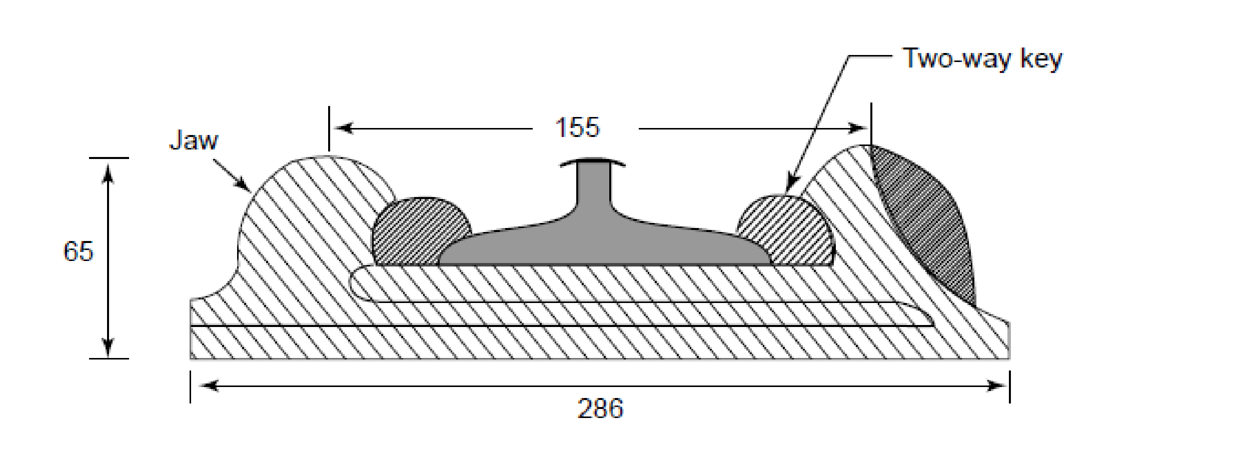
Fang bolt

- Elastic fastenings
  - Pandrol clip
  - CI inserts



Pandrol clip

- **Bearing plates**
- **Grooved rubber pads**



Bearing plate

- Ballast holds the sleepers in position, provides an elastic and firm bed, and distributes the loads on to a larger area of subgrade soil for ensuring stability of the track.

Permanent ballast materials:

- Broken stone
- Moorum
- Kankar

Size of ballast material: 50 mm

At special locations such as points and crossings: 25 mm

Graded ballast: 25 to 50 mm

Ballast cushion: 150 to 200 mm

250 to 300 mm on Trunk routes

Quantity of ballast: 1.167 m^3 to 1.588 m^3 per metre length –for ballast cushion ranging from 200 to 300 mm.

Temporary ballast materials:

- cinder
- broken brick
- selected earth

} for new tracks or for sidings

Ballast-less tracks are used for bridge decks and in tunnels.

- Formation or soil subgrade is meant to carry the pressure transmitted from above in a safe manner to the r foundation soil below. Treatment methods are available to strengthen subgrade soil, if necessary.
- Railway track drainage: This involves the interception, collection and disposal of water from, upon or under the track. Improper drainage adversely affects the stability of the embankment and the subgrade as the bearing power is significantly reduced. Differential settlement may occur, leading to subsidence of the track. Track drainage consists of
  - Surface drainage
  - Subsurface drainage

 Surface drainage

Side drains

 Sub-surface drainage

- Inverted filters, Catch-water drains, Sand piles, Perforated pipes, Blanket of free-draining material underneath the ballast cushion

- 'Tractive effort' is the power generated by the locomotive to pull the train; this depends on the engine characteristics and type of fraction- steam, diesel or electric. 'Hauling capacity' depends upon the number of driving axles, axle loads, and the coefficient of friction between the wheel and the rail-tractive effort should be equal to or a little greater than the hauling capacity. 'Rolling stock' comprises the locomotives, coaches and wagons.
  - Resistance to the motion of a train

    Frictional resistance, R_f where W is the weight of train in tonnes.

    Wave action resistance, R_{wa} where V is the speed of the train in km/h

    Atmospheric resistance, R_{at} where $\underset{\text{(in tonnes)}}{R_{at}} = 0.0000006 W.V^2$

    Gradient resistance, R_g where $R_g = W \times \frac{g}{100}$ and g is the gradient in percent. R_g is encountered only while negotiating an ascending grade

- Curvature resistance, R_c

  $R_c = 0.0004\ W.D$ for BG

  $R_c = 0.0003\ W.D$ for MG

  D is the Degree of the curve.

  Resistances during start and acceleration are considered to be relatively, negligible.

  'Grade compensation' or reduction of gradient on horizontal curves is practised to nullify the effect of curve resistance.

- Specifications for track structure

  Indian Railways have prescribed standard specifications for rails, sleepers, fastenings, and ballast on BG and on MG for trunk routes, main lines and branch lines.

- Stresses in the track components

  The track is taken to be continuously supported on an elastic bed. The initial track modulus is taken to be much smaller than the elastic track modulus.

Track modulus is defined as the load per unit length of the rail required to produce a unit depression of the track. Up to a certain initial load (around 4 tonnes for BG) the depressions are disproportionately high, the modulus being low. This is called the 'initial track modulus (U_i)'.

Beyond this load, smaller depressions occur for similar load increments, the elastic modulus being much higher than the initial value. This is called the 'Elastic Track Modulus (U_e)'

This 'Double Modulus' approach is considered to be more realistic and is used by the Indian Railway to calculate track stresses.

- Speed factor or Impact factor: This is used to augment the wheel load to take into account the impact or dynamic effect.
- Relief due to the effect of leading axle --lift of rail: There is supposed to be some relief in the bending moment in the rail due to this if the axles are near to each other.

- Talbot load: The net wheel load after these modifications, as applicable, is known as 'Talbot load'', after Prof. A.N. Talbot, an American Track engineer. This is used to calculate the track stresses.

  The bending moment causes compressive stress in the rail head and tensile stress in the rail foot.

- The relevant formulae are:

$$\underset{(\text{cm})}{X_{i,e}} = 42.33\left(\frac{I_{xx}}{U_{i,e}}\right)^{\frac{1}{4}}$$

$$\underset{(\text{cm}\cdot\text{t})}{M_0} = 0.319\,P \times X_{i,e}$$

$$\underset{(\text{t/cm}^2)}{f_c} = \frac{M_0}{Z_c}$$

$$\underset{(\text{t/cm}^2)}{f_t} = \frac{M_0}{Z_t}$$

$$\underset{(\text{cm})}{d} = \frac{9.25P}{\left(I_{xx} \times U^3_{i,e}\right)^{\frac{1}{4}}}$$

Here, $X_{i,e}$ = distance from the load to the point of contraflexure (i for initial load and e for elastic load)

M_o = bending moment immediately under an isolated wheel load, P

P = wheel load

$U_{i,e}$ = track modulus (kg.cm2) (i – initial load range) (e- elastic range)

I_{xx} = vertical moment of inertia of the rail section

Z_c = section modulus in compression

Z_t =Section modulus in tension

f_c = compressive stress in the rail head

f_t = tensile stress in the rail foot.

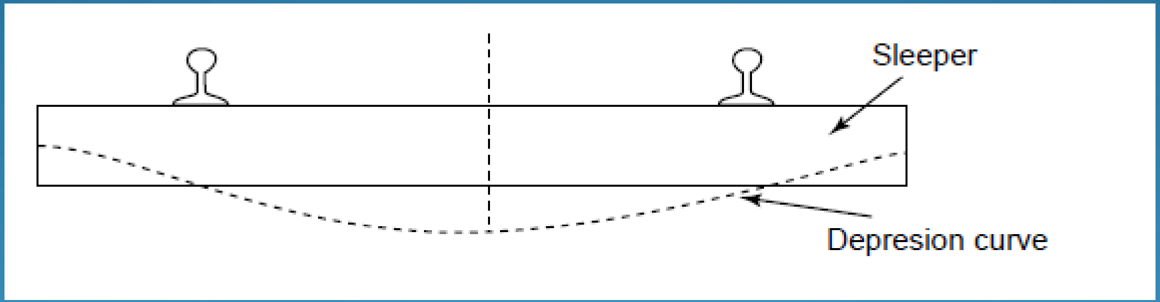
d = depression (or deflection) of the track.

- Stresses in sleepers

Pressure distribution under the sleeper is complex because of ballast packing. Ballast yields under the loads; therefore, pressure distribution under the sleeper varies with the standards of maintenance.

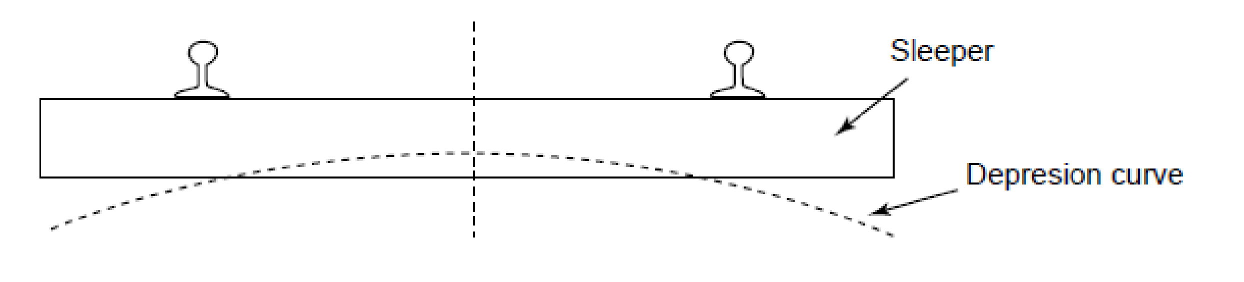
The two extreme conditions based on the packing of ballast are:

  - End-bound sleeper – Well-packed ballast



End-bound sleeper

  - Centre-bound sleeper – Loose ballast under rail seat



Centre-bound sleeper

- Stresses on ballast: Prof. Talbot has analysed the pressure distribution in the ballast, and found that it is bulb-shaped.
- Pressure on formation or subgrade: The maximum pressure, p_f (max) is given by

$$p_f(\max) = \frac{2PS}{\pi DL}\left[\frac{U_e}{64EI}\right]^{\frac{1}{4}}$$

Here, P = wheel load (tonnes)

S = sleeper spacing (cm)

D = depth of ballast cushion (cm)

L = effective length of sleeper under one rail seat (cm)

U_e = Track modulus in the elastic range (kg/cm^2)

E = Modulus of elasticity of rail steel (2.11×10^6 kg/cm^2)

I = Moment of inertia of worn rail about the horizontal axis (cm^4)

P_f(max) should be less than the safe bearing power of the soil (ranges from about 1.00 kg/cm^2 for loose soil to 3.00 kg/cm^2 for stiff or compacted soil.

Chapter 4: Geometric Design of Railway Track

- Geometric design of a railway track involves all elements relating to the geometry, primarily related to the geometry, primarily related to the vertical and the horizontal alignment. proper design of these parameters is necessary to ensure efficient and safe operation of trains at the maximum permissible speed and also to minimise maintenance needs
- Vertical alignment (gradients)

Gradients become necessary when the track cannot be kept horizontal due to terrain considerations.

Types of gradients

- Ruling gradient - Maximum gradient in a section - Determines the maximum load that can be hauled.

Gradients recommended on Indian Railways:

Plain terrain: 1 in 150 to 1 in 250

Hilly terrain: 1 in 100 to 1 in 150

(These are for single-engine haulage)

- Momentum gradient: Used in valleys to utilise the momentum gained on the falling grade to go up the rising grade, which could be a little greater than the ruling grade. (No obstacles or signals are permitted in this zone.)
- Pusher or helper gradient: Used in hilly terrain where gradients steeper than ruling grades – has to be adopted to achieve economy; in such cases, an extra engine, called a 'pusher' engine, is used to haul the train.
- Gradients in station yards: Necessarily flat to prevent standing vehicles from rolling away.

