RAILWAY & BRIDGE ENGINEERING

SPINTRONIC TECHNOLOGY & ADVANCE RESEARCH (STAR)

DEPARTMENT OF CIVIL ENGINEERING

DIPLOMA

LECTURE NOTES ON

RAILWAY & BRIDGE ENGINEERING

BY

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SECTION- A: RAILWAYS

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Chapter-1

INTRODUCTION

Transportation is regarded as an index of economic, social and commercial progress of a country. The transport industry, which undertakes nothing more than mere movement of persons and things from one place to another has constituted one of the most important activities of men in every stage of advanced civilization. No country can ever flourish if it lacks adequate transport facilities.

The first public railway in the world was opened to traffic on 27 September 1825 between Stockton and Darlington in the UK. The first railway in Germany was opened from Nuremberg to Furth in 1835. The USA opened its first railway line between Mohawk and Hudson in 1833.

The first railway line in India was opened in 1853. The first train, consisting of one steam engine and four coaches, made its maiden trip on 16 April 1853, when it traversed a 21-mile stretch between Bombay (now Mumbai) and Thane in 1.25 hours.Starting from this humble beginning, Indian Railways has grown today into a giant network consisting of 63,221 route km and crisscrossing this great country from the Himalayan foothills in the north to Cape Comorin (Kanyakumari) in the south and from Dibrugarh in the east to Dwarka in the west.

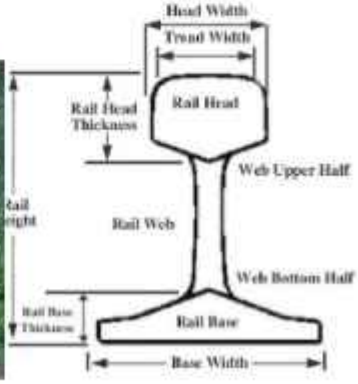
1.1: RAILWAY TERMINOLOGY:

The commonly used terms in Railway Engineering includes: -

Railway Engineering: Railway Engineering is that branch of civil engineering which deals with the construction and maintenance of the railway tracks for safe and efficient movement of trains on it.

Rails: Rails are steel girders which provide the hard and smooth surface for movement of wheels of a locomotive and railway vehicles.





Sleepers: Sleepers are the members laid transversely under the rails which are meant to support the rails over them and transfer the load from rails to ballast.



Gauge: The gauge of a track is the minimum distance between the inner running faces of the two rails.

Metre Gauge: The gauge of a track in which distance between the running faces of two track rails is one metre is called Metre Gauge.

Broad Gauge: The gauge of a track in which distance between the inner running faces of the two rails is 1.676 metres is termed as Broad Gauge.

Narrow Gauge: The gaugeof track in which the distance between the running faces of two rails is 0.762 metre is known as Narrow Gauge.

Railway Track: Railway track is the structure provided by rails fitted on sleepers, resting on ballast and subgrade for passage of wheels.

Bearing Plates: To reduce the intensity of pressure, particularly on soft variety of sleepers, a rectangular plate of mild steel or cast iron is introduced between the rails and sleepers. This plate is known as Bearing Plate. This plate distribute the loads on large area.

Ballast: Ballast is the granular material packed under and around the sleepers to transfer loads from sleepers to ballast. It helps in providing elasticity to the track.

Coning of wheels: The wheels are coned at a slope of 1 in 20 to prevent from rubbing the inside face of the rail head and to prevent lateral movement of the axle with its wheels. This is known as coning of wheels.

Creep of rails: Creep is the longitudinal movement of rails in a track. The effect of creep tends to drag the track if the ballast are insufficient to hold the rails.

Guard rails: Guard rails are extra rails provided over bridges to prevent damage and danger in case of derailment occurring on the bridge.

Embankments: The raised structure above the ground level for carrying the railway track is called embankment. When the height of the embankment is more, the side slopes are stepped for better stability of slopes.

Hogged rails: Those rails which get battered due to impact of wheels over the end of the rails are called hogged rails. These rails are get bent down and deflected at the ends.

Gradient: Any departure of the railway track from

The level is known as grade or gradient. It is called up gradient when the track rises in the direction of motion, and a down gradient when track falls in the direction of motion.

Fish plates: These plates resembling in shape to a fish, are used to provide the continuity between the two rails at the rail-joints. They also provide the required gap for expansion and contraction of rails due to temperature variations.

Locomotive: It is a machine which transfers chemical energy of fuel in mechanical energy of motion. Fuel may be water and coal or diesel or electricity.

Level crossing: When the railway line and a road cross each other at the same level, it is called level crossing.

Momentum Gradient: It is rising gradient, which takes advantages of falling gradient in developing the momentum and kinetic energy, tp negotiate this rising gradient.

Permanent Track: It is the track which is permanent nature and handles the normal commercial traffic for which it is meant. It is also called permanent way.

Points and crossings: Points, crossings, cross-overs and turnouts, etc. are arrangements by which different routes either parallel or diverging are connected to afford for the train to move from one track to another.

Pusher Gradient: The gradient which requires one or more additional locomotives for hauling the load over the rising gradient is called a pusher gradient.

Ruling Gradient: It is the maximum rising gradient which is provided keeping in view the power of the locomotives.

Railway Track: Railway track is the structure provided by rails fitted on sleepers, resting on ballast and subgrade for passage of wheels.

Sleeper Density: Sleeper density represents the number of sleepers per rail length in meters.

Track circuit: The length of track, which is connected by electric circuit to signal cabin, block telegraph apparatus, etc. required for indication of light or bell, is called a track circuit.

Turnouts: A complete set of points and crossing with the intervening lead rails is called a Turnout.

Derailment: Derailment occurs when moving wheels of a train or bogie get out of the rails. It causes by an accident and often results in loss of lives of property damages.

Super elevation or cant: On curves, to counter act the effect of centrifugal force, the level of outer rail is raised above the inner rail by a certain amount. This raising of outer rail over the inner rail is called super elevation or cant.

Cant deficiency: The equilibrium cant is provided on the basis of the average speed of different trains on the track. This equilibrium will fall short of that required for speeds higher than average speed. This shortage of can is called cant deficiency.

Buckling of rails: The railway track gets out of the original position due to buckling if the expansion of rails due to rise in temperature is prevented during hot weather. This is known as buckling due to rise in temperature.

Packing: The process of ramming the ballast underneath the sleeper is known as packing.

Wear of rails: Due to movement of very heavy loads at high speeds, the concentrated stresses often exceed the elastic limit of metal, resulting the metal flow. This flowed materials of rails is chipped off by the striking of wheels. The rail is them called worn out rail and this happening is called wear of rails.

1.2: ADVANTAGES OF RAILWAYS:

Railways have brought about many political, social and economic changes in the life of Indian people.

(a) Political advantages:
- (i) Railways have united the people of different castes, religions customs and traditions.
- (ii) With the adequate network of railways, the central administration has become more easy and effective.
- (iii) Railways have contributed towards development of a national mentality in the minds of people.
- (iv)The role of railways during emergencies in mobilizing troops and war equipment has been very significant.
- (v) Railways has helped in the mass migration of the population.

