

# RAILWAY ENGINEERING

## **INTRODUCTION**

Indian Railways is an Indian state-owned enterprise, owned and operated by the Government of India through the Ministry of Railways. It is one of the world's largest railway networks.

Railways were first introduced to India in the year 1853 from Bombay to Thane, nationalized as one unit, the Indian Railways, becoming one of the largest networks in the world. IR operates both long distance and suburban rail systems on a multi-gauge network of broad, metre and narrow gauges. It also owns locomotive and coach production facilities at several places in India and are assigned codes identifying their gauge, kind of power and type of operation.

As railway experience was gained, the design of rolling stock also evolved. Springing, body structure, wheels and axles all are subject to varying loads and stresses, when comparing slower speeds on rough roads to much faster speeds on railways, with a comparatively smoother ride.

Railway rolling stock generally runs on hard wheels on hard rails. The wheels are not only supported by the rails but are guided by them. The only exception to this is for a small number of metros where rubber tyres have been introduced. In this case the supporting function of the rail may be separated from the guiding function.

In all cases railway rolling stock will transmit vertical, horizontal and longitudinal forces to the track and its supports. Most railways have adopted twin rails and flanged wheels. Forces are transmitted to the rail structure either by direct bearing on the rail top from the wheel tyre, or by bearing laterally through the flange, or by longitudinal friction. Potential 'overturning' forces, caused by centrifugal force on curves, coupled with wind forces on exposed locations are resisted by vertical dead weight and super-elevation or 'cant' on curves.

## **Advantages of Railways**

The railways offers various advantages and for the purpose of convenience, they can be described in following three categories.

### **1. Economic Advantages**

- i) Employment to people in the form of staff required for smooth working of railways.
- ii) Encouragement to commercial farming.
- iii) Increase in cost of land thereby increase of national wealth.
- iv) Industrial development and growth because of mobility of labour and raw materials.

- v) Stabilization of prices due to easy, speedy & efficient mobility of products & natural resources.
- vi) Increase in mobility of people and thereby relieving some extent the congestion of big cities.
- vii) Transporting food and clothes in times of emergencies like floods and famines etc.

## 2. Political Advantages

- i) Easy control of the central administration.
- ii) Development of a national mentality in the minds of people.
- iii) Migrating population on a mass scale.
- iv) Mobilizing troops and war equipments in times of war and emergencies.
- v) Unity of people of different castes, customs and religions.

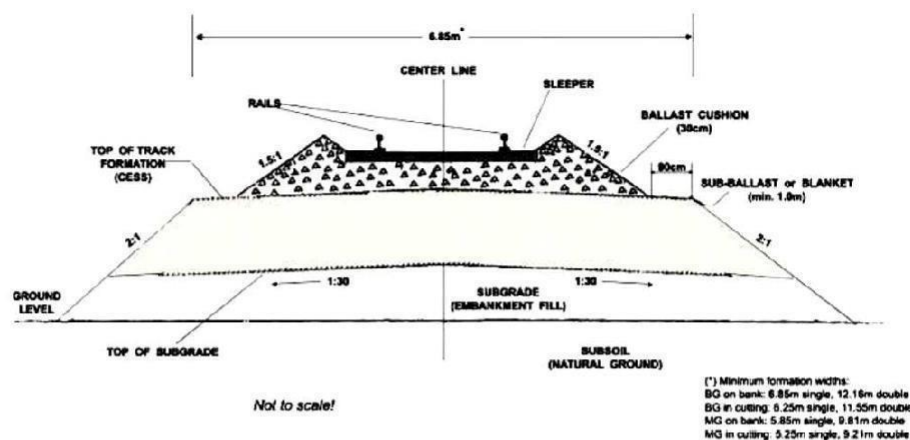
## 3. Social Advantages

- i) Broadening the social outlook of masses as people can visit all the parts of country and be proud of this great country.
- ii) Easy access to religious places of importance.
- iii) Providing convenient and safe mode of transport.
- iv) Removal of feeling of isolation as the railway has proved to be the most safe, economic and comfortable mode of conveyance.

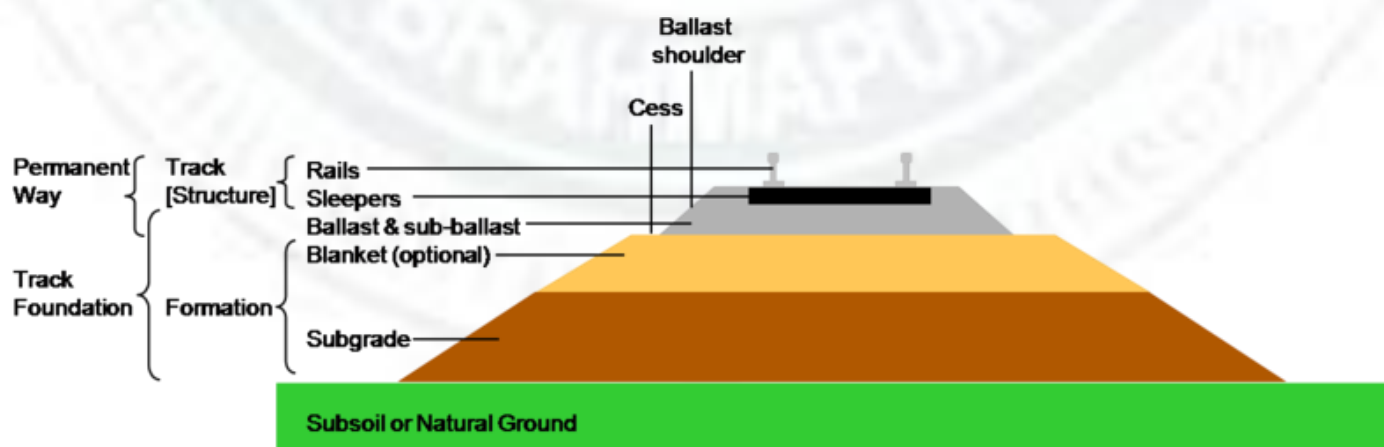
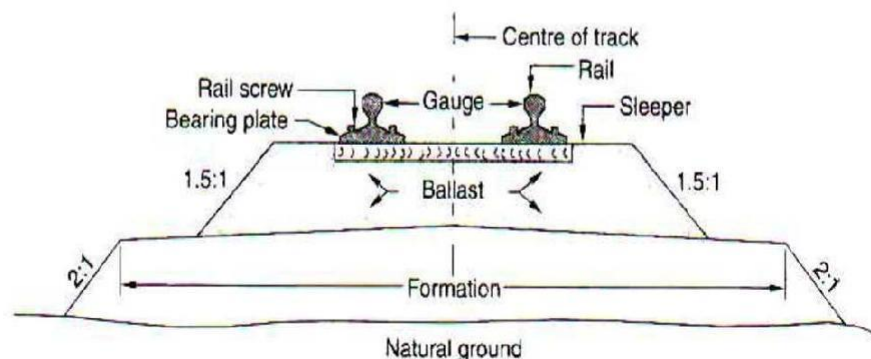
## CHAPTER-2

### Permanent way

Cross section of a permanent way:



Basic functions of various components of a railway track:



The finished or completed track of a railway line is commonly known as Permanent Way. It essentially consists of following three parts.

1. Rails
2. Sleepers
3. Ballast

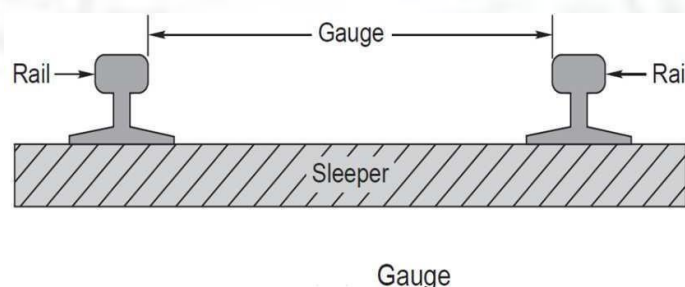
The rails are fixed with each other by means of various rail fastenings and they rest on sleepers which are laid at right angles to them. The sleepers in turn rest on ballast which is spread over the formation ground prepared for the railway track.

#### **Requirements of an ideal permanent way**

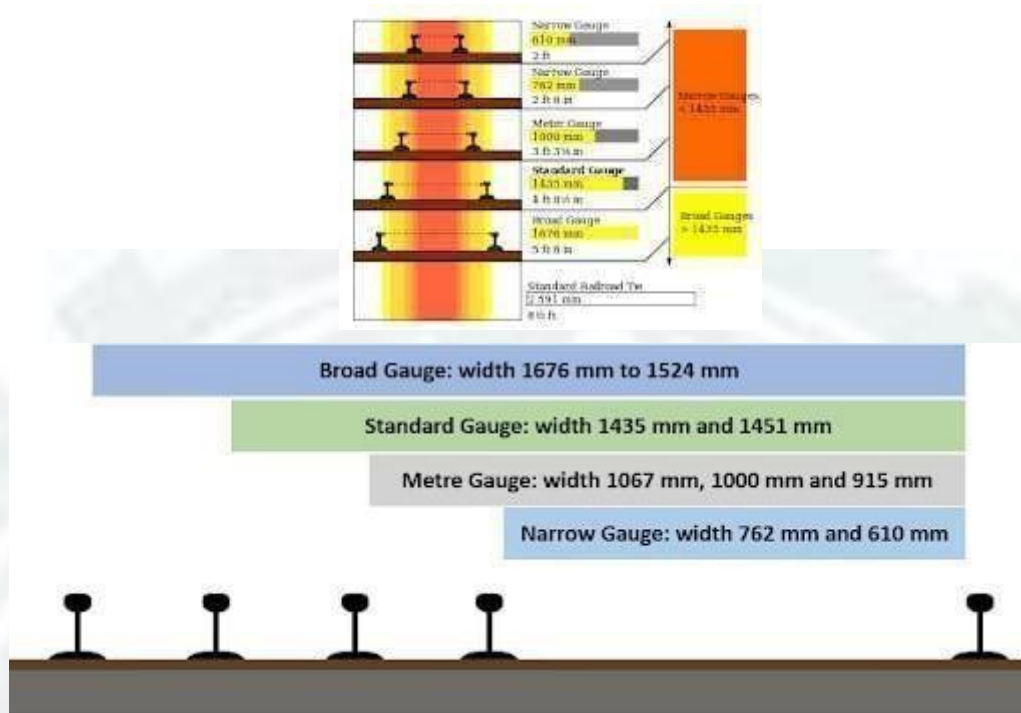
1. The gauge of track should be uniform and there should not be varying gauges.
2. There should be minimum friction between the wheels of rolling stock and the rails.
3. Facilities should be provided at various points along the permanent way to repair, replace or renew the damaged portion of the track.
4. The design of the permanent way should be such that the load of the train is uniformly distributed over it.
5. The components of the permanent way should be so selected as to produce a permanent way with a certain degree of elasticity to prevent the shocks due to impact.
6. The gradient provided on the permanent way should be even and uniform.
7. The special attention should be given on the design of permanent way on curves.
8. The overall construction of the permanent way should be such that it requires minimum maintenance.
9. The permanent way should possess high resistance to damage at the time of derailment.
10. The drainage facility should be perfect & The rail joints should be properly designed and maintained.

#### **Rail Gauges**

In India, the gauge of a railway track is defined as the clear minimum perpendicular distance between the inner faces of the two rails.







The different gauges used in India can be broadly classified as following four types.

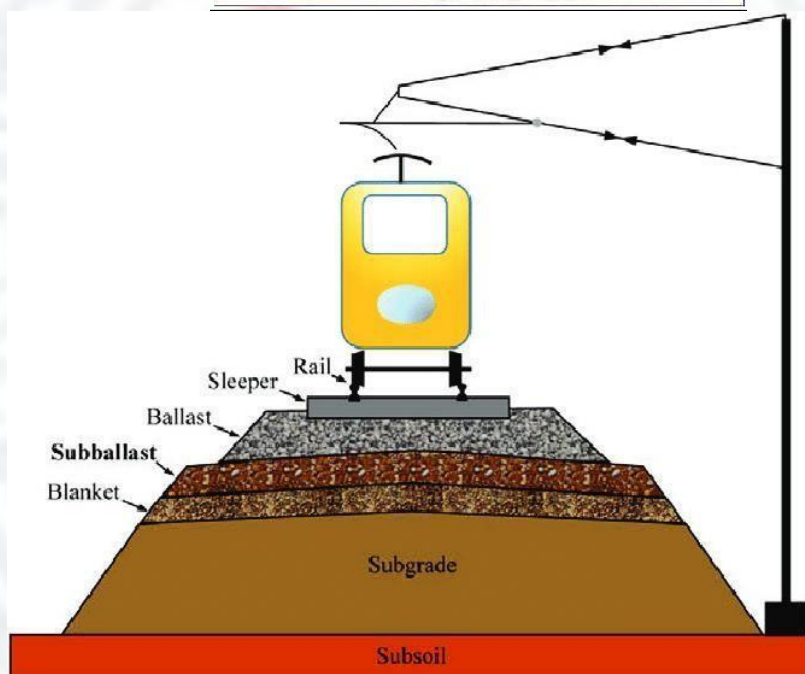
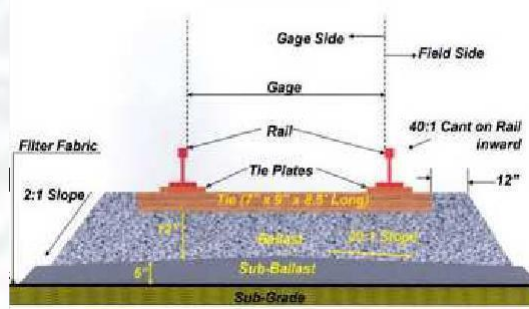
1. Broad Gauge : Width 1676 mm to 1524 mm.
2. Standard Gauge : Width 1435 mm and 1451 mm.
3. Meter Gauge : Width 1067 mm, 1000 mm and 915 mm.
4. Narrow Gauge : Width 762 mm and 610 mm.

#### **Suitability of these gauges under different conditions**

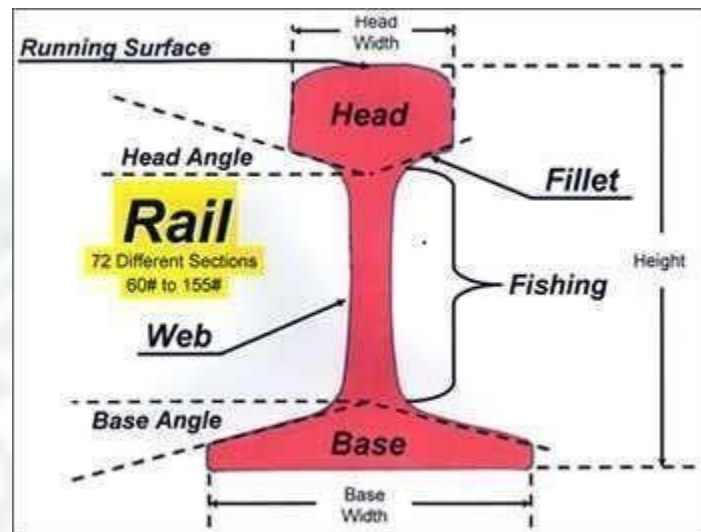
1. Traffic condition - If the intensity of traffic on the track is likely to be more, a gauge wider than the standard gauge is suitable.
2. Development of poor areas - The narrow gauges are laid in certain parts of the world to develop a poor area and thus link the poor area with the outside developed world.
3. Cost of track - The cost of railway track is directly proportional to the width of gauge. Hence, if the funds available is not sufficient to construct a standard gauge, a meter gauge or a narrow gauge is preferred rather than to have no railways at all.
4. Speed of movement - The speed of a train is a function of the diameter of wheels which in turn is limited by the gauge. The wheel diameter is usually about 0.75 times the gauge width and thus, the speed of a train is almost proportional to the gauge. If higher speeds are to be attained, the B.G. track is preferred to the M.G. or N.G. track.
5. Nature of Country - In mountainous country, it is advisable to have a narrow gauge of track since it is more flexible and can be laid to a smaller radius on the curves. This is the reason why some important railways, covering thousands of kilometers, are laid with a gauge as narrow as 610 mm.

## CHAPTER-3

## TRACK MATERIALS

***Typical Track Structure******Ballasted Track***

## RAILS



### Function of Rails

- i. To transmit the moving loads to the sleepers
- ii. To provide strong, hard and smooth surface for the train journey
- iii. To bear the stresses developed in the track due to temperature changes and loading patterns
- iv. To resist breaking forces caused due to stoppage of trains.

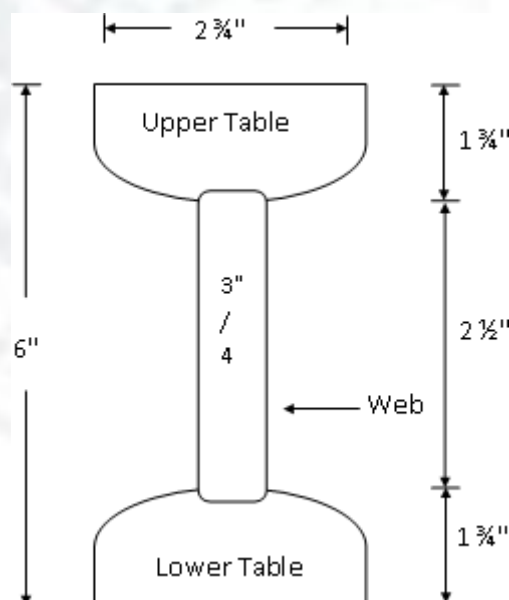
### Requirements of an Ideal Rail

1. The rail section consists of three components: head, web and foot. It should be designed for optimum nominal weight to provide for the most efficient distribution of metal in its various components.
2. The bottom of head and top of the foot should be given such shapes that fish-plates can easily be fitted.
3. The C.G. of the rail section should be located very near to the centre of height of rail so that maximum tensile and compressive stresses are more or less the same.
4. The depth of head of rail should be sufficient to allow for adequate margin of vertical wear.
5. The rail should possess adequate lateral and vertical stiff nesses.
6. There should be balanced distribution of metal in the head,web and foot of rail so that each of them is able to fulfill its assigned function.
7. The surface of rail table and gauge face of rail should be hard and should be capable of resisting wear.

