LECTURE NOTE

OF

RAILWAY & BRIDGE ENGINEERING

PREPARED
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LECTURE IN
CIVIL ENGG
IN
NIST POLYTECHNIC

CONTENT

CHAPTER-1 :- INTRODUCTION

Definition:

Railway engineering is a multi-faceted engineering discipline dealing with the design, construction and operation of all types of rail transport systems.

Advantages of Railways:

Economical aspects:

- Due to railways, the industrial development in for off places is possible, increasing the land values & standard of living of the people.
- Mobility of labour has contributed to industrial development.
- During famines, railways have played the vital role in transporting food & clothing to the affected areas.
- Commercial farming is very much helped by the railway network throughout the country.
- Speed movement of the commodities is possible through railways.

Cultural & Social aspects:

- Railway has made it easier to reach places of religious importance.
- Railway provides a convenient & safe mode of transport through out the country.
- During travel as people of different caste & religions sit together the interaction is developed.

Political aspects:

- Railways have helped in the mass migration of the population.
- Railways have created the sense of unity among the people of different religions, areas, castes & traditions.
- With adequate network of railways, the central administration has become easy & effective.

CHAPTER-2:-PERMANENT WAY

Definition:

A permanent way or a railway track can be defined as the combination of rails, fitted on sleepers and resting on ballast and sub grade.

Components of a Railway Track:

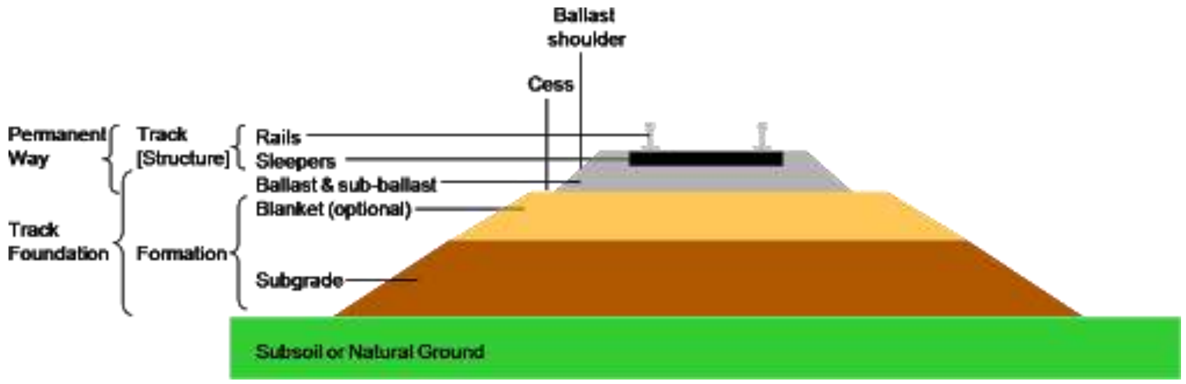
The Typical components are: 1. Rails

2. Sleepers (or ties)

3. Fasteners

4. Ballast (or slab track)

5. Sub grade



The rails are joined in series by fish plates and bolts & they are fixed to sleepers by different types of fastenings. The sleepers properly spaced, resting on ballast are suitably packed and boxed with ballast. The layer of ballast rests on the prepared sub grade is called as the formation.

The rails transmit the wheel load to the sleepers. The sleepers hold the rails in proper position and transmit the load from rails to ballast. The ballast distributes the load over the formation and holds the sleepers in position.

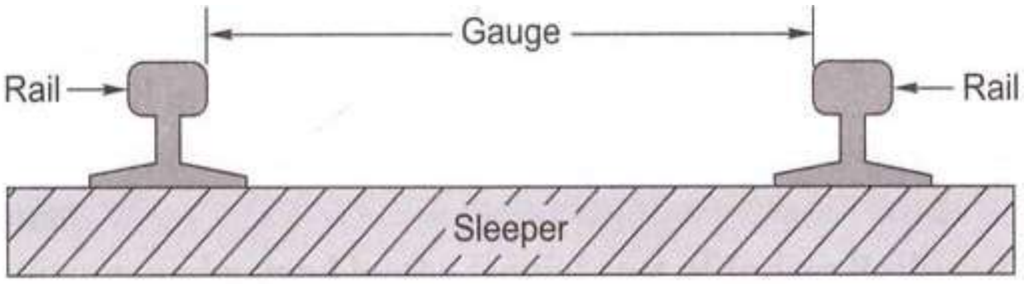
On curved tracks, super elevation is maintained by ballast and the formation is leveled. Minimum ballast cushion is maintained at inner rail, while the outer rail gets kept more ballast cushion. Additional quantity of ballast is provided on the outer cess of each track for which the base width of the ballast is kept more than for a straight track.

Requirements of an ideal permanent way:

- The gauge should be uniform and correct.
- Both the rails should be at the same level in a straight track.
- On curves proper super elevation should be provided to the outer rail.
- The permanent way should be properly designed so that the load of the train is uniformly distributed over the two rails.
- The track should have enough lateral strength.
- The radii and super elevation, provided on curves, should be properly designed.
- The track must have certain amount of elasticity
- All joints, points and crossings should be properly designed.
- Drainage system of permanent way should be perfect.
- All the components of permanent way should satisfy the design requirements.
- It should have adequate provision for easy renewals and repairs.

Gauge:

The clear minimum horizontal distance between the inner (running) faces of the two rails forming a track is known as Gauge. Indian railway followed this practice. In European countries, the gauge is measured between the inner faces of two rails at a point 14 mm below the top of the rail.



Various Gauges in Indian Railways:

Name of Gauge	Width(m)
Broad gauge(BG)	1.676
Meter gauge(MG)	1.00
Narrow gauge(NG)	0.762
	0.61

1. Broad Gauge: -

When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1676mm the gauge is called Broad Gauge (B.G) This gauge is also known as standard gauge of India and is the broadest gauge of the world. 50% India's railway tracks have been laid to this gauge.

Suitability: Broad gauge is suitable under the following Conditions:-

(i) When sufficient funds are available for the railway project.
(ii) When the prospects of revenue are very bright.

This gauge is, therefore, used for tracks in plain areas which are densely populated i.e. for routes of maximum traffic, intensities and at places which are centres of industry and commerce.

2. Metre Gauge: -

When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1000mm, the gauge is known as Metre Gauge (M.G). 40% of India's railway tracks have been laid to this gauge.

Suitability: Metre Gauge is suitable under the following conditions:-

(i) When the funds available for the railway project are inadequate.
(ii) When the prospects of revenue are not very bright.

This gauge is, therefore, used for tracks in under-developed areas and in interior areas, where traffic intensity is small and prospects for future development are not very bright.

3. Narrow Gauge:-

When the clear horizontal distance between the inner faces of two parallel rails forming a track is either 762mm or 610mm, the gauge is known as Narrow gauge (N.G) .10% of India's railway tracks have been laid to this gauge.

Suitability: Narrow gauge is suitable under the following conditions:-

(i) When the construction of a track with wider gauge is prohibited due to the provision of sharp curves, steep gradients, narrow bridges and tunnels etc.
(ii) When the prospects of revenue are not very bright.

This gauge is, therefore, used in hilly and very thinly populated areas. The feeder gauge is commonly used for feeding raw materials to big government manufacturing concerns as well as to private factories such as steel plants, oil refineries, sugar factories, etc.

Choice of Gauge:

The choice of gauge is very limited, as each country has a fixed gauge and all new railway lines are constructed to adhere to the standard gauge. However, the following factors theoretically influence the choice of the gauge:

Cost considerations:

There is only a marginal increase in the cost of the track if a wider gauge is adopted. In this connection, the following points are important:

(a) There is a proportional increase in the cost of acquisition of land, earthwork, rails, sleepers, ballast, and other track items when constructing a wider gauge.

(b) The cost of building bridges, culverts, and runnels increases only marginally due to a wider gauge.

(c) The cost of constructing station buildings, platforms, staff quarters, level crossings, signals, etc., associated with the railway network is more or less the same for all gauges.

(d) The cost of rolling stock is independent of the gauge of the track for carrying the same volume of traffic.

Traffic considerations:

The volume of traffic depends upon the size of wagons and the speed and hauling capacity of the train. Thus, the following points need to be considered:

(a) As a wider gauge can carry larger wagons and coaches, it can theoretically carry more traffic.

(b) A wider gauge has a greater potential at higher speeds, because speed is a function of the diameter of the wheel, which in turn is limited by the width of the gauge. As a thumb rule, diameter of the wheel is kept 75 per cent of gauge width.

(c) The type of traction and signalling equipment required are independent of the gauge.

Physical features of the country:

It is possible to adopt steeper gradients and sharper curves for a narrow gauge as compared to a wider gauge.

Uniformity of gauge:

The existence of a uniform gauge in a country enables smooth, speedy, and efficient operation of trains. Therefore, a single gauge should be adopted irrespective of the minor advantages of a wider gauge and the few limitations of a narrower gauge.

CHAPTER-3 :- TRACK MATERIALS

RAILS

Definition:

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

Functions of Rails:

Rails are similar to steel girders. They perform the following functions in a track:

- Rails provide a continuous and level surface for the movement of trains.
- They provide a pathway which is smooth and has very little friction. The friction between the steel wheel and the steel rail is about one-fifth of the friction between the pneumatic tyre and a metalled road.
- They serve as a lateral guide for the wheels.
- They bear the stresses developed due to vertical loads transmitted to them through axles and wheels of rolling stock as well as due to braking and thermal forces.
- They carry out the function of transmitting the load to a large area of the formation through sleepers and the ballast.

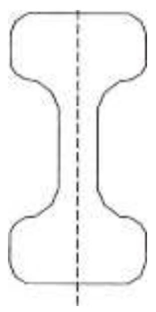
Requirements of an ideal Rail section:

- The rail should have the most economical section consistent with strength, stiffness, and durability.
- The centre of gravity of the rail section should preferably be very close to the mid-height of the rail so that the maximum tensile and compressive stresses are equal.
- A rail primarily consists of a head, a web, and a foot, and there should be an economical and balanced distribution of metal in its various components so that each of them can fulfill its requirements properly.
- The head of the rail should have adequate depth to allow for vertical wear. The rail head should also be sufficiently wide so that not only is a wider running surface available, but also the rail has the desired lateral stiffness.
- The web should be sufficiently thick so as to withstand the stresses arising due to the loads bore by it, after allowing for normal corrosion.
- The foot should be of sufficient thickness to be able to withstand vertical and horizontal forces after allowing for loss due to corrosion. The foot should be wide enough for stability against overturning. The design of the foot should be such that it can be economically and efficiently rolled.
- Fishing angles must ensure proper transmission of loads from the rails to the fish plates. The fishing angles should be such that the tightening of the plate does not produce any excessive stress on the web of the rail.
- Height of the rail should be adequate so that the rail has sufficient vertical stiffness and strength as a beam.

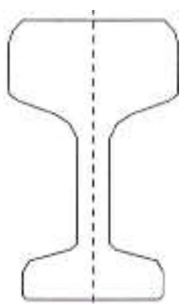
<u>Types of Rails:</u>

The rails used in the construction of railway track are of following types:

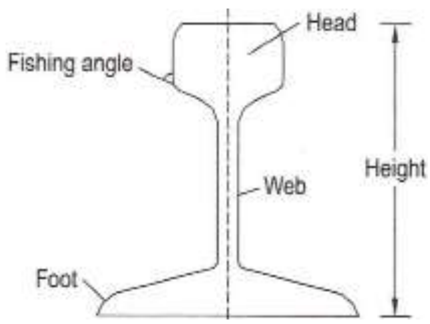
1. Double headed rails (D.H. Rails)
2. Bull headed rails (B.H.Rails)
3. Flat footed rails (F.F.Rails)



D.H. rail



B.H. rail



F.F. rail

Double headed rails:

The rail sections, whose foot and head are of same dimensions, are called Double headed or Dumb-bell rails. In the beginning, these rails were widely used in the railway track. The idea behind using these rails was that when the head had worn out due to rubbing action of wheels, the rails could be inverted and reused. But by experience it was found that their foot could not be used as running surface because it also got corrugated under the impact of wheel loads. This type of rail is not in use in Indian Railways now-days.