(b) Social advantages:
- (i) The feeling of isolation has been removed from the inhabitants of the Indian people.
- (ii) By travelling together into the compartment without any restriction of caste, the feeling of caste difference has disappeared considerably.
- (iii) The social outlook of the masses has been broadened through railway journeys.
- (iv) Railway has made it easier to reach places of religious importance.
- (v) Railways provide a convenient and safe mode of transport for the country.

(c) Economic Advantages:
- (i) Mobility of people has increased, there by congested areas can be relieved of congestion and the sparsely populated areas can be developed.
- (ii) Mobility of labour has contributed to industrial development.
- (iii) During famines, railways has played the vital role in transporting food and clothing to the affected people.
- (iv) Growth of industries has been promoted due to transportation of raw materials through railways.
- (v) Railways provide employment to millions of people and thus solving the problem of unemployment in the country.
- (vi) Trade developed due to railways thereby has increased the earnings and standard living of Indian people.
- (vii) Due to mobility of products through railways, the price stabilization of commodities could be possible.

(d) Techno-Economic Advantages:
- (i) Cost saving in transportation of long haul bulk traffic.
- (ii) Energy-efficiency

(iii) Environment friendliness.
(iv) Higher safety.
(v) Efficient land use and ease in capacity expansion.

1.3: Classification of Indian Railways:

(A)Classification based on importance of route, traffic carried and maximum permissible speed on the routes.

1. Trunk routes
2. Main lines
3. Branch lines

1. Trunk routes:The standards of trunk routes includes:-

ITEMS	B.G	M.G
Maximum permissible speed	120 km.p.h	80 km.p.h
Rail section	52 kg/m	37.5 kg/m
Sleeper density	n+7	n+7
Ballast cushion	25 cm below sleeper	25 cm below sleeper
Design speed for new track	160 km.p.h	100 km.p.h
Example	1. Delhi-Mughsarai-Howrah 2. Delhi-kota-Mumbai 3. Delhi-Jhansi-Nagpur-Chennai 4. Howrah-Bagpur-Mumbai 5. Mumbai-Guntakul-Chennai 6. Howrah-Vijayawada-Chennai	1. Lucknow-Gorakhpur-Guwahati 2. Delhi-Jaipur-Ahmedabad 3. Chennai-Madurai-Trivandrrum

2. Main lines: All lines other than trunk routes carrying 10 Gross Million Tonnes (GMT) per annum or more for B.G and 2.5 G.M.T or more for M.G. or where maximum permissible speed allowed is 100 km.p.h for B.G and 75 km.p.h for M.G. are classified as main lines.

ITEMS	B.G	M.G
GMT/annum	≥ 10	≥ 2.5
Maximum permissible speed	100 km.p.h	75 km.p.h
Rail section	52 kg/m	37.5 kg/m
Design speed for new track	120 km.p.h	75 km.p.h

3. Branch lines: These are classified on the basis of following criteria:

All those B.G lines which carry less than 10 GMT per annum and have max. Permissible speed of less than 100 km.p.h are classified as Branch lines.

For M.G tracks, all those lines which carry less than 2.5 GMT per annum and have max. Permissible speeds less than 75 km.p.h are classified as Branch lines.

(B) Classification based on speed criteria:

According to this B.G railway lines are classified into 5 groups:-

1. ***Group 'A' lines*:** They consists of those trunk routes on which the trains are running or are meant for running the trains at a speed of 160 km.p.h or more.

Example-i. New delhi-howrah by Rajdhani route

ii. New Delhi-Mumbai central

iii. New Delhi-Chennai central

iv. Howrah- Mumbai V.T.

2. ***Group 'B' lines:*** They consists of those routes on which the trains with a maximum sanctioned speed of 130 km.p.h are running or are intended to run. At present nearly 13 routes come under this category e.g., Allahabad to Bhusaval, Kalyan to Chennai, Kharagpur to Vijayawada, Howrah to New jalpariguri, Sitarampur to Mughalsarai, Kiuli to Barharwa, Delhi to Kolkata, Ambala to Pathankot, Ambala to Mughalsarai, Arkonam to Coimbatore, Vadodara to Ahmedabad and Jalanpet to Bangalore.
3. ***Group 'C' lines:*** They consists of all suburban routes of Mumbai, Kolkata and Delhi.
4. ***Group 'D' lines:*** All other routes in the country where maximum permissible speed at present is 100 km.p.h.
5. ***Group 'E' lines:*** The other routes and branch lines where the permissible speed limits are less than 100 km.p.h.

CHAPTER 02

PERMANENT WAY

2.1: Definition and components of a permanent way:

The combination of rails, fitted on sleepers and resting on ballast and subgrade is called the railway track or permanent way.

In a permanent way, the rails are joined in series by fish plates and bolts and then they are fixed to sleepers by different types of fastenings. The sleepers properly spaced, resting on ballast, are suitably packed and boxed with ballast. The layer of ballast rests on the prepared subgrade called the formation. The rails act as girders to transmit the wheel load to the sleepers. The sleepers hold the rails in proper position with respect to the proper tilt, gauge and level, and transmit the load from rails to the ballast. The ballast distributes the load over the formation and holds the sleepers in position.

Track Cross-section

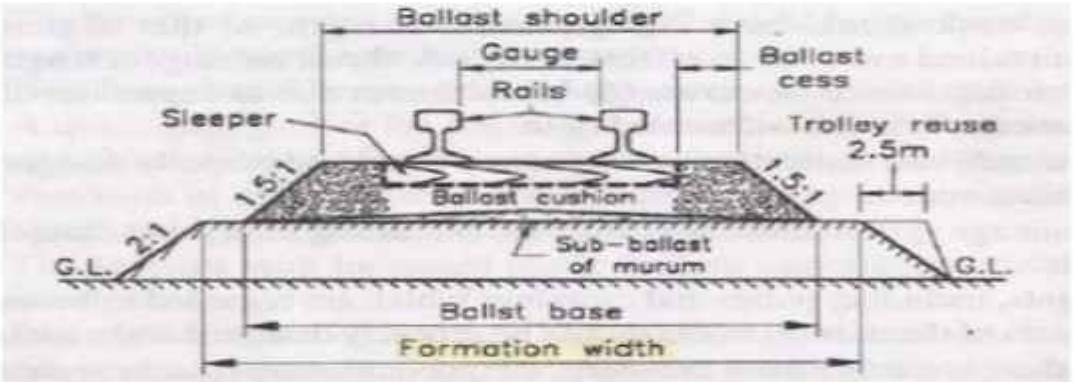


Fig. 3.1 Typical Cross-section of a Permanent Way on Embankment.

2.2: Concept of gauge, different gauges prevalent in India, suitability of these gauges under different conditions:

Definition:The 'Gauge' of a railway track is defined as the clear distance between inner or running faces of two track rails. The distance between the inner faces of a pair of wheels is called the wheel gauge.