### TYPES OF RAIL SECTIONS

#### **Double headed rails:**

These were the rails which were used in the beginning, which were double headed and consisting of a dumb-bell section. The idea behind using these rails was that when the head was worn out in course of time, the rail can be inverted and reused. But as time passed indentations were formed in the lower table due to which smooth running over the surface at the top was impossible.



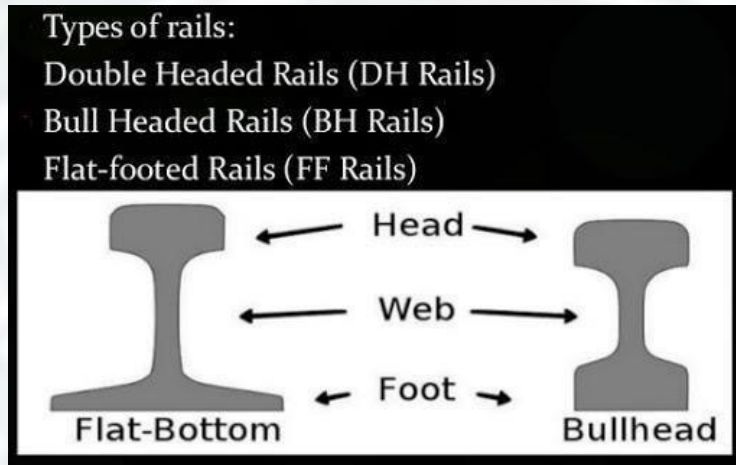
#### **Bull headed rails:**

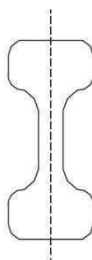
In this type of rail the head was made a little thicker and stronger than the lower part by adding more metal to it, so that it can withstand the stresses.



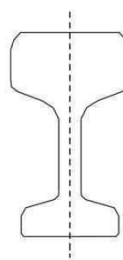
**Flat footed rails:**

These rails are also called as vignole's rails. Initially the flat footed rails were fixed to the sleepers directly and no chairs and keys were required. Later on due to heavy train loads problems arose which lead to steel bearing plates between the sleeper and the rail. at rail joints and other important places these are the rails which are most commonly used in India.

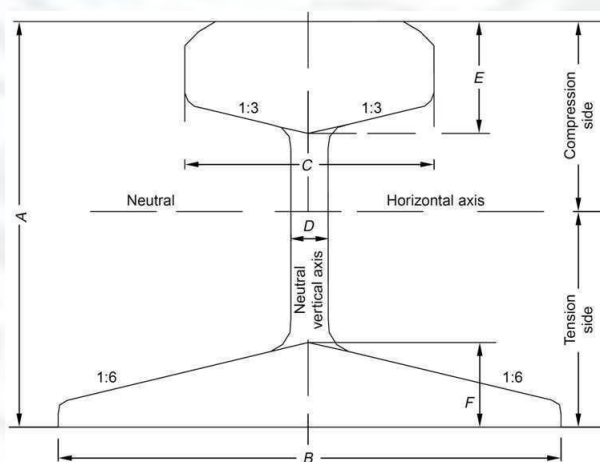
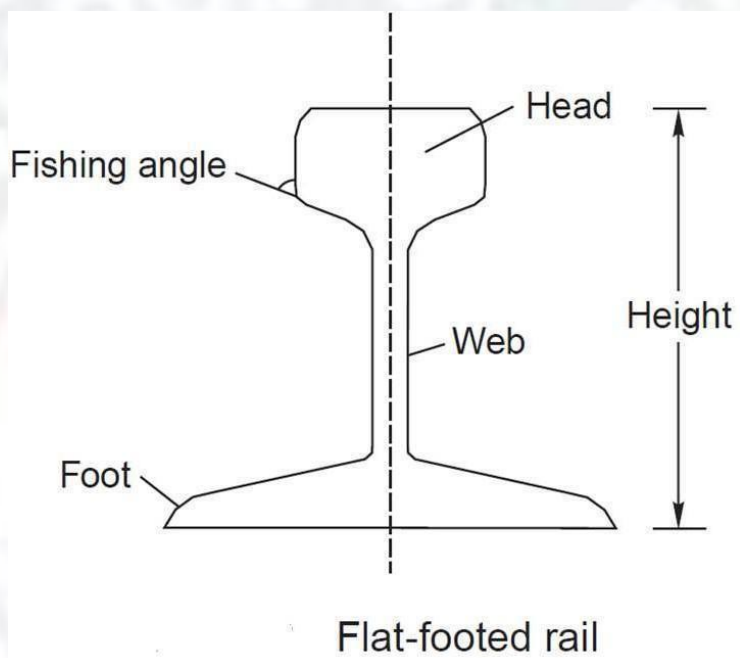




Double headed rail



Bull headed rail



Standard flat-footed rail section

**Length of the Rails:**

From the consideration of strength of the track maximum possible length is advisable as it will reduce the number of the joints, less number of fittings and fixtures and economical maintenance. But in practice the following factors are considered to decide the length of rails.

- i) Ease of transportation
- ii) Reasonable cost of manufacture
- iii) Ease in loading into the available wagons
- iv) Development of temperature stresses

Indian Railways have adopted the following length of rails in practice.

- i) For BG tracks = 13 m (42')
- ii) For MG & NG tracks = 12 m (39')

## **Rail Joints**

Rail joints are necessary to hold the adjoining ends of the rails in the correct position, both in the horizontal and vertical planes.

### **Types of Rail joints:**

The following are the type of rail joints

#### **Supported rail joints:**

When the rail ends rest on a single sleeper it is termed as supported joint. The duplex joint sleeper with other sleepers is an example of the supported joint.

#### **Suspended rail joint:**

When rail ends are projected beyond sleepers it is termed as suspended joint. This type of joint is generally used with timber and steel through sleepers.

#### **Bridge joints:**

When the rail ends are projected beyond sleepers as in the case of suspended joint and they are connected by a flat or corrugated plate called as bridge plate it is termed as a bridge joint.

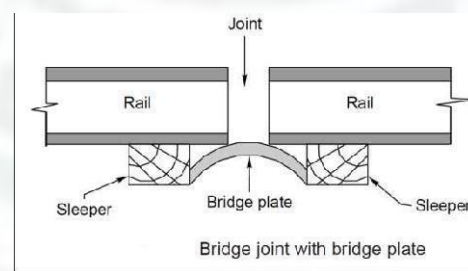
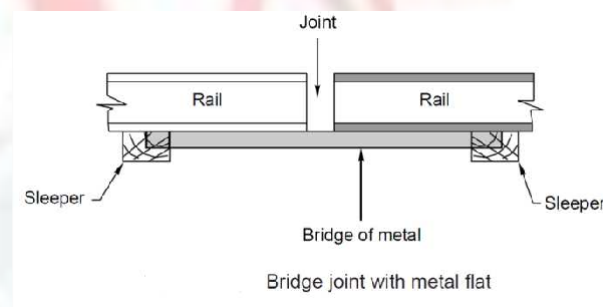
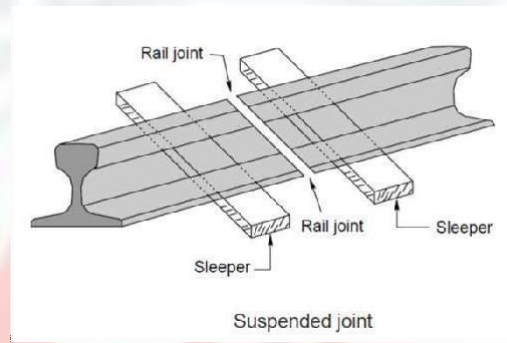
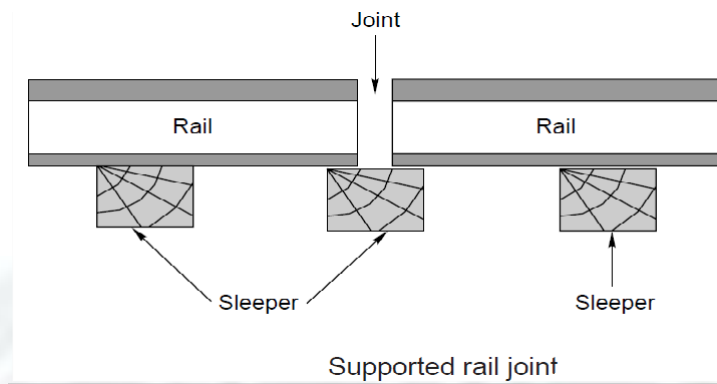
#### **Insulated joint:**

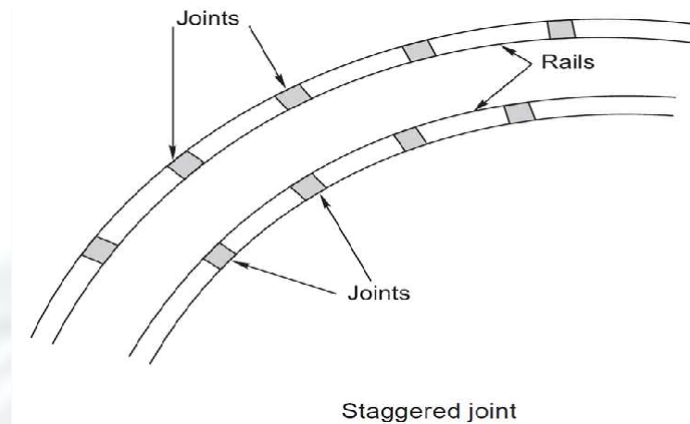
When an insulating medium is inserted in a rail joint to stop the flow of current beyond the track circuited part then that type of joint is called an insulated joint.

#### **Compromise joint:**

Where two different rail sections are required to be joined together it is done by means of fish plated which fit both rails and this joint is termed as compromise joint.







### **Requirements of an Ideal Rail Joint**

- i) Ends to remain true
- ii) Should be strong and stiff
- iii) Provision for expansion
- iv) Perfectly elastic
- v) Ends should not get battered
- vi) Provision for easy removal and replacement
- vii) Economical in cost

### **Welded rail joint:**



### **Purpose of Welding of Rails:**

- To increase the length of the rails
- To repair the worn out or damaged rails
- To build up worn out points and rails on the sharp curves

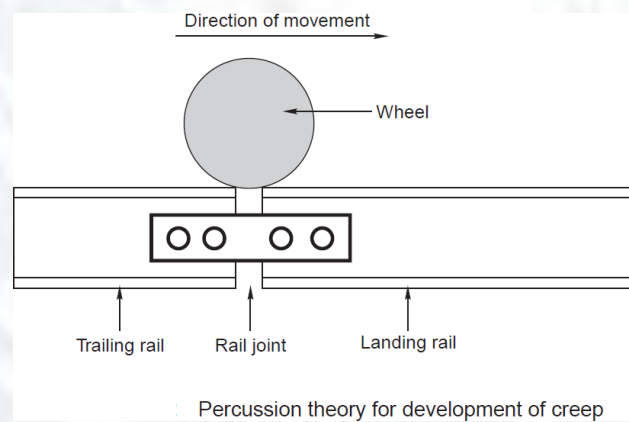
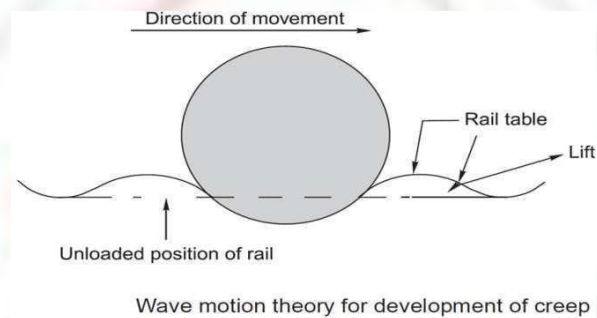
**Advantages of welding rails:**

- Reduces the creep and friction due to increase in length of rail.
- Expansion effect due to reduction in temperature.
- Increase the life of the rails due to decrease in wear.
- It facilitates track circuiting on electrified tracks.
- The cost decrease because as the length increase automatically the number of joints decreases.
- High frequency vibrations due to heavy moving loads are decreased due to the heaviness of the rails.

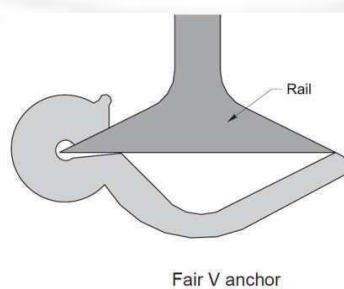
## CREEP OF RAIL



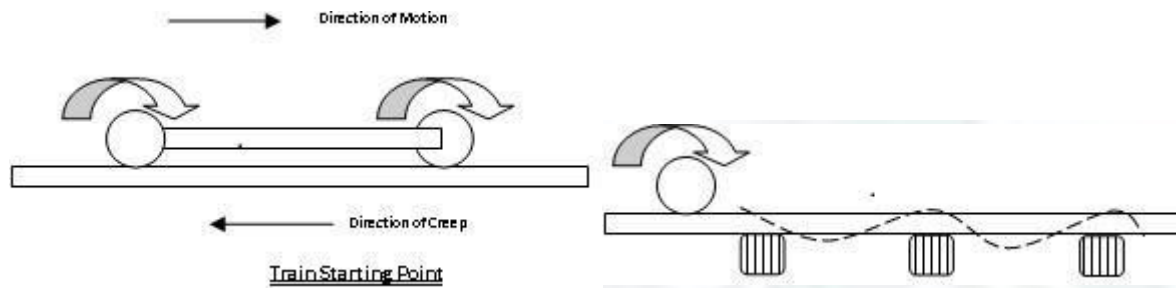
Creep in rails denotes longitudinal movement of rails in the track.



The following figure shows a type of Fair V-anchor which is used in the track to prevent creep of rails.







It is defined as the longitudinal movement of rails with respect to sleepers in a track.

#### Causes of creep:

1. Closing of successive expansion spaces at rail joints in the direction of creep and opening out of joints at the point from where the creep starts.
2. Marks on flanges and webs of rails made by spike heads by scraping or scratching as the rails slide.

#### Effects of Creep:

1. Sleepers move out of position which leads to the change in gauge and alignment of the track.
2. Rail joints are opened out of their limit in some case and stresses are set up in fish plates and bolts which leads to the breakage of the bolts.
3. Pints and crossings get disturbed.
4. Maintenance and replacement of tracks becomes difficult.
5. Smashing of fish plates and bolts, bending of bars, kinks at joints are other effects of creep.

## Sleepers & Ballast

#### Definition:

Sleepers (known in the US as railroad ties) are used as a base for laying railway tracks. Sleepers were traditionally made from wood but are now usually made from concrete. Ties are laid on top of sand, gravel or heavy crushed stone - called ballast.

### **Functions of sleepers**

The functions of sleepers are as follows

1. To hold the rails in correct gauge i.e exact gauge in the case of straight and flat curves, loose gauge in the case of sharp curves and tight gauge in the case of diamond crossings.
2. To act as an elastic medium between the ballast and rail to absorb the blows and vibrations of moving loads.
3. They also add to the longitudinal and lateral stability of the permanent track on the whole.
4. They also provide means to rectify track geometry during service life.
5. To support the rails at proper level in straight tracks and at proper super elevation on curves.
6. To distribute the load from the rails to the index area of ballast underlaying it or to the girders in the case of bridges.
7. To hold the rails in proper level.

### **Requirements of Good Sleepers**

1. It should be economical
2. It should be minimum possible initial and maintenance costs.
3. The fittings should be such that they can be easily adjusted.
4. Weight should not be too heavy or too light.
5. It should not be easily damaged by anti Nationals.
6. They should be capable of resisting shocks and vibrations.
7. The insulation of rails should be possible for track circuiting, if required through sleepers.
8. It should be designed that it could not be disturbed from its position easily by the passage of trains.

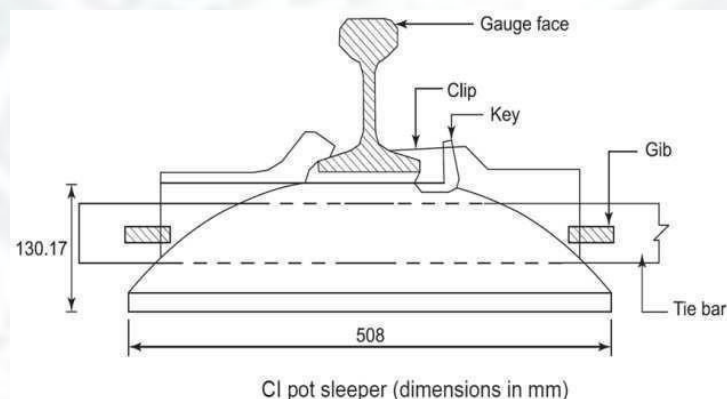
### **Classification of Sleepers**

Sleepers can be classified into the following types according to the material of construction.