Bull headed rails:

The rail section whose head dimensions are more than that of their foot are called bull headed rails. In this type of rail the head is made little thicker and stronger than the lower part by adding more metal to it. These rails also require chairs for holding them in position. Bull headed rails are especially used for making points and crossings.

Merits:

- B.H. Rails keep better alignment and provide more smoother and stronger track.
- These rails provide longer life to wooden sleepers and greater stability to the track.
- These rails are easily removed from sleepers and hence renewal of track is easy

Demerits:

- B.H. rails require additional cost of iron chairs.
- These rails require heavy maintenance cost.
- B.H. rails are of less strength and stiffness.

Flat footed Rails:

The rail sections having their foot rolled to flat are called flat footed or vignole`s rails. This type of rail was invented by Charles Vignole in 1836. It was initially thought that the flat footed rails could by fixed directly to wooden sleepers and would eliminate chairs and keys required for the B.H. rails. But later on, it was observed that heavy train loads caused the foot of the rail to sink into the sleepers and making the spikes loose. To remove this defect, steel bearing plates were used in between flat footed rails and the wooden sleeper. These rails are most commonly used in India.

Merits:

- F.F. rails have more strength and stiffness.
- No chairs are required for holding them in position.
- These rails require less number of fastenings.
- The maintenance cost of track formed with F.F. rails is less.

Demerits:

- The fittings get loosened more frequently.
- These rails are not easily removed and hence renewal of track becomes difficult.
- It is difficult to manufacture points and crossings by using these rails.

Length of rail:

The longer is the rail, the lesser would be the number of joints and fittings required and the lesser the cost of construction and maintenance. Longer rails are economical and provide smooth and comfortable rides.

Indian Railways has standardized a rail length of 13 m (previously 42 ft) for broad gauge and 12 m (previously 39 ft) for MG and NG tracks.

RAIL JOINTS

Definition:

A rail joint is an integral part of the railway track as it holds together the adjoining ends of rails in correct position, both in horizontal and vertical planes.

Ill Effects of Rail joints:

A rail joint is the weakest link in the track. At a joint, there is a break in the continuity of the rail in both the horizontal and the vertical planes because of the presence of the expansion gap and imperfection in the levels of rail heads. A severe jolt is also experienced at the rail joint when the wheels of vehicles negotiate the expansion gap. This jolt loosens the ballast under the sleeper bed, making the maintenance of the joint difficult. The fittings at the joint also become loose, causing heavy wear and tear of the track material.

Requirements of an ideal rail joint:

An ideal rail joint provides the same strength and stiffness *a*s the parent rail. The characteristics of an ideal rail joint are briefly summarized here.

- ***Holding the rail ends*:** An ideal rail joint should hold both the rail ends in their precise location in the horizontal as well as the vertical planes to provide as much continuity in the track as possible. This helps in avoiding wheel jumping or the deviation of the wheel from its normal path of movement.
- ***Strength:*** An ideal rail joint should have the same strength and stiffness as the parent rails it joins.
- ***Expansion gap*:** The joint should provide an adequate expansion gap for the free expansion and contraction of rails caused by changes in temperature
- ***Flexibility*:** It should provide flexibility for the easy replacement of rails, whenever required.
- ***Provision for wear:*** It should provide for the wear of the rail ends, which is likely to occur under normal operating conditions.
- ***Elasticity*:** It should provide adequate elasticity as well as resistance to longitudinal forces so as to ensure a trouble-free track.
- ***Cost*:** The initial as well as maintenance costs of an ideal rail joint should be minimal.

Types of Rail Joints:

The nomenclature of rail joints depends upon the position of the sleepers or the joints.

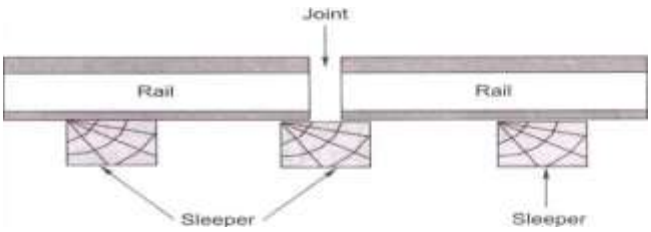
Classification According to Position of Sleepers:

Three types of rail joints come under this category.

i. Supported Joints
ii. Suspended Joints
iii. Bridge Joints

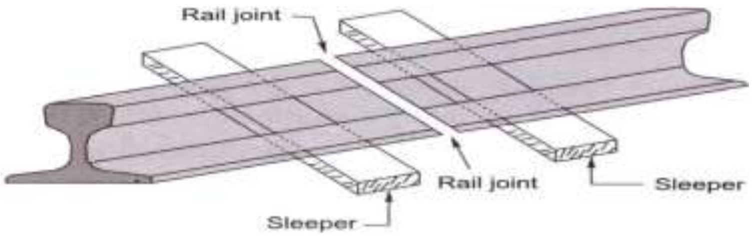
Supported joint:

In this type of joint, the ends of the rails are supported directly on a sleeper called as 'joint sleeper'. The support tends to slightly raise the height of the rail ends. As such, the run on a supported joint is normally hard. There is also wear and tear of the sleeper supporting the joint and its maintenance presents quite a problem. The duplex sleeper is an example of a supported joint.



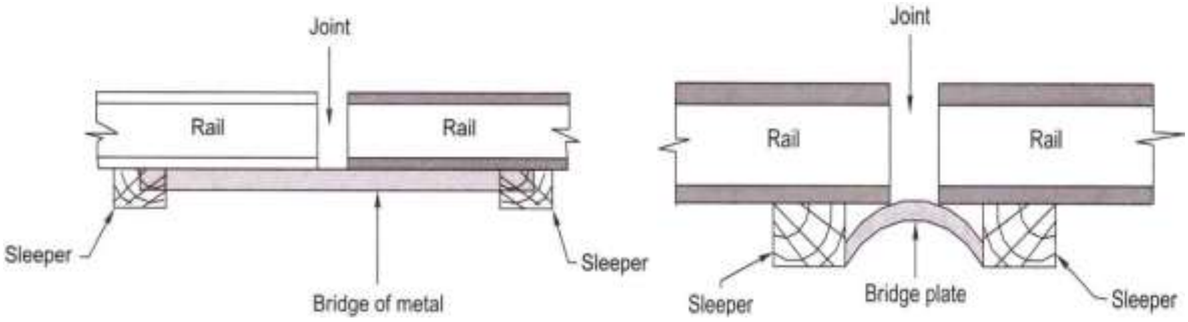
Suspended joint:

In this type of joint, the ends of the rails are suspended between two sleepers and some portion of the rail is cantilevered at the joint. As a result of cantilever action, the packing under the sleepers of the joint becomes loose particularly due to the hammering action of the moving train loads. Suspended joints are the most common type of joints adopted by railway systems worldwide, including India.



Bridge joints:

The bridge joint is similar to the suspended joint except that the two sleepers on either side of a bridge joint are connected by means of a metal flat or a corrugated plate known as a bridge plate. This type of joint is generally not used on Indian Railways.



(Bridge joint with metal flat Joint) (Bridge joint with bridge plate)

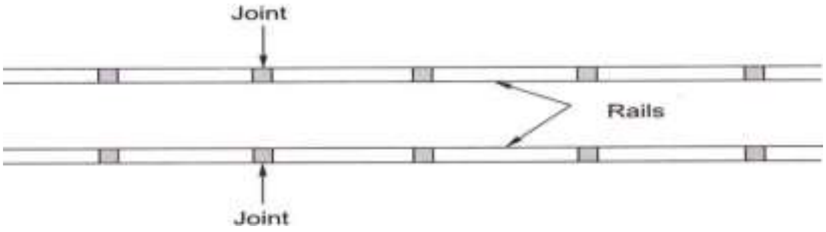
Classification Based on the Position of the Joint:

Two types of rail joints fall in this category.

i. Square Joints
ii. Staggered Joints

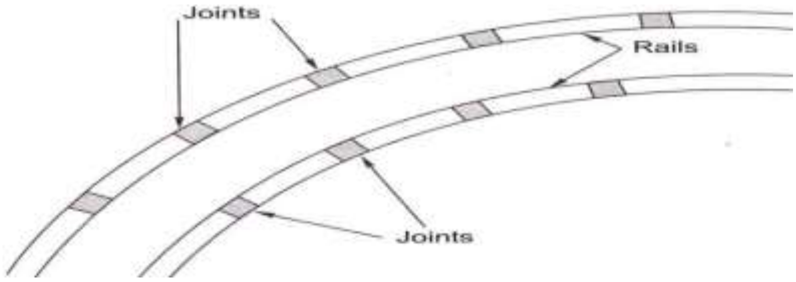
Square joint:

In this case, the joints in one rail are exactly opposite to the joints in the other rail. This type of joint is most common on Indian Railways.



Staggered joint:

In this case, the joints in one rail are somewhat staggered and are not opposite the joints in the other rail. Staggered joints are normally preferred on curved tracks because they hinder the centrifugal force that pushes the track outward.



WELDING OF RAILS

Welding is the best joint as it fulfils all the requirements of an ideal rail joint or perfect joint.

Purpose of Welding of Rails:

- To increase the length of the rails by joining two or more rails & thus to reduce the no of joints & requirements of fish plates which lead to economy and strength.
- To repair the worn out or damaged rails thus increasing their life.
- To build up worn out points and rails on sharp curves.
- To build up the burnt portion of rail head which is caused due to slippage of wheels over the rails or other defects or spots in rail steel.

Advantages of Welding of Rails:

- It satisfies the condition of a perfect joint and hence increases the life of rail as also the reduction in maintenance cost of track by about 20 to 40%.
- It reduces the creep doe to increase in length of rail and in turn friction as well.
- It reduces expansion effect due to temperature.
- Due to discontinuity of joints, a source of track weakness is reduced.
- It increases the life of rails due to decrease in the wear of rails at joints.
- Welded rails provided on large bridges for the span length are helpful as they result in better performance.
- The cost of track construction by welding of rails decreases due to les no of joints.

Methods of Welding of Rails:

1. Electric Arc or Metal Arc Welding
2. Gas Pressure Welding
3. Flash butt Welding
4. Thermit /Chemical Welding

Electric Arc Welding:

In this method, the current is passed through the rail and at the same time through a thin rod known as electrode. As the electrode approaches the rail an electric arc is formed and with its heat the electrode gets melted, and finally the molten metal gets deposited on the rail, providing a firm bond.

- Electric arc welding plant consists of an engine, generator and some accessories.
- This method is also known as Metal arc welding.
- This method is used for building up worn out points and crossing, damaged rails and for small welding operations.

Gas Pressure Welding:

In this method, intense heat is produced by combining the oxygen and acetylene gas, which melts the electrode and deposits the molten metal on the rail.

- This plant consists of two cylinders, one for oxygen and other for acetylene gas.
- This method is also known as oxyacetylene welding.
- This method is used for repairing worn out or damaged parts of points and crossing.

Flash butt Welding:

In this method a powerful current is passed through two rails, the ends of which are to be joined. The width of the gap between two rails is varied till both the ends get heated up to a required temperature. Then, they are brought in contact with each other resulting in a flash. Finally the current is stopped and rails are pressed together under a pressure of 20 tonnes.

- This is the most satisfying method of welding.
- It involves heavy welding plant and hence immobile.
- This is used for welding of rails in workshop.
- For large jobs at site it is economical method of welding of rails.

Thermit Welding:

In this method two chemicals Aluminium(Al) and Iron oxide(Fe_2O_3) are mixed in powder form and ignited. On ignition, the chemical reaction takes place and produces intense heat because this reaction is exothermic.

$Fe_2O_3 + 2Al = Al_2O_3 + 2Fe + \Delta$

After the reaction, iron gets separated and is deposited in the gap of the rail ends which are preheated. These two ends with chemical mixture in between the gap are entrapped in a mould to prevent the flow of mixture. The heating of the two ends is done by the use of a furnace placed at the bottom of the rail joint. After the mixture solidifies the mould is removed and surface gridding is done.