Different gauges in india: In India, the East India Company adopted 1.676 m. gauges as the standard gauge (Broad gauge). In 1871, in order to build cheap railways for the development of the country, the government adopted a metre gauge i.e. 1 m wide. In addition to broad gauge and metre gauge for hilly areas and for developing poor areas, India has 0.762 m. and 0.610 m. narrow gauges tracks and feeder gauge tracks.

Types of gauge	*Gauge width*
Broad gauge	1.676 m.
Metre gauge	1.0 m.
Narrow gauge	0.762 m.
Feeder track gauge	0.610 m.

Selection of gauge: The following factors govern the choice of different gauges:-

1. **Cost of construction:** There is little increase in the initial cost if we select a wider gauge.
   i. The cost of bridges, tunnels, station buildings, staff quarters, cabins and level crossing is same for all gauges.
   ii. The cost of earth work, ballast, sleepers, rails, etc. would proportionally increase with increase in gauge width.
   iii. There is increase in the acquisition of land for permanent track with increase in gauge.
2. **Volume and nature of traffic:** For greater traffic and greater load carrying capacity, the trains should be run by a better traction technique or by better locomotives. For heavier loads and high speed, the wider gauges are required.
3. **Development of the Areas:** Narrow can be used to develop the thinly populated areas by joining the under developed areas with developed or urbanized areas.
4. **Physical features of the country:** Use of narrow gauge is warranted in hilly regions where broad gauge and meter gauges are not possible due to steep gradients and sharp curves.
5. **Speed of movement:** The speed of a train is almost proportional to the gauge. Speed is the function of diameter of wheel, which in turn is limited by the gauge. Lower speed discourage the customers, and so for maintaining high speeds, the broad gauge is preferred

Broad Gauge and its suitability:.

When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1.676 m. then that is known as Broad gauge.

The countries using broad gauge are India, Pakistan, Bangladesh, Sri Lanka, Brazil, Argentina etc. 50% of India's railway tracks have been laid by this gauge.

Broad gauge is suitable under following conditions:-

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

Metre Gauge and its suitability:

When the clear horizontal distance between the inner faces of two parallel rails forming a track is 1 m, the gauge is known as Metre gauge. The countries using metre gauge are France, Switzerland, Argentina, India etc. 40% of India's railway tracks have been laid to this gauge.

Metre gauge is suitable under following conditions:-

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

Narrow Gauge and its suitability:

When the clear horizontal distance between the inner faces of two parallel rails forming a track is 0.762 m. the gauge is known as narrow gauge. The countries using narrow gauge are Britain, India, South Africa etc. About 10% India's railway track have been laid to this gauge.

Narrow gauge is suitable under following conditions:-

i. When the construction of a track with wider gauge is prohibited due to the provision of sharp curves, steep gradients, narrow bridges and tunnels etc.
ii. This gauge is therefore, used in hilly and very thinly populated areas.

Feeder gauges: The feeder gauges are commonly used for feeding raw materials to big government manufacturing concerns as well as to private factories such as steel plants, oil refineries, sugar factories etc.

CHAPTER 03

TRACK MATERIALS

3.1: Rails:

The rails on the track are steel girders used for the purpose of carrying axle loads and smooth movement of the locomotives. They are made up of high carbon steel to withstand wear and tear.

3.1.1: Functions and requirement of rails:

Functions: Rails in the railway track serve the following purposes: -

i. Rails provide a hard, smooth and unchanging surface for the passage of heavy moving loads with a minimum friction between the steel rails and steel wheels.
ii. Rails bear the stresses developed due to heavy vertical loads, lateral and braking forces and thermal stresses.
iii. The rail material used is such that it gives minimum wear to avoid replacement charges and failures of rails due to wear.
iv. Rails transmit the loads to sleepers and consequently reduce pressure on ballast and formation below.

Requirements of rails:Rails act as continuous girders carrying axle loads. They should meet the following requirements:-

i. They should be of proper composition of steel and should be manufactured by open hearth or duplex process.
ii. The vertical stiffness should be high enough to transmit the load to several sleeper underneath. The height of rail should, therefore, be adequate.
iii. Rails should be capable of withstanding lateral forces.
iv. The head must be sufficiently deep to allow for an adequate margin of vertical wear. The wearing surface should be hard.
v. Web of rails should be sufficiently thick to bear the load coming on it and should provide adequate flexural rigidity in horizontal plane.
vi. Foot should be wide enough so that rails are stable against overturning, especially on curves.

vii. Bottom of the head and top of the foot of rails should be so shaped as to enable the fish plates to transmit the vertical load effectively from the head to the foot at rail joints.

viii. Relative distribution of material of rail in head, web and foot must be balanced, for smooth transmission of rails.

ix. The Centre of gravity of the rail section must lie approximately at mid-height so that maximum tensile and compressive stresses are equal.

x. The fillet radii must be large to reduce the concentration of stresses.

xi. The tensile strength of rail section must not be less than 72 kg/m2.

xii. The rail specimen should withstand the blow of "Falling weight test" as specified by Indian Railway Standards without fracture.

3.1.2: Types of rail sections, length of rails

Types of rail sections :

The three types of rail sections generally used for the construction of railway track are:

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

1.Double headed rails (D.H.Rails):

In the beginning Double headed rails of a dumb-bell section are used. The idea behind using of these rails was that when the head has worn out in course of time, the rail can be inverted and reused. But experience showed that such indentations are formed in lower table due to which smooth running over that surface at the top was impossible.

2.Bull headed rails (B.H.Rails):

In bull headed rails the head was made a little thicker and stronger than the lower part, by adding more metal to it, so that even after wear, it can withstand stresses. Side by side with the bull headed rails, flat footed rails also called Vignola's rails after the name of the inventor.

Merits:

i. They keep better alignment and give more solid and smoother track.

ii. They are easily disconnected from sleepers as they have no direct connection with the sleepers.

iii. The heavy chairs with larger bearing on sleepers give longer life to wooden sleepers and greater stability to the track.

Demerits:

i. They require additional cost of iron chairs.
ii. They have less strength and stiffness.
iii. They require heavy maintenance cost.

3.Flat footed rails (F.F.Rails):

Initially it was thought that the flat footed rails could be fixed to sleepers directly and would eliminate the need of chairs and keys required for the bull headed rails. However it was observed that heavy train loads caused the foot of the rail to sink into the wooden sleeper, making the spikes work loose.

Merits:

i. They have more strength and stiffness, both vertically and laterally, than bull headed rails.
ii. Fitting of rails with sleepers is simpler, so they can be easily laid and re-laid.
iii. No chairs and keys are required as in case of bull headed rails.
iv. In points and crossings, the arrangements are simpler than bull headed rails.

Demerits:

i. The fittings get loosened more frequently than in case bull headed rails. The impact of rolling wheels directly affects the fittings.
ii. The straightening of bent rails, replacing of rails and dehogging of battered rails are difficult.