#### **1. Wooden sleepers**

#### **2. Metal sleepers**

- Cast iron sleepers



### 3. Steel sleepers

### 4. Concrete sleepers

- Reinforce concrete sleepers
- Prestressed concrete sleepers

### **Timber or Wooden Sleepers**

wooden sleepers are regarded as the best as they satisfy almost all the requirements of a good sleeper. The life of timber sleepers depend upon their ability to resist

- Wear and tear
- Decay
- Attack by white ants
- Quality of the timber used

#### **Advantages:**

- It is easily available in all parts of india
- Fittings are few and simple in design
- They are easy to lay, relay, pack, lift and maintain
- They are suitable for all types of ballast
- They are able to resist the shocks and vibrations of the heavy moving loads
- They are economical

#### **Disadvantages:**

- They are subjected to decay, attack by white ants, warping, cracking and end splitting
- It is difficult to maintain the gauge in the case of wooden sleepers.
- It is difficult to maintain the alignment in the case of wooden sleepers.
- They have got minimum service life(12 to 15 yrs) as compared to other types of sleepers



## **Concrete Sleepers**

Concrete sleepers are made of a strong homogeneous material, impervious to effects of moisture and unaffected by the chemical attacks. It is moulded easily to size and shape required and it is an ideal material to withstand stresses introduced by fast and heavy traffic.

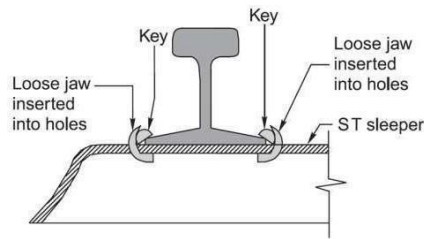
### **Advantages**

1. The concrete sleepers are quite heavy and thus provide longitudinal, lateral and vertical stability. Because of their weight, these sleepers are more suitable to LWR tracks.
2. The concrete sleepers result in reduced rail bending stresses.
3. The concrete sleepers reduce the wear of rolling stocks.
4. The concrete sleepers produce less vertical motion and thus provide a comfortable journey due to less noise.
5. The concrete sleepers have flat bottoms. That's why modern method of track maintenance i.e. MSP and machine maintenance can be suitably employed.
6. The concrete sleepers are neither inflammable nor subjected to damage by corrosion or termite.
7. These sleepers have a long useful life of 50 years. It means rail and sleeper renewals can be matched.
8. The concrete sleepers with their fastening system maintain gauge, cross levels, twist, alignment, longitudinal level and unevenness of the track.
9. The concrete sleepers are suitable for track circuiting.
10. The concrete sleepers can be manufactured from local resources.

### **Disadvantages**

1. They are not economical because of high cost of construction.
2. In case of derailments, heavy damage is caused.
3. High standard of maintenance of track is required.
4. The design and construction are both complicated.
5. They are more rigid.
6. They do not have any scrap value.

## **Steel sleepers**



Sleeper with loose jaws inserted into holes

Steel sleepers are lightweight, dimensionally more accurate than wooden or concrete and regarded as an effective technical solution for modern rail networks.

### Advantages of steel Sleepers

1. They are manufactured by a simple operation.
2. They can be easily handled as these are light in weight as compared to other types of sleepers. Hence, damages during handling and transporting are less.
3. Less number of fastenings are required and that too simple in nature.
4. The maintenance and adjustment of gauge are easy as compared to the other of sleepers.
5. These sleepers are rolled sections in one piece.
6. Their life is longer than that of other types of sleepers.
7. They provide better lateral rigidity to the track.
8. They are not attacked by vermins.
9. They are not susceptible to fire hazards.
10. Their scrap value is good.

### Disadvantages of Steel of Sleepers

1. The steel sleepers possess the following disadvantages:
2. They get easily rusted and corroded.
3. They develop cracks at rail seats or near lugs.
4. Their lugs get broken easily.
5. The steel sleepers do not provide effective track circuiting.
6. The steel sleepers can only be for the type of rails for which these are manufactured.
7. These develop the tendency to become center bound because of slope at both ends.
8. The overall cost of steel sleepers is more than that of timber sleepers.

## **Ballast**

### **Definition:**

It is a layer of broken stones, gravel or any other such gritty material laid and packed below and around sleepers.

### **Functions of ballast:**

- To distribute the loads uniformly over the subgrade.
- To provide good drainage for the track structure.
- To provide elasticity and resilience to track for getting proper riding comfort.
- To held the track structure to line and grade.
- To reduce dust.
- To prevent growth of brush and weeds.

### **Requirements of Good Ballast**

1. It should be tough and should not crumble under heavy loads.
2. It should not make the track dusty or muddy.
3. It should offer resistance to abrasion and weathering.
4. It should not produce any chemical reaction with rails and sleepers.
5. The materials should be easily workable.
6. It should retain its position and should not be distributed.

### **Materials used as Ballast**

1. Broken Stone - Broken stone is one of the best materials for railway ballast to be used on the railway tracks. Almost all the important railway tracks are provided with broken stone. The stone to be used as railway ballast should be hard, tough nonporous and should not decompose when exposed to air and light. Igneous rocks like quartzite and granite forms the excellent ballast materials. When these are not available then lime stone and sand stone can also be used as good ballast material.

1. Gravel - Gravel ranks next in its suitability for use as materials for ballast and is used in many countries of the world in very large quantities. Gravel consists of worn fragments of rocks occurring in natural deposits. Gravel or shingle may be obtained from river bed or it may be dug out from gravelpits.

### Advantages of Gravel

1. It is cheaper in its cost as it has not to be broken as like stone ballast
2. It has got excellent drainage properties, if properly cleaned

### Disadvantages of Gravel

1. It easily rolls down under the vibrations and packing under the sleepers get tense
2. The variation in size is considerable and hence requires screening before use
3. Gravel as obtained from gravel pits, is full of earth and hence requires proper cleaning if proper drainage of the track is to be done.

3. Cinders Or Ashes- The residue from the coal in locomotives or other furnaces is called cinder or ashes. It is one of the universal forms of ballast as it is a byproduct of all the railway which uses coal as a fuel.

### Advantages of Cinders or Ashes

1. Handling of the material is not cumbersome this material can be handle easily
2. Cost is very low and hence can also be used for sidings
3. It has got fairly good drainage properties
4. Large quantities of this material can be made available at short notice.
5. In case of emergence such as caused by the destruction of portion of railway track during floods. This material proves to be very useful and is used in the formation repairing as well as for packing of track.

### Disadvantages of Cinders or Ashes

1. It is highly corrosive and cannot be used where steel sleepers are fixed
2. The foot of the rails get affected due to use of this type of material as ballast
3. It is very soft and can easily be reduced to powder under vibrations and hence the track becomes very dusty. This is objectionable particularly in dry weather.

4. Sand- Sand is another good materials for railway ballast , coarser sand is to be preferred to finer sand and the best sand is that which contains a quantity of fine gravel varying in size from 1/8 upwards.

### Advantages of Sand

1. If the sand is free from earth and vegetation then it has good excellent properties to drain off water immediately
2. It is cheaper if available in nearby locality
3. It produces very silent track and hence are suitable for packing cast iron pot sleepers.

### Disadvantages of Sand

1. It gets easily disturbed under vibrations and hence its maintenance is very difficult
2. The sand can be easily washed off or blown away and hence requires frequent renewal.
3. The sand particles may get into the moving parts of the vehicles and produces friction.



This leads to heavy wear of vehicles.

5. Kankar- Kankar a lime agglomerate is found in many places in the form of nodules of varying sizes.

Advantages of Kankar:

- i. Kankar is suitable Materials for ballast when other good material for ballast is not available
- ii. Kankar is good for light traffic on metre and narrowgauge

Disadvantages of Kankar

- 1. It is very soft and can be reduced to powder form easily, hence, making the track dusty.
- 2. The maintenance of track is very difficult

6. Moorum-The decomposition of laterite results into the formation of moorum. It has red and sometimes yellow color. The best moorum is that which contains large quantities of small laterite stones.

Advantages of Moorum

- 1. Moorum is good materials for ballast when other material for ballast is not available.
- 2. Moorum can be safely used on newly laid track and acts as a soling when broken stones are laid afterwards.
- 3. Moorum has got good drainage properties

Disadvantages of Moorum

- 1. Moorum is very soft and reduces to powder and hence to dust form in short time.
- 2. Maintenance of tracks laid with this material is difficult

7. Brick Ballast Or Brick Bats-Sometimes the broken pieces of over burnt bricks, called brickbats, are used as materials for ballast.

#### Advantages of Brick Ballast

1. It has got excellent drainage properties
2. They can be used as good ballast material where suitable material for ballast is either unavailable or uneconomical

#### Disadvantages of Brick Ballast

1. Brickbats turn down into powder form easily and hence the track becomes dusty
2. Maintenance of the track laid with this material as ballast is very difficult.
3. Rails are often corrugated on the tracks laid with this material as ballast

8. Selected Earth-Selected earth may be used as material for railway ballast for sidings and also for newly laid tracks.

#### **Track fixtures for BG**

Rail joints – Fish plates – Fish bolts- Fang bolts- Hook bolts – Rail chairs and keys – Bearing plates – Blocks – Spikes-Elastic fastenings- Anchors & Anti creepers

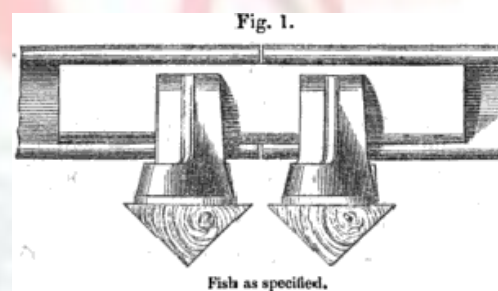
#### **Fastening**

A rail fastening system is a means of fixing rails to railroad ties. The terms rail anchors, tie plates, chairs and track fasteners are used to refer to parts or all of a rail fastening system. Various types of fastening have been used over the years.

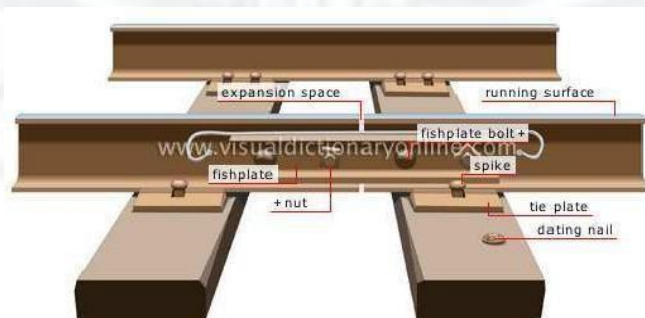
## Fish Plates

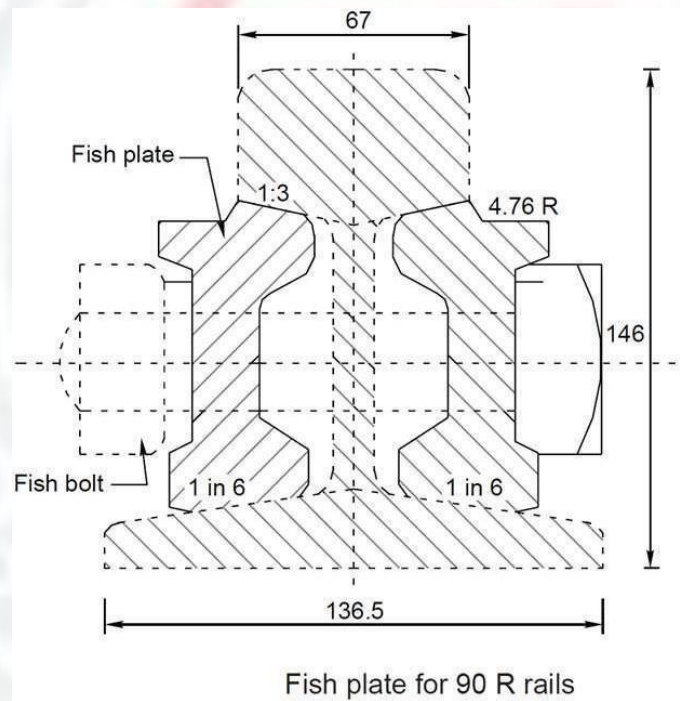
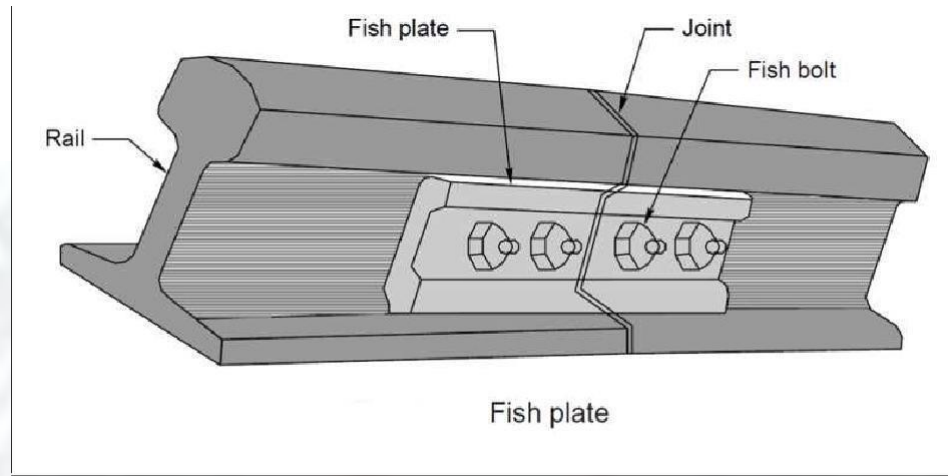


In rail terminology, a fishplate, splice bar or joint bar is a metal bar that is bolted to the ends of two rails to join them together in a track. The name is derived from fish, a wooden bar with a curved profile used to strengthen a ship's mast. The top and bottom edges are tapered inwards so the device wedges itself between the top and bottom of the rail when it is bolted into place. In rail transport modelling, a fishplate is often a small copper or nickel silver plate that slips onto both rails to provide the functions of maintaining alignment and electrical continuity.

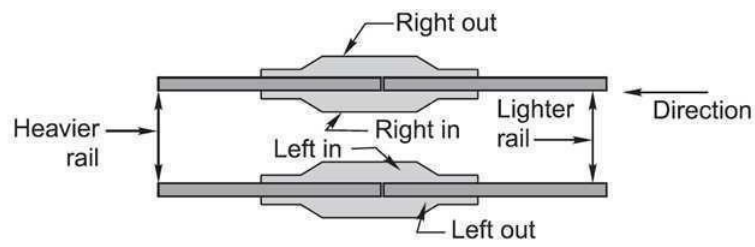


## **The first railway fishplate**

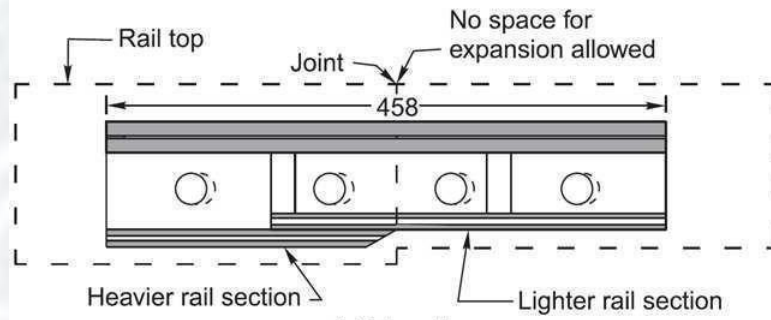




### **Combination Fish Plates**

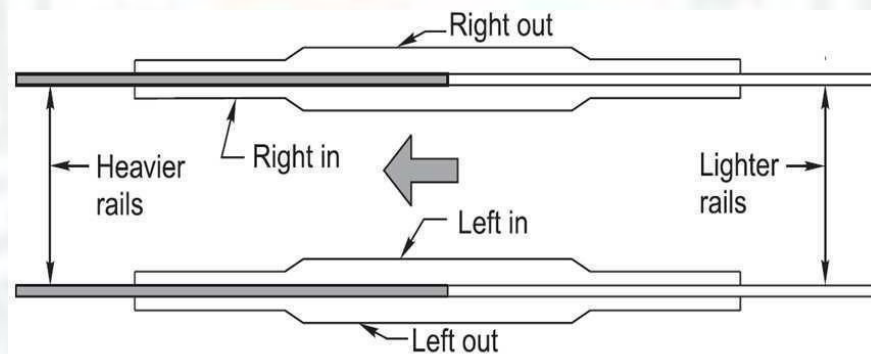


(a) Plan



(b) Elevation

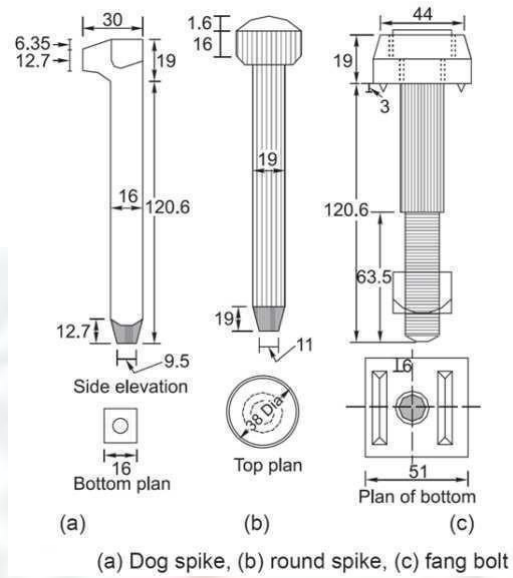
Combination fish plate (dimensions in mm)