- This method is also known as chemical welding.
- This method is adopted in the process of renewal of rals.

CREEP OF RAILS

Definition:

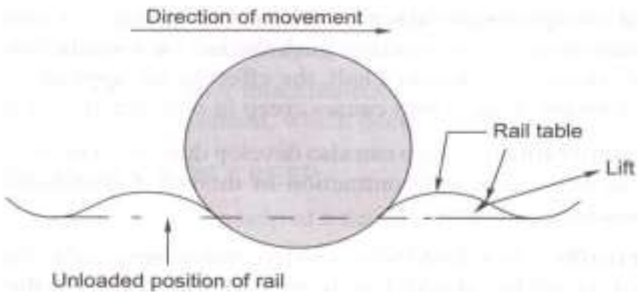
Creep of rails can be defined as the longitudinal movement of rails with respect to sleepers in a track. Rails have a tendency to gradually move in the direction of dominant traffic. Creep is common to all railway tracks, but its magnitude varies considerably from place to place; the rail may move by several centimetres in a month at few places, while at other locations the movement may be almost negligible.

Theories for the development of creep:

Various theories have been put forward to explain the phenomenon of creep and its causes, but none of them have proved to be satisfactory. The important theories are briefly discussed in the following subsections.

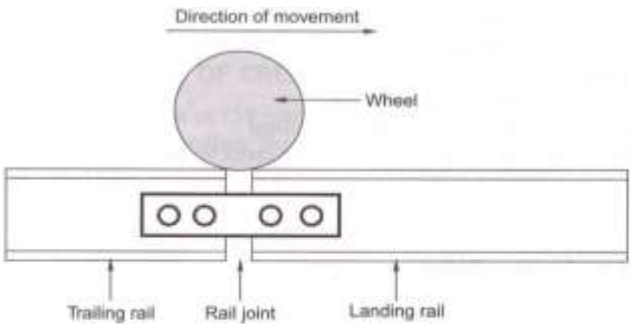
Wave Motion Theory:

According to wave motion theory, wave motion is set up in the resilient track because of moving loads, causing a deflection in the rail under the load. The portion of the rail immediately under the wheel gets slightly depressed due to the wheel load. Therefore, the rails generally have a wavy formation.



Percussion Theory:

According to percussion theory, creep is developed due to the impact of wheels at the rail end ahead of a joint. As the wheels of the moving train leave the trailing rail at the joint, the rail gets pushed forward causing it to move longitudinally in the direction of traffic, and that is how creep develops. Though the impact of a single wheel may be nominal, the continuous



movement of several wheels passing over the joint pushes the facing or landing rail forward, thereby causing creep.

Drag Theory:

According to drag theory, the backward thrust of the driving wheels of a locomotive has the tendency to push the rail backwards, while the thrust of the other wheels of the locomotive and trailing wagons pushes the rail in the direction in which the locomotive is moving. This results in the longitudinal movement of the rail in the direction of traffic, thereby causing creep.

Causes of Creep:

The main factors responsible for the development of creep are as follows.

- **Ironing effect of the wheel:** The ironing effect of moving wheels on the waves formed in the rail tends to cause the rail to move in the direction of traffic, resulting in creep.

- **Starting and stopping operations** When a train starts or accelerates, the backward thrust of its wheels tends to push the rail backwards. Similarly, when the train slows down or comes to a halt, the effect of the applied brakes tends to push the rail forward. This in turn causes creep in one direction or the other.

- **Changes in temperature** Creep can also develop due to variations in temperature resulting in the expansion and contraction of the rail. Creep occurs frequently during hot weather conditions.

- **Unbalanced traffic** In a double-line section, trains move only in one direction, i.e., each track is unidirectional. Creep, therefore, develops in the direction of traffic. In a single-line section, even though traffic moves in both directions, the volume of traffic in each direction is normally variable. Creep, therefore, develops in the direction of predominant traffic.

- **Poor maintenance of track** Some minor factors, mostly relating to poor maintenance of the track, also contribute to the development of creep. These are as follows:
  - Improper securing of rails to sleepers
  - Limited quantities of ballast resulting in inadequate ballast resistance to the movement of sleepers
  - Improper expansion gaps
  - Badly maintained rail joints
  - Rail seat wear in metal sleeper track
  - Rails too light for the traffic carried on them
  - Yielding formations that result in uneven cross levels
  - Other miscellaneous factors such as lack of drainage, and loose packing, uneven spacing of sleepers

Prevention of Creep:

The remedies of creep are as follows:

1. Pulling back the rails
2. Provision of anchors or anti creepers
3. Use of steel sleepers

Pulling back the rails:

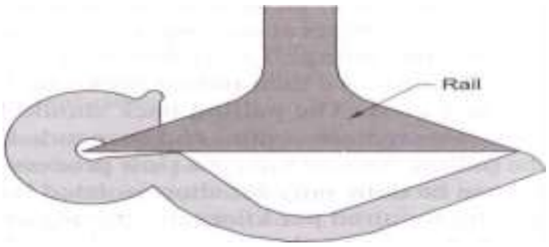
When creep is in excess of 150 mm resulting in maintenance problems, the same should be adjusted by pulling the rails back. The various steps involved in the adjustment of creep are as follows:

- A careful survey of the expansion gaps and of the current position of rail joints is carried out.
- The total creep that has been proposed to be adjusted and the correct expansion gap that is to be kept are decided in advance.
- The fish plates at one end are loosened and those at the other end are removed. Sleeper fittings, i.e., spikes or keys, are also loosened or removed.
- The rails are then pulled back one by one with the help of a rope attached to a hook. The pulling back should be regulated in such a way that the rail joints remain central and suspended on the joint sleepers.

The pulling back of rails is a slow process since only one rail is dealt with at a time and can be done only for short isolated lengths of a track. Normally, about 40-50 men are required per kilometre for adjusting creep. When creep is required to be adjusted for longer lengths, five rail lengths are tackled at a time. The procedure is almost the same as the preceding steps except that instead of pulling the rails with a rope, a blow is given to them using a cut rail piece of a length of about 5 m.

Provision of Anchors and anti creepers:

Creep anchors can effectively reduce the creep in a track. At least eight of these creep anchors must be provided per panel. Out of the large number of creep anchors tried on Indian Railways, the 'fair T' and 'fair V anchors, have been standardized for use. The fair V anchor is most popular. The creep anchor should fit snugly against the sleeper for it to be fully effective.



Use of steel sleepers:

Sleepers should be of such a type & such fittings that they effectively prevent the rails from creeping on them. The sleepers must have a good grip with the ballast to resist the movement of the sleepers in the ballast. And steel sleepers are the best for this purpose. Increase in no of steel sleepers will help in the prevention of creep.

SLEEPERS

Definition:

Sleepers are transverse members of the track placed below the rails to support and fix them in position.

Functions of Sleepers:

Sleepers serve the following functions:

- To hold the rails to proper gauge.
- To transfer the loads from rails to the ballast.
- To support and fix the rails in proper position.
- To keep the rails at a proper level in straight tracks and at proper super elevation on curves.
- To provide elastic medium between the rails and the ballast.
- To provide stability to the permanent way on the whole.

Requirements of good sleepers:

The following are the requirements of good sleepers:

- The sleepers should be sufficiently strong to act as a beam under loads.
- The sleepers should be economical.
- They should maintain correct gauge.
- They should provide sufficient bearing area for the rail.
- The sleepers should have sufficient weight for stability.
- Sleepers should facilitate easy fixing and taking out of rails without disturbing them.
- They should facilitate easy removal and replacement of ballast.
- They should not be pushed out easily of their position in any direction under maximum forces of the moving trains.
- They should be able to resist impact and vibrations of moving trains.
- They should be suitable to each type of ballast.
- If track-circuiting is done, it should be possible to insulate them from the rails.

Types of Sleepers:

Sleepers are of the following types:

1. Wooden sleepers.
2. Steel sleepers.
3. Cast iron sleepers.
4. R.C.C. sleepers.
5. Pre stressed concrete sleepers.

1. Wooden Sleepers:

These sleepers are regarded to be the best as they satisfy all the requirements of good sleepers and are the only sleeper suitable for track circuiting. The life of wooden sleepers depends upon their ability to resist wear, attack by white ants and quality of timber used. Timbers commonly used in India for sleepers are Sal, Teak, Deodar and chair wood.

The standard sizes of wooden sleepers for different gauges are as follows: For
B.G. – 2740 mm X 250 mm X 130 mm
For M; .G. – 1830 mm X 203 mm X 114 mm
For N.G. – 1520 mm X 150 mm X 100 mm

Advantages:

- Timber is easily available in all parts of India.
- Wooden sleepers are suitable for all types of ballast.
- Wooden sleepers require less fastening and simple in design.
- These sleepers give less noisy track.
- These sleepers absorb shocks and vibrations more than any other sleepers.
- These sleepers are best suited for track circuiting.

Disadvantages:

- The life of wooden sleeper is less as compared to other types of sleepers.
- It is difficult to maintain gauge of the track in case of wooden sleepers.
- These sleepers are subjected to wear, decay, and attack by white ants etc.
- Track laid over wooden sleepers is easily disturbed.
- Maintenance cost is more as compared to other sleepers.

2. Steel Sleepers:

These sleepers consist of steel troughs made of 6 mm thick sheets, with its both ends bend down to check the running out of ballast. At the time of pressing of sleepers, an inward slope of 1 in 20 on either side is provided to achieve required tilt of rails. The standard length of these is 2680 mm.

Steel sleepers are of two types:

I. Key type steel sleepers
II. Clip and bolt type steel sleepers

Key type steel sleepers:

In this type of sleepers lugs or jaws are pressed out of metal and keys are used for holding the rails. These are of two types:

a. Lug type
b. Loose jaw type

Clip and bolt type steel sleepers:

In this type of sleeper, clips and bolts are used for holding the rails. Cracks are not developed in the sleepers as the holes for the bolts are small and circular. It requires four clips and four bolts for holding each rail.

Advantages:

- Steel sleepers are light in weight and can be handled easily.
- These require fewer fastenings.
- The life of steel sleepers is more than the wooden sleepers.
- The gauge can be easily maintained and adjusted.
- The scrap value is more than the wooden sleepers.
- The track laid on steel sleepers has good lateral and longitudinal rigidity.
- Creep of rails can be checked by using steel sleepers.

Disadvantages:

- Initial cost of these sleepers is more than wooden sleepers.
- Cracks are developed at rail seat of these sleepers.
- Steel sleepers are not suitable for track circuiting.
- These are not suitable for all types of ballast.
- These are liable to corrosion.

3. Caste Iron Sleepers:

The sleepers made of cast iron, known as cast iron sleepers, have been extensively used in India as compared to other countries in the world. Cast iron sleepers are of the following types:

I. Pot or bowl sleeper
II. Plate sleeper
III. Box sleeper
IV. CST-9 sleeper
V. Duplex sleeper

Pot or bowl sleeper:

Pot sleeper consist of two bowls placed under each rail and connected together by a tie-bar. The total effective area of both the pots is 0.464 sq. m. Each pot is provided with two holes foe inspection and packing of ballast. On the top of each pot, a rail seat is provided to hold rails at an inward slope of 1 in 20. Gibbs and cotters are so casted that by interchanging them gauge is slackened by 3 mm.

Plate sleeper:

Plate sleepers consist of two rectangular plates of 864 mm X 305 mm in size with short side parallel to rail. The plates are provided with projecting ribs in the bottom to provide a grip in the ballast for lateral stability. The plates are held in position by tie-bar. Stiffeners are provided at the top of the plate to increase the strength. It provides the effective bearing area of 0.464sq. m per sleeper.

Box Sleeper:

These sleepers are not in user these days. Box sleepers are similar to plate sleepers. In this type of sleeper, a box is provided at the top of each plate to hold the rails.

CST-9 Sleeper:

CST-9 sleeper is more satisfactory than other C.I. Sleepers and is extensively used in Indian Railways since last thirty years. It is a combination of pot, plate, and box sleeper. CST-9s sleeper consists of a triangular inverted pot one on each side of rail seat. Rail seat is provided at the top to hold rails at 1 in 20 inward slope. The pots are connected across the track by means of a tie- bar.