Comparison of Rail Types:

SI No	*Point of comparison*	*Flat footed rails*	*Bull headed rails/ Double headed rails*
01	Strength and stiffness	These have more strength and stiffness for the same weight, both laterally and vertically.	These have less strength and stiffness.
02	Laying and relaying	Fitting of these rails is simpler and so can be easily laid and relaid. No chairs are required.	The fitting of these rails is difficult and time consuming as they are supported on chairs.
03	Arrangements at points, crossings and at sharp curves	The arrangements are simpler and easy.	The arrangements are complicated and difficult.
04	Alignment and stability of track	In this impact of rolling wheels affects the fittings and the loosening of fittings disturbs the alignment and gives less stability	These rails when fitted on chairs, provide a more solid, smooth track and better stable alignment.
05	Initial cost	These rails require lesser and cheaper fastenings, so the initial cost is less.	These require more and costly fastenings and hence initial cost is more.
06	Rigidity	These rails can be used without bearing plates on sleepers as these rails are strong to withstand vertical loads. Hence they are more rigid.	These rails without cannot be used on inferior type of sleepers, being less strong against vertical loads. Hence they are less rigid.
07	Inspection	Daily inspection is not necessary as no special risk is involved.	In case of B.H or D.H. rails, daily inspection of wooden keys is necessary.
08	Replacement of rails	In F.F. rails, the dog spikes have to be taken out in addition to fish bolts and fish plates to change the rails. So replacement is difficult.	These rails can be changed easily by driving out the keys and taking out fish plates, without disturbing sleepers.
09	Maintenance cost	The maintenance cost is less.	It requires heavy maintenance cost.
10	Suitability	These are more suitable due to better stability, economy, strength and stiffness.	These are more suitable when lateral loads are more important rather than vertical loads.

length of rails:

The rails of larger length are preferred to smaller length of rails, because they give more strength and economy for railway track. The weakest point of a track is the joint between two rails. Lesser the number of joints, lesser would be the number of fish plates and this would lead to lesser maintenance cost, smoother running of trains and more comfort to the passengers. Moreover the more number of joints would increase wear and tear of the vehicle components, including wheels.

Though the long length of the rails is desired, however, the length is governed by the following factors:

1. The length of the rails is so chosen that the manufacturing cost is more reasonable.
2. It depends upon the transportation facilities, so only those lengths of rails are possible which can be transported by longest wagons available on the railways.
3. To some extent, the length is also limited by the facilities of lifting and handling, during the loading and unloading of wagons.
4. More the length of the rail, more will be the gap required for expansion of rail due to temperature but, however, the expansion is not proportional to gap because fastenings check the movement of rails, so expansion gap is not limiting factor for length of rails though it affects to some extent.

On Indian Railways the standard lengths are the following:

Length = 12.80 m. (42 ft) for B.G. (say 13 m)

And Length = 11.89 m (39 ft) for M.G. (say 12 m)

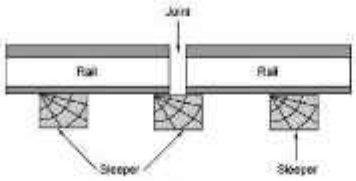
3.1.3: Rail joints – types, requirement of an ideal joint:

Rail joints are necessary to hold tighter the adjoining ends of the rails in the correct position, both in the horizontal and vertical planes. Rail joints form the weakest part of the track. It is observed that strength of a rail joint is only 50 percent of the strength of a rail.

Types of rail joints:

The following types of joints are commonly used on railways:-

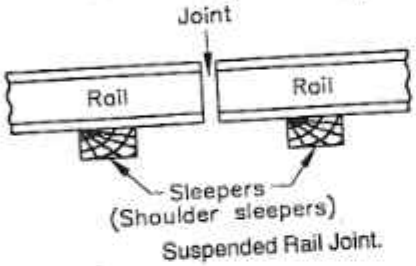
1. *Supported rail joint:* When the rail ends rest on a single sleeper called a joint sleeper is termed as supported joint.



Supported Rail Joint

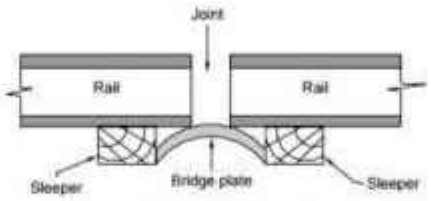
Three sleeper support with long fish plates, i.e combined supported and this joint is most objectionable. Because in this case when the packing under the outer sleeper gets loose, undue load comes on central sleeper and in turn the loose central sleeper converts this joint into a weak suspended joint.

2. *Suspended rail joint*: When rail ends are projected beyond sleepers called shoulder sleeper it is termed as suspended joint. This type joint is generally used with timber and steel trough sleepers on Indian and foreign railways.



Suspended Rail Joint.

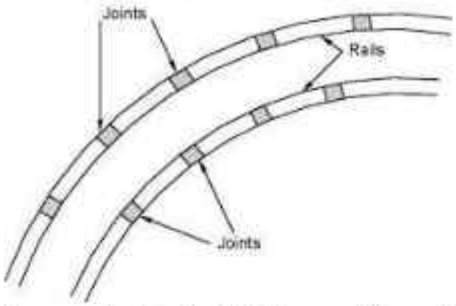
3. *Bridge joint:* When the rail ends are projected beyond sleepers as in case of suspended joint and they are connected by a flat or corrugated plate called a bridge plate is termed as a Bridge joint. This type of joint is not used on Indian railways.



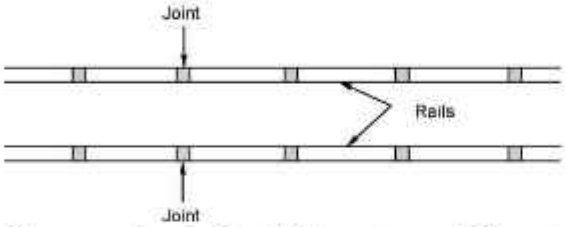
Bridge Plate with Bridge Plate

4. *Base joint:* This is similar to the bridge joint, with the difference that the inner fish plates are of bar type and outer fish plates are of the special angle type, in which the horizontal leg is further extended over the sleepers to be bolted to both bridge plate and sleeper. Due to complicated design this is not generally used.
5. *Welded rail joints:* These are the best joints as they fulfil nearly all the requirements of an ideal or perfect joint.
6. *Staggered or Broken joint:* In this, position of joints on railway track is the basis of its nomenclature. In this type of joint, the joints of one rail track are not directly opposite to the joints of the other rail track. These joints are generally provided on curves,

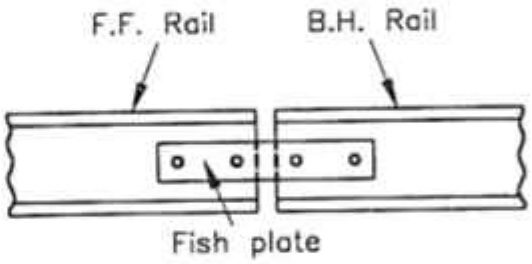
where the length of outer curved track is greater than the length of inner curved track.