  Recommended values: 1 in 400 to 1 in 1000

  Some minimum gradient is needed for drainage.

- Grade compensation on horizontal curves: Gradient is reduced with respect to the ruling value in order to nullify the curve resistance to traction; this is known as grade ‘compensation’.

Values recommended on Indian Railways:

 BG: 0.04 % per degree curvature, or 70/R %, whichever is smaller

 MG: 0.03% per degree curvature, or $\frac{52.5}{R}\%,$ whichever is smaller.

(R is the radius of the curve in metres)

- Horizontal curve

     Simple curves – Single circular arc connecting two straights or tangents.

  - Degree of curve, $D = \frac{1750}{R}$ (for a 30.5 m chord)

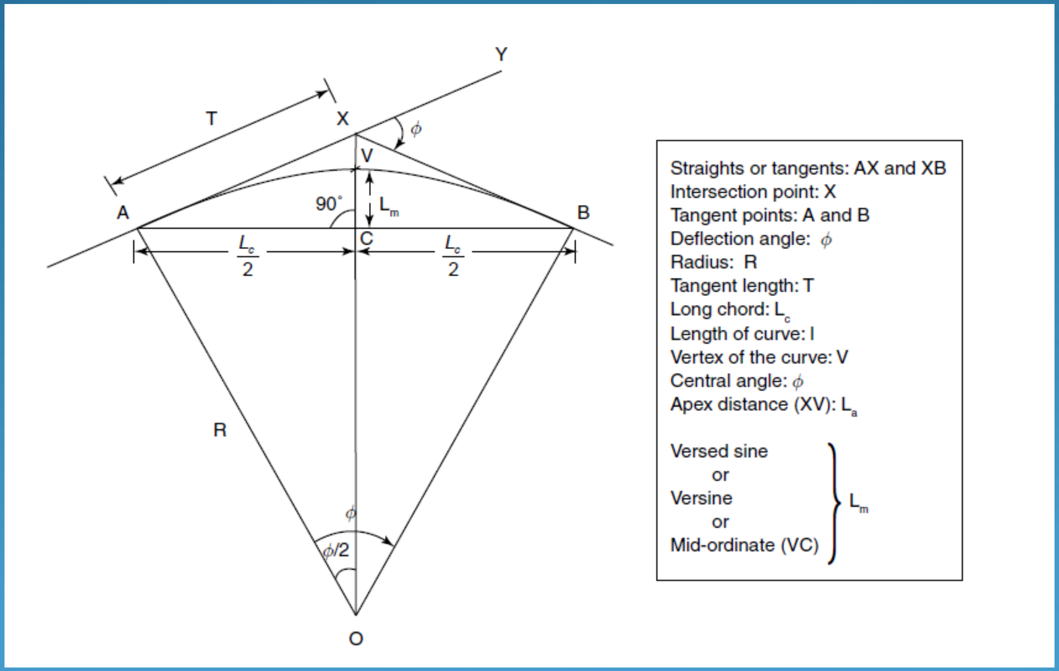
  For curves of large radii, as in Railways, it is immaterial whether the standard length is that of the chord or the arc.

  - Versine of the curve:

    The mid-ordinate of the curve, $L_m = \frac{L_c^2}{8R},$

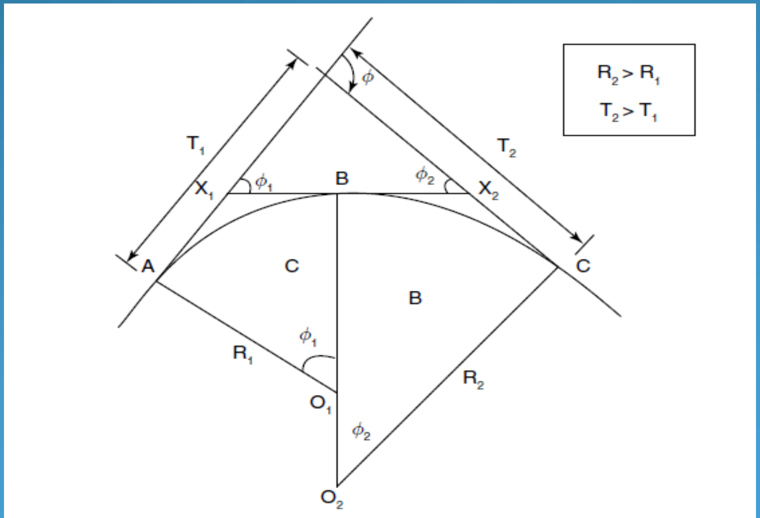
    L_c being the long-chord

Versine of the curve in centimetres on a 11.8 m chord is equal to the degree of the curve; this relation is used in the field during maintenance of horizontal curves.



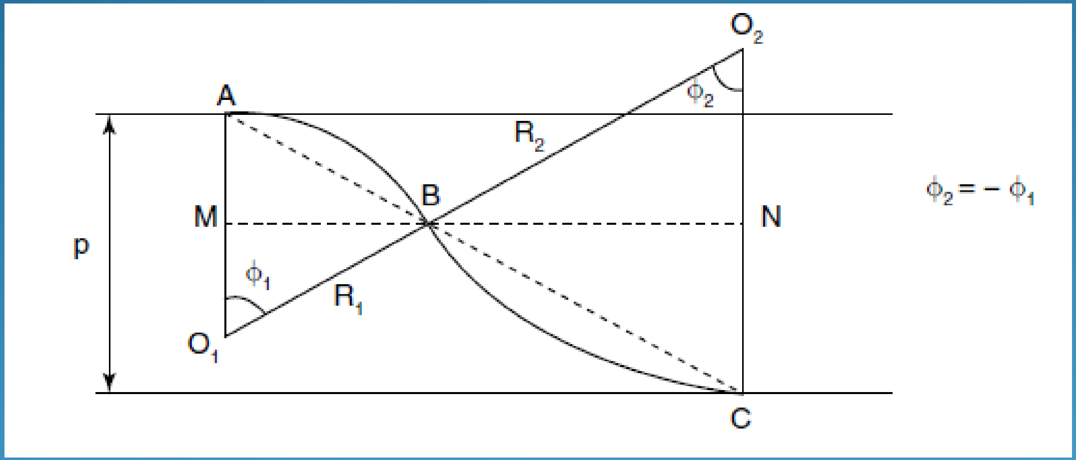
Elements of a simple curve

- Setting out simple curves: There are different methods available to set out simple curves in the field, using offsets and or tangential angles – with theodolite and tapes.
- Compound curves: A compound curve consists of two or more circular arcs of different radii, curving in the same direction. Such curves may be required when space restrictions or property boundaries preclude the use of a simple curve. The common tangent is at the junction.



Geometry of a compound curve

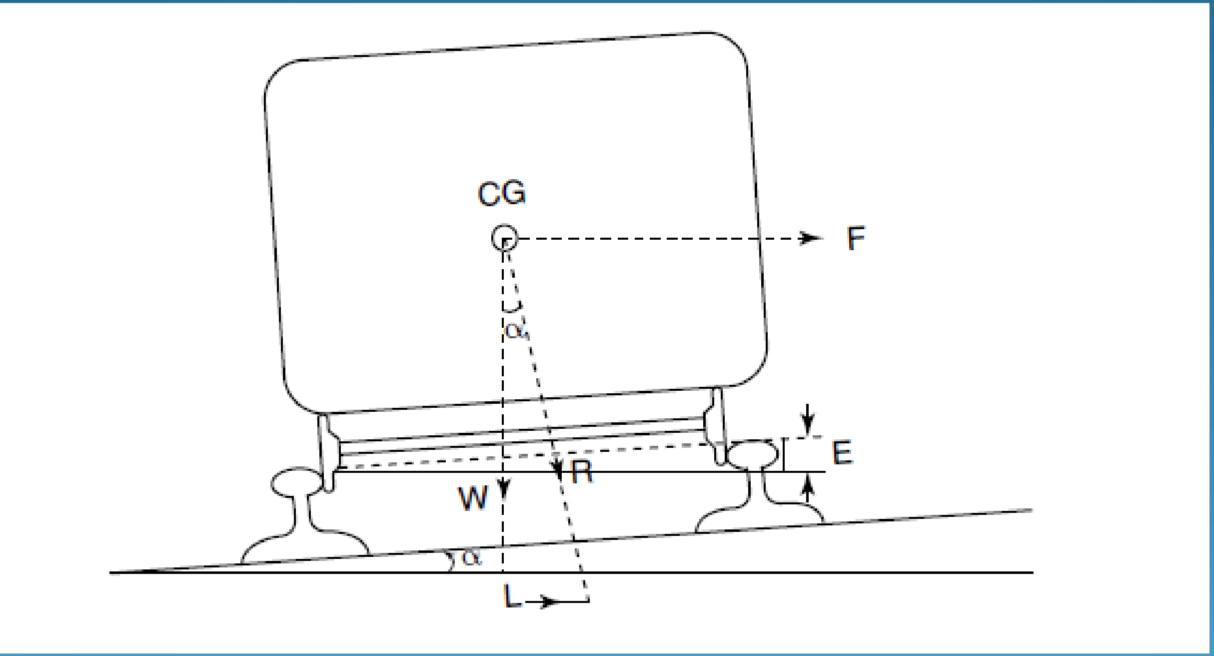
- Reverse curves: Two circular arcs curving in opposite directions constitute a reverse curve. the common tangent is at the junction.
- The radii of the two arcs may or may not be equal.
- Reverse curve between parallel tangents: This is a social case, popularly used for cross-over between parallel tracks in railways.



Reverse curve between parallel tangents

- Super-elevation or cant: Provided on horizontal curves to counteract the centrifugal force acting on a vehicle moving along the curve at constant speed.

- This consists of raising the outer rail above the inner, which results in equalising the pressure on both the outer and inner wheels of the axle, and minimising the discomfort to the passengers.



Counteracting centrifugal effect by superelevation

- Superelevation, $E = \frac{G \times V^2}{127R}$

G: Dynamic gauge (Gauge plus width of rail head)

V: speed in km/h

R: Radius of curve in metres.

E will have the same units as G

This is the 'equilibrium cant' for the speed V.

- **Equilibrium speed**: Goods, passenger and express trains run at different speeds. The cant is provided for the weighted average speed of all the trains running in the section. This speed is called the 'equilibrium speed'.

For Broad Gauge, the dynamic Gauge, G is taken as 1750 mm.

Therefore, $E_{(mm)} = \frac{1058V^2}{127R} = \frac{13.78V^2}{R}$ (V in km/h, R in m)

For Metre Gauge, G is taken as 1058 mm

Therefore, $$E_{(mm)} = \frac{1058V^2}{127R} = \frac{8.33V^2}{R}$$

- Maximum values of cant on Indian Railways:

  BG: 165 mm for A, B and C routes, and

  140 mm for D and E routes

  MG: 90 mm for all routes

- **Cant deficiency and cant excess**: The extent by which the actual cant provided falls short of that required for fast trains is known as the 'cant deficiency'.
  - Maximum permissible cant deficiency on Indian Railways:

  BG: 75 mm

  MG: 50 mm

The extent by which the actual cant exceeds that required for slow trains is called 'cant excess'

- Maximum cant excess values:

BG: 75 mm
MG: 65mm

- **Negative cant**: When a branch line takes off in a curved manner from a main line of reverse curvature, the outer rail of the branch line becomes the inner one of the main line for a short distance from the point of take off. In this part of the branch line, negative cant occurs due to the cant of the main line.

Limits for negative cant are governed by those for cant deficiency.

- **Transition curves**: A 'transition curve' is a non-circular arc which permits gradual increase of curvature between a straight portion and a circular curve.