Duplex Sleepers:

Duplex sleepers are also known as rail free duplex sleepers and have been used at rail joints in conjunction with CST_9 sleepers. These sleepers are used at rail joints to prevent cantilever action between two supports of the CST-9 sleepers. These consist of two plates, each of size 850 mm X 750 mm. The plates are placed with the longer side parallel to the rails and are connected with a tie-bar.

Advantages:

- The life of C.I sleepers is more.
- The maintenance cost of these sleepers is low.
- Gauge can be easily maintained and adjusted with these sleepers.
- These sleepers are more durable.
- Creep rails can be checked by using these sleepers.

Disadvantages:

- More ballast is required than any other type of sleepers.
- The number of fittings required is more.
- These sleepers are liable to break.
- C.I. Sleepers are liable to break.
- These are not suitable for all types of ballast.

4. R.C.C. Sleepers:

Reinforced cement concrete sleepers are of two types:
(i) Through type
(ii) Block and tie type

Through type R.C.C. Sleeper:

This is also known as one piece or mono-block sleeper. In this type of sleeper cracks develop on the tension side when stressed. These cracks are very small and almost invisible but tend to enlarge with the repetition of impact loading, causing failure.

Block and tie type R.C.C. Sleeper:

This type of sleeper consists of two R.C.C. blocks connected by a metal tie of inverted T-section. These sleepers are not subjected to any degree of tensile stress as in through type.

Advantages:

- Concrete sleepers have long life, generally 40to 60 years.
- These are free from natural decay and attack by insects etc.
- These sleepers require less fittings.
- Track circuiting is possible in these sleepers.
- These sleepers provide more lateral and longitudinal rigidity as compared to other sleepers.
- The maintenance cost is low.
- Due to higher elastic modulus, these can withstand the stresses due to fast moving trains.

Disadvantages:

- Due to heavy weight, handling and transportation of these sleepers are difficult.
- If not handled properly, the chance of breaking is more.
- The renewal of track laid with these sleepers is difficult.
- The scrap value is nil.

5. Pre stressed Concrete Sleepers:

Pre stressed concrete sleepers are now-a-days extensively used in Indian Railways. These sleepers have high initial cost but are very cheap in long run due to their long life. In these sleepers, high tension steel wires are used. These wires are stretched by hydraulic jack to give necessary tension in the wires. The concrete is then put under a very high initial compression. These sleepers are heavily damaged in case of derailment or accidents of trains.

BALLAST

Definition:

Ballast is a layer of broken stones, gravel, rnoorum, or any other granular material placed and packed below and around sleepers for distributing load from the sleepers to the formation. It provides drainage as well as longitudinal and lateral stability to the track.

Functions of Ballast:

The ballast serves the following functions in a railway track.

- It provides a level and hard bed for the sleepers to rest on.
- It holds the sleepers in position during the passage of trains.
- It transfers and distributes load from the sleepers to a large area of the formation.
- It provides elasticity and resilience to the track for proper riding comfort.
- It provides the necessary resistance to the track for longitudinal and lateral stability.
- It provides effective drainage to the track.
- It provides an effective means of maintaining the level and alignment of the track.

Requirements of good ballast:

- It should have sufficient strength to resist crushing under heavy loads of moving trains.
- It should be durable enough to resist abrasion and weathering action.
- It should have rough and angular surface so as to provide good lateral and longitudinal stability to the sleepers.
- It should have good workability so that it can be easily spread of formation.
- It should be cheaply available in sufficient quantity near and along the track.
- It should not make the track dusty or muddy due to its crushing to powder under wheel loads.
- It should allow for easy and quick drainage of the track.
- It should not have any chemical action on metal sleepers and rails.

Types of Ballast:

In India, the following materials are used as ballast.

1. Broken stone
2. Gravel
3. Sand
4. Ashes or Cinders
5. Kankar
6. Moorum
7. Blast furnace slag
8. Brick ballast
9. Selected earth

1. **Broken Stone:**

This is the best type of ballast as it possesses all the characteristics of good ballast. It holds the track to correct alignment and gradient due to its high interlocking action. The stones which are non porous, hard and do not flake on breaking should be used. Igneous rocks such as granite, quartzite and trap make excellent ballast. This type of ballast is used for high speed tracks.

Advantages:

- It is hard and resists crushing under heavy loads.
- It has angular and rough surface and hence gives more stability to the sleepers.
- Its drainage property is excellent.

Disadvantages:

- It is expensive.
- It is not so easily available.

2. **Gravel:**

Gravel is the second best material for ballast. This is obtained either from river beds or from gravel pits and has smooth rounded fragments. Gravel obtained from pits usually contains earth which should be removed by washing. Gravel obtained from river beds is screened and required size gravel is used. Larger size gravels are broken into required size. Round edges gravels are broken to increase their interlocking action.

Advantages:

- Gravel is cheaper than stone ballast.
- The drainage property is excellent'
- It holds the track to correct alignment and gradient.
- It is easy to use gravel ballast than stone ballast in certain places where formation is unstable.

Disadvantages:

- It requires screening before use due to large variation in size.
- Gravel obtained from pits requires washing.
- Due to round faces the packing under sleeper is loose.
- Gravel rolls down easily due to vibrations.

3. **Sand:**

Sand is reasonably a good material for the ballast. Coarse sand is generally preferred to fine sand for ballast. This type of ballast is suitable for packing pot sleepers. It is used only on unimportant tracks.

Advantages:

- It is a cheaper ballast material.
- It has very good drainage quality.
- It is available in large quantities and hence can be used in emergency.
- Sand ballast produces a silent track.

Disadvantages:

- It has no stability and gets disturbed by the vibrations caused by moving train.
- It causes wear of rail, seats and keys.

4. Ashes or Cinders:

These are waste products obtained from steam locomotives. This type of ballast is normally used in yards and sidings or as the initial ballast in new constructions.

Advantages:

- It is a cheaper ballast material.
- It has very good drainage quality.
- It is available in large quantities and hence can be used in emergency.
- The handling and transportation are easy.

Disadvantages:

- It is very soft and gets crumbled to powder under heavy loads.
- It has got corrosive quality and corrodes steel sleepers and foot of the rails.

5. Kankar:

It is natural material in the form of nodules from which lime is prepared.

Advantages:

- It is cheaper.
- It has good drainage property.

Disadvantages:

- It is soft and crumbles to powder under traffic load.
- The tracks laid on kankar ballast are difficult to maintain.
- It has corrosive quality.

6. Moorum:

It is a soft aggregate and is obtained by the decomposition of laterite. It has red or yellow colour. It is used in unimportant lines and sidings.

Advantages:

- It is easily available in most parts of India.
- It has good drainage properties.
- It is used as blanket for new embankment.

Disadvantages:

- It is soft and easily crumbles to powder under heavy loads.
- Maintenance of track laid on moorum ballast is very difficult.

7. Blast furnace slag:

It is a waste product obtained from the blast furnace of steel industry. High grade slag fulfils all the characteristics of good ballast.

Advantages:

- It is a cheap material.
- It has good drainage properties.
- It is a strong material.
- It holds the track in correct alignment and gradient.

Disadvantages:

- It is not available in large quantity.
- Spreading of this material on the formation is difficult.
- Maintenance of track laid on slag ballast is difficult.

8. Brick Ballast:

At places where good ballast material is not available over-burnt bricks are broken into suitable size to be used as ballast.

Advantages:

- It is a cheap material.
- It prevents growth of vegetation.
- It has good drainage properties.

Disadvantages:

- It is soft and easily crumbles to powder under heavy loads.
- The rails laid over such ballast get corrugated.

9. Selected Earth:

Hardened clay and decomposed rock are suitable for use as ballast. When tracks are laid on new formation, then sleepers are packed with earth for a few months. When the formation is consolidated and surface becomes hard, good type of ballast is laid. The use of earth ballast in the beginning is to prevent the loss of good ballast by sinking into soft formation.

FIXTURES AND FASTENINGS

Definition:

Fixtures and fastenings are fittings required for joining of rails end to end and also for fixing the rails to sleepers in a track.

Functions of Fixtures and Fastenings:

Rail fixtures and fastenings have the following functions:

- To join the rails end to end to form full length of track.
- To fix the rails to sleepers.
- To maintain the correct alignment of the track.
- To provide proper expansion gap between rails.
- To maintain the required tilt of rails.
- To set the points and crossings in proper position.

Types of Fixtures and Fastenings:

Fixtures and fastenings commonly used in a permanent way are of following types:

1. Fish plates
2. Bearing plates
3. Spikes
4. Chairs
5. Bolts
6. Keys
7. Anti creepers

Fish Plates:

Fish plates are used in rail joints to maintain the continuity of the rails. Two types of fish plates are commonly used on Indian Railways for joining F.F. and B.H. rails, each fish plate is 457 mm long and provided with four holes 32 mm dia. at a spacing of 114 mm c/c. These are manufactured of steel and are so designed that they fit in between the head and foot of the rail.

Bearing Plates:

Bearing plates are cast iron or steel plates placed in between the F.F rail and wooden sleepers of a railway track. F.F. rails if fixed directly on wooden sleepers sink in the sleeper due to the heavy loads of trains and thus loosen the spikes. To overcome this difficulty bearing plates are used under F.F. rails to distribute the load over a wider area and bring the intensity of pressure within limit. Bearing plates give the required 1 in 20 inward slope to the rail directly and no adzing is required in the wooden sleeper. These are fixed to sleepers by spikes.

Spikes:

Spikes are used to fix rails to wooden sleepers. Spikes are of following types:
(a) Dog spikes
(b) Round spikes
(c) Screw spikes
(d) Elastic spikes

- **Dog spikes** are the cheaper type of spikes which hold the rails at correct gauge and can be easily fixed and removed. These are commonly used for holding F.F. rails. Four dog spikes are used per sleeper, two on either side of the rail. The disadvantage of dog spikes is that these become loose under the wave action caused by the moving train.

- **Round spikes** are used for fixing chairs of B.H. rails to wooden sleepers and also for fixing slide chairs of points and crossings. These have either cylindrical or hemispherical head or blunt end.

- **Screw spikes** are tapered screws with V-threads. Their head is circular with a square projection and are used to fasten rails with wooden sleepers. The holding power of these spikes is more than double to that of dog spikes and can resist the lateral thrust better than the dog spikes.

- **Elastic spikes** are used for fixing F.F. rails to wooden sleepers. These give better grip and result in reduction of wear and tear of rail. The advantage of this type of spike is that it is not pulled up by the wave action of the moving train.

Bolts:
Different types of bolts used in Indian Railway are:

(a) Fish bolts
(b) Hook bolts
(c) Fang bolts

- **Fish bolts** are used for connecting fish plates with the rails. Four bolts are required for each pair of fish plates. These bolts are inserted from outside the track and bolted on the inside of the track.
- Fish bolts have to withstand shear due to heavy transverse stresses, hence they are manufactured of medium or high carbon steel. The length of fish bolt depends on the type of fish plate used. For 44.70kg rail, the fish bolts of 25 mm dia and 127.6 mm length are used. These bolts get loosened due to vibration of moving train and hence these are to be tightened time ot time. Too much tightening of bolts is prohibited as it prevents free expansion or contraction of rails due to temperature vibrations.

- **Hook bolts** are also known as dog bolts due to the shape of their heads. These bolts are used to fix sleepers which rest directly on a girder. Two bolts per sleeper are used. Dog bolts are of two types.
  (i) Sloping lips- for fixing sleepers to plate girder spans.
  (ii) Straight lips- for fixing sleepers to joist spans.

- **Fang bolts** are used for fixing side chairs to sleepers. These are alternative to screw or round spikes. The fang bolts are found to be more effective but are not generally used, because fixing and removal of these bolts are difficult.

Keys:

These are small tapered pieces of timber or steel used to fix rails to chairs on metal sleepers. Keys are of two types

1. Wooden keys
2. Metal keys

- **Wooden keys** are small straight or tapered pieces of timber. These are cheap and easily prepared. These are not strong and become loose under vibrations. These require frequent maintenance. Wooden keys are not used now-a days in Indian Railways.