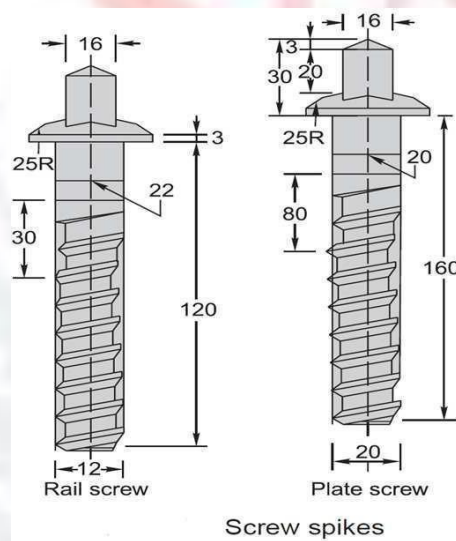
Marking of combination fish plates

**Fang Bolts**

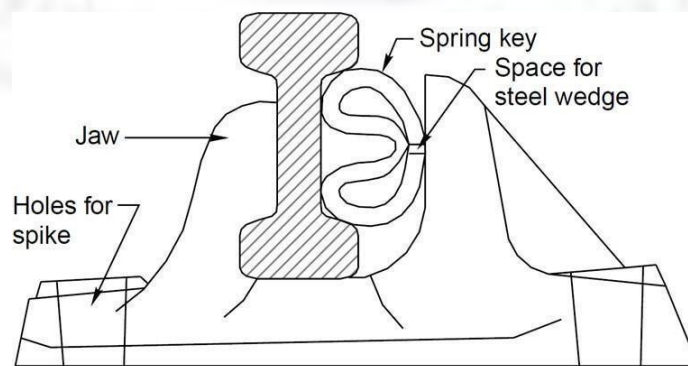
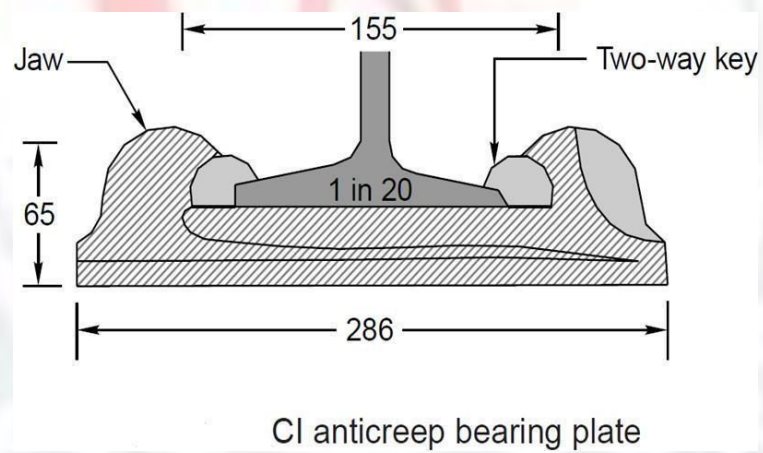
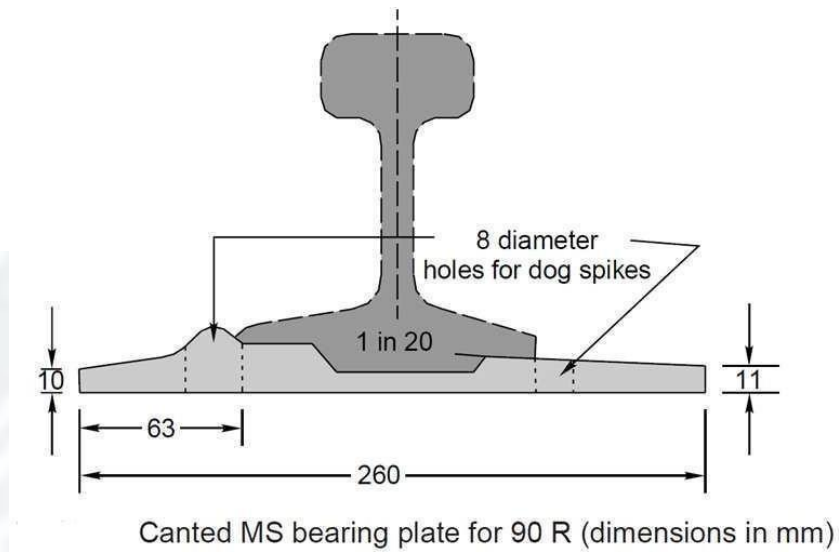




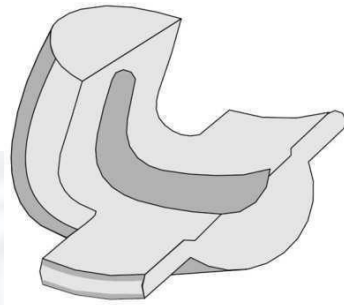
### Screw Spikes



### Bearing Plates

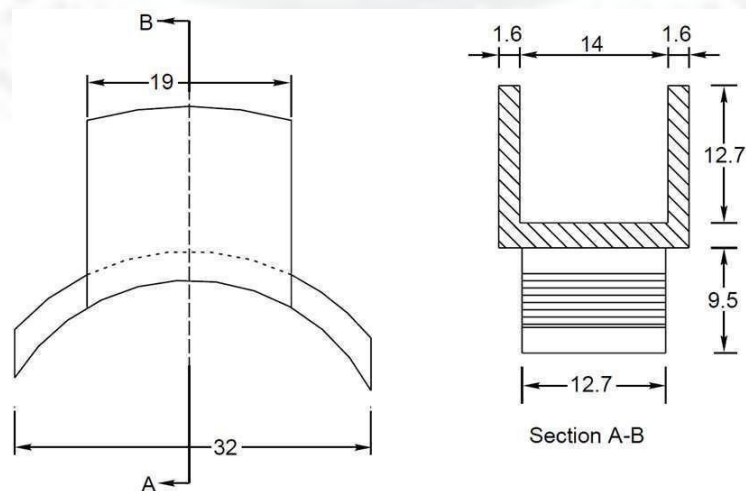
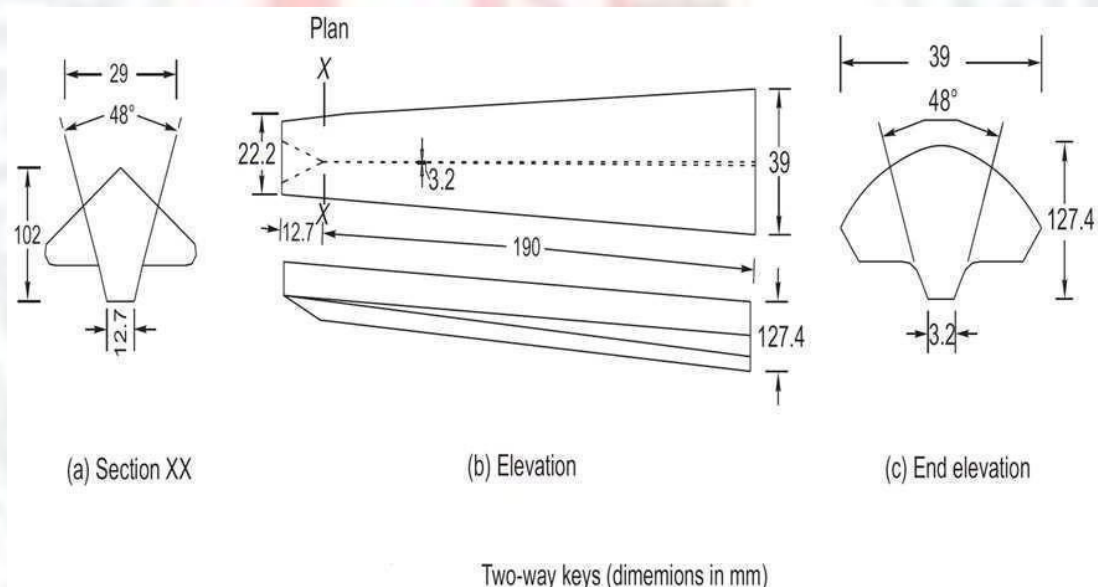


### Fittings of Steel Trough Sleepers

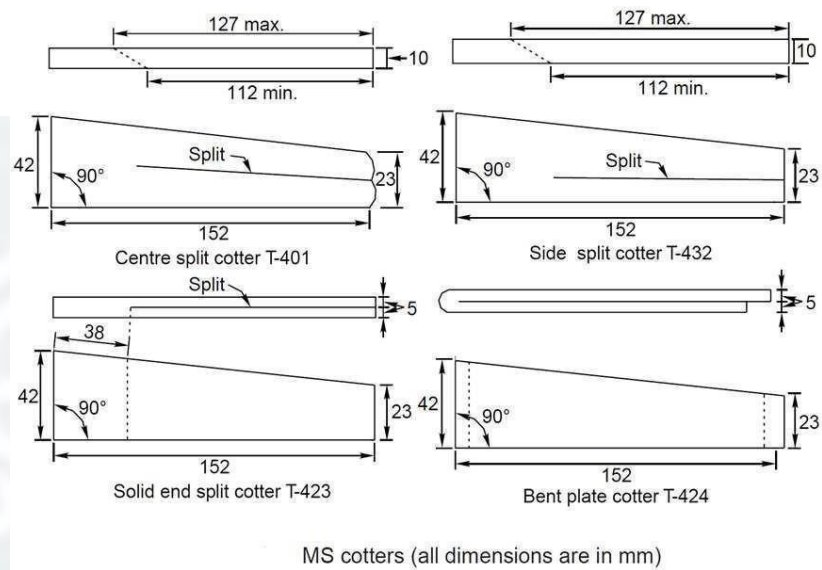


Spring steel loose jaw

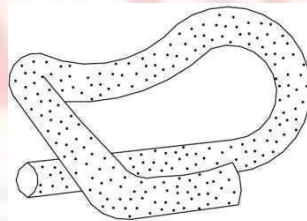
### Rubber Coated & Epoxy-coated Fish Plates



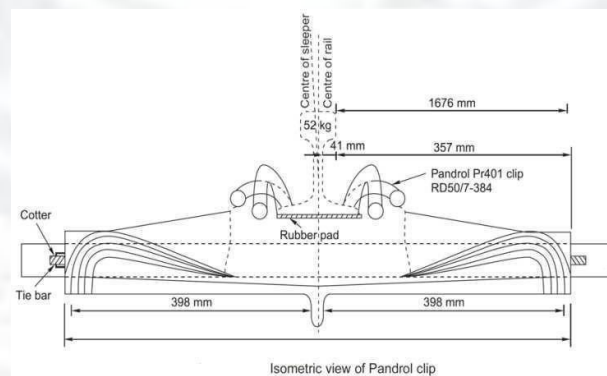
Mota Singh liner (all dimensions are in mm)



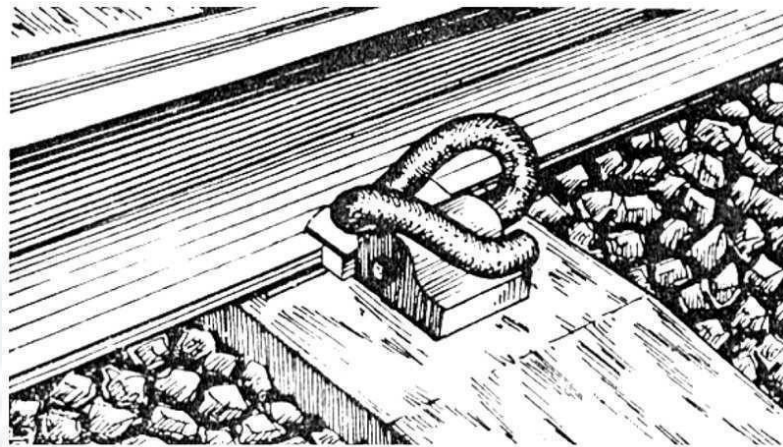
MS cotters (all dimensions are in mm)



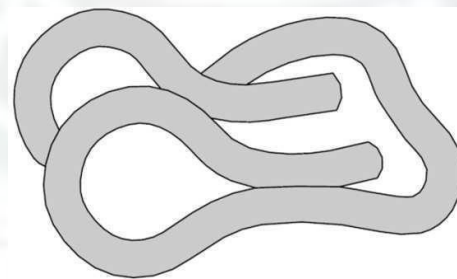
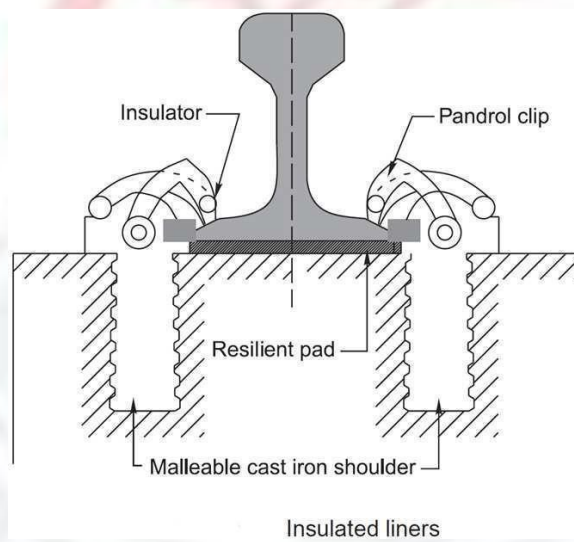
Pandrol clip or elastic rail clip



Isometric view of Pandrol clip

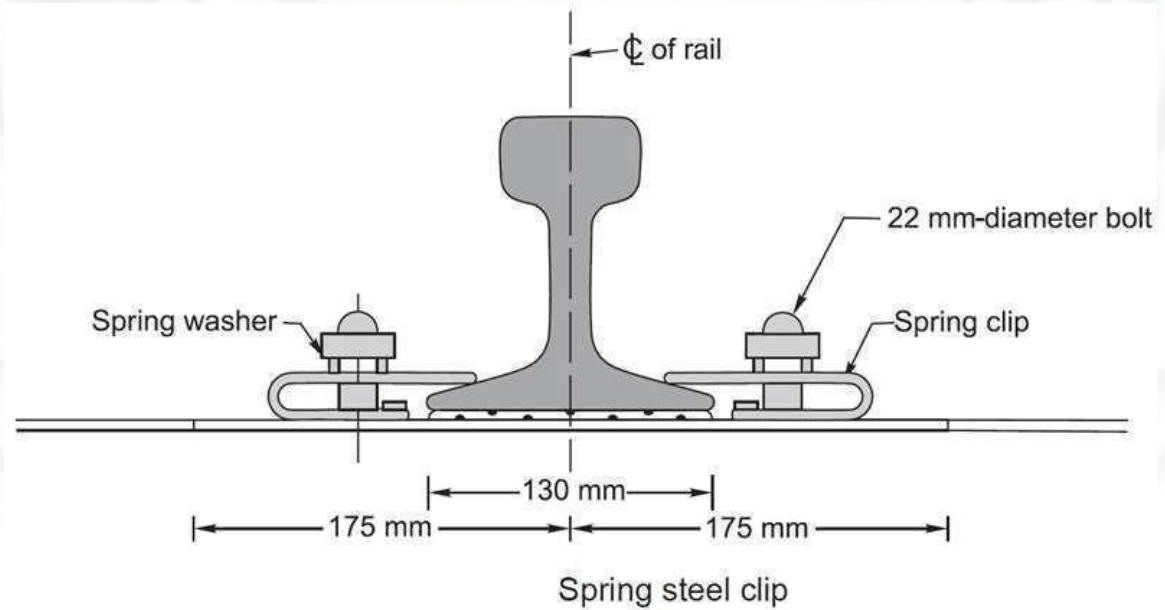
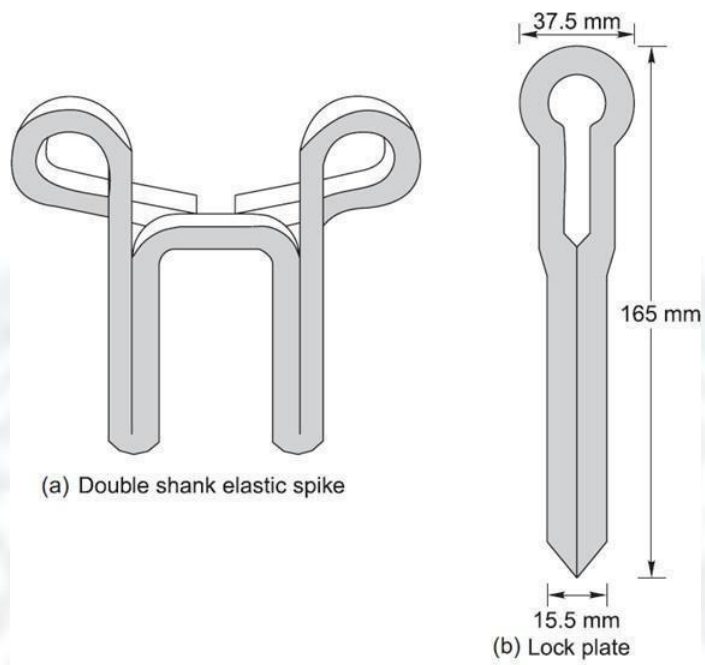