7. *Square joint:* In this the position of rail joint is the basis of its nomenclature, the joints of one rail track are directly opposite to the joints of other rail track. This is generally used on straight tracks.



8. *Compromise joint:* Where two different rail sections are required to be joined together, it is done by means of fish plates which fit both the rails and this joint is termed as compromise joint.



. Compromise Joint.

9. *Insulated joint:* When insulating medium is inserted in a rail joint to stop the flow of current beyond the track-circuited part, it is called insulated joint.
10. *Expansion joint:* In bridges, provision for expansion and contraction is kept for girders and rails both. This gap is 2.2 cm in case of mitred joint and 7.2 cm for halved joint.

The number of joints can be reduced by the process of welding of rails. Welded joints are considered as the most perfect and strongest type of joints.

Requirement of an ideal joint:

An ideal or perfect rail joint is one which provides the same strength and stiffness as the other rail section of the track. The following requirements should be met by an ideal joint:-

(i) The two rail ends should remain true in line both laterally and vertically when trains move on the track. This is necessary to avoid wheel jumping or changing its correct path of movements.

(ii) The rail joint should be as strong and stiff as the rail itself and should be elastic both laterally and horizontally.
(iii)The rail joint should provide enough space for free expansion and contraction to account for the effect of temperature variations.
(iv)A good joint should be easily disconnectable so that it can be easily taken out without disturbing the whole track for the purpose of changing rail or a fish plate, and lubricating the contact faces.
(v) It should not allow the rail ends to get battered in any case.
(vi)The joint should fulfil the above requirements with the minimum of initial and maintenance cost(i.e it should be economical).

3.1.4 Purpose of welding of rails & its advantages:

Purpose of welding:

Welding of rails serves the following purposes:-

(i) To increase the length of the rail by joining two or more rails and thus to reduce the number of joints, and requirements of fish plates, which lead to economy and strength.
(ii) To repair the worn out or damaged rails and thus increase their life.
(iii)To build up worn out points and rails on the sharp curves.
(iv)To build up the burnt portion of rail head which is caused due to slippage of wheels over the rails or other defects or spots in rail steel.

Advantages of welding rails:

1. It satisfies the condition of a perfect joint and hence increases the life of the rail, as also the reduction in maintenance cost of track by about 20 to 40 percent.
2. It reduces the creep due to increase in the length of rail in turn friction as well.
3. Expansion effect due to temperature is reduced which in turn also reduces the creep.
4. Due to discontinuity of joints, a source of track weakness is reduced. The defects, such as hammering at rail joints, displacement of joints, disturbance in alignment and running surface, which result in bad riding quality, are eliminated.
5. Long rail length being heavier, dampen the intensity of high frequency vibrations due to moving loads.
6. Welding increases the life of rails due to decrease in the wear of rails at joints.
7. Welding facilitates track circuiting on electrified tracks.
8. Welding rails provides on large bridges for the span length are helpful as they result in better performance.
9. The cost of track construction by welding of rails decreases due to less number of rail joints.

3.1.5 Creep- definition, cause & prevention:

Definition:

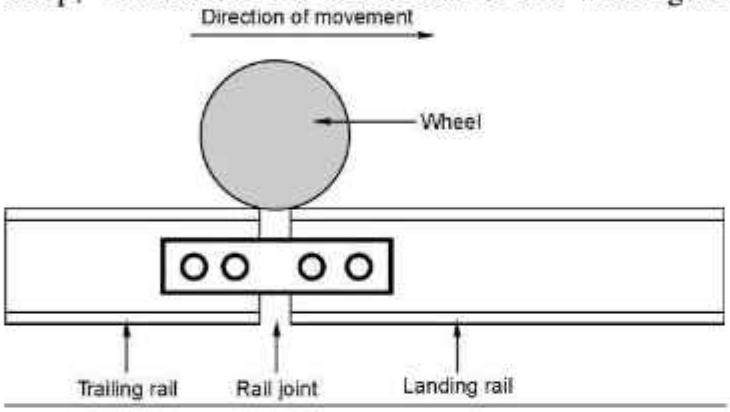
Creep is defined as the longitudinal movement of rails with respect to sleepers in a track. Creep is common to all railway tracks, but varies in magnitude, the rail in some

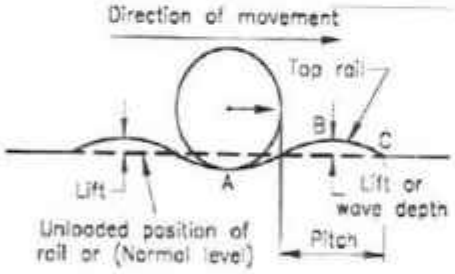
places, moves by several centimeters in a month while in other locations the movement of rails may be negligible.

Causes/Theories of creep:

The various theories propounded for explaining the probable causes of creep in rails are:-

(i) *Wave action or wave Theory:* Wave motion is set up by moving loads of wheels. The vertical reverse curve ABC is formed in the rails ahead of the wheels, resulting from the rail deflection under the load, is the chief cause of creep. The wheels push the wave with a tendency to force the rail in the direction of traffic. As the wheels move, the lift in front of the moving load is thus carried forward by the wheels and causes creep, whereas the lift at the rear of the wheel gets back to its normal position.

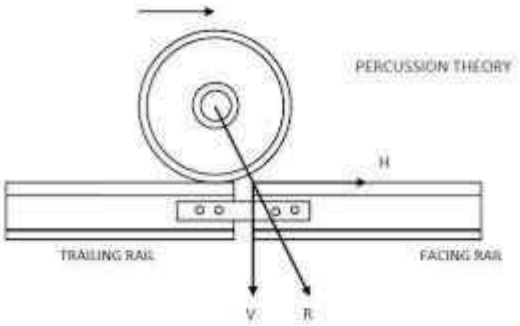




The pitch and depth of wave depend upon the following:-
1. Track modulus
2. Stiffness of track
3. Stability of formation

The wave action can be reduced by adopting following measures:-
1.Angular and heavy ballast-which develops good interlock
2.Increased stiffness of track
3.Lesser sleeper spacing
4.Bigger section of the rail

(ii) *Percussion Theory:* This theory states that the creep is due to impact of wheels at the rail end ahead at joints. The horizontal component 'P' of 'R' tends to cause creep while the vertical component tends to bend down the rail end vertically i.e to make a battered rail end. Hence as and when the wheels leave the trailing rail and strike the facing rail end at each joint, it pushes the rail forward resulting in creep. Though the creep is very small in single impact but cumulative effect of number of wheels in quick succession results in sufficient creep.



The creep by this theory will increase due to following factors:-

1. Due to weak and loose fish bolts.
2. Due to worn out fish plates
3. Due to loose packing at joints
4. Due to wide expansion gap
5. Due to heavy axle loads moving at high speed.