Functions of transition

- Minimising discomfort to passengers by eliminating the sudden occurrence of centrifugal force on the curve
- Providing a medium of gradual introduction of cant so that the full value of cant needed on the circular curve is attained at the junction.

Length of transition

- Permissible rate of change of cant:

$$L = 0.008\,E_a \times V_m$$

L= Length of transition (m)

E_a = actual cant (mm)

V_m = maximum speed (km/h)

- Permissible rate of change of radial accelerations:

$$L = 0.008 \times E_d \times V_m$$

[E_d: cant deficiency (mm)

- Permissible rate of change of radial acceleration: $L = 0.72\,E_a$

  The greatest of these values is adopted.

[The first two are based on rate of gain of cant and cant deficiency of 35 mm/s as a vehicle travels along the transition. The third equation is based on spatial-rate of cant gradient of 1.4 mm per metre or 1 in 720.]

- Types of transition curves
  - Euler spiral
  - Cubic spiral
  - Bernoulli's lemniscate
  - Cubic parabola (Froude's transition)

  Cubic parabola is popularly used in railways because of the simplicity of setting out calculations.

  Both the curvature and cant increase linearly, so that the full cant is attained at the start of the circular curve.

[The circular curve gets shifted due to the introduction of transitions. Transitions are needed in the case of compound and reverse curves at the junctions of circular arcs and at either end.]

- Extra widening of gauge on curves is provided to reduce rail-head wear; however, this is limited to 10 mm on BG to prevent accidents. Check rails are also provided on curves to prevent accidents.
- Safe speed on curves
  - Transitioned curves: The equilibrium speed calculated for the sum of cant and max cant deficiency. This is subject to the maximum permissible sanctioned speed for the section.
- Vertical curves: Needed when change of gradient is more than 0.4 per cent. Usually a parabolic arc is used
- The minimum radius prescribed is 4000 m for BG high-speed routes.

- Length of vertical curve: Maximum permissible rate of change of gradient: 0.1 % for summits and 0.05% for sags

New method: $$L = R \times G$$

R: Radius of vertical curve – minimum recommended value

G: Algebraic difference of gradients (in radians)

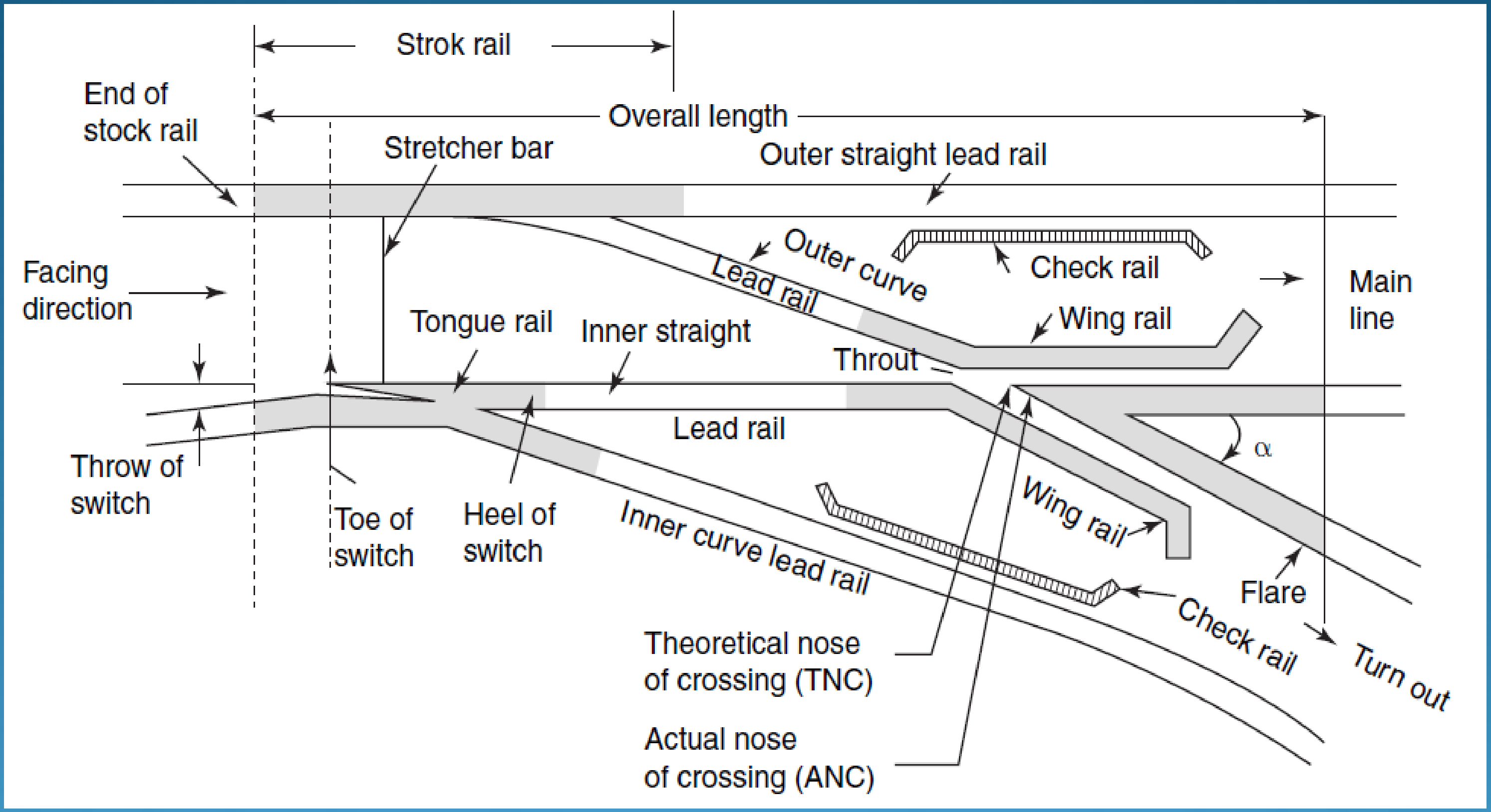
This value is less than that set as per the earlier norms, and is considered to be adequate.

Chapter 5: Points and Crossings

- Points and crossings are special arrangements needed to move a train from one track to another; the need for this arises owing to the inside flanges of wheels, requiring gaps for their movement.

  Points or switches divert a vehicle while crossings help the flanged wheels roll over the gaps in the desired direction.
- A ‘turnout’ consists of one set of switches and a crossing; the simplest layout is a turnout taking off from a straight track.

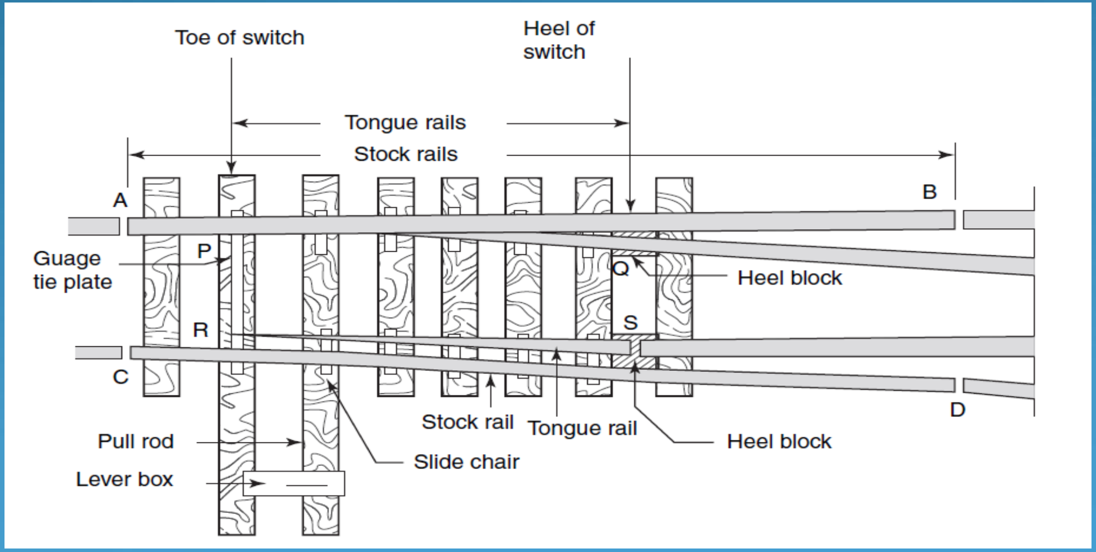
  A turnout is designated as a right hand or a left hand turnout depending on the direction in which it diverts the traffic, as viewed in the facing direction. (Standing at the points or switches gives, looking towards the crossing, gives the facing direction; the reverse of this is the trailing direction.)



Schematic plan view of a right-hand turnout

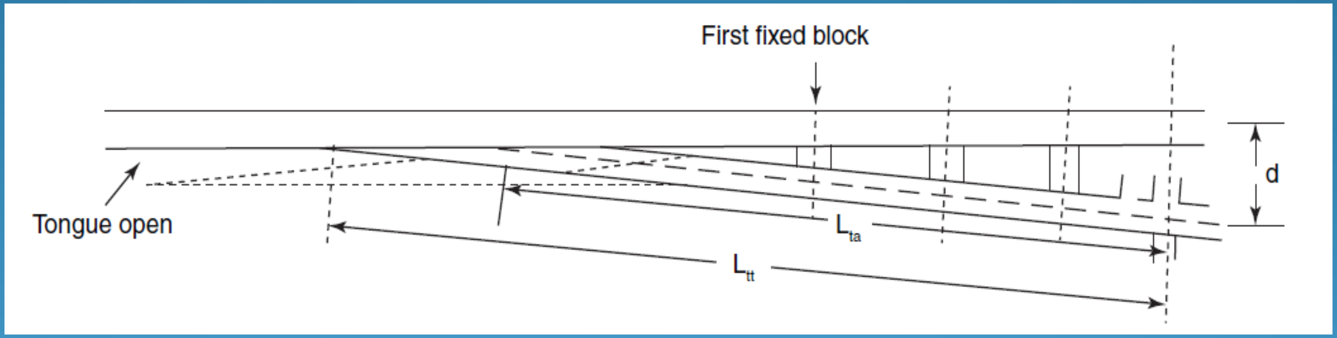
The main parts of a turnout are a pair of switches or points, a crossing and four lead rails.

- Points or Switches: The components are
  - One pair of stock rails
  - One pair of tongue rails tapered towards the toe
  - Stretcher bars connecting the tongue rails at the toe
  - One pair of heel blocks
  - Slide chairs
  - Gauge tie-plate



Details of a switch

- Types of Switches: 'Split switch' is the more commonly used one; it consists of a pair of stock rails and a pair of tongue rails.
- There are two types of split switches:
  - Fixed heel switch
  - Straight type: tongue rail is straight from toe to heel of switch.
  - Curved type: tongue rail is curved to the same radius of the turnout.



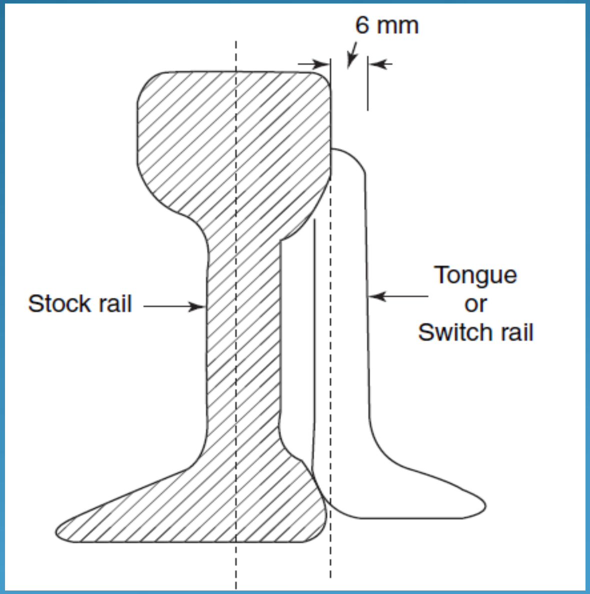
Schematic of a fixed heel switch

  - Loose-heel switch: The tongue rails pivot about heel joints, held in position by heel blocks and fish plates. These are not preferred for new layouts.