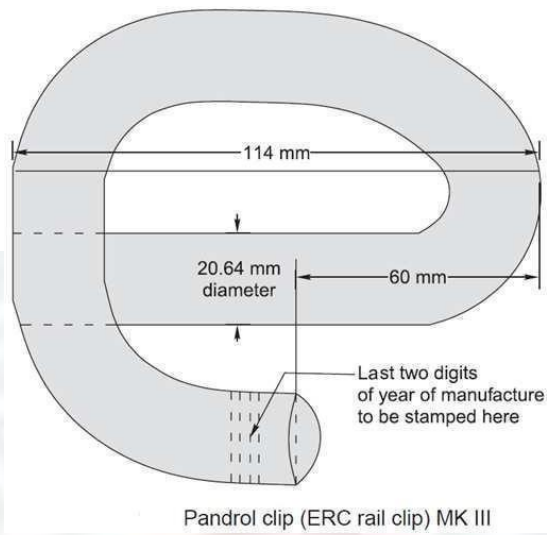
Pandrol clip fixed to the rail seat



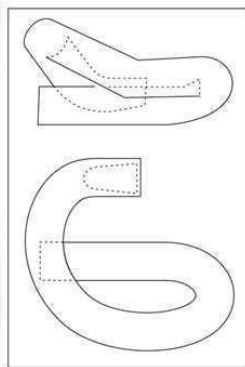
IRN 202 clip



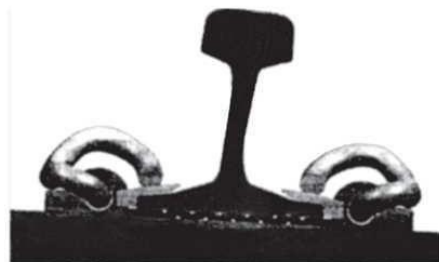




### **New Elastic Fastening ( G Clip)**



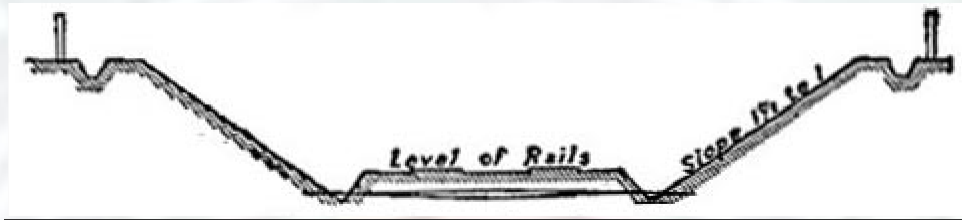
Logwell G clip



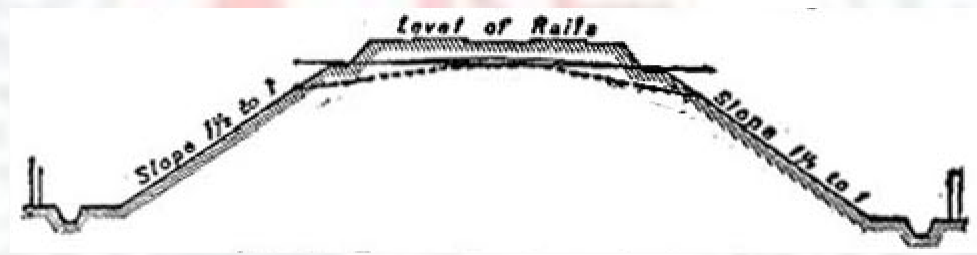
Isometric view of G clip assembly

## CHAPTER-4

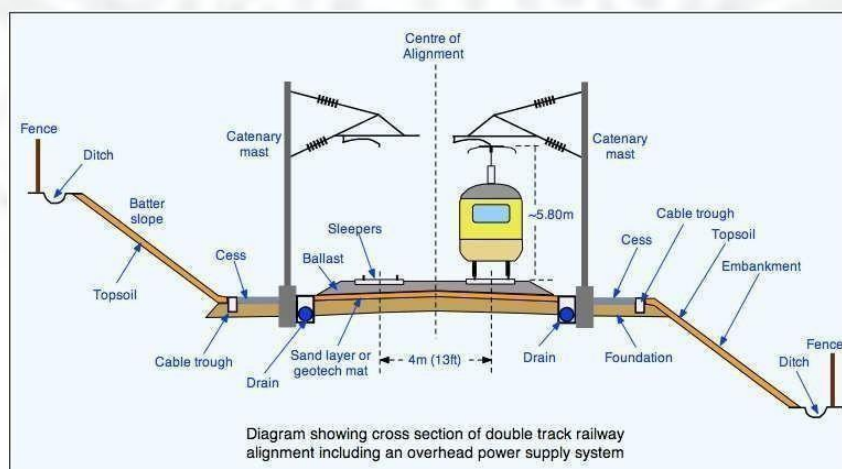
### Geometric for Broad gauge



Typical Section of Railway in Cutting.



Typical Section of an embankment.



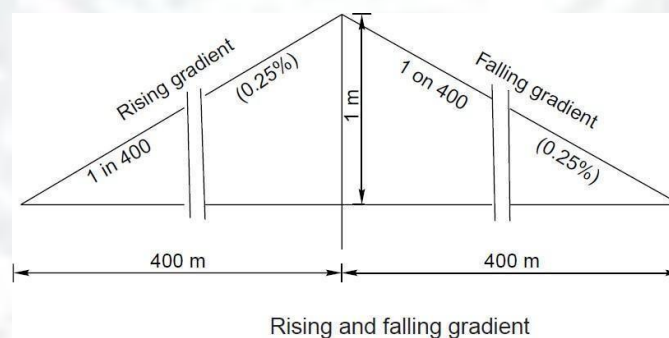
**Classification of Railway Land.** With a view to determine what the disposition of the land will probably be on the completion of the work for which it had been acquired, the classification given in paragraph 818 etc. should be adopted.

## ❓ (ii) temporary land width

**Permanent land width** is land which will be required permanently after the railway is open for traffic and the work of construction is complete. Under this head will be included all land to be occupied by the formation of the permanent line of railway with side slopes of banks and cuttings, and the berms connected therewith; catchwater drains and borrow pits or such parts of them as it is necessary to retain; the entrances to tunnels and shafts belonging to them; the sites of bridges, and protection or training works; station yards; landing places for railway ferries; ground to be occupied by works belonging to the railway such as gas works, arrangements for water supply, septic tanks, collecting pits, filter beds and pumping installations, & c., ground for the storage manufacture or acquisition of materials; land for sanitary zones, cemeteries, churches, plantations; gardens, and recreation grounds, sites for stations, offices, workshops; dwelling houses and other buildings required for the purposes of the railway, or the accommodation of the staff, with the grounds, yards, roads, & c., appertaining thereto. Under this head will also be included land outside the permanent railway boundary, which will be required for the permanent diversion of roads or rivers, or for other works incidental to the construction of the railway, which are made for public purposes and will not on completion of the works be maintained by the railway authorities.

**Temporary land width** is land which is acquired for temporary purposes only, and which is disposed of after the work of construction is completed.

### Gradients for drainage



Drainage is defined as interception, collection and disposal of water away from track. Drainage is the most important factor in track maintenance and for stability of banks/cuttings. When water seeps into the formation, it weakens the bonds between the soil particles, softens the soil and results in creation of ballast pockets. On one hand, ingress of water into bank/cutting adds to weight of soil mass trying to slide, thereby increasing propensity for slope-slide, on the other hand, it reduces shear strength of soil, thereby decreasing factor of safety for stability of slope. Therefore, quick disposal of water from formation top/slopes is very essential. Drainage

system should be effective in preventing the stagnation of water and allow quick disposal of water. At present, drainage is not being given its due importance in field. Provisions relating to drainage





have been detailed in various guidelines issued by RDSO from time to time, however, the present Guidelines highlight the salient features of drainage arrangement in embankment as well as cuttings.

## CONVENTIONAL DRAINAGE SYSTEMS

- ❑ SURFACE DRAINAGE
- ❑ SIDE DRAINS
- ❑ CATCH WATER DRAINS
- ❑ SUB SURFACE DRAINS

## SUPER ELEVATION

- (1) **Cant or super elevation** is the amount by which one rail is raised above the other rail. It is positive when the outer rail on a curved track is raised above inner rail and is negative when the inner rail on a curved track is raised above the outer rail.
- (2) **Equilibrium speed** is the speed at which the centrifugal force developed during the movement of the vehicle on a curved track is exactly balanced by the cant provided.
- (3) **Cant deficiency**- Cant deficiency occurs when a train travels around a curve at a speed higher than the equilibrium speed. It is the difference between the theoretical cant required for such higher speed and actual cant provided.
- (4) **Cant excess** - Cant excess occurs when a train travels around a curve at a speed lower than the equilibrium speed. It is the difference between the actual cant and the theoretical cant required for such a lower speed.
- (5) **Maximum permissible speed of the curve**-It is the highest speed which may be permitted on a curve taking into consideration the radius of the curvature, actual cant, cant deficiency, cant excess and the length of transition. When the maximum permissible speed on a curve is less than the maximum sectional speed of the section of a line, permanent speed restriction becomes necessary.
- (6) **Cant gradient** and cant deficiency gradient indicate the amount by which cant or deficiency of cant is increased or reduced in a given length of transition e.g., 1 in 1000 means that cant or deficiency of cant of 1 mm. is gained or lost in every 1000mm. of transition length.
- (7) **Rate of change of cant** or rate of change of cant deficiency is the rate at which cant or cant deficiency is increased or reduced per second, at the maximum permissible speed of the vehicle passing over the transition curve, e.g., 35 mm. per second means that a vehicle when traveling at a maximum speed permitted will experience a change in cant or deficiency of cant of 35mm. in each second of travel over the transition.
- (8) **Transition curve** is an easement curve, in which the change of radius is progressive throughout its length and is usually provided in a shape of a cubic parabola at each end of the circular curve. It affords a gradual increase of curvature from zero at the tangent point to the specified radius of circular arc and permits a gradual increase of super elevation, so that the full superelevation is attained simultaneously with the curvature of the circular arc.

## Superelevation, Cant deficiency and Cant excess

### (1) Superelevation/cant

(a) The equilibrium superelevation/cant necessary for any speed is calculated from the formula

$$C = \frac{GV^2}{127R}$$

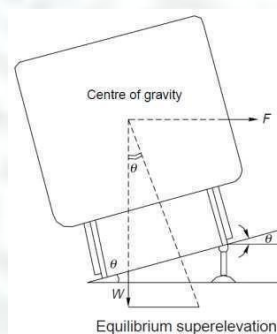
Where C is cant/superelevation in mm. G is the gauge of track width of rail head in mm. R is the radius of the curve in metres.

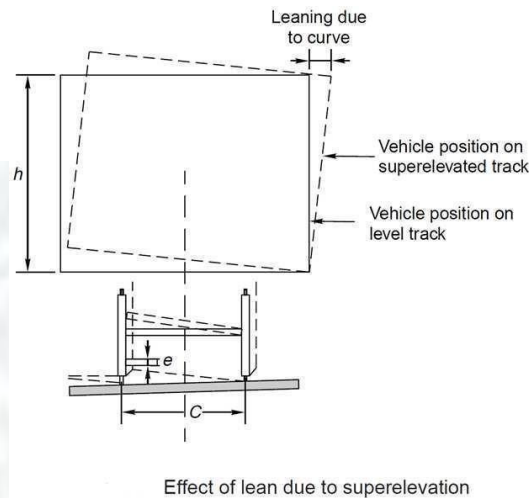
### Necessity of SuperElevation

In order to counteract the effect of centrifugal force the outside rail of the curve may be elevated above the inside rail effectively moving the centre of gravity of the rolling stock laterally toward the inside rail. This procedure is generally referred to as super elevation.

If the combination of lateral displacement of the centre of gravity provided by the super elevation, velocity of the rolling stock and radius of curve is such that resulting force becomes centered between and perpendicular to a line across the running rails the downward pressure on the outside and inside rails of the curve will be the same.

The super elevation that produces this condition for a given velocity and radius of curve is known as the balanced or equilibrium elevation.





### **Limitation of Super elevation**

#### **For Mixed Passenger & Freight Routes**

Typical early railway operation resulted in rolling stock being operated at less than equilibrium velocity (all wheels equally sharing the rolling stock weight), or coming to a complete stop on curves. Under such circumstances excess super elevation may lead to a downward force sufficient to damage the inside rail of the curve, or cause derailment of rolling stock toward the centre of the curve when draft force is applied to a train. Routine operation of loaded freight trains at low velocity on a curve super elevated to permit operation of higher velocity passenger trains will result in excess wear of the inside rail of the curve by the freight trains.

**Thus on these types of routes, super elevation is generally limited to not more than 6 inches. For High Speed Passenger Routes**

Modern high speed passenger routes, do not carry slower speed trains, nor expect trains to stop on curves, so it is possible to operate these routes with higher track super elevation values. Curves on these types of route are also designed to be relatively gentle radius, and are typically in excess of 2000m (2km) or 7000m (7km) depending on the speed limit of the route.

## CHAPTER -5.0

### POINTS AND CROSSING

#### Necessity:-

- I. Points and crossing are provided to help transfer railway vehicle from one track to another.
- II. The track may be parallel to diverging from or converging with each other point and crossing are necessary because the wheels of railway vehicles are provided with inside flange and therefore they require this in special arrangement in order to navigate their way on the rail.
- III. The points or switches aid in diverting the vehicles and the crossing provide gaps in the rails so as to help the flanged wheels to roll over them.
- IV. A complete set of points and crossings, along with lead rails, is called a turnout.

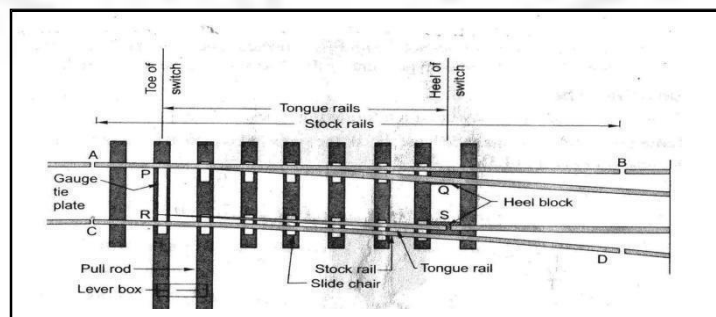
#### Points or Switches

A pair of tongue rail and stock rail with necessary connection and fitting forms a switch

Crossing: - it is a device introduced at the junction where two rails cross each other to permit the wheel flanges of a railway vehicle to pass from one track to another

#### Switches

- A pair of stock rail, AB and CD made of medium-manganese steel.
- A pair of tongue rails, PCS and RS also known as switch rails made withstand wear. The tongue rails are machined to very thin section to obtain a snug fit with the stock rail is called 'toe' and thicker end is called the 'heel'
- A no. of slide chairs to support the tongue rail and enable from stock rail.
- Two or more stretcher bars connecting both the tongue rails close to the toe for the purpose of holding them at a fixed distance from each other.
- A gauge ties plate to fix gauges and ensure correct gauge at the points.





## Types of Switches

Switches are of two types, namely 'stud switches' and 'split switch'.

In 'stud switch' no separate tongue rail is provided and some portion of the track is moved from one side to the other side.

In 'split switch' a pair of stock rail and pair of tongue rails are present, split switches are two types:-

### 1) Loose Heel type:-

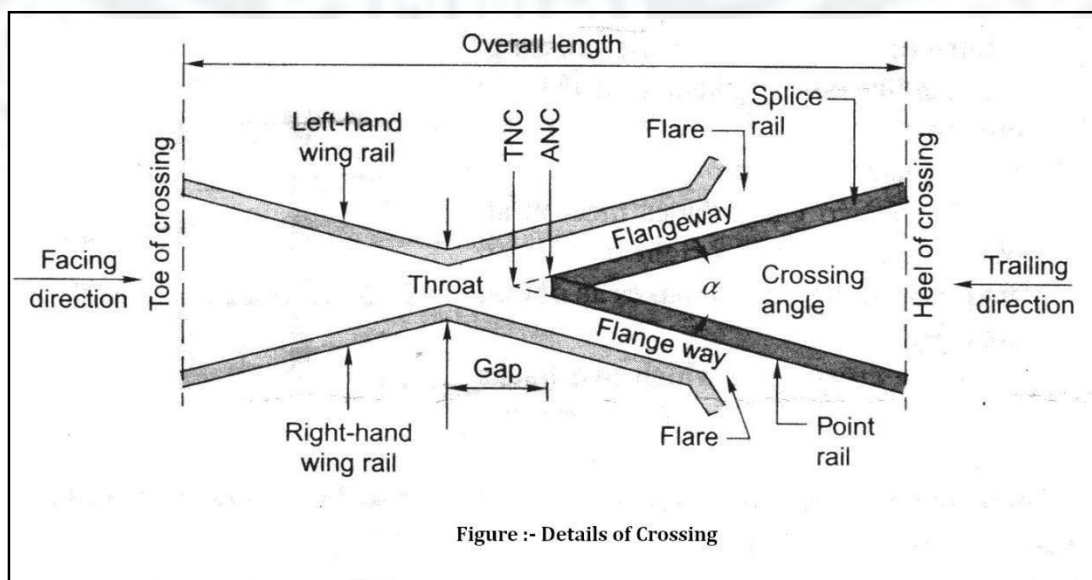
- In this type of split switch, the switch or tongue rail finishes at the heel of the switch to enable movement of the free end of the tongue rail.
- The fish plates holding the tongue rail may be straight or highly bent.
- The tongue rail is fastened to the stock rail with the help of a fishing fit block and four bolts.
- All the fish bolts in the lead rail are tightened while those in the tongue rail are kept loose or snug to allow free movement of the tongue.
- As the discontinuity of the track at the heel is a weakness in the structure, the use of these switches in structures, the use of these switches is not preferred.