(iii) *Drag or Dragging Theory:* It states that backward thrust on driving wheels of the locomotive of train has got a tendency to push the rail off the track backward while the other wheels of the locomotive and the vehicles push the rail in the direction of travel as explained in wave action theory and they have greater effect as compared to drag effect. This results in creep of rails in the direction of movement of trains.

(iv) *Starting, Accelerating, slowing down or stopping of a Train:* When a train is starting or accelerating, the backward thrust of the engine driving wheels tends to push the rails backward. When it is slowing down or coming to a stop, the braking effect tends to push the rails forward.

(v) *Expansion or contraction rails due to Temperature:* Creep also occurs due to variation in temperature. The creep in this case is influenced by the range in temperature variation, location of track, whether exposed or shady surroundings, etc.

(vi) *Unbalanced-Traffic:* (a)In a single line system if heavy equal traffic runs in both directions, the creep is almost balanced. Otherwise heavy traffic in one direction will cause creep, which is partly balanced by light traffic in opposite direction. (b) In the double line system trains on a particular line being unidirectional, creep occurs in both the lines.

Remedies or Prevention of Creep:

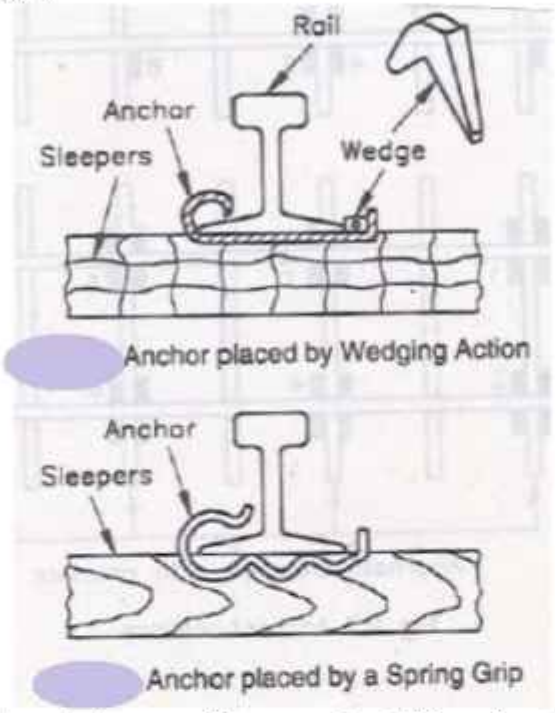
Prevention is always better than cure. If creep is not prevented in time, it will result in derailment. Following are the common methods adopted to prevent creep.

a) *Pulling Back the Rails:* If creep is distinctly visible, the remedy is to pull back the rails to their original position. For doing this first inspect the track, note the extent of pulling back distance and determine the point from which to begin. Now start pulling the rails back to their original positions by means of crow bars and hooks provided through the fish bolt holes of rails. In pulling back, the positions of joints relative to sleepers must be maintained, and both the rail joints must be in their relative positions. Pulling back the rails is a very slow and tedious process and is only possible when a small length is to be dealt.

b) *Provision of Anchors or Anticreepers:* The creep of the track can be prevented by use of anchors and sufficient crib ballast. For creep of 7.5 cm to 15 cm, in a month 4-

anchors per rail and for creep of 22.5 cm to 25 cm 6-anchors per rail are used in the Indian practice.

Anchors are fastened to the foot of rail and kept in perfect contact with the side of the sleeper being the side opposite to the direction of creep. If creep occurs in both directions, anticreepers are provided on both the sides of sleepers, starting from the centre of the rail and should never be fixed near the joints. Anchors are fixed to rails either (i) by wedging action (ii) by clamping or (iii) by a spring-grip



c) *Use of steel sleepers:* Sleepers should be of such a type and with such fittings that they effectively prevent the rail from creeping on them. Secondly, the sleepers must have a good grip with the ballast to resist the movement of the sleepers in the ballast. Steel trough sleepers are the best for this purpose. Increase in the number of sleepers will also help in the prevention of creep.

3.2 Sleepers:

3.2.1 Definition, function & requirements of sleepers

Definition:

Sleepers are the members generally laid transverse to the rails on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade below.

Functions of Sleepers:

Sleepers perform the following functions:-

(a) To hold the rails to correct gauge.
(b) To hold the rails in proper level or transverse tilt i.e, level in turnouts, cross-overs, etc., and at 1 in 20 tilt in straight tracks, so as to provide a firm and even support to rails.

(c) To act an elastic medium in between the ballast and rails to absorb the blows and vibrations of moving loads.
(d) To distribute the load from the rails to the index area of ballast underlying it or to the girders in case of bridges.
(e) To support the rails at a proper level in straight tracks and at proper super elevation on curves.
(f) Sleepers also add to the longitudinal and lateral stability of the permanent track on the whole.
(g) They also provide means to rectify track geometry during service life.

Requirements of Sleepers:

An ideal sleeper should possess the following characteristics:-

(a) The sleepers to be used should be economical, i.e., they should have minimum possible initial and maintenance costs.
(b) The fittings of the sleepers should be such that they can be easily adjusted during maintenance operations such as easy lifting, packing, removal and replacement.
(c) The weight of sleepers should not be too heavy or excessively light, i.e., they should have moderate weight, for ease of handling.
(d) The design of sleepers should be such that the gauge, alignment of track and levels of the rails can be easily adjusted and maintained.
(e) The bearing area of sleepers below the rail seat and over the ballast should be enough to resist the crushing due to rail seat and crushing of the ballast underneath the sleeper.
(f) The sleeper design and spacing should be such as to facilitate easy removal and replacement of ballast.
(g) The sleepers should be capable of resisting shocks and vibrations due to passage of heavy loads of high-speed trains.
(h) The design of the sleepers should be such that they are not damaged during packing processes.
(i) The insulation of rails should be possible for track circuiting, if required, through sleepers.
(j) The design of sleepers should be such that they are not pushed out easily due to moving trains especially with steel sleepers with rounded ends.
(k) An ideal sleeper should also have an anti-sabotage and anti-theft qualities.

3.2.2 Classification of sleepers:

Sleepers can be classified according to the materials used in their construction:

1. Wooden sleepers
2. Metal sleepers: (i) Cast iron sleepers (ii) Steel sleepers
3. Concrete sleepers: (i) Reinforced concrete sleepers (ii) Prestressed concrete sleepers

3.2.3 Advantages & disadvantages of different types of sleepers:

1.Wooden/Timber sleepers:

Wooden sleepers are regarded to be best as they fulfil almost all the requirements of an ideal sleeper. The life of timber sleepers depends upon their ability to resist (i) Wear, (ii) Decay, (iii) Attack by vermin, i.e., white ants and (iv) Quality of the timber used.

Advantages:

(a) Timber is easily available in all parts of India.
(b) Fittings of wooden sleepers are few and simple in design.
(c) These sleepers are able to resist the shocks and vibrations due to heavy moving loads and also give less noisy track.
(d) Wooden sleepers are easy to lay, relay, pack, lift and maintain.
(e) These wooden sleepers are suitable for all types of ballast.
(f) They are best for track-circuited operations and moreover, wooden sleepers are over-all economical.