- **Metal keys** are small tapered or spring like pieces of steel. These keys are much more durable than wooden keys. Metal keys are of two types.
  (i) Stuart`s key and
  (ii) Morgan key

Anti-Creepers:

Anti-creepers are used to prevent creep in a railway track. Different shapes of anti-creepers are available and are fixed to the foot of rail.

CHAPTER-4 :- GEOMETRIC FOR BROAD GAUGE

Introduction:

Geometric design of a railway track discusses all those parameters which affect the geometry of the track. These parameters are as follows:

1. Gradients in the track

2. Curvature of the track: radius or degree of the curve, cant or super elevation on curves

3. Alignment of the track

Necessity of Geometric Design:

The need for proper geometric design of a track arises because of the following considerations:

- To ensure the smooth and safe running of trains
- To achieve maximum speeds
- To carry heavy axle loads
- To avoid accidents and derailments due to a defective permanent way
- To ensure that the track requires least maintenance
- For good aesthetics

Gradients:

Gradients are provided to negotiate the rise or fall in the level of the railway track. A rising gradient is one in which the track rises in the direction of movement of traffic and in a down or falling gradient the track loses elevation the direction of movement of traffic.

Gradients are provided to meet the following objectives:

- To reach various stations at different elevations
- To follow the natural contours of the ground to the extent possible
- To reduce the cost of earthwork
- To drain off rain water.

Types of gradient:

1. Ruling gradient
2. Momentum gradient
3. Pusher gradient
4. Station yard gradient

Ruling Gradient:

Ruling gradient is the maximum gradient to which the track may be laid in a particular section. It depends on the load of the train and additional power of the locomotive. While deciding the ruling gradient of a section, it is not only the severity of the gradient, but also its length as well as its position with respect to the gradients on both sides that have to be taken into consideration. The power of the locomotive to be put into service on the track also plays an important role in taking this decision, as the locomotive should have adequate power to haul the entire load over the ruling gradient at the maximum permissible speed.

In plain terrain: 1 in 150 to 1 in 250
In hilly terrain: 1 in 100 to 1 in 150

Momentum Gradient:

The gradient which is steeper than ruling gradient and where the advantage of momentum is utilized is known as momentum gradient. A train gets momentum when moving in down gradient and this momentum can be utilized for up gradient. A train while coming down a gradient gains sufficient momentum. This momentum gives additional kinetic energy to the moving train which would help the train to rise a steeper gradient than the ruling gradient for a certain length of the track. This rising gradient is called momentum gradient. In such gradients no signals are provided to stop the train.

Pusher or Helper Gradient:

Pusher gradient is the gradient where extra engine is required to push the train. These are steeper gradient than ruling gradient and are provided at certain places of mountains to avoid heavy cutting or to reduce the length of track. A pusher gradient of 1 in 37 on Western Ghats with B.G. track is provided. On Darjeeling Railway with N.G. track, a ruling gradient of 1 in 25 is provided.]

Station Yard Gradient:

Station yard gradient is the minimum gradient provided in station yard for easy draining of rain water. In station yards, maximum limit of gradient is fixed as 1 in 400 and minimum gradient recommended is 1 in 1000 for easy drainage of rain water.

The gradients in station yards are quite flat due to the following reasons:

(a) It prevents standing vehicles from rolling and moving away from the yard due to the combined effect of gravity and strong winds.

(b) It reduces the additional resistive forces required to start a locomotive to the extent possible.

Grade compensation on curves:

Grade compensation on curves is the reduction in gradient on curved portion of a track. On curves extra pull is required to pull the train due to more tractive resistance. It is expressed as percentage per degree of curve. The grade compensation provided on Indian Railways is as follows:

a. On B.G. curves – 0.04 percent / degree or 70/R, whichever is minimum
b. On M.G. curves – 0.03 percent / degree or 52.5/R, whichever is minimum
c. On N.G. curves – 0.02 percent / degree or 35/R, whichever is minimum
   where R is the radius of the curve in metres.

Radius or Degree of Curve:

A curve is denned either by its radius or by its degree. The degree of a curve (D) is the angle subtended at its centre by a 30.5 m or 100 ft arc.

The value of the degree of the curve can be determined as indicated below.

- Circumference of a circle = $2\pi R$
- Angle subtended at the centre by a circle with this circumference = 360°
- Angle subtended at the centre by a 30.5 m arc, or
- Degree of curve = 360°/$2\pi R$ x30.5 = 1 750/R (approximately R is in meter)

In cases where the radius is very large, the arc of a circle is almost equal to the chord connecting the two ends of the arc.

The degree of the curve is thus given by the following formulae:

- $D = 1750/R$ (when R is in metres)
- D = 5730/ R (when R is in feet)

Maximum permissible degree of curves:

The maximum permissible degree of a curve on a track depends on various factors such as gauge, wheel base of the vehicle, maximum permissible super elevation, and other such allied factors. The maximum degree or the minimum radius of the curve permitted on Indian Railways for various gauges is given in Table below.

Gauge	On plain track		On turnouts	
	Max. Degree	Min. Radius	Max. Degree	Min. Radius
B.G	10	175	8	218
M.G	16	109	15	116
N.G	40	44	17	103

Superelevation:

Superelevation is the raised elevation of the outer rail above the inner rail at a horizontal curve. It is denoted by 'e'.
When a vehicle moves on curve it is subjected to a centrifugal force. The centrifugal force exerts a horizontal force on the outer rail and the weight on the outer rail increases. This horizontal force and uneven load on rails will cause derailment. This centrifugal force can be counteracted by introducing the centripetal force by raising the outer rail with respect to inner rail. This raising of outer rail with respect to inner rail is known as 'superelevation' or 'canting'.

Objects of Providing Super elevation:

The following are the objects of providing superelevation:

- To introduce centripetal force to counteract the centrifugal force to avoid derailment and reduce the side wear of rails.
- To distribute the wheel loads equally on the two rails. This reduces the top wear of rails and results in saving of maintenance cost.
- To ensure comfortable ride to passengers and safe movements of goods.

Analysis of Super elevation:

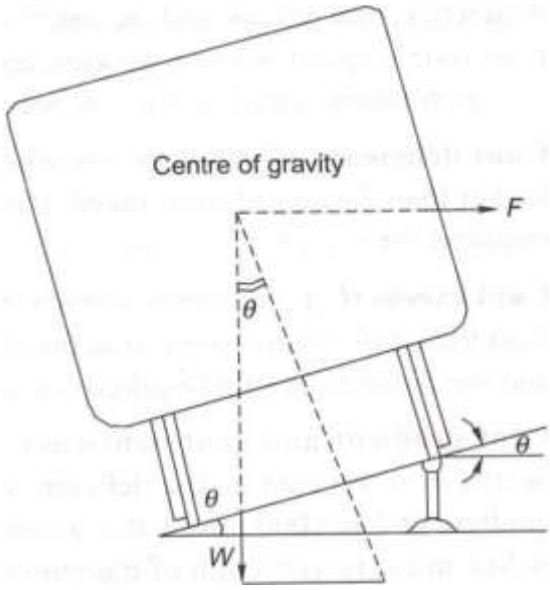
- A vehicle has a tendency to travel in a straight direction, which is tangential to the curve, even when it moves on a circular curve. As a result, the vehicle is subjected to a constant radial acceleration.
- Radial acceleration: **$a = V^2/R$,**

  Where **V** is the velocity (metres per second) and **R** *is* the radius of curve (metres). This radial acceleration produces a centrifugal force which acts in a radial direction away from the centre.
- The value of the centrifugal force is given by the formula:

  Force = mass * acceleration,

  $F = m \times (V^2/R) = (W/g) \times (V^2/R)$,

  Where **F** *is* the centrifugal force (Kilo Newton), **W** *is* the weight of the vehicle (tons), **V** is the speed (m/s), **g** *is* the acceleration due to gravity (m/s2), and **R** is the radius of the curve in metres.
- To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the *super elevation.*
- A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the super elevation is enough to bring the resultant of the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve is known as *equilibrium super elevation.*



Equilibrium Superelevation:

- In Fig. above, if θ *is* the angle that the inclined plane makes with the horizontal line, then superelevation:
  - **tan θ** = Superelevation / Gauge = **e/ G**
  - **tan θ** = Centrifugal force/weight = **F/W**
- From these equations:
  - e/ G = F/W
  - e = f x G/W e

    = W/g x V^2/R x G/R

e = GV^2 / gR

Here, **e** *is* the equilibrium superelevation in metres, **G** is the gauge in metres, **V** *is* the velocity in metres per second, **g** is the acceleration due to gravity, and **R** *is* the radius of the curve in metres.

- In the metric system equilibrium superelevation is given by the formula:

e = GV2 / 127R

Where **e** is the superelevation in millimetres, **V** *is* the speed in km per hour, ***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 equall to 1750 mm for BG tracks and 1058 mm for MG tracks.

Maximum value of Super elevation:

The maximum value of superelevation generally adopted on many railways around the world is one-tenth to one-twelfth of the gauge. The values of maximum super elevation prescribed on Indian Railways are given in Table below.

Gauge	Limiting Value of Cant(mm)	
	Under normal conditions	With special permission
B.G	165	185
M.G	90	100
N.G	65	75

Cant Deficiency:

Cant deficiency is the difference between the actual cant provided and equilibrium cant necessary for the maximum permissible speed on a curve.
Cant deficiency should be as low as possible and is limited due to following reasons:

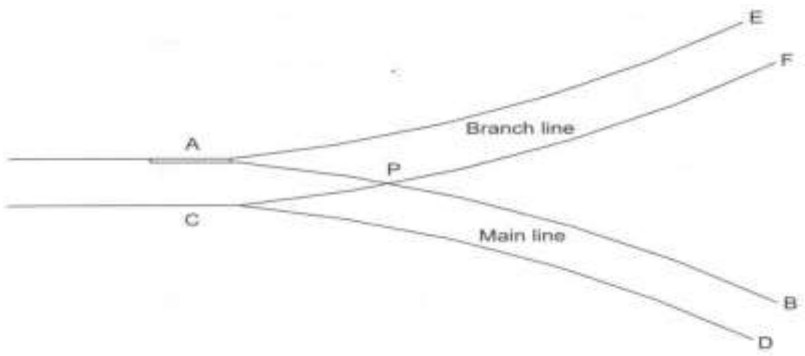
- Higher discomfort to passengers due to higher cant deficiency
- Higher cant deficiency results in higher unbalanced centrifugal force and hence extra pressure and lateral thrust on the outer rails, requiring strong track and more fastening for stability.
- Side wear and creep of outer rails of the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

Limits of cant deficiency for different gauges on Indian Railways:

Gauge	Cant Deficiency(mm)	
	For speeds up to 100 km/hr	For speeds higher than 100 km/hr
B.G	76	100
M.G	51	Not specified
N.G	38	Not specified

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 **Fig**. below, AB, which is the outer rail of the main line curve, must he 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 superelevation and, therefore, speeds on both tracks must be restricted, particularly on the branch line.



(Fig: Negative super elevation)

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 $\mathbf{e = GV^2 / 127R}$

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

$$\mathbf{x = e - C_d}$$

where *x* is the super elevation, *e* is the equilibrium super elevation, and C_d is 75 mm for BG and 50 mm for MG. The value of C_d 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 +** $\mathbf{C_d}$**).**

CHAPTER-5 :- POINTS AND CROSSINGS

Definition:

Points and crossings are provided to facilitate the change of railway vehicles from one track to another. The tracks may be parallel, diverging, or converging to each other. Points and crossings are necessary due to the inside flanges of wheels of railway vehicles and, therefore require special arrangement to navigate their way on the rails. The points or switches aid in diverting the vehicles and the crossings provide gaps in the rails so as to help the flanged wheels to roll over them. A complete set of points and crossings, along with lead rails, is called a *turnout.*

Turnout:

Turnout is an arrangement of points and crossings with lead rails by which trains may be diverted from one track to another moving in the facing direction.