### (2) Fixed Heel Type:-

In this type of split switch the tongue rail does not end at the heel of the switch, but extends further and is rigidly connected. The movement at the toe of the switch is made possible on account of flexibility of tongue rail.

### Crossing:-

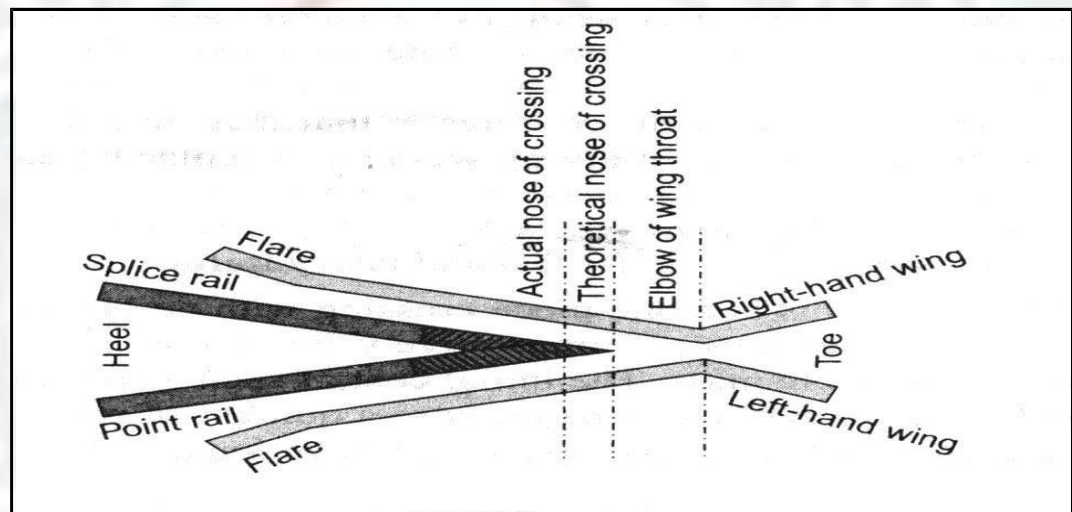
A crossing or Frog is a device introduced at the point/junction where two gauge faces / rails cross each other to permit the wheel flanges of a railway vehicle to pass from one track to each other.





**A crossing consists of the following components.**

- (i) Two rails, **point rails and splice rails**, which are machined to form a nose. The 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 a knife edge of point rail would break off under the movement of traffic. The point rail therefore, has its fine end slightly cut off to form a blunt nose, with a thickness of 6mm. The toe of the blunt nose is called the **actual nose of crossing (ANC)** and the theoretical point where the gauge faces form both sides intersect is called the **theoretical nose of crossing (TNC)**. The 'V' rail is planed to a depth of 6mm (1/4") at the nose and runs out in 89mm to stop a wheel running in the facing direction from hitting the nose.



**Figure: - Point Rail and Splice Rail**

- (ii) 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.
- (iii) A pair of check rails to guide the wheel flanges 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.

#### **TYPES OF CROSSING:**

**A crossing may be of the following types:-**

- (a) **An acute angle crossing or 'V' crossing** in which the intersection of two gauge faces forms an acute angle. For example when a right rail crosses a left rail, it makes an acute crossing. So unlike rail crossing from an acute crossing.

- (b) **An obtuse or diamond crossing** in which the two gauge faces meet at an obtuse angle. When a right on left rail crosses a similar rail, it makes an obtuse crossing.
- (c) **A square crossing** in which two tracks crossing at right angles, such crossings are rarely used in actual practice. For manufacturing purposes, crossing is of following types.

**According to manufacture, the crossing may be classified as mentioned under:- (a) Built up crossing:-**

In a built-up crossing two wing rails and a V-section consisting of splice and point rails are assembled together by means of bolts and distance blocks to form a crossing.

Advantages:-

- (a) Initial cost is low.
- (b) Repair can be carried out by welding.

**(b) Cast steel crossing:-**

This is one piece crossing with no bolts and therefore requiring very little maintenance.

Comparatively

**Advantages:-**

- (a) Longer life.

**Disadvantages:-**

- (a) Initial cost is high.
- (b) Repair and maintenance causes a no of problem.

**(c) Combined rail and cast crossing:-**

is a combination of a built-up and cast steel crossing and consists of a cast steel nose finished to ordinary rail faces to form the two legs of the crossing.

Through it allows the welding of worn-out wing rails, the nose is still liable to fracture suddenly.

**CMS Crossing:-** Due to increase in traffic and the use of heavier axle loads, the ordinary built-up crossing manufacturer from medium –manganese rails subjected to vary heavy wear and tear, especially in fast lines and suburban sections with electric traction. Past experience has shown that life of such crossings varies six months to two years, depending on their location and service conditions. CMS crossings possess higher strength, offer more resistance to wear and consequently have a longer life.

**Advantages:-**

- Less wear and tear.
- Longer life.
- Free from bolts as wheel as other components that normally to get loose as a result of movement of traffic.

**Spring or Movable Crossing:-**

In a spring crossing, one wing rail is movable and held against the V of the crossing with a

movable wing rail is snug with crossing and the vehicle does not need to negotiate any gap at the crossing. In case the vehicle has to pass over a turnout track, the movable wing is forced out by the wheel flanges and the vehicle has to negotiate a gap as in normal turnout

This type of crossing is useful when there is high-speed traffic on the main track and slow-speed traffic on the turnout track



## CHAPTER 6

### METHODS OF LYING & MAINTENANCE OF TRACK:-

#### Essential of Track Maintenance:-

1. The gauge should be correct or within the specified limits.
2. There should be no difference in cross levels except on curves, where cross levels vary in order to provide superelevation.
3. Longitudinal levels should be uniform.
4. The alignment should be straight and kink-free.
5. The ballast should be adequate and sleepers should be well packed.
6. The track drainage should be good and formation should be well trained.

Railway track can be maintained either conventionally by manually labour or by the application of modern methods of track maintenance, such as mechanical tamping or measured shovel packing. The major maintenance operations performed in a calendar year (12-months) are as follows for achieving the above mentioned standards:-

- 1) **Through Packing:-**
- 2) **Systematic Overhauling**
- 3) **Picking up slacks**
- 1) **Through Packing**

Through Packing is carried out in a systematic and sequential manner as described as follows:

#### ➤ **Opening of road:-**

The ballast is dug out on either side of the rail seat for a depth of 50mm (2") below the bottom of the sleeper with the help of a shovel with a wire claw. On the outside, the width of the opening should extend up to the end of the sleeper.

On the inside it should extend from the rail seat to a distance of 450mm (18") in case of BG, 350mm (14") in case of MG, and 250mm (10") in case of NG.

#### ➤ **Examination of rails, sleepers and fastening:-**

The rails, sleepers and fastening to be used are thoroughly examined. Defective sleepers are removed and loose fastening are tightened. Any kinks in rails are removed.

#### ➤ **Squaring of sleepers:-**

- (a) To do this one of the rails is taken as the sighting rail and the correct sleeper spacing is marked on it.

(b) The position of the sleeper is checked with reference to the second rail with the



- (c) The sleeper attended to after this defects have been established, which may include their being out of square or at incorrect spacing.

➤ **Aligning the track:-**

- (a) The alignment of the track is normally checked visually, where in the rail is visually assessed from a distance of about four rail lengths or so.
- (b) Small errors in the alignment are corrected by slewing the track after loosening the cores at the ends and drawing out sufficient ballast at the ends of the sleeper.
- (c) Slewing is carried out by planting crowbar deep into the ballast at an angle not more than 30° from the vertical.

**Advantages of Track Maintenance:-**

1. If the track is suitably maintained, the life of the track as well as that of the rolling stock increases since there is lesser wear and tear of their components.
2. Regular track maintenance helps in reducing operating costs and fuel consumption.
3. Small maintenance jobs done at the appropriate time, such as tightening a bolt or key, hammering the dog spike, etc., help in avoiding loss of concerned fitting and thus saving on the associated expenditure.
4. When track maintenance is neglected for along time, it may render the track beyond repair, calling for heavy track renewals that entail huge expenses

**Gauging:-**

The gauge should be checked and an attempt should be made to provide a uniform gauge within permissible tolerance limits.

**2. Systematic overhauling:-**

The systematic overhauling of the track should normally commence after the completion of one cycle of through packing. It involves the following operations in sequence:-

- (a) Shallow screening and making up of ballast section.
- (b) Replacing damaged or broken fittings.
- (c) Including all items in through packing.
- (d) Making up the cess.

**3. Picking up stacks:-**

Stacks are those points in the track where the running of trains is faulty. Slacks generally occur in the following cases:-

- (a) Stretches of yielding formation.
- (b) Improperly aligned curves.
- (c) Portions of track with poor drainage.
- (d) Approaches to level crossing, girder bridges etc.
- (e) Section with an inadequate or unclean ballast cushion.

No through packing is done during the raining season and slacks are only picked up in



### **Duties of a permanent way Inspector (PWI)**

The PWI is generally responsible for the following:-

- (a) Maintenance and inspection of the track to ensure satisfactory and safe performance.
- (b) Efficient execution of all works incidental to track maintenance, including track relaying work.
- (c) Accounts and periodical verification of the stores and tools in his or her charge.
- (d) Maintenance of land boundaries between stations and at important stations as may be specified by the administration.

The PWI also carries out inspection of the following facts of a track.

- (a) Testing the track.
- (b) Inspection of track and gauge.
- (c) Level crossing inspection.
- (d) Point and crossing inspection.
- (e) Curve inspection.
- (f) Safety of track.

In addition to the inspections, a PWI also carries out following duties:-

- (a) Check the proximity of trees that are likely to damage the track and get them removed.
- (b) Check night patrolling at least once a month by train as well as by trolley.
- (c) Takes the necessary safety measures while executing maintenance work that affects the safety of the track.
- (d) Periodically inspects and respects LWR tracks to ensure their safety.
- (e) Ensures the cleanliness of station yards.
- (f) Keeps proper records of the training out of ballast.
- (g) Looks after all establishment work, including the welfare of the staff working under his charge and maintains their service records.
- (h) Ensures the safety of the track during the execution of work that affects the track.

## SECTION-B

### CHAPTER-7

#### BRIDGE ENGINEERING

#### DEFINATION

The following definitions of certain important terms used in Bridge Engineering are given below:

1. **Bridge:** - A structure is facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river, stream, channel, road or railway. The communication route may be a railway track, a tramway, a roadway, footpath, a cycle track or a combination of them.
2. **High Level Bridge or Non-submersible Bridge:** - The Bridge which does not allow the high flood waters to pass over them. All the flood water is allowed to pass through its vents. In other words it carries the roadway above the highest flood level of the channel.
3. **Submersible Bridge:** - A submersible bridge is a structure which allows flood water to pass over bridge submerging the communication route. Its formation level should be so fixed as not to cause interruption to traffic during floods for more than three days at a time nor for more than six times in a year.
4. **Causeway:** - It is a pucca submersible bridge which allows floods to pass over it. It is provided on less important routes in order to reduce the construction cost of cross drainage structures. It may have vents for low water flow.
5. **Foot Bridge:** - The foot bridge is a bridge exclusively used for carrying pedestrians. Cycles and animals.
6. **Culvert:** - When a small stream crosses a road with linear waterway less than about 6 meters. The cross drainage structure so provided is called culvert.
7. **Desk Bridge:** - These are the bridge whose floorings are supported at top of the superstructures
8. **Through Bridge.** These are the bridges whose floorings are supported or suspended at the bottom of the superstructures.
9. **Semi-Through Bridges:** - These are the bridges whose floorings are supported at some intermediate level of the superstructure.
10. **Simple Bridges:** - They include all beam, girder or truss bridges whose flooring is supported at some intermediate level of superstructure.
11. **Cantilever Bridges:** - Bridges which are more or less fixed at one end and free at other. It can be used for spans varying from 8 meters to 20 meters.
12. **Continues Bridges:** - Bridges which continue over two or more spans. They are used for large spans and where unyielding foundations are available.

13. **Arch Bridge:** - These are the bridges which [produce inclined pressures on supports under vertical loads. These bridges can be economically used up to spans about 20 meters. The arches may be in the barrel form or in the form of ribs.
14. **Rigid Frame Bridges:** - In these bridges the horizontal deck slab is made monolithic with the vertical abutments walls. These bridges can be used up to span about 20 meters. Generally this type of bridge is not found economical for spans less than 10 meters.
15. **Square Bridge:** - These are the bridges at right angles to axis of the river.
16. **Square Bridge:** - These are the bridges not at right angles to axis of the river.
17. **Suspension Bridges:** - These are the bridges which are suspended on cables anchored at ends.
18. **Under-Bridges:** - It is a bridge constructed to enable a road to pass under another work or obstruction.
19. **Over-Bridges:** - it is a bridge constructed to enable one from of land communication over the other.
20. **Class AA Bridges:** - These are bridges designed for I.R.C. class AA loading and checked for class A loading. Hey are provided within certain municipal limits, in certain existing or contemplated industrial area, in other specified areas, and along certain specified highways.
21. **Class A Bridges:** - These are permanent bridges designed for I.R.C. class A loading.
22. **Class B Bridges:** - These are permanent bridges designed for I.R.C. class B loading.
23. **Viaduct:** - It is a long continues structure which carries a road or railways like Bridge over a dry valley composed of series of span over trestle bents instead of solid piers.
24. **Apron:** - It is a layer of concrete, masonry stone etc. placed like flooring at the entrance or out of a culvert to prevent scour.
25. **Piers:** - They are the intermediate supports of a bridge superstructure and may be solid of open type.
26. **Abutments:** - They are the end supports of the superstructure.
27. **Curtain Wall:** - It is a thin wall used as a protection against scouring action a stream.
28. **Effective Span:** - The centre to centre distance between any two adjacent supports is called as the effective span of a bridge.
29. **Clear Span:** - The clear distance between any two adjacent supports of a bridge is called clear Span.
30. **Economic Span:** - the span, for which the total cost of bridge structure is minimum is known as economic span.
31. **Afflux:** - due to construction of the Bridge there is a contraction in waterway. This results in rise of water level above its normal level while passing under the Bridge. This rise is known as afflux.
32. **Free Board:** - Free Board at any point is the difference between the highest flood level after allowing for afflux, if any, and the information level of road embankment on the approaches or top level of guide bunds at the points.
33. **Headroom:** - Headroom is the vertical distance between the highest points of a vehicle or vessel and the lowest points of any points of any protruding member of a Bridge.

35. **Liner Waterway:** - The liner waterway of a Bridge shall be the length available in the bridge between extreme edges of water surface at the highest flood level, measures at right angles to the abutment faces.
36. **Low Water Level (L.W.L.):** - The low water level is the of water surface obtained generally in the dry season.
37. **Ordinary Flood Level (O.F.L.):** - It is average level of a high flood which is expected to occur normally every year.
38. **Highest Flood Level (H.F.L.):** - It is the level of highest flood every recorded or the calculated level for the highest possible flood.
39. **Effective Liner Waterway:** - Effective linear waterway is the total width of waterway of a bridge minus the effective width of obstruction. For calculating the effective linear waterways, the width of mean obstruction due to each pier shall be taken as mean submerged width of the pier at its foundation up to maximum scour level. The obstruction at ends due to abutments or pitched slopes should be ignored.

### **COMPONENTS OF A BRIDGE**

#### **The bridge structure is divided mainly into two components:**

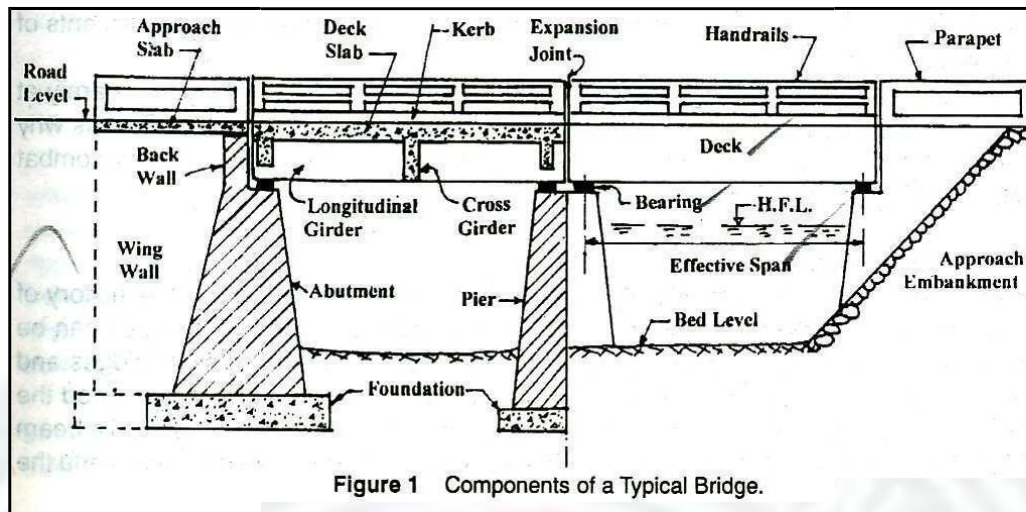
##### **1) Substructure**

- The function of substructure is similar to that of foundations, columns and walls etc. of a building. Thus the substructure supports the superstructure and distributes the load into the soil below through foundation.
- The substructure consists of foundation piers and abutment piers, foundation for the piers, abutments, wing walls, and approaches.
- The above all supports the superstructure of the bridge.