Disadvantages:

(a) The sleepers are subjected to wear, decay, attack by white ants, spike killing, warping, cracking, end splitting, rail cutting, etc.
(b) It is difficult to maintain the gauge in case of wooden sleepers.
(c) Track is easily disturbed, i.e., alignment maintenance is difficult.
(d) Wooden sleepers have got minimum service life as compared to other types of sleepers.
(e) Maintenance cost of wooden sleepers is highest as compared to other sleepers.

2.Metal sleepers:

Due to the growing of wooden sleepers, their high cost and short life, metal sleepers are now being widely adopted in India. Metal sleepers are either of steel or cast iron. Cast iron is in greater use than steel for sleepers because it is less prone to corrosion.

Advantages:

(a) Metal sleepers are uniform in strength and durability.
(b) In metal sleepers, the performance of fittings is better and hence lesser creep occurs.
(c) Metal sleepers are economical, as life is longer and maintenance is easier.
(d) Gauge can be easily adjusted and maintained in case of metal sleepers.
(e) For metal sleepers, frequent renewal is not required.
(f) They have good scrap value, easy in manufacturing and not susceptible to fire-hazards.

Disadvantages:

(a) More ballast required are greater in number, and difficult to maintain and inspection.
(b) Metals, C.I., or steel, are liable to rusting/corrosion.
(c) Metal being good conductor of electricity interferes with track circuiting.
(d) Metal sleepers are unsuitable for bridges, level crossings and in case of points and crossings.
(e) These sleepers are only suitable for stone ballast and for rails for which they are manufactured.

Cast iron sleepers have been extensively used in India and on a small scale in South America. They are of following types:- (1) Pot or Bowl sleepers (2) Plate sleepers (3) Box sleepers (4) C.S.T-9 sleepers (5) Rail free Duplex sleeper.

The various types of steel sleepers used in India are:- (1) Key type (2) Clip-bolt type (3) Saddle or spring type

3.Concrete Sleepers:

These sleepers were added due to chronic shortage of wooden sleepers and need for better design and economy of sleepers on suitable basis. These sleepers are mainly of two types:-

(a) Reinforced concrete sleepers
(b) Pre-stressed concrete sleepers

Advantages:

(a) These sleepers are free from natural decay and attacks by vermin, insects, etc.
(b) They have maximum life when compared to other sleepers, the life under normal conditions is 40-60 years as compared to 15-20 years for wooden sleepers.
(c) This is not affected by moisture, chemical action of ballast, cinder and sub-soil salt.
(d) There is difficulty in the track-circuiting, required for electrifying the track.
(e) The high weight of sleepers helps in minimizing joint maintenance by providing longer welded lengths, greater stability of the track and better resistance against temperature variation.
(f) The sleepers have higher elastic modulus and hence can withstand the stresses induced by fast and heavy traffic.
(g) Concrete sleepers in the elastic fastenings offers an ideal track in respect of gauge, cross-level and alignment.

Disadvantages:

(a) The weight of concrete sleeper is as high as 2.5 to 3 times of wooden sleeper, requiring the mechanical appliances for handling.
(b) These sleepers require pads and plugs for spikes.
(c) They damage the bottom edge during the packing.
(d) The scrap value is almost nil.
(e) The damages to the concrete sleepers is very heavy in case of derailment.

3.3 Ballast:

Ballast is the granular material usually broken stone or brick, shingle or kankar, gravel or sand placed and packed below and around the sleepers to transmit load from sleepers, to formation and at the same time allowing drainage of the track. It provides a suitable foundation for the sleepers and also hold the sleepers in their correct level and position, preventing their displacement by lateral or longitudinal thrusts.

3.3.1 Functions & requirements of ballast:

Functions of Ballast:

Ballast perform the following functions:

(i) It transfers the load from the sleeper to the subgrade and then distributes it uniformly over a larger area of the formation.
(ii) It holds the sleepers in position and prevents the lateral and longitudinal movement, due to dynamic loads and vibrations of moving trains.
(iii) It imparts some degree of elasticity to the track.
(iv) It provides easy means of maintaining the correct levels of the two lines of a track and for correcting track alignment.
(v) It providesgood drained foundation immediately below the sleepers and helps to protect the top surface of the formation. This is achieved by providing coarse and rough aggregates with plenty of voids.

Requirements of ballast:

(a) It should be able to withstand hard-packing without disintegrating.
(b) It should not make the track dusty or muddy due to powder under dynamic wheel loads but should be capable of cleaned to provide good drainage.
(c) It should allow for easy drainage with minimum soakage and the voids should be large enough to prevent capillary action.
(d) It should offer resistance to abrasion and weathering. Abrasion means wear due to rubbing action of particles with each other and weathering means cracking and shattering of the material due to variation in temperature, moisture and feezing.
(e) It should retain in position laterally and longitudinally under all conditions of traffic, particularly on curves, where it should be able to prevent transverse displacement of sleepers.
(f) It should not produce any chemical action with rail and metal sleepers.
(g) The size of stone ballast should be 5 cm for wooden sleepers, 4 cm for metal sleepers and 2.5 cm for turnouts and crossovers.
(h) The materials should be easily workable by means of the implements in use.
(i) The ballast should be available in nearby quarries so that it reduces the cost of supply. It should also fulfil the requirements of quality, amount of traffic, life and maintenance cost.

3.3.2 Materials for Ballast:

The different matrerials used as ballast in India are broken stone, gravel, sand, soft aggregates like moorum, kanker, overburnt and broken brickbats, blast furnace slag and sometimes selected earth.

1. ***Broken stone:*** This is the best material for the ballast and almost all important tracks are provided with stone ballast. Broken stone satisfies all the specifications and requirements of good ballast. The best stone for ballast is a nonporous, hard and angular, which does not flake when broken. For stability graded broken stone ballast is better than ungraded one. Graded stone of 5.08 cm to 1.9 cm size is found to provide the maximum stability, where as workability is better with smaller size ballast.