Parts of a Turnout:

1. A pair of tongue rails
2. A pair of stock rails
3. Two check rails
4. Four lead rails
5. A Vee crossing
6. Slide chairs
7. Stretcher bar
8. A pair of heel blocks
9. Switch tie plate or gauge tie chair
10. Parts for operating points – Rods, cranks, levers etc.
11. Locking system which includes locking box, lock bar, plunger bar etc.

- ***Tongue Rails*** along the stock rails in a turnout form a pair of points or switches. The tongue rails facilitate the diversion of a train from the main track to a branch track.

- ***Stock Rails*** are the main rails to which the tongue rails fit closely. The stock rails help in smooth working of tongue rails.

- ***Check rails*** are provided adjacent to the lead rails, one in main track and another in branch track. These rails check the tendency of wheels to climb over the crossing.

- ***Lead Rails*** lead the track from heel of switches to the toe of crossing.

- ***A Vee crossing*** is formed by two wing rails, a point rail and a splice rail. It provides gaps between the rails so that wheel flanges pass through them without any obstruction.

- ***Slide chairs*** are provided to support the tongue rail throughout their length and to allow lateral movement for changing of points.

- ***Stretcher bar*** connects toes of both the tongue rails so that each tongue rail moves through the same distance while changing the points.

- ***Heel Blocks*** keep the heel ends of both the tongue rails at fixed distance from their respective stock rails.

- ***Switch Tie Plate*** holds the track rigidly to the definite gauge at the toe of switches. These are provided below the slide chairs.

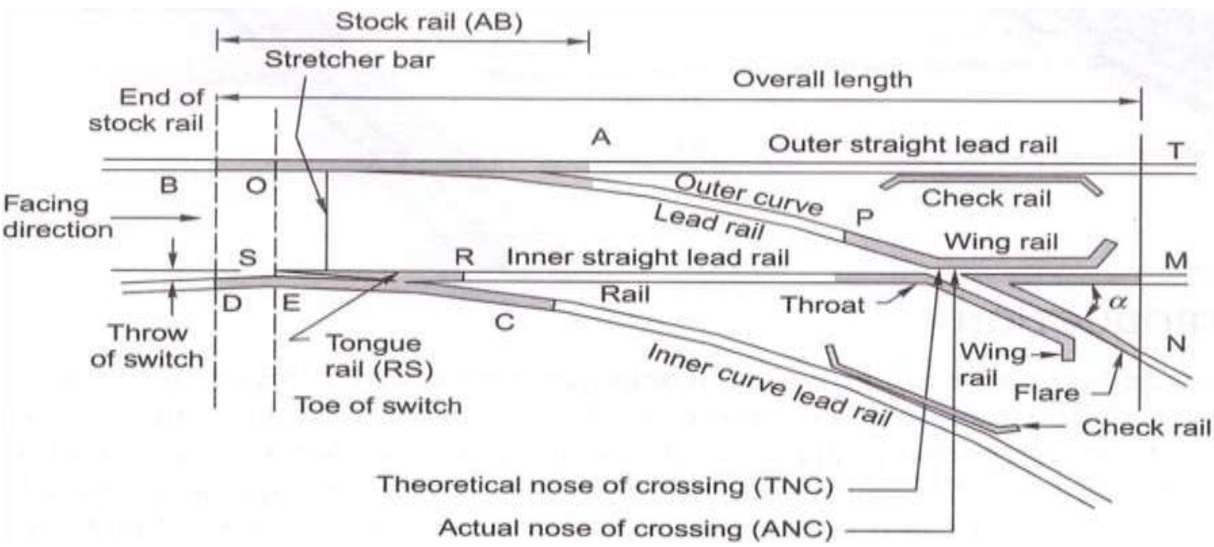
Direction of a turnout:

- A turnout is designated as a right-hand or a left-hand turnout depending on whether it diverts the traffic to the right or to the left.

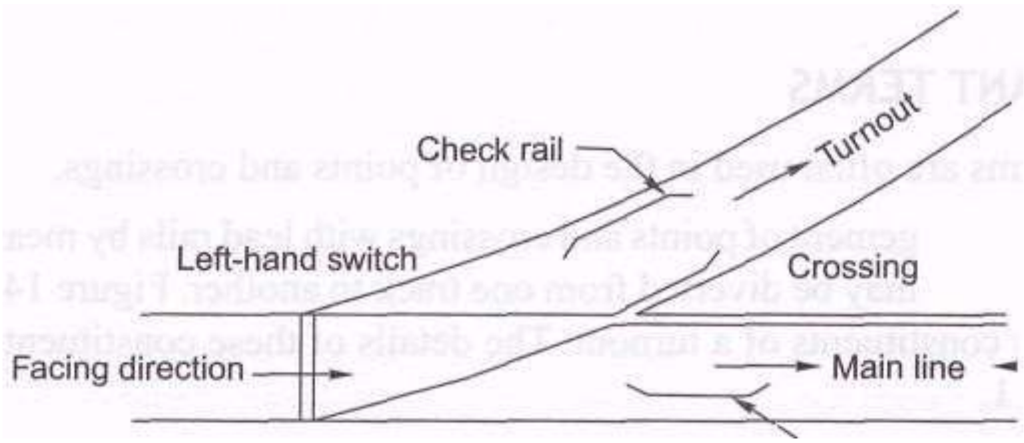
- The direction of a point (or turnout) is known as *the **facing direction*** if a vehicle approaching the turnout or a point has to first face the thin end of the switch.

- The direction is ***trailing direction*** if the vehicle has to negotiate a switch in the trailing direction, that is, the vehicle first negotiates the crossing and then finally traverses on the switch from its thick end to its thin end.

- Therefore, when standing at the toe of a switch, if one looks in the direction of the crossing, it is called *the facing direction* and the opposite direction is called the *trailing direction.*



(Constituents of a turnout)



(Left-hand turnout)

<u>Switches:</u>

A set of points or switches consists of a pair of stock rails, a pair of tongue rails, a pair of heel blocks, several slide chairs, two or more stretcher bars, and a gauge tie plate.

Types of Switches:

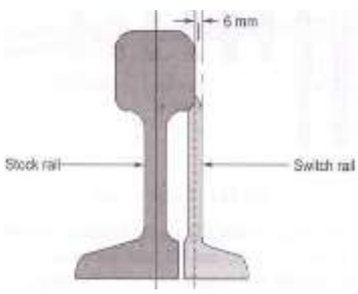
Switches are of two types, namely stud switch and split switch. In a stud type of switch, no separate tongue rail is provided and some portion of the track is moved from one side to the other side. Stud switches are no more in use on Indian Railways. They have been replaced by split switches. These consist of a pair of stock rails and a pair of tongue rails.

Split switches may also be of two types:

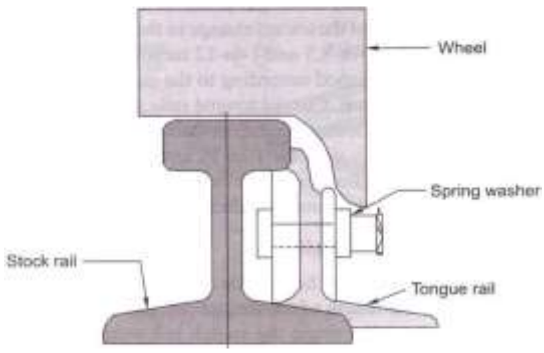
- Loose heel type
- Fixed heel type.

The toe of the switches may be of the following types.

- **Undercut switch:** In this switch the foot of the stock rail is planned to accommodate the tongue rail.
- **Overriding switch:** In this case, the stock rail occupies the full section and the tongue rail is planed to a 6 mm (0.25")-thick edge, which overrides the foot of the stock rail.



(Undercut switch)



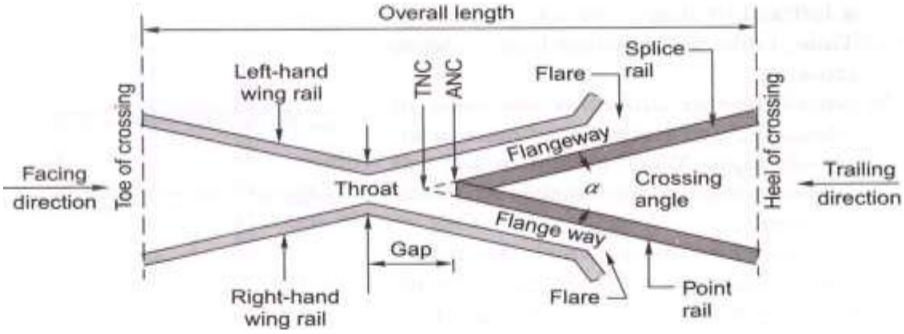
(Overriding switch)

Crossing:

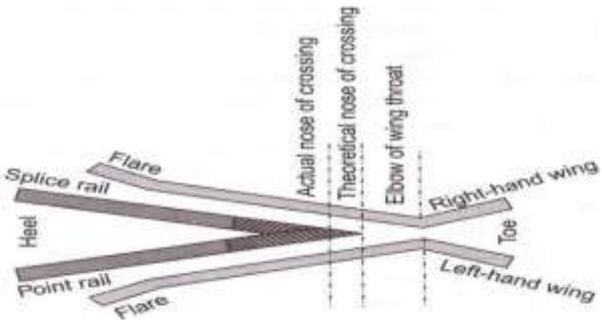
A crossing or frog is a device introduced at the point where two gauge faces across each other to permit the flanges of a railway vehicle to pass from one tract to another (Fig. below). To achieve this objective, a gap is provided from the throw to the nose of the crossing, over which the flanged wheel glides or jumps. In order to ensure that this flanged wheel negotiates the gap properly and does not strike the nose, the other wheel is guided with the help of check rails.

A crossing consists of the following components:

- **Two rails, point rail and splice rail**, which are machined to form a nose. Tic point rail ends at the nose, whereas the splice rail joins it a little behind the nose. Theoretically, the point rail should end in a point and be made as thin as possible, but such a knife edge of the point rail would break off under the movement of traffic. The point rail, therefore, has its fine end slightly cut off form a blunt nose, with a thickness of 6 mm (1/4"). The toe of the blunt nose is called the ***actual nose of crossing*** (ANC) and the theoretical point where the gauge faces from both sides intersect is called the ***theoretical nose of crossing*** (TNC). The 'V rail is planed to a depth of 6 mm (1/4") at the nose and runs out in 89 mm to stop a wheel running in the facing direction from hitting the nose.
- **Two wing rails** consisting of a right-hand and a left-hand wing rail that converge to form a throat and diverge again on either side of the nose. Wing rails are flared at the ends to facilitate the entry and exit of the flanged wheel in the gap.
- **A pair of check rails** to guide the wheel flanges and provide a path for them, thereby preventing them from moving sideways, which would otherwise may result in the wheel hitting the nose of the crossing as it moves in the facing direction.



(Details of a crossing)



(Point rail and splice rail)

Types of Crossings:

Crossings can be classified as follows:

On the basis of shape of crossing:

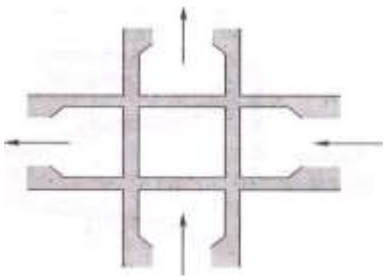
1. Square crossing
2. Acute angle or V-crossing or Frog
3. Obtuse angle or Diamond crossing

On the basis of assembly of crossing:

1. Ramped crossing
2. Spring or movable crossing.

Square Crossing:

Square crossing is formed when two straight tracks of same or different gauge, cross each other at right angles. This type of crossing should be avoided on main lines because of heavy wear of rails.

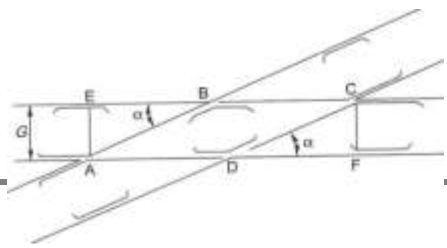


Acute Angle Crossing:

Acute angle crossing is formed when left hand rail of one track crosses right hand rail of another track at an acute angle or vice versa. This type of crossing consists of a pair of wing rails, a pair of check rails, a point rail and a splice rail. This crossing is widely used. This is also called V-crossing or frog.