##### **2) Superstructure**

- The superstructure of a bridge is analogues to a single story building roof and substructure to that of walls, columns and foundations supporting it.
- Superstructure consists of structural members carrying a communication route
- It consists of handrails, parapets, roadways, girders, arches, wall trusses over which the road is support.
- It is that part of the bridge over which the traffic moves safely



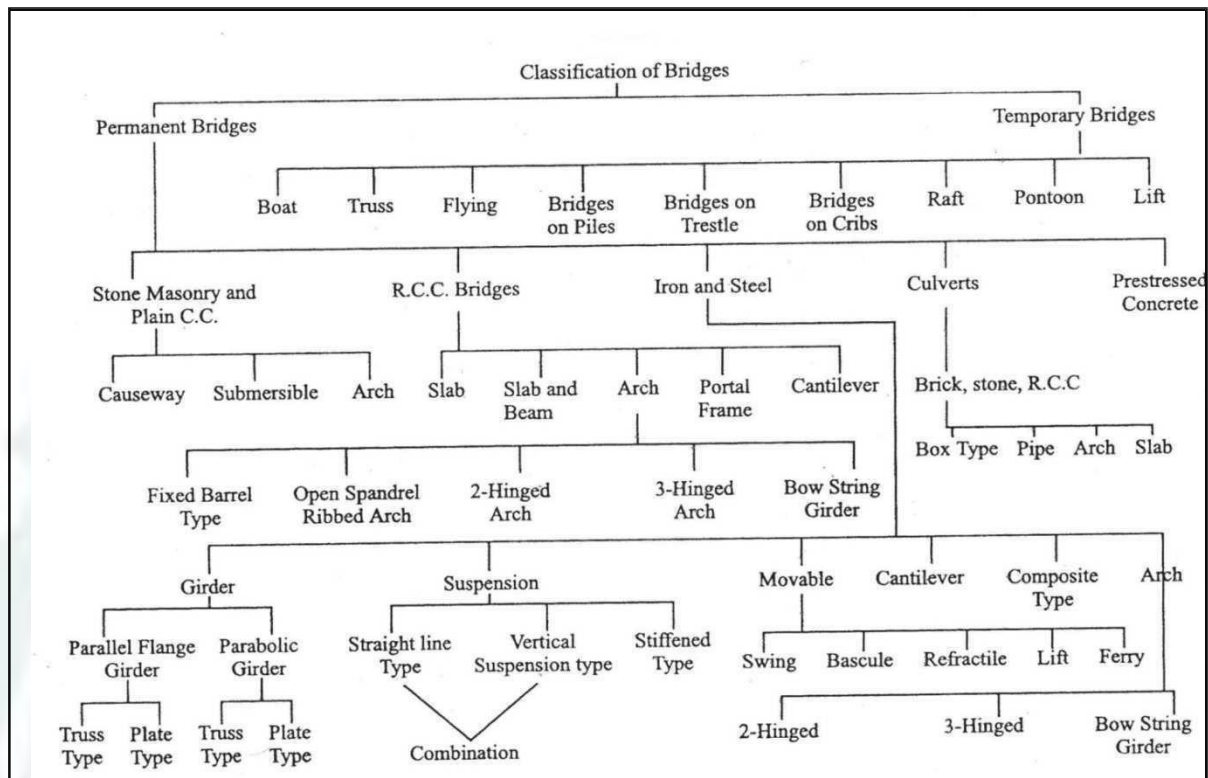


### Classification of a Bridge: -

The bridges may be classified depending upon the following factors:-

- (a) Their functions or purpose as railway, highway Foot Bridge, aqueduct etc.
- (b) Their material of construction used as timber masonry, R.C.C. Steel, prestresses concrete etc.
- (c) Nature or life span such as temporary permanent bridge etc.
- (d) Their relative position of floor such as deep bridge, through bridges etc.
- (e) Type of super-structure such as arched girder, truss, suspension bridge etc.
- (f) Loadings: - Road Bridges and culverts have been classified by I.R.C. into class AA, Class A, Class B bridges according to the loadings they are designed to carry.
- (g) Span Length:- Under this category the bridges can be classified as
  - Culverts (Span Less than 8m) i.e. BOX Type, Hume Pipe Type,
  - Minor Bridge ( Span length = 8 to 30m) i.e. BOX type, Girder Type
  - Major Bridge (Span Length =above than 30m)
- (h) Degree of Redundancy: - Under this the bridges can be classified as indeterminate bridges
- (i) Types of Connection:- Under this category the steel bridges can be classified as pinned connected , riveted or welded bridges.





### Classification of Bridge

#### REQUIRMENTS OF AN IDEAL BRIDGE:-

An ideal bridge meets the following requirements to fulfil the three criteria of efficiency, effectiveness and equity

- It serves the intended function with utmost safety and convenience
- It is aesthetically sound
- It is economical

The site characteristic of an Ideal Bridge has been discussed below:

1. The stream at the bridge side should be well defined and as narrow as possible.
2. There should be a straight reach of stream at bridge site
3. The site should have firm, permanent, straight and high banks.
4. The flow of water in the stream at the bridge site should be in steady regime condition. It should be free from whirls and cross-current
5. There should be no confluence of large tributaries in the vicinity of bridge site
6. It should be reliable to have straight approach roads and square alignment, i.e. right-angle crossing
7. There should be minimum obstruction of a natural waterway so as to have minimum afflux
8. In order to achieve economy there should be easy availability of labour, construction material and transport facility in the vicinity of bridge site.
9. In order to have minimum foundation cost, the bridge site should be such that no excessive work is to be carried inside the water

11. In case of curved alignment the bridge should not be on the curve, but preferably on the tangent since otherwise there is a greater likelihood of accident as well as an added centrifugal force which increases the load effect on the structure and will require modification of design.
12. There should be no adverse environmental impact
13. The bridge site should be such that adequate vertical height and waterway is available
14. Underneath the bridge for navigational use.

In actual practice the determination of best possible site for any proposed bridge is truly an economic problem. The various factors which should be carefully examined before setting finally upon the layout of a bridge as follows:

- i. Grade on alignment,
- ii. Geographical Conditions,
- iii. Government requirements,
- iv. Commercial influences ,
- v. Adjacent property consideration,
- vi. General features of the bridge structure,
- vii. Future trends for enlargement,
- viii. Time Consideration,
- ix. Foundation Considerations,
- x. Construction facilities available,
- xi. Erection Consideration,
- xii. Aesthetics,
- xiii. Maintenance and repairs,
- xiv. Environment Impact

## CHAPTER-8

### Bridge site investigation, hydrology & planning:-

Depending upon the angle which the bridge makes with the axis of the river, the alignment may be of two types:

a) Square Alignments: - In this the bridge is at right angle to the axis of the river.

b) Skew Alignments: - In this the bridge is at some angle to the axis of the river which is not a right angle.

Note: - As far as possible, it is always desirable to provide the square alignment. The skew alignment suffers from the following disadvantages:-

(i) A great skill is required for the construction of skew Bridges. Maintenance of such type of Bridges is also difficult.

(ii) The water-pressure on piers in case of skew alignment is also excessive because of non-uniform flow of water underneath the bridge superstructure.

(iii) The foundation of skew bridge is more susceptible to scour action.

### **Flood Discharge: -**

One of the essential data for the bridge design is fair assessment of the maximum flow which could be expected to occur at the bridge site during the design period of the bridge. The conventional practice in India for determination of flood discharge is to use a few convenient formulae or past records.

Note: - This faulty determination of flood discharge which led to failure of many hydraulic structures.

As per I.R.C. recommendation the maximum discharge which a bridge on a natural stream should be designed to pass determined by the following methods:-

(a) From the rainfall and other characteristics of the catchment.

(i) By use of an empirical formula applied to that region, or

(ii) By a rational method, provided it is possible to evaluate for the region concerned the various factors employed in the method.

(b) From the hydraulic characteristics of the stream such as cross-sectional area, and slope of the stream allowing for velocity of flow.

(c) From the records available, if any, of discharges observed on the stream at the site of the bridge, or at any other site vicinity.

### Empirical Methods for Estimation of Flood Discharge:-

In these methods area of basin or catchment is considered mainly. All other factors which influence peak flow are merged in a constant.

A general equation may be followed in the form:-

$$Q = C \cdot M^n$$

Here, Q= Peak Flow or rate of maximum discharge  
C= a constant for the catchment

M= area of catchment, and 'n' is an index

The constant for catchment is arrived at, after taking the following factors into account:

#### (A) Basin Characteristics

- a) Area
- b) Shape
- c) Slope

#### (B) Storm Characteristics

- a) Intensity
- b) Duration
- c) Distribution

#### Limitations

These methods do not take frequency of flood into consideration. These methods cannot be applied universally

Fixing of constant is very difficult and exact theory cannot be put forth for its selection.

### 1) Dicken's Formula

$$Q = C. M^{3/4}$$

Here, Q= Discharge in  
cum/sec C= a constant  
M= area of catchment in sq .km.





## 2) Ryve's formula

$$Q = C. M^{2/3}$$

Here, Q= Discharge in cum/sec

C= 6.74 for area within 24 km from coast or,

C= 8.45 for areas within 24-161 km from coast or, C= 10.1 for limited hilly areas

In worst case C goes up to 40.5

M= area of catchment in sq .km.

## 3) Inglis Formula

This formula used only Mahastra state and here three different cases are taken into consideration.

(a) For small areas only (It is also applicable for fan-shaped catchment)

$$Q = 123.2 \sqrt{M}$$

(b) For areas between 160 to 1000 square km.

$$Q = 123.2 \sqrt{M - 2.62(M - 259)}$$

( c) For all type of catchment

$$Q = 123.2 M / \sqrt{M + 10.36}$$

In all equations, M= area of catchment in sq .km.

## 4) Nawab Jang Bahadur's Formula :-

$$Q = C (M / 2.59)^{(a - b \cdot \log A)}$$

Here, a, b, and C are constant.

a= 0.993 and b= 1/14

C = 59.5 for North India or,

= 48.1 for South India

## 5) Creager's Formula :-

$$q = C.M^n$$

Here, q=the peak flow per sq. km of a basin

M= area of catchment in sq. km. and 'n' is some index

By multiplying both sides of the above equation are of the basin M, we get

$$Q = C. M^{n+1}$$

Where Q is peak value



Equation given by Creager , Justin and Hinds is

$$Q = 46. CM (0.849M - 0.048)$$

#### 6) Khosla's Formula :-

It is a rational formula, It is based on the equation  $P = R + L$  Or  $R = P - L$

Here, R is round off, P is rainfall and L is losses.

$L = 4.82 T_m$ , where L is in mm and  $T_m$  is in centigrade {in C.G.S. System}  $R = P - 4.82 T_m$

#### 7) Besson's Formula :-

This formula is very rational and can be used in any case:



$$Q_m = (P_m \times Q_r) / (P_r)$$

Here,  $Q_m$  = Peak flow expected

$Q_r$  = Some observed peak

flow  $P_r$  = Observed rainfall

$P_m$  = expected rainfall

#### Rational Methods for Estimation of Flood Discharge:-

This method is applicable for determination of flood discharge for small culverts only. In order to arrive at a rational approach, a relationship has been established between rainfall and runoff under various circumstances. The size of flood depends upon the following factors.

(i) Climate or Rainfall Factors. This includes

(a) Intensity (b) Distribution and (c) Duration of Rainfall

(ii) Catchment Area Factors. This includes:

(a) Catchment Area (b) its slope (c) its shape (d) porosity of soil

(e) Vegetable cover (f) initial state of wetness

#### **WATERWAY**

The area through which the water flows under a bridge superstructure is known as the waterway of the bridge. The linear measurement of this area along the bridge is known as the linear waterway. This linear waterway is equal to the sum of all the clear spans. This may be called

Due to the construction of a bridge the natural waterway gets contracted thereby increasing the velocity of flow under a bridge. This increased velocity results into heading up of water on the upstream of the river or stream, known as Afflux.

**Economic Span:** - the economic span of a bridge is the one which reduces the overall cost of a bridge to be minimum. The overall cost of a bridge depends upon the following factors

- a. Cost of material and its nature.
- b. Availability of skilled labour
- c. Span Length.
- d. Nature of stream to be bridged.
- e. Climatic and other conditions.

**Notes:-**

It is not in the hand of engineers to bring down the cost of living index or price of the materials like cement, steel, timber, etc. but they can help in bringing down the cost of bridges by evolving economical designs.

Considering only variable items, the cost of superstructure increases and that of sub-structure decreases with an increase in the span length. Thus most economic span length is that which stultifies the following :-

i.e. The cost of Super Structure = The cost of the Sub-Structure

**AFFLUX**

When a bridge is constructed, the structure such as abutments and piers cause the reduction of natural waterway area. The contraction of stream is desirable because it leads to tangible saving in the cost specially for alluvial stream whose natural surface width is too large than required for stability. Therefore, to carry the maximum flood discharge, the velocity under a bridge increases. This increased velocity gives rise to sudden heading up of water on the upstreamside of the stream. The phenomenon of heading up of water on the upstream side of the stream is known as “**AFFLUX**”

Greater the afflux greater will be the velocity under the downstream side of the bridge and greater will be the depth of scour and consequently greater will be depth of foundations required.

**Afflux is calculated by one of the following formula**

**(A) Marriman’s Formula**

$$h_a = (V^2 / 2g) \{ (A/Ca)^2 - (A/A_1) \}$$

Here,  $h_a$  = Afflux in meters

V = Velocity of approach in meters per second  
 A = Natural Waterway area at the site  
 a = Contracted area in square meters

$C = \text{Coefficient of Discharge} = 0.75 + 0.35 (a/A) - 0.1(a/A)^2$  approximately

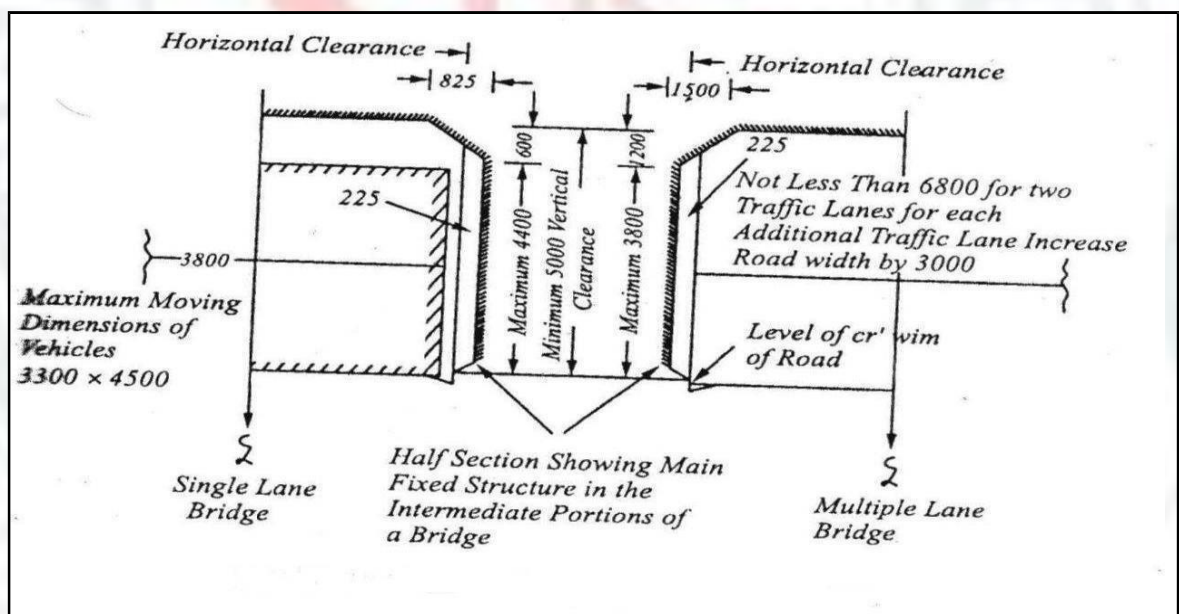
#### (A) Molesworth's Formula

$$h_a = \left[ \frac{V^2}{17.9} + 0.015 \right] \{ (A/a)^2 - 1 \}$$

Here,  $V$ ,  $A$  and  $a$  have the same meaning as in the Murrman's Formula

#### CLEARANCE

To avoid any possibility of traffic striking any structural part clearance diagram are specified. The horizontal clearance should be the clear width and vertical clearance of the clear height, available for the passage of vehicular traffic as shown in the clearance diagram in the figure below.



#### Clearance Diagram for Road Bridges

**Note :** - For a bridge constructed on a horizontal curve with superelevated road surfaces, the horizontal clearance should be increased on the side of inner kerb by an amount equal to 5m multiplied by the superelevation. The minimum vertical clearance should be measured from the super elevated level of roadway.



## FREE BOARD

Free board is the vertical distance between the designed high flood level, allowing for the afflux, if any, and level of the crown of the bridge at its lowest point.

It is essential to provide the free board in all types of bridges for the following reasons:-

- Free Board is required to allow floating debris, fallen tree trunks and approaches waves to pass under the bridge.
- Free board is also required to allow for the afflux during the maximum flood discharge due to contraction of waterway.
- Free board is required to allow the vessels to cross the bridges in case of navigable rivers. The value of free-board depends upon the types of the bridge.

### Collection of Bridge Design Data: -

For a complete and proper appreciation of the bridge project the engineer in charge of the investigation should carry out studies regarding its financial, economic, social and physical feasibility. The detailed information to be collected may cover loading to be used for design based on the present and anticipated future traffic, hydraulic data based on stream characteristics, geological data, subsoil data, climatic data, alternative sites, aesthetics, cost etc.