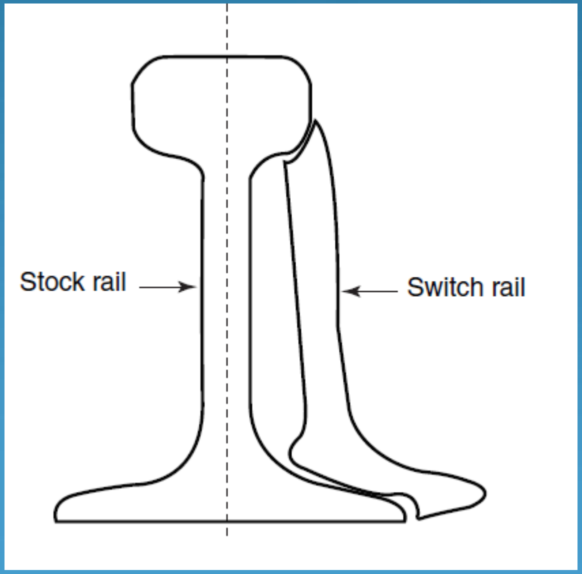
Based on the design of the toe portion of the switch, switches are of two types:

- Undercut switch: The foot of the stock rail is planned to accommodate the tongue rail.
- Overriding switch: The foot of the tongue rail is planned to override that of the stock rail, the full section of the stock rail being maintained.

Overriding switches are standardised and used on Indian Railways.



Undercut switch



Overriding switch

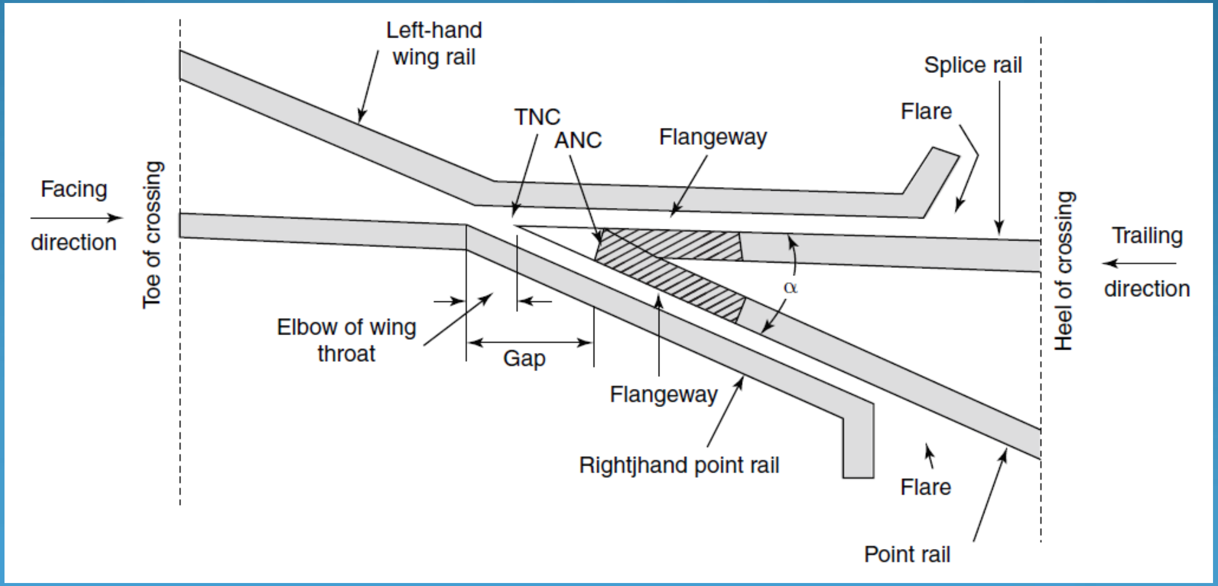
Important design elements of a switch:

- Heel divergence: The shortest distance between the gauge faces of the stock rail and the tongue rail at the heel of the switch. (shown as *d* in Figure on Slide 49)
- Switch angle: Angle between the gauge faces of the stock rail and the tongue rail at the toe of the switch, when the switch is in the closed position. It is related to the heel divergence (d) and the length of the tongue rail (L_{ta}):

$$Sinb = \frac{d}{L_{ta}}$$ (ignoring the thickness of tongue rail at toe)

- Throw of switch: Distance through which a tongue rail moves at its toe from its closed position to its open position. This is 115 mm for BG and 100 mm for MG, so as to get the minimum flangeway clearance of 44 mm and 41 mm respectively.

- Crossings: A crossing is a device introduced at the point where two rails cross each other so as to permit the flanges of the wheels to pass from one track to another. As the wheel negotiates the gap at the nose of the crossing, the other wheel is guided by means of a check rail.
- Components of a crossing:
  - Point rail
  - Splice rail
  - Check rail
  - Wing rail



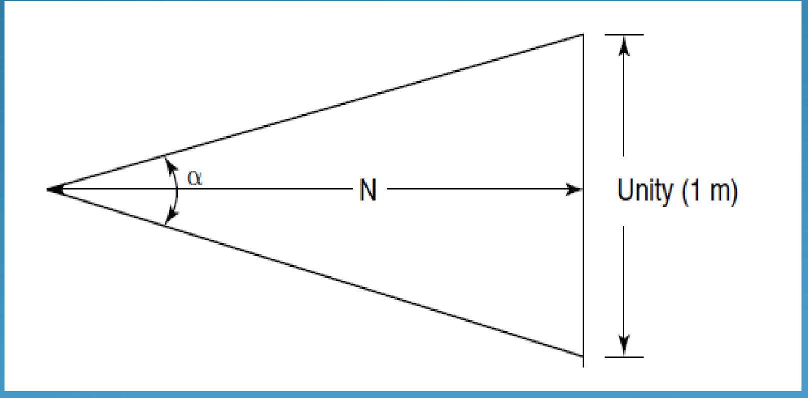
Components of a crossing

- Types of crossings
  - Based on geometry:
  - Acute-angled or Vee-crossing
  - Obtuse-angled crossing
  - Based on the method of manufacture:
  - Built-up crossing: The components are assembled together by means of bolts ad nuts and distance blocks. This is commonly used on Indian Railways, although it lacks rigidity in view of certain advantages such as low cost and convenience of repair of each of the components.
  - Cast steel crossing: Cast Manganese Steel (CMS) crossings, developed by the Indian Railways, are considered to be strong and durable.
  - Spring or movable crossing: A strong helical spring controls the movements. This type is considered advantageous for high-speed traffic on the main track and low-speed traffic on the turnout.

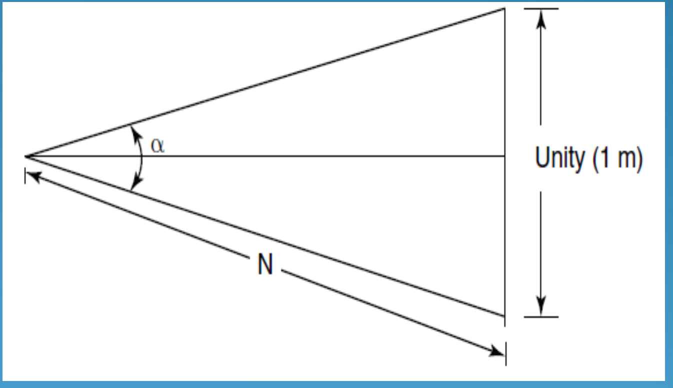
- Designation of a crossing: A crossing is designated either by the angle of the crossing (*a*) between the gauge faces of the point and splice rails, or by the crossing number (N), which is more common.

Methods of relating *a* and N:

- Centre- line method $N = \frac{1}{2}\cot\frac{a}{2}$
- Isosceles triangle method $N = \frac{1}{2}\operatorname{cosec}\frac{a}{2}$



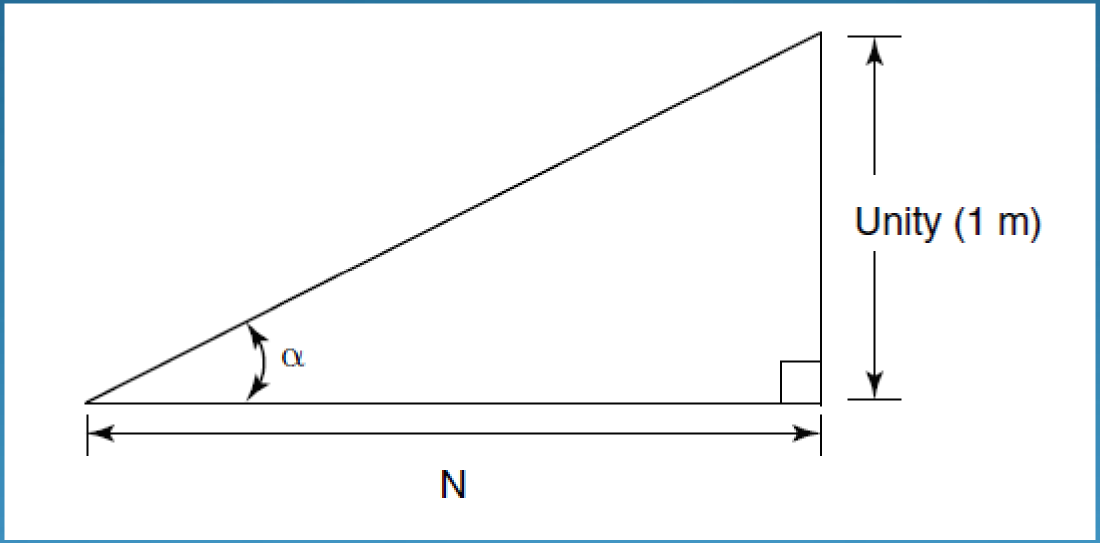
Centre line method for *N*



Isosceles triangle method for *N*

- Right angle method (Cole's method): $N = \text{Cot}\,\alpha$

Right angle method for *N*: This gives the smallest angle for a given crossing number, and is adopted by the Indian Railways.



- Design of a turnout: The simplest turnout is one which takes off from a straight main track, and consists of a set of points (or switches and a crossing).

Definitions

- Radius of turnout, $R = R_0 + \frac{1}{2}G$

R_o = radius of the centre line of the turnout curve

G = Gauge

As R is usually very large compared to G,

$R \approx R_o$, for all practical purposes.