Obtuse Angle Crossing:

Obtuse angle crossing is formed when left hand rail of one track crosses right hand rail of another track at an obtuse angle or vice versa. This type of crossing consists mainly of two acute angle and two obtuse angle angle crossings. This is also called Diamond crossing.



BRIDGE

CHAPTER-1:- INTRODUCTION TO BRIDGE

Introduction of Bridge-

A bridge is a structure which is built over some physical obstacle such as a body of water, valley, or road, and its purpose is to provide crossing over that obstacle. It is built to be strong enough to safely support its own weight as well as the weight of anything that should pass over it. A bridge is a structure which maintains the communication over a physical obstacle, e.g.

- Channel/river
- Road
- Railway line
- Vally

Bridge Designations

- If it carries road traffic or railway traffic or a pipe lineover a channel or a valley: Bridge
- If it carries the traffic or pipe over a communication system like roads or railways: Fly-over/Over-Bridge
- Bridge (several small spans) constructed over a busy locality, a valley, dry or wetland, or forming a flyoverto carry the vehicular traffic: Viaduct

History

- History of bridges begins with a tree log accidentallyfallen across water courses.
- Natural rock arches formed due to erosion beneath.(Arch Bridge)
- Climbers suspended above a deep gorge. Hanging creepers from one tree (Banyan trees) to other, bytying a bunch of long creepers with the trees situated on either side of water course

Classification of Bridges

Bridges are mainly classified according to:-

A. Materials used in their construction.
B. Various structural forms.
C. Construction and function

A: Classification According to Material

- Timber
- Masonary
- Concrete (r.c.c or pre-stressed)
- Steel

B: According to various structural forms

- Slab(0-12m)
- Beam(10-30m)
- Cantilever/balanced cantilever(30-500m)
- Box-girde(18-30m; 60-70mwith pre- stressing)
- Truss (35- 300m)
- Arch (20-500m)
- Cable stayed (90-350m)
- Suspension (300-2000m)

Distinctive Features of Slab Bridges

- Usually used for Short spans
- Carry loads in Shear and Flexural bending

- Have sufficient torsional stiffness
- Bearings are not required
- Simple Shattering/formwork is required becomes heavy (increase in D.L) for large spans. Hollow slabs are sometimes provided for mediumspans

Distinctive Features of Beam/Girder Bridges

- Oldest and most common bridge type known
- Usually used for Short and Medium spans
- Carry loads in Shear and Flexural bending

- In modern girder bridges, steel I-Beams replaceConcrete BeamsLow torsional stiffness

Distinctive Features of Box Girder Bridges

- In addition to flexural stiffness and shearresistance, these bridges have sufficient torsional stiffness
- Most suitable for curved plan and longer spanbridges

Distinctive Features of Truss Bridge

- The primary member forces are axial loads
- The open web system permits the use of a greater overall depth than for an equivalent solid web girder, hence reduceddeflections and rigid structure
- Both these factors lead to economy in material and a reduceddead weight. The increased depth also leads to reduced deflections, that is, a more rigid structure.
- High maintenance and fabrication costs. Aesthetic appearance is debatable mainly because ofcomplexity of elevation. Used economically in the span range of upto 300m.

Distinctive Features of Cantilever Bridge

- Cantilever bridges can be of steel or concrete.
- In a cantilever bridge, the roadway is constructed out from the pier in two directions at the same timeso that the weight on both sides counterbalance each other.
- Notice the larger section at the support to resistnegative moments.

Distinctive Features of Arch Bridge

- Arch action reduces bending moments
- Economical as compared to equivalent straight simplysupported Girder or Truss bridge
- Suitable; when site is a deep gorge with steep rockybanks.
- Conventional curved arch rib has high Fabrication andErection costs.
- Unlike girders, can be built from stones
- Considered the most beautiful of bridge types
- Used in the span range of upto 250m.

CHAPTER-2 :-BRIDGE SITE INVESTIGATION,HYDROLOGY& PLANNING

Introduction

This chapter presents bridge engineers basic concepts, methods, and procedures used in bridge hydraulic analysis and design. It involves hydrology study, hydraulic analysis, on-site drainage design, and bridge scour evaluation. Hydrology study for bridge design mainly deals with the properties, distribution, and circulation of water on and above the land surface. The primary objective is to determine either the peak discharge or the flood hydrograph, in some cases both, at the highway stream crossings. Hydraulic analysis provides essential methods to determine runoff discharges, water profiles, and velocity distribution. The on-site drainage design part of this chapter is presented with the basic procedures and references for bridge engineers to design bridge drainage. Bridge scour is a big part of this chapter. Bridge engineers are systematically introduced to concepts of various scour types, presented with procedures and methodology to calculate and evaluate bridge scour depths, provided with guidelines to conduct bridge scour investigation and to design scour preventive measures.

Hydrology

Collection of Data

Hydraulic data for the hydrology study may be obtained from the following sources: as-built plans, site investigations and field surveys, bridge maintenance books, hydraulic files from experienced report writers, files of government agencies,rainfall data from local water agencies, stream gauge data, USGS and state water agency reservoir regulation, aerial photographs, and floodways, etc. Site investigations should always be conducted except in the simplest cases. Field surveys are very important because they can reveal conditions that are not readily apparent from maps, The typical data collected during a field survey include high water marks, scour potential, stream stability, nearby drainage structures, changes in land use not indicated on maps, debris potential, and nearby physical features.

Drainage Basin

The area of the drainage basin above a given point on a stream is a major contributing factor to the amount of flow past that point. For given conditions, the peak flow at the proposed site is approximately proportional to the drainage area. The shape of a basin affects the peak discharge. Long, narrow basins generally give lower peak discharges than pear-shaped basins. The slope of the basin is a major factor in the calculation of the time of concentration of a basin. Steep slopes tend to result in shorter times of concentration and flatter slopes tend to increase the time of concentration. The mean elevation of a drainage basin is an important characteristic affecting runoff. Higher elevation basins can receive a significant amount of precipitation as snow. A basin orientation with respect to the direction of storm movement can affect peak discharge. Storms moving upstream tend to produce lower peaks than those moving downstream.

Discharge

There are several hydrologic methods to determine discharge. Most of the methods for estimating flood flows are based on statistical analyses of rainfall and runoff records and involve preliminary or trial selections of alternative designs that are judged to meet the site conditions and to accommodate the flood flows selected for analysis. Flood flow frequencies are usually calculated for discharges of 2.33 years through the overtopping flood. The frequency flow of 2.33 years is considered to be the mean annual discharge. The base flood is the 100-year discharge (1% frequency). The design discharge is the 50-year discharge (2% frequency) or the greatest of record, if practical. Many times, the historical flood is so large that a structure to handle the flow becomes uneconomical and is not warranted. It is the engineer's responsibility to determine the design discharge. The overtopping discharge is calculated at the site, but may overtop the roadway some distance away from the site.

Changes in land use can increase the surface water runoff. Future land-use changes that can be reasonably anticipated to occur in the design life should be used in the hydrology study. The type of surface soil is a major factor in the peak discharge calculation. Rock formations underlying the surface and other geophysical characteristics such as volcanic, glacial, and river deposits can have a significant effect on runoff. Detention storage can have a significant effect on reducing the peak discharge from a basin, depending upon its size and location in the basin. The most commonly used methods to determine discharges are

1. Rational method
2. Statistical Gauge Analysis Methods
3. Discharge comparison of adjacent basins from gauge analysis
4. Regional flood-frequency equations
5. Design hydrograph

Waterway Analysis

When determining the required waterway at the proposed bridge, the engineers must consider all adjacent bridges if these bridges are reasonably close. The waterway section of these bridges should be tied into the stream profile of the proposed structure. Structures that are upstream or downstream of the proposed bridge may have an impact on the water surface profile. When calculating the effective waterway area, adjustments must be made for the skew and piers and bents. The required waterway should be below the 50-year design HW stage. If stream velocities, scour, and erosive forces are high, then abutments with wing wall construction may be necessary. Drift will affect the horizontal clearance and the minimum vertical clearance line of the proposed structure. Field surveys should note the size and type of drift found in the channel. Designs based on the 50-year design discharge will require drift clearance. On major streams and rivers, drift clearance of 2 to 5 m above the 50-year discharge is needed. On smaller streams 0.3 to 1 m may be adequate.

Afflux

Afflux is an increase in water level that can occur upstream of a structure, such as a bridge or culvert, that creates an obstruction in the flow. The afflux is illustrated in Figure 1 for a bridge structure located in a watercourse. The dashed line represents the normal water surface for the undisturbed watercourse. The solid line represents the water surface when the structure is present. Afflux is shown as the maximum increase of water level above normal depth in the undisturbed stream. Note that the afflux differs from the head loss across the structure, as the latter varies depending on the upstream and downstream locations of measurement.

Side elevation at a bridge contraction, When a structure such as a bridge or culvert is placed in a stream, there is a local loss of stream energy. This is due to the fluid friction in contact with the structure, and the stagnation zones that border the contracting (Sections 4 to 3) and expanding (Sections 2 to 1) flow reaches. To maintain a steady flow, this local loss of energy is compensated by an increase in potential energy immediately upstream of the structure. A backwater is thus created which begins at the afflux location.

Importance of Afflux

Elevated water levels upstream of bridges and culverts are a potential source of flood risk. In general, the afflux increases with increasing flow rates and with an increasing degree of obstruction, which may be related to the size and form of the structure or to transient debris blockage. Whilst bridges and culverts can be located anywhere, they tend to be concentrated in urban areas, and so the consequences of even quite small increases in level above a threshold may be severe in terms of property flooding or disruption of infrastructure. The effects of bridges and culverts on flood water levels need to be understood for design, planning, hydraulic modelling (including models used for flood mapping), risk analysis, maintenance and incident management. The hydraulics of bridges and culverts are complex, and not all applications justify a costly, detailed analysis. But what methods should be used for analysis or modeling.

Requirements for afflux analysis

The choice of analysis method should be influenced by the impact of the study and should in turn drive the investment made in collecting data (in particular river survey), the time allocated, and the experience of the analyst. It is useful to think of two types of application. The first is a 'high impact', application, for example an important bridge or culvert in a high flood risk urban area, where the costs of river survey and modeling are justified by the value gained from a detailed analysis. The second, 'low impact' application would not 3a.1.3 justify as much data and analysis, but require a simpler, and much quicker, approach to analysis the structure; an example might be a pipe culvert for a farm access. One of the objectives of the research reported in this paper was therefore been to provide methods for both the 'high impact' and 'low impact' applications within a consistent theoretical framework.

Clearance : The shortest distance between boundaries at a specified position of bridge structure.

Freeboard : The difference between H.F.L. (allowing afflux) and foundation level of road embankment on approaches.

H.F.L. : Highest flood level is the level of highest flood ever recorded or the calculated level for design discharge.

L.W.L. : Lowest flood level is the level of the water surface obtained in dry season.

Length of Bridge : The length of a bridge structure will be taken as overall length measured along the center line of the bridge between inner faces of dirt wall.

Linear Waterway : Width of waterway between the extreme edges of water surface at H.F.L. measured at right angles to the abutment face.

Vertical clearance : The height from the design highest flood level with afflux of the channel to the lowest point of the bridge superstructure at the position along the bridge where clearance is denoted.

CHAPTER-3 :-BRIDGE FOUNDATION

INTRODUCTION

Bridges have been the most visible testimony to the contribution of engineers. Bridges have always figured prominently in human history. They enhance the vitalities of the cities and aid the social, cultural and economic improvements of the locations around them. Bridge is a structure providing passage over an obstacle without closing the way beneath. The required passage may be for a road, a railway, pedestrians, a canal or a pipeline and the obstacle to be crossed may be a river, a road, railways or a valley. The portion of the bridge structure below the level of the bearing and above the founding level is generally referred to as the substructure. The design of bridge substructure is an important part of the overall design for a bridge and affects to a considerable extent the aesthetics, the safety and the economy of the bridge. Bridge sub structure are very important part of a bridge as it safely transfers the loads.