The following drawings containing information as indicated should be prepared

1. INDEX MAP
2. CONTURE SURVEY PLAN
3. SITE PLAN
4. CROSS-SECTION
5. LONGITUDINAL SECTION
6. CATCHMENT AREA MAP
7. SOIL PROFILE

### **Design data for major**

#### **bridge:- A- General data:-**

- (i) Name of the road and its classification.
- (ii) Name of the stream.
- (iii) Location of nearest G.T.S. bench mark and its reduced level.
- (iv) Chainage at centre line of the stream.
- (v) Existing arrangement for crossing the stream.

a) During Monsoon      b) During dry season

(vi) Liability of the site to earthquake disturbance

**B- Catchment Area and Run Off Data:-**

## (i) Catchment Area

- (a) Hilly Area                      b) In plains

(ii) Maximum recorded intensity and frequency of rainfall in catchment.

(iii) Rainfall in centimeter per year in a season

(iv) Length of catchment in kilometres.

(v) Width of catchment in kilometres.

(vi) Longitudinal slope of catchment.

(vii) Cross slope of catchment.

(viii) The nature of catchment and its shape.

**C- Data Regarding Nature of Stream****Sub-Surface****Investigation:-**

Sub-Surface investigation is essential for to know the properties of the bridge site soil. The field and laboratory investigations required to obtain the necessary soil data for the design are called soil exploration.

The principal requirements of a complete investigation can be summarized as follows:-

1. Nature of the soil deposits up to sufficient depth.
2. Depth, thickness and composition of each soil stratum.
3. The location of ground water.
4. Depth to rock and composition of rock.
5. The engineering properties of soil and rock strata that affect the design of the structure.

In exploration programme the extent of distribution of different soils both in the horizontal and vertical directions can be determined by the following methods:

1. By use of open pits.
2. By making bore holes and taking out samples.
3. By Soundings.
4. By use of geophysical methods.

**Equipments for laboratory Work:-**

The disturbed soil sample as taken from bed level to scour level at every one meter interval or at depths wherever strata changes are tested to determine the following properties:-

1. Liquid Limit, Plastic Limit and Plasticity Index
2. Organic Content
3. Harmful Salts
4. Sieve Analysis
5. Silt Factor



The undisturbed soil samples as taken below the scour level to a level where the pressure is about 5% of the pressure at the base are tested to determine

1. Particle size analysis.
2. Values of cohesion and angle of internal friction by shear test.
3. Compression index and pre-consolidation pressure by consolidation test.
4. Density specific gravity and moisture content.

**Advantage of Sub-Surface Investigation:-**

There are manifold advantages of carefully planned investigation programme. These can be summarized as below:-

1. A suitable and economical solution can be worked out.
2. The construction schedule can be properly planned.
3. The extent and nature of difficulties likely to be met with can be determined.
4. The rate and amount of settlements can be determined.
5. The variation in the water –table, of the presence of artesian pressures can be found out.

## CHAPTER 9

### Depth of Scour:-

DEPTH OF SCOUR (D) is the depth of the eroded bed of the river, measured from the water level for the discharge considered. Well-laid foundation is mostly provided in road and railway bridges in India over large and medium-sized rivers. The age-old Lacey–Inglis method issued for estimation of the design scour depth around bridge elements such as pier, abutment, guide bank, spur and groyene. Codal provisions are seen to produce too large a scour depth around bridge elements resulting in bridge sub-structures that lead to increased construction costs. Limitations that exist in the codes of practice are illustrated in this paper using examples. The methods recently developed for estimation of the scour are described. New railway and road bridges are required to be built in large numbers in the near future across several rivers to strengthen such infrastructure in the country. It is strongly felt that provisions in the existing codes of practice for determination of design scour depth require immediate review. The present paper provides a critical note on the practices followed in India for estimating the design scour depth.

Indian practices on estimation of design scour depth

1. Lacey–Inglis method
2. Comments on Lacey’s method
  - The probable maximum depth of scour for design of foundations and training and protection works shall be estimated considering local conditions.
  - Wherever possible and especially for flashy rivers and those with beds of gravel or boulders, sounding for purpose of determining the depth of scour shall be taken in the vicinity of the site proposed for the bridge. Such soundings are best taken during or immediately after a flood before the scour holes have had time to silt up appreciably. In calculating design depth of scour, allowance shall be made in the observed depth for increased scour resulting from:
    - (i) The design discharge being greater than the flood discharge observed.
    - (ii) The increase in velocity due to the constriction of waterway caused by construction of the bridge.
    - (iii) The increase in scour in the proximity of piers and abutments.
  - 4.6.3 In the case of natural channels flowing in alluvial beds where the width of waterway provided is not less than Lacey’s regime width, the normal depth or Scour (D) below the foundation design discharge ( $Q_f$ ) level may be estimated from Lacey’s formula as indicated below

$$D = 0.473 (Q_f^f / f)^{1/3}$$

Where D is depth in metres  $Q_f$  is in cumecs and ‘f’ is Lacey’s silt factor for representative sample of bed material obtained from scour zone.

- Where due to constriction of waterway, the width is less than Lacey’s regime width for  $Q_f$  or where it is narrow and deep as in the case of incised rivers and has sandy bed, the normal depth of scour may be estimated by the following formula:

$$D = 1.338 (Q_f^2 / f)^{1/2}$$



Where 'Q<sub>f</sub>' is the discharge intensity in cubic metre per second per metre width and f is silt factor The silt factor 'f' shall be determined for representative samples of bed material collected from scour zone using the formula :  $f = 1.76 \sqrt{m}$  where m is weighted mean diameter of the bed material particles in mm. Values of 'f' for different types of bed material commonly met with are given below :

Type of bed	Material Weighted mean dia of particle(mm)	Value of 'f'
(i) Coarse silt	0.04	0.35
(ii) Fine sand	0.08	0.50
	0.15	0.68
(iii) Medium sand	0.3	0.96
	0.5	1.24
(iv) Coarse sand	0.7	1.47
	1.0	1.76
	2.0	2.49

The depth calculated (vide clause 4.6.3 and 4.6.4 above) shall be increased as indicated below, to obtain maximum depth of scour for design of foundations, protection works and training works:-

Nature of the river	Depth of scour
In a straight reach	1.25D
At the moderate bend conditions e.g. along apron of guide bund	1.5D
At a severe bend	1.75D
At a right angle bend or at nose of piers	2.0D
In severe swirls e.g. against mole head of a guide bund.	2.5 to 2.75D

In case of clayey beds, wherever possible, maximum depth of scour shall be assessed from actual observations.

### **Bridge Foundation:-**

**Definition:-** A foundation is the part of the structure which is in direct contact with the ground. It transfers the load of the structure to the soil below. Before deciding upon its size, we must ensure that:

- (i) The bearing pressure at the base does not exceed the allowable soil pressure.
- (ii) The settlement of foundation is within reasonable limits
- (iii) Differential settlement is to limited as not to cause any damage to the structure.

Broadly, foundation may be classified under two categories i.e.

1. Shallow foundation
2. Deep Foundation

**Shallow Foundation:-** According to Trezaghi, a foundation is said to be shallow if its depth is equal or less than its width.

**Deep Foundation:-** According to Trezaghi, a foundation is said to be deep, the depth is greater than its width and it cannot be prepared by open excavation.

#### Types of Bridge Foundation:-

The selection of foundation type suitable for a particular site depends on the following considerations:- 1 ) Nature of Subsoil

- 2) Nature and extent of difficulties, e.g. presence of boulder, buried tree trunks, etc. Likely to be met with, and
- 3) Availability of expertise and equipment.

Depending upon their nature and depth, bridge foundation can be categories as follows:

- i. **Open Foundation,**
  - ii. **Raft Foundation,**
  - iii. **Pile Foundation,**
  - iv. **Well foundation,**
- (i) Open Foundation in**

#### **Bridges:-**

1. An open foundation or spread foundation is a type of foundation and can be laid using open excavation by allowing natural slopes on all sides.
2. This type of foundation is practicable for a depth of about 5m and is normally convenient above the water table.
3. The base of the pier or abutment is enlarged or spread to provide individual support.
4. Since spread foundations are constructed in open excavation, therefore, they are termed as open foundation.
5. This type of foundation is provided for bridges of moderate height built on sufficiently firm ground.
6. The piers in such cases are usually made with slight batter and provided with footings widened at bottom. Where the ground is not stiff the bearing surface is further extended by a wide layer of concrete at bottom (see the figure).

#### **(ii) Raft Foundation:-**

1. A raft foundation or mat is a combined footing that covers the entire area beneath a bridge and supports all the piers and abutments.
2. When the allowable soil pressure is low, or bridge loads are heavy, the use of spread footing would cover more one-half of the area, and it may prove more economical to use raft foundation
3. They are also used where the soil mass contains compressible lenses so that the differential settlement would be difficult to control.
4. The raft tends to bridge over the erratic deposits and eliminates the differential settlement.

5. Raft foundation is also used to reduce the settlement above highly compressible soils by making the weight of bridge and raft may undergo large settlement without causing harmful differential settlement. For this reason, almost double settlement of that permitted for footings is acceptable for rafts.
6. Usually when hard soil is not available within 1.5 to 2.5 m a raft foundation is adopted.
7. The raft is composed of reinforced concrete beams a relatively thin slab underneath, figure

### **(iii) Pile foundation in Bridges:**

1. The pile foundation is constructions for the foundation of a bridge pier or abutment supported on piers.
2. A pile is an element of construction composed of timber, concrete or steel or combination of them.
3. Pile foundation may be defined as a column support type of foundation which may be cast-in-situ or precast.
4. The piles may be placed separately or they may be placed in form of a cluster throughout the length of the pier or abutment.
5. This type of construction is adopted when the loose soil extends to great depth.
6. The load of the bridge is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles.

#### **Classification of piles:-**

Piles are broadly classified into two categories:-

- i- Classification based on the function
- ii- Classification based on the materials and composition

#### **Classification based on the function**

- Bearing Pile.
- Friction Pile.
- Screw Pile.
- Compaction Pile.
- Uplift Pile.
- Batter Pile.
- Sheet Pile.

#### **Classification based on the function**

- Cement concrete piles.
- Timber Piles.
- Steel Piles.
- Sand Piles.

#### (iv) Well Foundation in bridges

- a) Well foundations are commonly used for transferring heavy loads to deep strata in river or sea bed for bridges, transmission towers and harbour structures. The situation where well foundations are resorted to are as below:
- Wherever consideration of scour or bearing capacity require foundation to be taken to depth of more than 5 M below ground level open foundation becomes uneconomical. Heavy excavation and dewatering problem coupled with effort involved in retaining the soil makes the open foundation costlier in comparison to other type of foundation.
  - Soil becomes loose due to excavation around the open foundation and hence susceptible to scouring. This is avoided in well foundation which is sunk by dredging inside of the well.
  - From bearing pressure considerations, a well foundation can always be left hollow thereby considerably reducing bearing pressure transmitted to the foundation material. This is very important in soils of poor bearing capacity, particularly in clayey soils. In other type of foundation, the soil displaced is occupied by solid masonry/concrete which are heavier than the soil displaced and hence this does not give any relief in respect of adjusting bearing capacity. However in case of well foundation this is easily achieved because of cellular space left inside the well.

#### Caisson:-

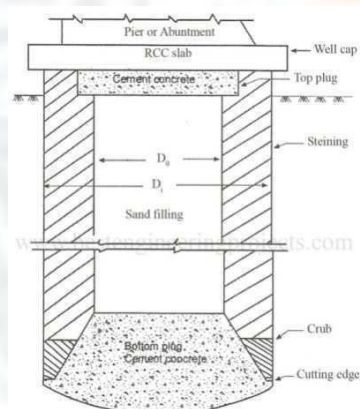


Fig 1 Parts of a Well Foundation

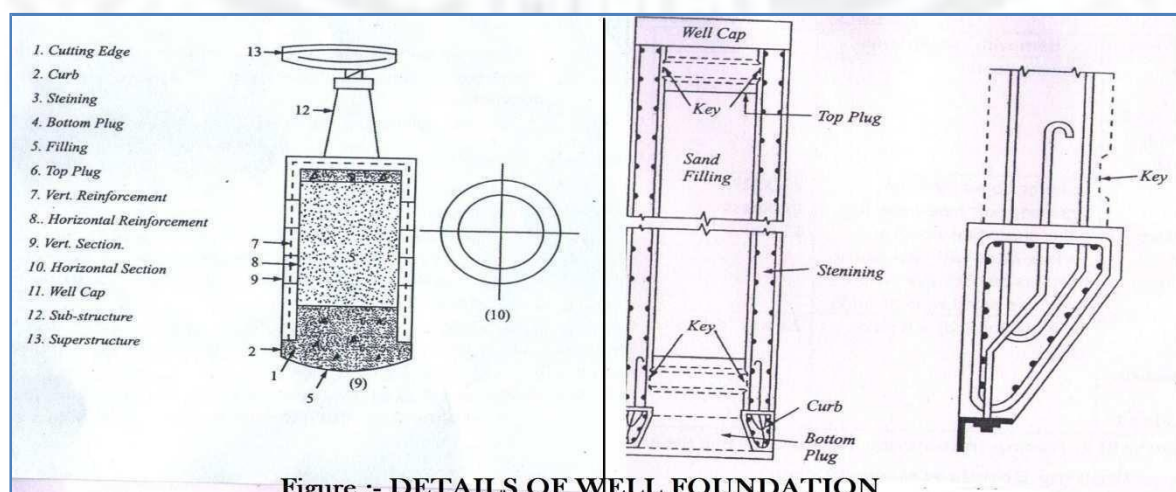


Figure :- DETAILS OF WELL FOUNDATION



Caisson: - The caisson is a structure used for the purpose of placing as foundation in correct position under water. The term caisson is derived from the French word 'caisse' meaning a box. It is a member with hollow portion, which after installing in place by any means is filled with concrete or other material. Caissons are prepared in sandy soils the caissons can be divided in the following three groups

- a. Box Caissons
- b. Open Caissons or Wells
- c. Pneumatic Caissons

#### **Well components and their functions:**

- **Cutting edge:** - It provides a comparatively sharp edge to cut the soil below during sinking operation. It usually consists of a mild steel equal angle of side 150mm.
- **Curb:** - It has a two-fold purpose. During sinking it acts as an extension of cutting edge and also provided support to the well steining and bottom plug while after sinking it transfers the load to the soil below. It is made up of reinforced concrete using controlled concrete of grade M200.
- **Steining:** - It is the main body of the well. It serves dual purpose. It acts as a cofferdam during sinking and structural member to transfer the load to the soil below afterwards. The steining may consist of brick masonry or reinforced concrete. The thickness of steining should not be less than 4.5 cm not less than that given by equation.

$$t = K \left\{ \left( \frac{H}{100} \right) + \left( \frac{D}{10} \right) \right\}$$

Here,  $t$  = minimum concrete steining thickness.

$H$  = well depth below bed

$D$  = External diameter of Well

$K$  = a constant which is 1.0 for sandy strata.

- **Bottom Plug:** - Its main function is to transfer load from the steining to the soil below.
- **Sand Plug:** - Its utility is doubtful. It is supposed to afford some relief to the steining by transforming directly a portion of load from well cap to bottom plug.
- **Top Plug:** - The opinion is divided about the top plug. It, at least, serves as a shuttering for laying well cap.



- Well Cap: - It is needed to transfer the loads and moments from the pier to the well or wells below. The shape of well cap is similar to that of the well with a cantilevering of about 15cm. Whenever 2 or 3 wells of small diameter are needed to support the sub-structure, the well cap is designed as a slab resting over the well or wells with partial fixity at the edges of the wells.
- Depth of Well Foundation:- As per I.R.C. Bridge Code (Part-III), the depth of well foundation is to be decided on the following consideration
  1. The minimum depth of foundation below the H.F.L. should be  $1.33D$ , Where  $D$  is the anticipated max. Depth of scour below H.F.L. Depth should be provided proper grip according to some rational formula.
  2. The max bearing pressure on the subsoil under the foundation resulting from any combination of the loads and forces except wind and seismic forces should not exceed the safe bearing capacity of the subsoil, after taking into account the effect of scour.  
 With wind and seismic forces in addition, the max. Bearing pressure should not exceed the safe bearing capacity of the subsoil by more than 25%.
  3. While calculating max. Bearing pressure on the foundation bearing layer resulting from the worst combination of direct forces and overturning moments, the effect of a passive resistance of the earth on sides of the foundation structure may be taken into account below the max. depth of the scour only.
  4. The effect of skin friction may be allowed on the portions below the max. depth of scour. Accordingly for deciding the depth of well foundation, we require correct estimation of the following.
    1. Max. Scour depth.
    2. Safe bearing capacity.
    3. Skin friction.
    4. Lateral earth support below max. Scour level.

It is always desirable to fix the level of a well foundation on a sandy strata with adequate bearing capacity. Whenever a thin stratum of clay occurring between two layers of sand is met with, in that case well must be pierced through the clayey strata. If at all foundation has to be laid on clayey layer it should be ensured that the clay is stiff.

Design loads and Forces. The forces acting on a bridge structure, to be considered for the design of a well foundation, are as follows:

Vertical

- (i) Dead load,
- (ii) Live load,
- (iii) Buoyancy.

### Horizontal

- (i) Wind force.
- (ii) Force due to water currents.
- (iii) Longitudinal forces caused by the tractive effort of vehicle or by braking effect of vehicles.
- (iv) Longitudinal force on account of resistance of the bearing against movement due to variations of temperature.
- (v) Seismic force.
- (vi) Earth pressure.
- (vii) Centrifugal force.

The I.R.C. Bridge code II stipulates the magnitude of above loads and forces. The magnitude, direction and point of application of all the above forces can be resolved into two horizontal forces, P and Q and a single vertical force W under the worst possible combinations.