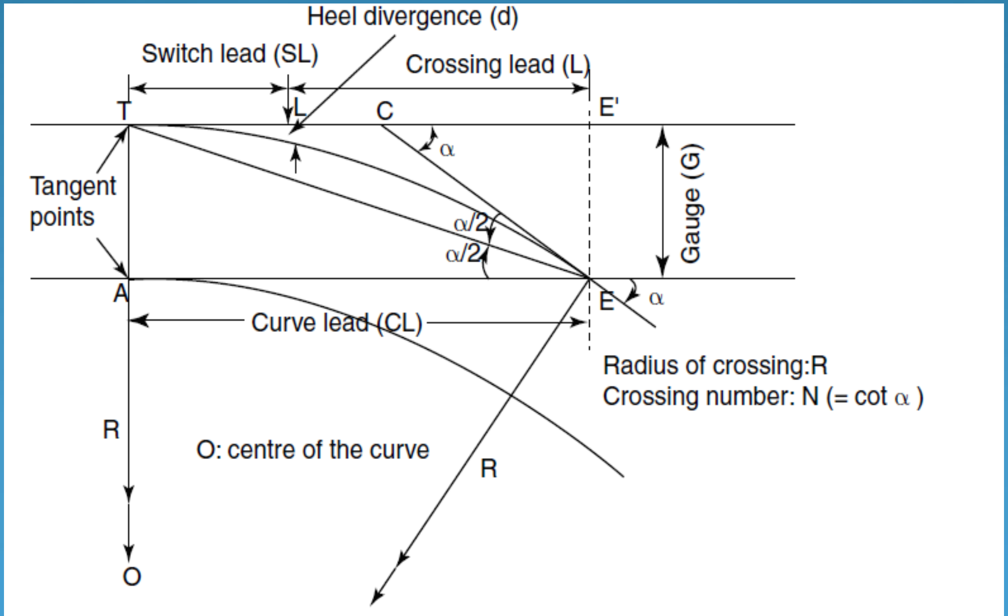
  - Curve lead (*CL*): This is the distance from the tangent point to the theoretical nose of crossing, measured along the line of the main track.
  - Switch lead (*SL*): This is the distance from the tangent point to the heel of the switch, measured along the line of the main track.
- Crossing lead (or lead of crossing) (*L*): This is the curve lead and switch lead. $L = (CL - SL)$
- [Heel divergence (*d*) and angle of crossing (*a*) are already defined.]
- The design consists of determining the three leads – *CL*, *SL* and *L*.

Methods of design:

(a) Cole's method

(b) IRS method

- Cole's method: The curvature is taken to start from a point on the straight main track ahead of the toe of the switch, and end at the theoretical nose of crossing.



Design of turnout (Cole's method)

$$CL = GN + G\sqrt{1+N^2} = 2GN(\text{approx})$$

$$SL = \sqrt{2Rd - d^2}$$

$$L = 2GN - \sqrt{2Rd - d^2}(\text{approx})$$

$$R = G(1+N^2) + GN\sqrt{1+N^2}$$

$$= 1.5G + 2GN^2(\text{approx})$$

The disadvantage is that three kinks occur – at the actual toe of the switch, at the heel of the switch, and at the first distance block of the crossing. This is due to the fact that the tongue rail and the wing rail up to the theoretical nose of crossing are usually straight.

- IRS method: This is the standard layout used on Indian Railways. The curve begins at the heel of the switch and ends at the toe of the crossing (at the centre of the first distance block). The only kink occurs at the toe of the switch. The calculations are more involved than in Cole's method, but the layout is more superior and marginally greater speeds may be permitted on the crossings.

Sleepers are laid to cover both the tracks for some distance at points and crossings.

The standard turnouts used are:

1 in 8.5 (N = 8.5) (for slow traffic)

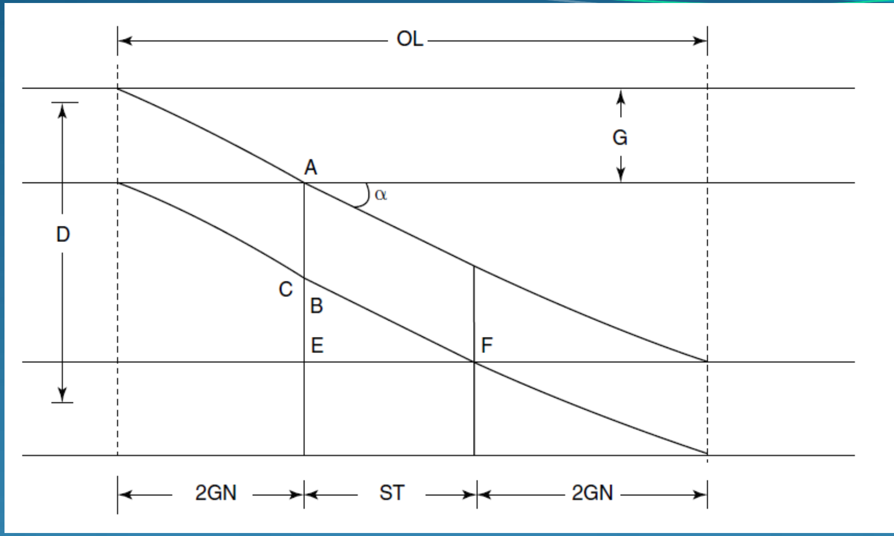
$$\left.\begin{array}{l}1 \text{ in } 12\\ 1 \text{ in } 16\end{array}\right\}\text{(for passenger traffic)}$$

Permissible speeds are much less on turnouts than on tracks.

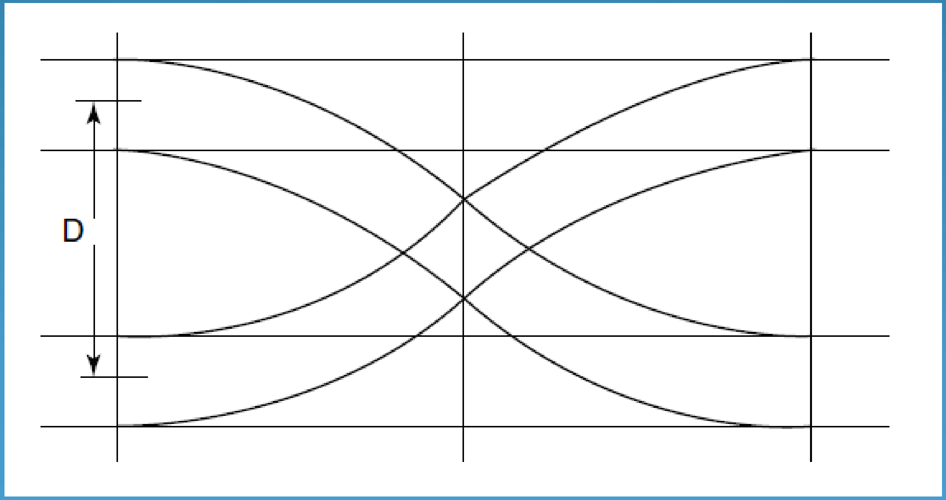
- Track junctions and layouts: Used in station yards to fulfill specific needs. Involve several sets of points and crossings.

Layouts:

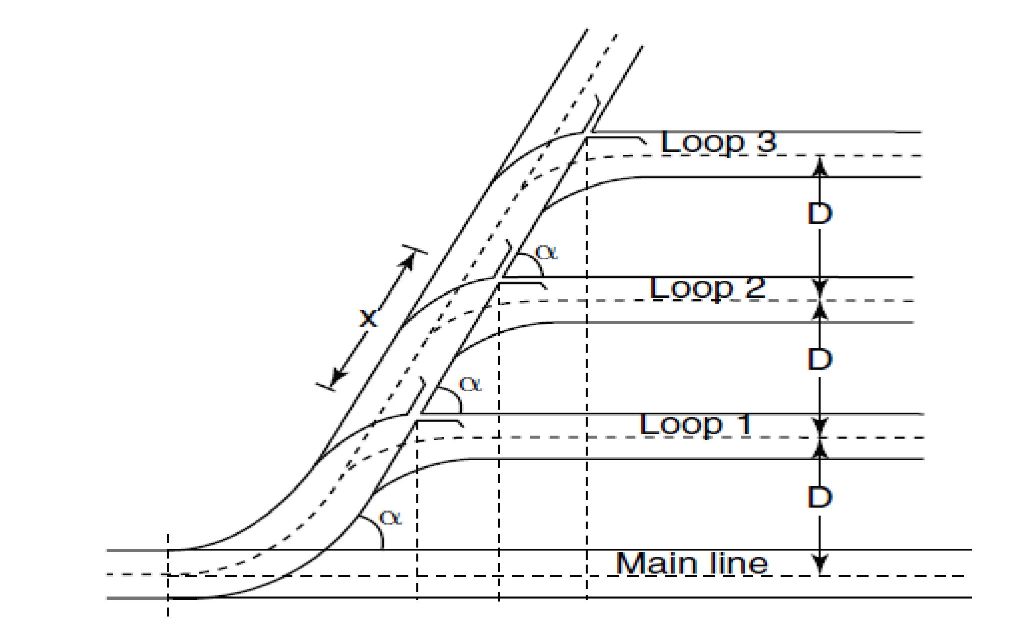
- Crossover between parallel tracks
- Diamond crossing (with single slip and double slips)
- Scissor’s crossover
- Gathering line



Schematic of a crossover between parallel tracks



Schematic of a scissors crossover



Gathering line at crossing angle (ladder track)

- Level crossings: Provided when a railway line and a road cross each other at the same level. They are classified based on the class of road, volume of road traffic, number of trains passing at the point, and visibility conditions.

Chapter 6: Stations and Yards – Layout and Equipment

- The purpose of a railway station is to book passenger and goods traffic and operate trains; also this facilitates passengers to entrain and alight and goods to be loaded and unloaded.
- Criteria for site selection of a railway station
  - Availability of adequate land for the present needs, as also for future expansion
  - Fairly level ground in plain terrain
  - Alignment of the track near station must be preferably straight for clear visibility of signals.
  - Availability of basic amenities like water and power supply
  - Accessibility from nearly towns and villages

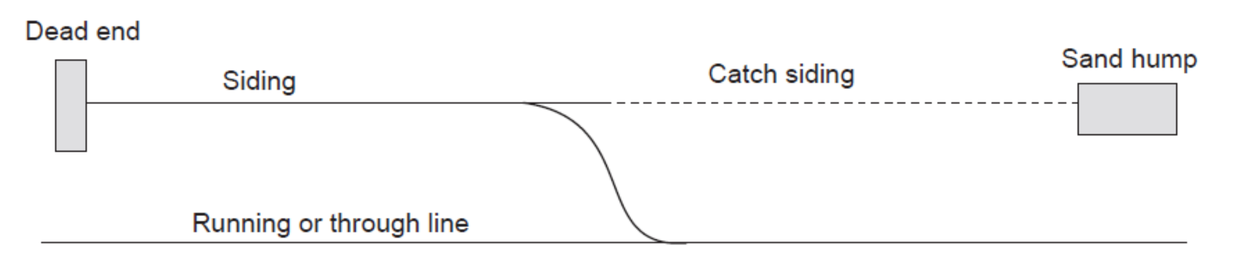
- Facilities required at railway stations
  - Passenger requirements:
  - Waiting halls and rooms and retiring rooms
  - Booking and reservation facilities and enquiry
  - Refreshment rooms
  - Bathrooms and toilets
  - Telephones
  - Drinking water
  - Public address systems
  - Train indications of arrivals and departures
  - Foot overbridges, escalators, and so on.

- Traffic requirements:
  - Station buildings
  - Station master's and ASM's offices
  - Room for ticket collector, TTEs, guards
  - Running rooms for drivers
  - Station equipment for control of trains
  - Signals and cabins
  - Sidings and yards
  - Locomotive sheds and workshops
  - Water and fuelling arrangements and so on.
- Classification of railway stations
- Operational consideration:
  - Block station: A-, B- and C- class stations
  - Non-block stations: D- class or Flag stations

- Functional considerations
  - Halts
  - Wayside stations
  - Junctions and terminus stations
- Financial considerations
  - Depending upon passenger and goods earnings:
  - A-, B-, C-, D-, E-, and F- stations.
  - Block station is one at which a train driver should receive the authority to proceed and enter the next block station. This is relevant to the Absolute Block Station of operation in which only one train is allowed to be in one block section, the track between two consecutive block stations. Further classification into A-, B-, and C- classes is based on the traffic and importance. The corresponding facilities depend on these criteria.

- A ‘halt’ is the simplest station where a few trains stop for two minutes for the convenience of passengers. ‘Flag’ stations have a station building and staff to book passengers.
- Wayside stations or crossing stations have facilities to control the movement of trains; crossing facilities are available for trains in opposite directions by providing a loop line along with a platform.
- Junction and Terminus stations are large in size, with several platforms and various facilities.