A bridge may have either have the following types of foundations:

1. **Well foundations:**

It is the most common type of foundation in India for both road & railway bridges. Such foundation can be sunk to great depths and can carry very heavy vertical and lateral loads. Well foundations can also be installed in a boulder stratum. It is a massive structure and is relatively rigid in its structural behavior.

2.**Pile foundations:**

It consist of relatively long and slender members, called piles which are used to transfer loads through weak soil or water to deeper soil or rock strata having a high bearing capacity. They are also used in normal ground conditions for elevated road ways. The analysis and the design of all the components of a bridge particularly with reference to the bridge substructure can become a very lengthy and laborious task if the calculations are attempted manually.

Types of Pile Foundations Based on Their Function or Uses

Based on function piles are classified as,

1. End Bearing Pile
2. Friction Pile
3. Composite Pile
4. Tension Pile
5. Anchor Pile
6. Fender Pile
7. Better Pile
8. Sheet Pile

3.**Spread Foundation**

The spread footing is utilized to support the column & walls and additionally to convey & disseminate the load coming to the structure to the soil below it.With loads provided within the upward direction, this footing actually acts like an inverted cantilever, and this sort of footing is typically a rigid element & they're orthogonal just in case of symmetric footing. This type of footing may be a circular, square, or rectangular slab of uniform thickness and to spread the load over a sizeable area sometimes it's stepped. The base of spread footing is slightly wider than load-bearing foundation base. This is also called a stepped spread foundation.

Types of Spread Foundation:

1. Wall Footing.
2. Isolated Footing or Column Footing.
3. Combined Footing.
4. Strap Footing or Cantilever Footing.
5. Continuous Footing.
6. Inverted Arch Footing.
7. Grillage Footing.
8. Raft Foundation or Mat Foundation**.**

4.Caisson Foundation

A caisson foundation also called as pier foundation is a watertight retaining structure used as a bridge pier, in the construction of a concrete dam, or for the repair of ships. It is a prefabricated hollow box or cylinder sunk into the ground to some desired depth and then filled with concrete thus forming a foundation. **C**aisson foundation is Most often used in the construction of bridge piers & other structures that require foundation beneath rivers & other bodies of water. This is because caissons can be floated to the job site and sunk into place. Caisson foundations are similar in form to pile foundations, but are installed using a different method. It is used when soil of adequate bearing strength is found below surface layers of weak materials such as fill or peat. It is a form of deep foundation which are constructed above ground level, then sunk to the required level by excavating or dredging material from within the caisson. Caissons (also sometimes called "piers") are created by auguring a deep hole into the ground, and then filling it with concrete. Steel reinforcement is sometimes utilized for a portion of the length of the caisson. Caissons are drilled either to bedrock (called "rock caissons") or deep into the underlying soil strata if a geotechnical engineer finds the soil suitable to carry the building load. When caissons rest on soil, they are generally "belled" at the bottom to spread the load over a wider area. Special drilling bits are used to remove the soil for these "belled caissons". The caisson foundations carry the building loads at their lower ends, which are often bell-shaped.

Types of Caisson Foundations

- Box Caissons
- Excavated Caissons
- Floating Caissons
- Open Caissons
- Pneumatic Caissons
- Sheeted Caisson

<u>Afflux</u>

Afflux is an increase in water level that can occur upstream of a structure, such as a bridge or culvert, that creates an obstruction in the flow. The afflux is illustrated in Figure 1 for a bridge structure located in a watercourse. The dashed line represents the normal water surface for the undisturbed watercourse. The solid line represents the water surface when the structure is present. Afflux is shown as the maximum increase of water level above normal depth in the undisturbed stream. Note that the afflux differs from the head loss across the structure, as the latter varies depending on the upstream and downstream locations of measurement.

Importance of Afflux

Elevated water levels upstream of bridges and culverts are a potential source of flood risk. In general, the afflux increases with increasing flow rates and with an increasing degree of obstruction, which may be related to the size and form of the structure or to transient debris blockage. Whilst bridges and culverts can be located anywhere, they tend to be concentrated in urban areas, and so the consequences of even quite small increases in level above a threshold may be severe in terms of property flooding or disruption of infrastructure. The effects of bridges and culverts on flood water levels need to be understood for design, planning, hydraulic modeling (including models used for flood mapping), risk analysis, maintenance and incident management. The hydraulics of bridges and culverts are complex, and not all applications justify a costly, detailed analysis

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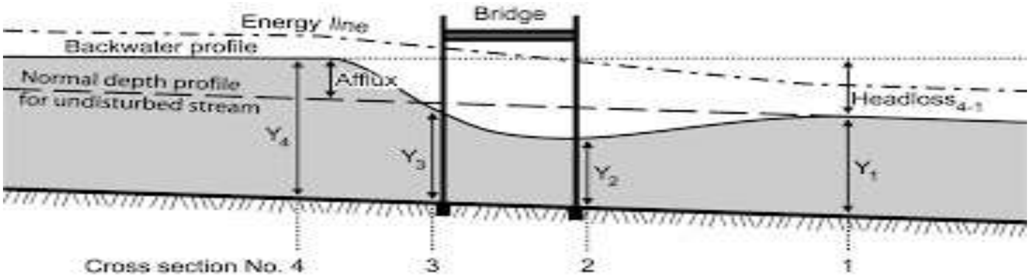

<u>**Cofferdam**</u>

Cofferdam foundation is defined as a temporary structure that is used to prevent soil erosion in the construction area as well as to prevent water from entering the excavated area when excavation is to be done by digging deeper along the river bank or coast.

The following points should be kept in mind in the cofferdam construction.

- Cofferdam should be watertight as possible. It should be inserted to a hard level in the ground. Often a layer of concrete is laid at the bottom in the cofferdam.
- The design of Cofferdam should be done for maximum water level as well as other destructive forces. Due to that, it is safe in case of bursting, overturning, sliding.
- Water discharged by cofferdam may be above ground or below ground. This water can be shallow or deep, steady, or flowing.
- Materials like clay, wood, steel, and concrete are used for the construction of cofferdam.
- A cofferdam is usually built on the worksite.

Types of cofferdam:

The different types of cofferdams are as follows:

1. Earthen cofferdam
2. Rockfill cofferdam
3. Crib or braced cofferdam
4. Single wall cofferdam
5. Double wall cofferdam
6. Cellular cofferdam

CHAPTER-5:- CULVERT & CAUSE WAYS

Defination:
Culvert is defined as a tunnel structure constructed under roadways or railways to provide cross drainage or to take electrical or other cables from one side to other. It is totally enclosed by soil or ground. Pipe culvert, box culvert and arch culvert are the common types used under roadways and railways. The design of culvert is based on hydraulic, water surface elevation, and roadway height and other conditions. These are used for water flow in a controlled way. Culverts are like pipes but very large in size.
They are made of many materials like

- Concrete
- Steel
- Plastic
- Aluminum
- high density polyethylene

Pipe Culvert
Pipe culverts are the most common types of culverts due to competitive price and easy installation. They are found in different shapes such as circular, elliptical and pipe arch. Generally, their shapes depend on site conditions and constraints. Pipe culverts on a small scale represent normal pipes like concrete pipes.

Advantages of Pipe Culvert
The main features of pipe culverts are: It can be constructed of any desired strength by proper mix design, thickness, and reinforcement. They are economical.These pipes can withhold any tensile stresses and compressive stresses.The crossing of water is under the structure.

Disadvantages of Pipe Culvert
The main disadvantage of pipe culvert is that it can be easily corroded at the crown because of bacteria's organic matter and release of harmful gas, which is known as Crown corrosion.

Pipe-Arch Culvert (Single or Multiple)
Arch culverts are suitable for large waterway opening where fishes can be provided with a greater hydraulic advantage. Moreover, they provide low clearance and are definitely, much artistic. Pipe arches are particularly useful for sites where headroom is limited and also have a hydraulic advantage at low flows.

Advantages of Pipe-Arch Culvert

The features of pipe arch culverts are:

- Limited headroom condition
- Improved hydraulic capacity at a low flow
- Aesthetic shape and appearance
- Lightweight
- Easy to install

Box Culvert

Box culverts are made up of concrete and especially, RCC (Reinforced Concrete). The most challenging part in constructing a box culvert is that dry surface is needed for installing it. However, due to the strength of the concrete floor, water direction can be changed when a large amount of water is expected. This feature makes box culverts, one of the most commonly found types of the culvert.

Advantages of Box Culvert

Box Culverts are economical for the reasons mentioned below:

- The box culvert is a rigid frame structure and very simple in construction
- It is Suitable for non-perennial streams where scrub depth is not significant but the soil is weak. The bottom slab of the box culvert reduces pressure on the soil.
- Box culverts are economical due to their rigidity and monolithic action and separate foundations are not required.
- It is used in special cases, weak foundation.

Arch Culvert

An arch culvert is made up of metal, stone masonry, concrete, RCC etc. Construction does not take a lot of time and unlike box culvert, water diversion is not necessary, as it can be installed without disturbing the water current. Thus, it can be termed as a Low Profile Culvert. This type of culvert maintains the natural integrity of the wash bed. Arch culvert. Source:

Advantages of Arch Culvert

The advantages of using arch culverts over traditional box culverts and pipe culverts are as follows:

- Cost savings
- Accelerated construction schedule
- Greater hydraulic efficiency
- Pleasing aesthetics
- Design-build advantage

Bridge Culvert

Bridge culverts serve a dual purpose. It acts both as a bridge and a culvert. Generally, rectangular in shape, bridge culverts are constructed on rivers and canals. A foundation is laid under the ground level and pavement surface is laid on top of the series of culverts. Generally, we can term it as a Multi-Purpose culvert.

Advantages of Bridge Culvert Following are the main features of bridge culvert:

- Extension of the network by acting as a repeater
- Very strong

- Allows traffic to pass on it
- Highly strong foundation
- Most expensive river crossings

Metal Box Culvert

The metal box culvert is the economic alternative of the bridge. These bridges are manufactured from a standard structural plate or deep-corrugated structural plate. They are the perfect bridge replacement maintaining the same road grade level.

Advantages of Metal Box Culvert

The advantages are as follows:

- Durability
- Shorter construction period and easy installation
- Deformation ability
- Long service life

In most cases concrete culverts are preferred.

Concrete culverts may be reinforced or non reinforced. In some cases culverts are constructed in site called cast in situ culverts. Precast culverts are also available. By the combination above materials we can also get composite culvert types.

<u>causeway</u>

A causeway is a track, road or railway on the upper point of an embankment across "a low, or wet place, or piece of water" It can be constructed of earth, masonry, wood, or concrete. Timber causeways may also be described as both boardwalks and bridges. A causeway might of course as well be incorporated with one or a series of bridges in its midst. Design If the culverts are concentrated in the centre of the causeway, the high speed water jets coming out of these culverts will cause heavy scour at the sides of the culverts. This implies that in designing causeways the culverts should be distributed evenly throughout the length of the structure. When the water flows over the causeway it moves. The forward roller shown on the right moves the sand forward. The back roller makes the sand surface on the left side steeper and steeper until it collapses. This effect causes the foundation to be exposed very quickly unless effective protective measures are taken.

Construction Two trenches are dug at the up and downstream edges of the causeway. The trench at the downstream side should be at least 1.50 metres deep if an overflow of 50 cm over the roadway is expected . Between these trenches a suitable bed for the culverts is prepared of a well-graded gravel material. The provision of a 7.5 cm concrete floor is recommended. This floor should be indented to accommodate the shape of the culvert, so that the culvert is evenly supported. After the culverts are laid the head walls are constructed up to the road level and the area between the head walls is backfilled with a well-graded stony/gravelly material. Lean concrete may be used also as a backfilling material, although the costs of the structure will be considerably higher in this case.

The main types of causeway are:

1. Non-vented causeways;
2. Vented causeways;
3. High level causeways and low level submersible bridges.