- Sidings
- Passenger sidings for passenger trains
- Goods siding for goods trains
- Catch siding for trapping and stopping runaway wagons, by providing a bufferstop or a sand-hump at the end



A typical catch siding

- Platforms

➢ Passenger platform

g Rail-level
g Low-level } depending on the importance of the station
g High-level

- Goods platforms

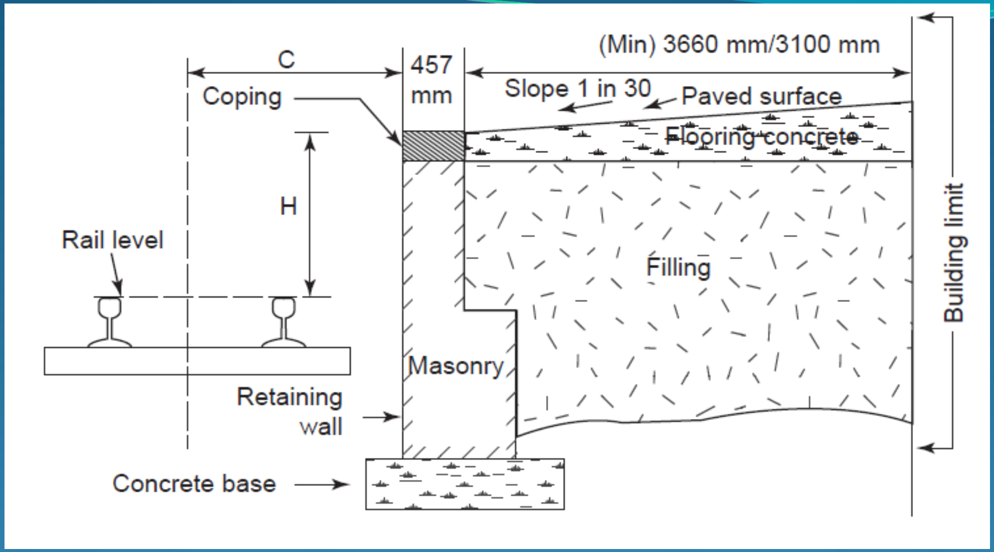
Height: 1.07 m for BG

Length: minimum 60 m

Width: minimum 3.1 m

Paving: Bituminous carpet

Other facilities: Weighing facilities, mobile cranes, and adequate storage facilities.



A typical section of a platform

- Station yards

➢ A system of tracks laid to serve a specific purpose in the station premises.

➢ Passenger yards for passenger trains

➢ Goods yards for goods trains and handling goods traffic.

➢ Marshalling yards for reception, sorting and despatch of trains

➢ Locomotive yards

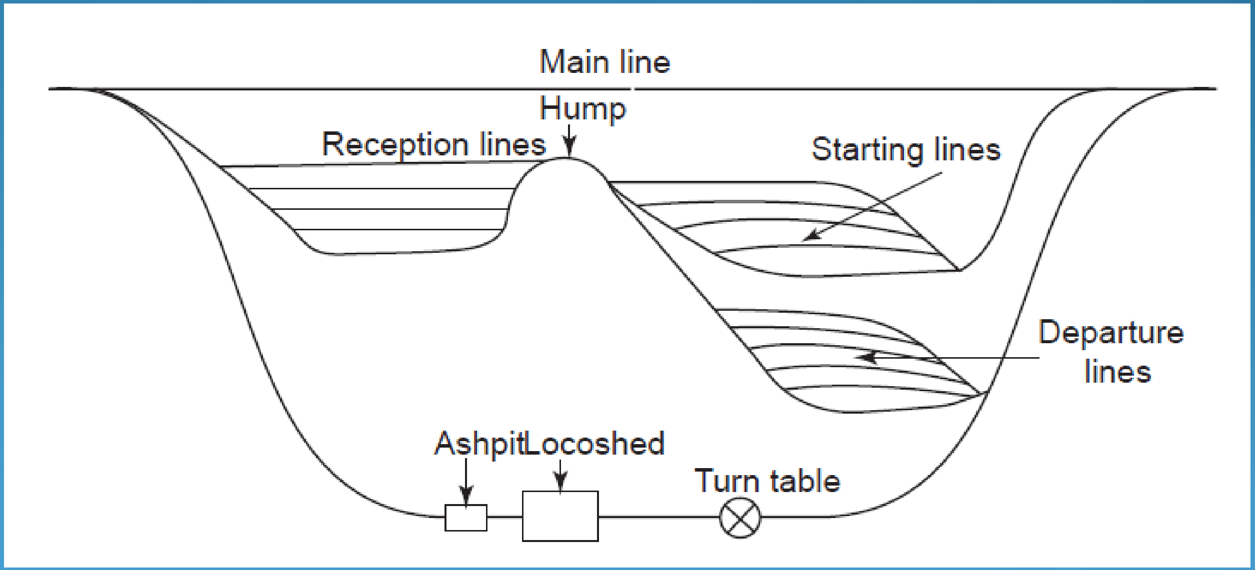
➢ Sick line yards – for defective and sick coaches and wagons until they are attended to for repairs.

- Marshalling yards: Yard where trains are received, sorted out, and new trains are formed according to destinations; they arranged in station order, properly marshalled and despatched in the appropriate routes.
- Sub- yards in marshalling yards:

➢ Reception lines

➢ Sorting lines

➢ Departure lines



Typical layout of a marshalling yard

Types of marshalling yards

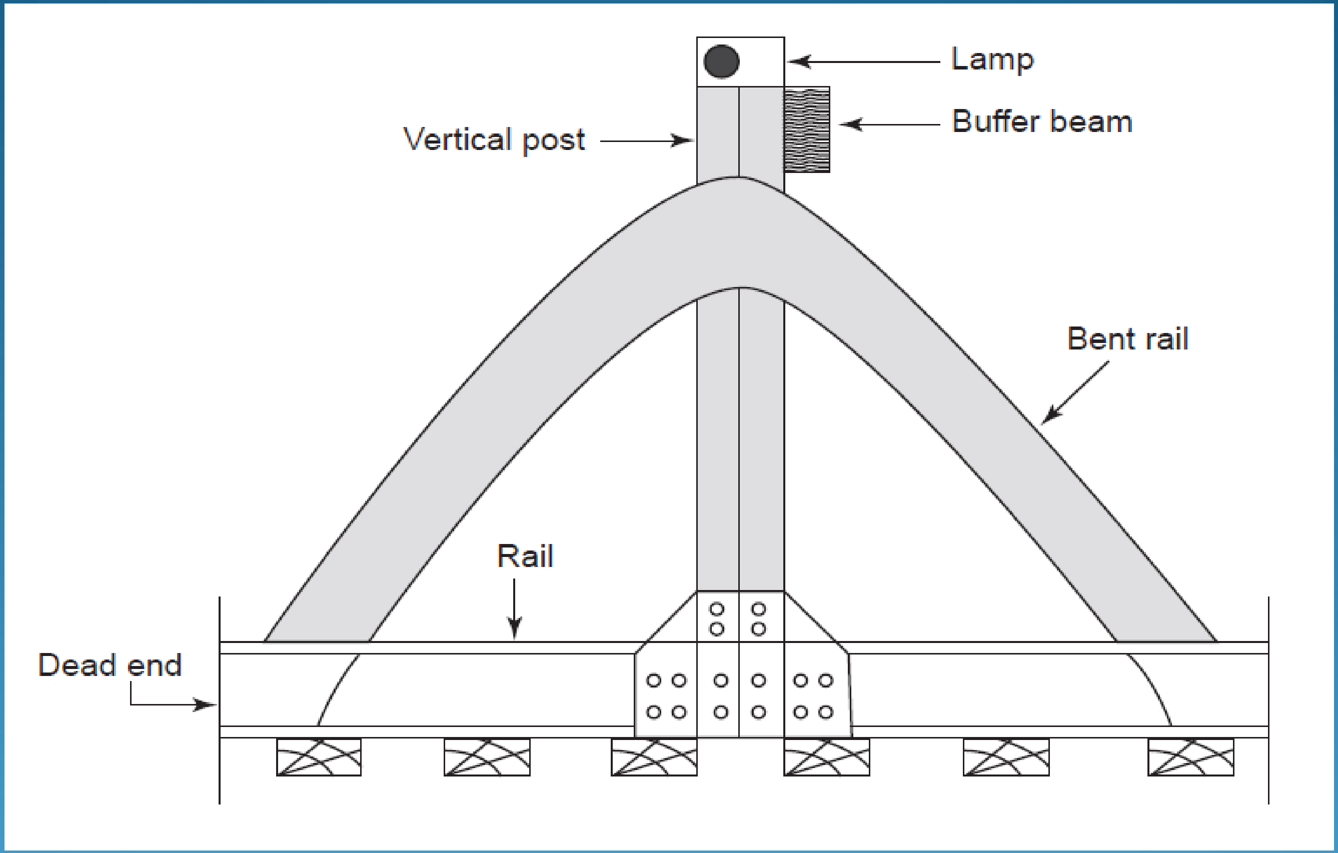
- Flat type: Wagons are moved by an engine
- Gravitation type: Gravity is used to move wagons and coaches under favourable terrain conditions.
- Hump type: Wagons are pushed up to the hump by means of an engine and allowed to move under gravity into their respective appropriate lines.

Speed regulation of wagons:

- Mechanical: by automatic braking
- Non-mechanical: by hand brakes and skids

- Equipment at station yards

- General: Clocks, telephones, CCTV, elevators, train control equipment, flags and lamps, public address systems, water coolers, etc.
- Yard equipment: Cranes, weigh bridge, loading ramps, examination pits, water columns, turn-table (for reversal of an engine). Buffer stops, sand humps, fouling marks, washing platform, and so on.



Buffer stop

Chapter 7: Signalling, Interlocking and Train Control

- The purpose of signalling and interlocking is to control the movement of trains for ensuring safety and efficiency of operation. A well-designed system of signalling, supported by an appropriate method of interlocking achieves the objectives to a large extent.
- Classification of signals

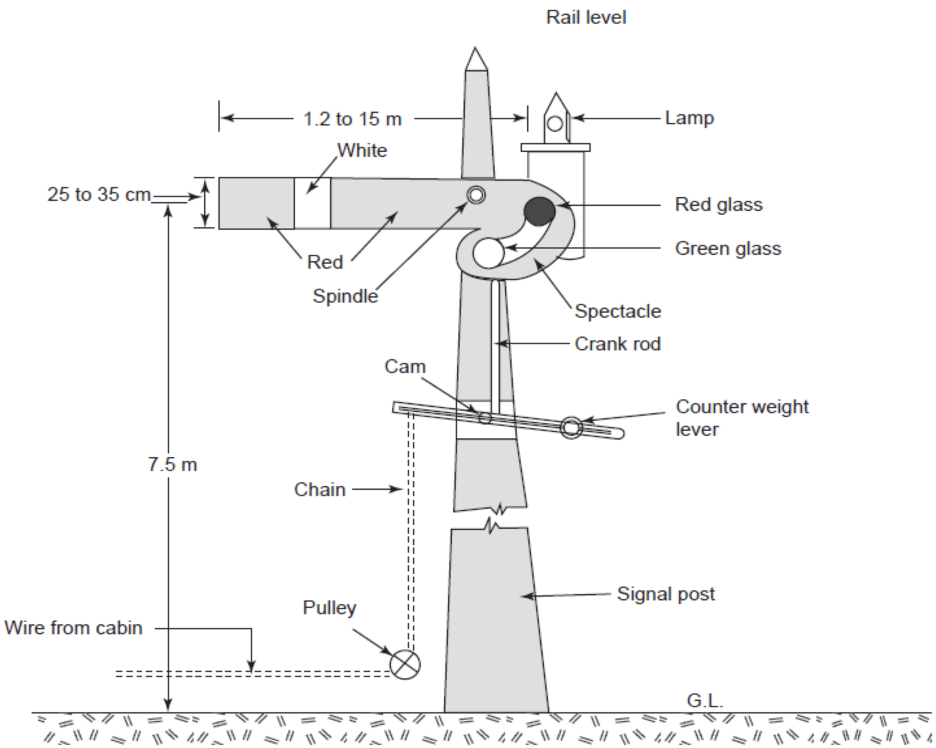
Based on operation:

- Audible or detonating signals (used in foggy weather)
- Visible signals
  - Hand signals – Flags and coloured lights (red and green)
  - Fixed signals

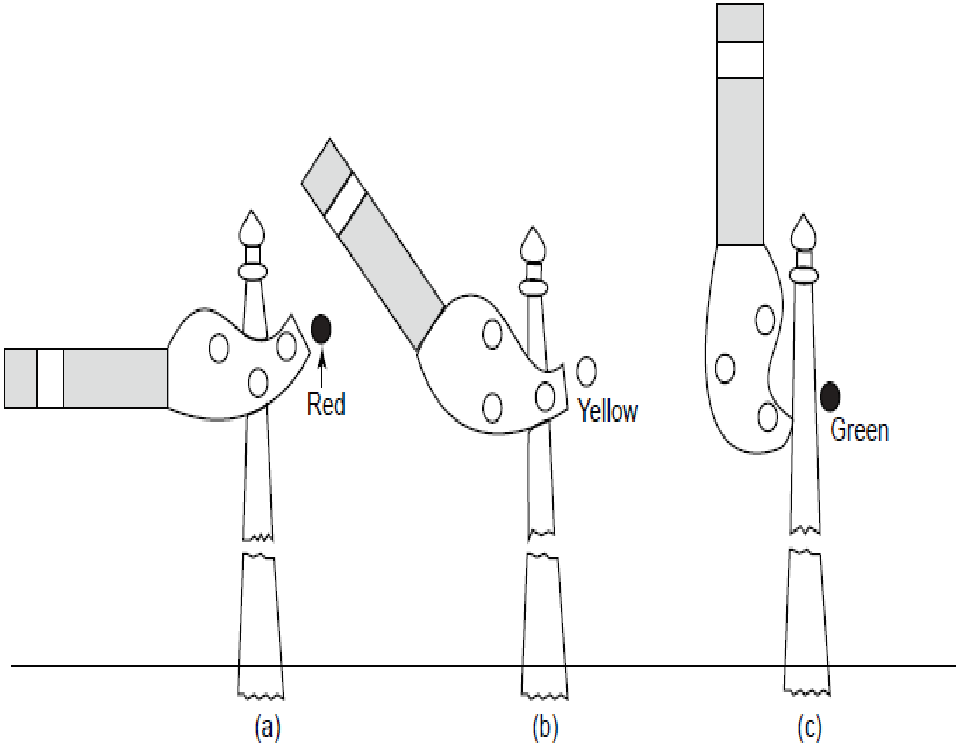
- Based on function:
  - Stop signals
  - Permission or caution signals
  - Shunting signals
- Based on location near a station:
  - Reception signals
  - Outer
  - Router
  - Home
  - Departure signals
  - Starter
  - Advance starter

  These are all stop signals.

- Based on construction:
  - Semaphore signals
  - Two-aspect (lower quadrant)
  - Three-aspect (upper quadrant)
  - Coloured light signals
  - Two-aspect, Three-aspect and Four-aspect types.
- Based on special purposes:
  - Reaper
  - Router
  - Home and warner
  - Point indicator
  - Temporary signals
- Caution, speed, stop, shunting limit indicators
  - Semaphore signals: A typical semaphore signal and a typical three-aspect semaphore signal are shown on the next slide



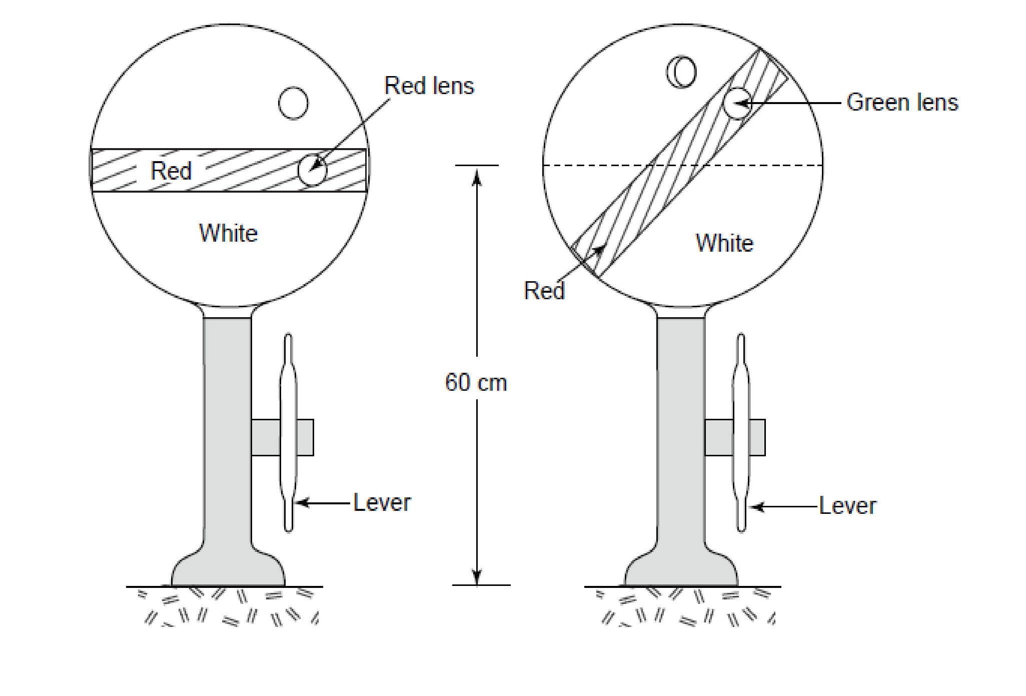
A typical semaphore signal



Schematic of a three-aspect semaphore signal

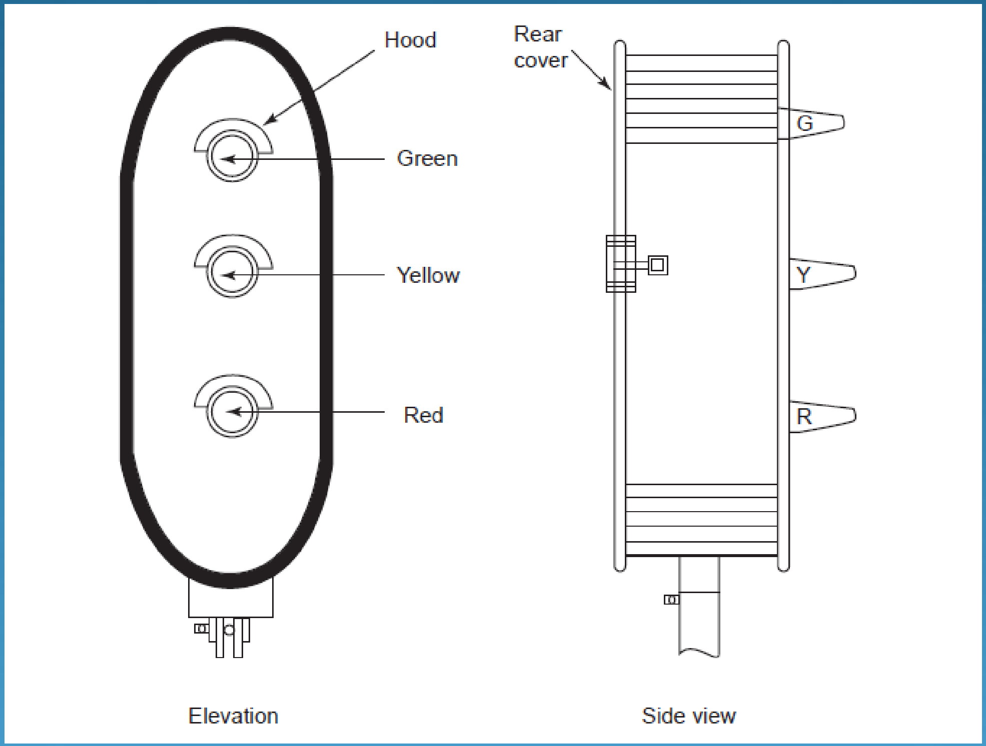
(a) ON-stop	Red	Stop
(b) OFF-caution	Yellow	Proceed with caution and check for the next signal
(c) OFF-proceed	Green	Proceed at maximum permitted speed.

- Disc-type shunting signals: A typical shunting signal is shown below:



Disc-type shunt signals

- Coloured light signals: Only one aspect is displayed at a time.



Schematic of a three-aspect coloured light signal

- Signalling systems

(a) Mechanical system

(b) Electrical system

Primary components:

- Signals and points-operated systems
- Signals
- Points
- Point locks
- Detectors
- Lock bar
- Transmission system: Pulling a lever in a cabin is transmitted to the operated units like signals or sets of points by means of a transmitted system.
- Single-wire system
- Double-wire system (superior type)

Electrical system of signalling:

- Transmission of power is done electrically, and the signals and points are operated using push buttons. The monitoring system consists of point detectors, track circuiting and axle counters. A ‘track circuit’ is formed along the rails and connected to the signal and cabin. The purpose is to indicate the presence or otherwise, of a railway vehicle on the track, thereby showing whether the line is clear or not. Track-circuited sections are electrically insulated from the rest of the track by insulated joints on either side of these sections.
- Interlocking: This is a system used to ensure the safety of trains. By this, it is ensured that before a signal is turned ‘off’, giving ‘green signal’ or ‘line clear’ indication to the train. The points for this line are properly set, locked, and held in that position until the train goes on this line. The signalling and interlocking systems are so designed that the failure of any device automatically brings the signal to the ON position, thereby ensuring safety. The essential principles of interlocking are so formulated as to ensure safety.

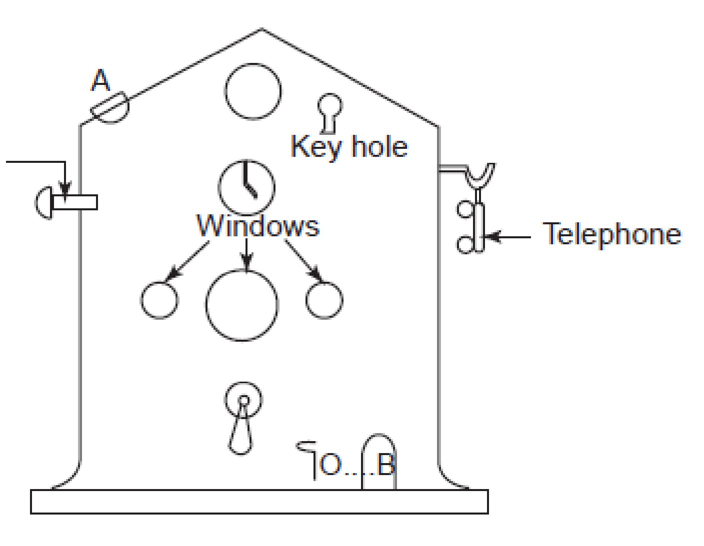
- Standards of interlocking on Indian Railways

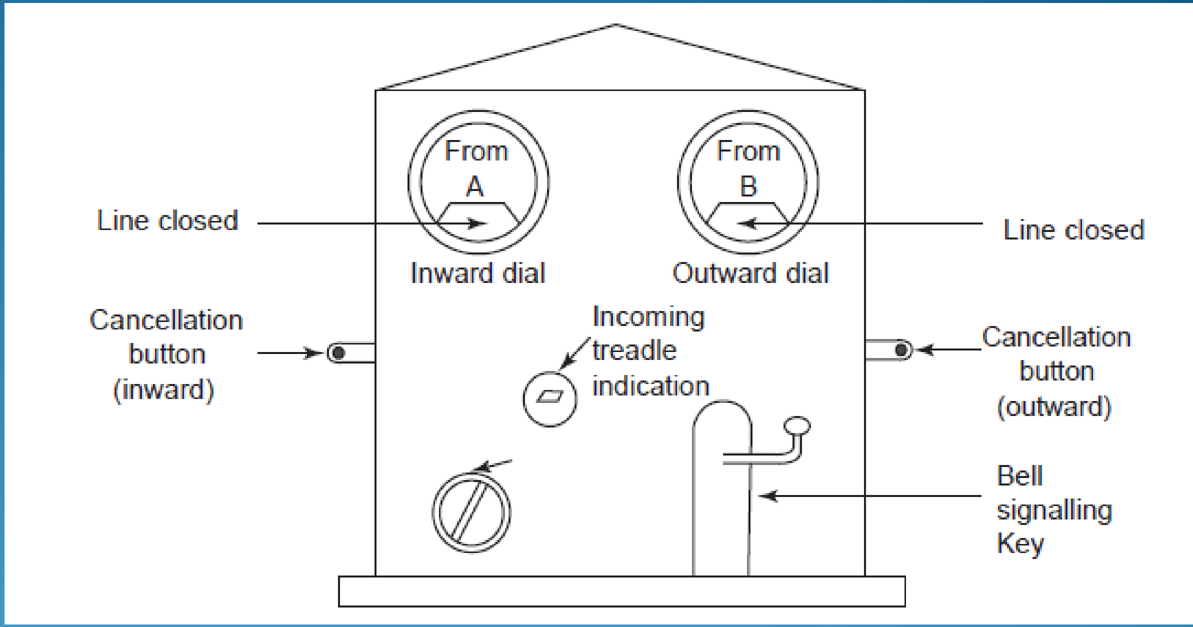
Speed	Standard
Up to 50 km/h	I
Up to 100 km/h	II
Up to 130km/h	III
Up to 160 km/h	IV

- Methods of interlocking
  - Mechanical system
  - Electrical system
  - Electronic system
- Mechanical method: Tappets and locks are used in this method, which is the most commonly used one. Interlocking tables are prepared to indicate the locking, releasing and back-locking operations achieved by the pulling of levers for various points and signals.
- Electrical method: Relays are used in this method.

- Electronic method: The programme of interlocking is loaded into a computer system. When the signals are controlled by more than one operator, inter – cabin control is achieved by the slotting of signals.
- Train Control Systems: Presently, the following systems are used on the Indian Railways:
  - Absolute block system
  - Automatic signalling system
  - Modern methods
    - Panel interlocking
    - Route relay interlocking
    - Centralised Train Control (CTC)
    - Train Protection and Warning System (TWAS)
    - Automatic Warning System (AWS)

- Absolute Block System:
  - Block instruments
  - Single-line
  - Double-line





Schematic of a block instrument (single-line)

Block instrument for a double-line section

The working procedure needs co-ordination between the station masters at either end of the block section with the help of telephonic communication.

Chapter 8: Track Construction and Maintenance

- ‘Plate laying’ means laying out sleepers and rails on a prepared formation and connecting them correctly to produce a railway track, which is then ballasted. This may be required for a new route, doubling, or gauge conversion.
- Steps in the construction of a new railway track
  - Land acquisition
  - Earth-work formation
  - Construction of cross-drainage works such as culverts and bridges
  - Plate laying and track- liking
  - Ballasting
  - Opening to traffic

- Methods of plate – laying or track construction

There are manual methods and mechanised methods.

The *manual* methods are:

a) Train-linking method: A temporary line to transport materials is built parallel to the proposed railways.
b) American method: Assembled panels of rails and sleepers transported to the site, laid and ballasted.
c) Telescopic method: Popularly used on Indian Railways.

The materials required – rails, sleepers and rail fastenings are transported to the rail head (the point up to which the track is already laid); they are properly linked and packed with ballast. The track already laid is used to transport materials to the rail head.

- Track – linking procedure:
  - Transporting materials to rail head: Material gangs are the labour force involved in loading at the depot and unloading at the rail head. New material depots may be set up after adequate progress is achieved.
  - Linking of track: Linking gangs are the labour force involved in laying the rails, fitting the sleepers on them and treating the rail joints appropriately with fish-plates and bolts
  - Packing of track: Packing gangs are the labour force that take care of gradients, horizontal curves, if any, and superelevation or cant at the stage of packing.
  - Ballasting of track: Permanent ballasting is done at least one or two monsoons after construction of a new route, in order to allow the formation to settle. Ballast has to be packed under the track to the designed section and cushion.

- Requirements of track materials: These are calculated per km and transported in advance to the rail head.
- Modern methods of construction:
    - Modern surveying techniques
    - New techniques of stabilisation of soil subgrade and formation as needed.
    - Mechanised track construction
  - Simple portable equipment: Rail panels of 2 to 3 rails are placed on the formation by truck mounted cranes; rails are joined by fish-plated joints, with appropriate expansion gaps. Robel's machine and its components are used for sleeper-laying and rail-threading. Plasser tamping machine is used for tamping ballast. Track-laying machines, such as the one by Plasser and Theurer, may be used for fully mechanised construction.

- Track maintenance: This involves the maintenance of
  - Gauge
  - Longitudinal and cross levels
  - Rails and rail joints
  - Sleepers
  - Ballast section
  - Drainage structures such as cross-drainage works and side drains
- Conventional method of track maintenance: A systematic programme is drawn up for regular track maintenance; each major activity is taken up at a certain specified periodicity in a cyclic manner.
- Annual maintenance cycle:
  - Through packing
  - Overhauling
  - Picking-up-slacks

- Through packing:
  - Opening up the track
  - Squaring of sleepers
  - Correcting the alignment
  - Correcting the gauge
  - Packing of sleepers in the ballast
  - Correction of ballast section
- Overhauling:
  - Shallow screening and making up of ballast
  - Through packing of track (as above)
  - Making up of cess or side berms
- Picking up slacks: Slacks are the places where railway vehicles run in a faulty manner, due to loose pockets in ballast, especially at rail joints, approaches to bridges, level crossings, etc.
- Points and crossings need attention throughout the year.

- ‘Deep screening’ of ballast is done for the entire depth; a special sequence involving two sleepers at a time has been evolved so as not to affect the stability of the track.
- Maintenance of rails

The following common defects are to be corrected:

Hogging of joints

Rail joints:
- High joints
- Blowing joints
- Pumping joints

Rails:
- Rail surface defects
- Rail creep
- Buckling of track
- Renewal of corroded rails

- Maintenance of sleepers
  - Squaring the sleepers
  - Picking- up sleepers
  - Packing under the sleepers
  - Renewal of defective sleepers

- Equipment and tools for track maintenance
  - Rail gauge – for checking gauge
  - Gauge-cum-level – to check the gauge as also cross level.
  - Cant board – to check the cant on horizontal curves
  - Canne-a-boule (wooden mallet) – to assess voids under sleepers
  - T-square – to check the squareness of sleepers
  - Rail tong – to lift and carry rails
  - Beater – to pack ballast under sleeper
  - Jim crow – to bend the rails
  - Spiking hammer – to drive spikes
  - Wire claw or ballast rake – to draw out ballast
  - Phowrah (shovel) – to cut earth or pull out ballast.
- Track patrolling is carried out on a regular basis; further, special patrolling during heavy rains and monsoon periods is carried out.

- Track recording cars are used to identify defects and their location in the track for rectification later.
- Modern method of track maintenance involves a mechanised approach using off- track and on-track tampers.
- Measured shovel packing (MSP) is the process of packing only disturbed and loosened sleepers, without touching well-settled sleepers. This needs special implements such as dansometer and fleximeter for assessing the loosening of the ballast under the sleepers. Based on the result, the ballast feed required for packing is calculated and used.
- Directed Track Maintenance (DTM)
    - This is a 'need-based' approach; defects in track are located and rectified. This is a precursor to the scientific approach of Modern Track Management

- Track rehabilitation involves attending to worn out components to extend the service life pending track renewal. Dedicated freight corridors are being developed for fast and efficient transportation of goods traffic; the track standards for these are superior.
- Primary track renewal involves the use of new components; secondary renewal uses released serviceable components. Criteria for renewal are fixed on the basis of the research by the RDSO in terms of rail wear and sleeper defects.
- Mechanised track renewal involves the use of Plasser Quick Relaying System (PQRS), which is semi- mechanised, or Track Relaying Train (TRT), which is fully mechanised.

Chapter 9: Modernisation Of Railways and Urban Railway Systems

- Track modernisation for high speed may be achieved through upgradation of an existing track by improving track structure and track geometry, track maintenance, and improved methods of signalling and interlocking.
- Modernisation involves the use of:
  - Heavier rail sections
  - Long welded rails with switch-expansion joints
  - Pre-stressed concrete sleepers and high sleeper density
  - Elastic fastenings
  - Curved switches of 1 in 16 and 1 in 20 size at points and crossings
  - Modern and mechanised track maintenance systems (MSP, DTM, and TMS)

- Modern track monitoring systems (Amsler's track recording car) to aid track maintenance
- Superior rolling stock – diesel and electric locomotives and specially designed coaches and wagons

All these help in developing dedicated high-speed corridors.

- Tilting train technology may be used on high-speed and super-high-speed routes to maintain high speeds even on sharp curves.
- For achieving super-high speed, friction at rail–wheel contact should be eliminated and curves should be flatter. Tracked Air Cushion Vehicle (TACV) or Aerotrains run on Linear Induction Motor (LIM) concept. MAGLEV trains use the magnetic levitation concept coupled with LIM, and move with a levitation of about 100mm. Electromagnetic suspension (EMS) or Electrodynamic suspension (EDS) is used for achieving high speeds. Ballast-less track assemblies are used for these tracks.

- Dedicated Freight Corridors (DFCs) for fast movement of goods, container transport service, increase in axial loads, and rail grinding for enhancing the service life of rails are a few of the modern developments on Indian Railways.
- Konkan Railways and Kashmir Link Railway are two challenging railway projects – the first one completed and the second in an advanced stage of construction. Several major bridges and tunnels are a part of these big projects.
- Urban railway systems primarily consist of Mass Rapid Transit System (MRTS). They may be surface railways consisting of suburban railway systems with electric traction and EMUs as rolling stock.

- Examples: Suburban railway systems of Mumbai and Chennai. Underground railways (at less than 10m depth below the ground) and Tube railways (at depths ranging from 10m to 30m), which involve the use of tunnels, are excellent examples of Mass Rapid Transit Systems. Elevated railway systems are supported on bridge structures so that they do not hinder the road traffic. Delhi Metro, Mumbai Metro and Kolkata Metro are all combinations of these systems, depending upon the site conditions. Delhi Metro is considered to be a world-class facility, designed to superior standards. Metros are under construction in several Indian cities such as Bengaluru, Jaipur, Thane, Chennai, Hyderabad, Gurgaon, Ahmedabad and Kozhikode.
- Tunnels are required for railways in mountainous or hilly terrain, or for underground / tube railways . Various methods are available for tunnelling in hard rock and in soft ground.

- Modern developments in tunnelling:
  - Shield tunnelling
  - Tunnel Boring Machine (TBM)

These are used in major projects under special circumstances. Ventilation, lighting, drainage, lining and maintenance aspects of tunnels need special attention. Ballast-less tracks and electric traction are preferred in railway tunnels.

- Environmental impact assessment (EIA) studies and recommendations to mitigate the possible adverse effects have become mandatory for any new project such as a new railway route. The Konkan Railway Project and the Jaipur Metro Railway Project are two recent examples where such studies have been conducted.