2. ***Gravel:*** Gravel comes next in the rank for its suitability for use as ballast and used in large quantities in many countries. This is obtained either from river beds or from gravel pits.
3. ***Ashes or cinders:*** This material is available in large quantities on railways from coal being used in locomotives. It has excellent drainage properties as it is very porous. It is cheap and largely used in sidings but cannot be used for main lines as it is very soft and gets reduced to powder under wheel loads and makes the track very dusty. The great drawback of ashes is its corrosive quality and therefore it corrodes steel sleepers and foot of the rails.
4. ***Sand:*** It is reasonably good material as ballast as it is cheap and provides good drainage. The great drawback of the sand is its blowing effect due to vibration. Sand ballast is sometimes covered with a layer of stone or brick or some such material to prevent it from blowing about too much. The coarse sand is preferred to fine sand. The best sand consists of a good quantity of fine gravel and sand which is used on narrow gauge tracks.
5. ***Moorum:*** It is the soft aggregate and is the result of decomposition of laterite and has a red or sometimes a yellow colour. The best moorum for ballast is that which contains large quantities of small laterite stone. It is recommended as a ballast for sidings and main tracks when they are newly laid and the embankments are not sufficiently consolidated.
6. ***Kanker:*** It is lime agglomerate which is common in certain clayey soils and is dug out of the ground. Where stone is not available, it is used as road metal and as ballast for railway tracks. It is soft in nature and reduces to powder under loads. It is used for M.G and N.G tracks with light traffic and where a better type of the ballast is not available.
7. ***Brick ballast:*** Where no stone or substitute is available for use as ballast, over burnt bricks are broken into small sizes and used. It powders easily and produces a dusty track. Rails of tracks laid on brick ballast many a time get corrugated. Brick ballast is good for drainage.
8. ***Blast Furnace slag:*** It is a by-product in the manufacture of pig iron and is suitable for ballast material. Slag suitable for use as ballast is obtained by pouring molten slag collected at the blast furnace into shallow pits of thin layers, allowing it to cool, and then by digging, crushing and screening.
9. ***Selected earth:*** For sidings, earth, if of suitable quality is sometimes used as ballast. It is also sometimes used on new formation as a temporary measure. Hardened clay and decomposed rock are suitable materials.

3.4 Fixtures for Broad gauge:

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

The different functions of these fittings are:-

(a) To keep the rails in the proper positions.
(b) Connection of rail to rail.
(c) To set points and crossings properly.
(d) To allow for expansion and contraction of rails.

They includes:-

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

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

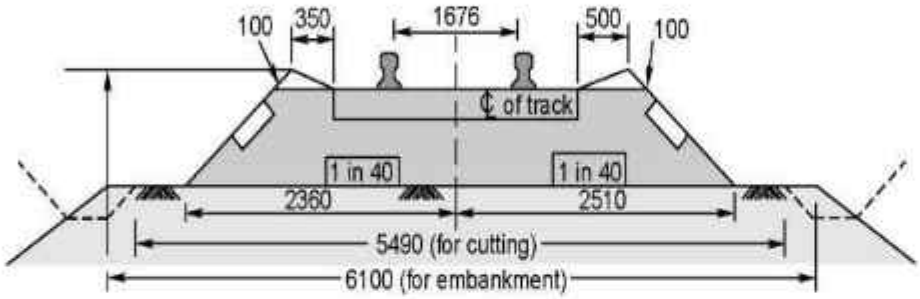
1. ***Fish plates:*** These plates are used to maintain proper alignment of the rail line. They maintain the continuity of the rails and also allow expansion or contraction of rails caused due to temperature variations. Generally these plates are made up of mild steel and 20 mm in thick. They are 45.6 cm long and provided with 4 nos. of 32 mm diameter holes.
2. ***Spikes:*** They are used to hold the rails to the wooden sleeper. A good spikes should have following qualities:- (a) It should have sufficient strength to hold the rail in position. (b) It should help in maintaining proper gauge. (c) It should be easy to fix and replace from the sleepers. Indian railways uses different types of spikes such as dog spikes, screw spikes, round spikes, standard spikes and Elastic spikes.
3. ***Bolts:*** They are used for connecting (a) Fish plates to the rails at each rail joint. (b) bearing plates to timber sleepers. (c) Sleepers to bridge girders. etc. Different types of bolt used in Indian railways are Hook bolts, Fish bolts, Fang bolts, Rag bolts.
4. ***Chairs:*** They are used to hold the double headed and bull headed rails in required position. They are made of cast iron having two jaws and a rail sheet. In order to fix the double headed or bull headed rail to a chair, the rail is placed between the two jaws of the chair.
5. ***Keys:*** They are small tapered pieces of timber or steel to connect rails to chairs on metal sleepers.
6. ***Blocks:*** They are inserted in between the two rails running close to each other and bolted to maintain the required distance.
7. ***Bearing plates:*** They are placed in between the flat footed rails and timber sleepers on a track. They are made up of cast iron or steel.

Geometric for broad gauge

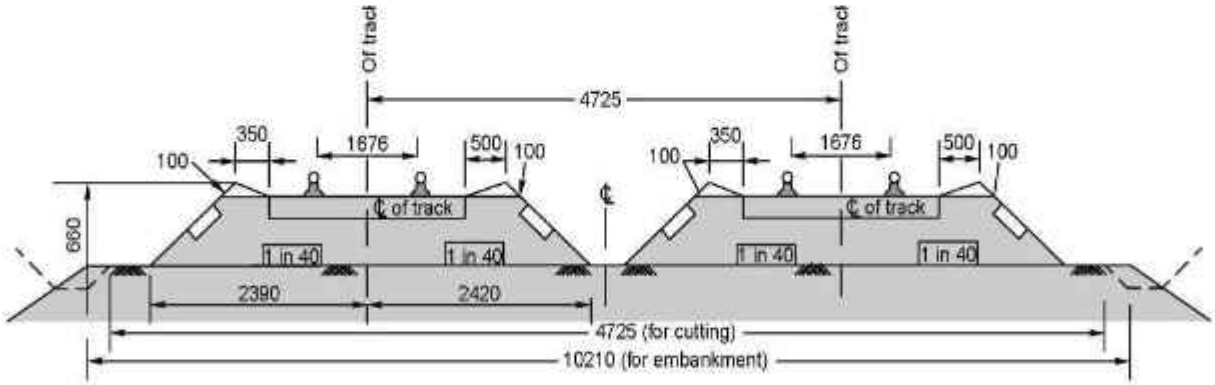
Topics to be covered in this chapter..

4.1Typical cross – sections of single & double broad gauge railway track in cutting and embankment
4.2 Permanent & temporary land width
4.3 Gradients for drainage
4.4 Super elevation – necessity & limiting valued

4.1Typical cross:



-: Single line Broad Gauge track:-



-:Double line Broad Gauge Track:-

SI No	Particulars		B.G	Slope
01	Embankment width of bank	1. Single line	6100mm	2:1
		2. Double line	10210mm	
02	Width of cutting excluding side drains	1. Single line	5490mm	1.5:1
		2. Double line	10000mm	

Terms:

1. Subgrade : Subgrade is the naturally occurring soil, which is prepared to receive the ballast, sleepers and rails for constructing the railway track. This prepared surface is also called formation. Formation could be in embankment, level or cutting, depending upon the ground conditions.
2. Embankment: It is the raised bank of earth or other materials constructed above the natural ground. It is constructed when railways have to be carried in low grounds or valleys.
3. Cutting: The raised ground or hill is cut or excavated for providing the line at the required level below ground level.
4. Level: It is prepared surface which receives ballast without raising or lowering level of the ground.
5. Formation: The prepared surface which is ready to receive ballast is called dformation. The stability of the track depends upon the quality of the formation under it.

4.2 Permanent & temporary land :

Permanent land:

Permanent land 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; catch water 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:

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

4.3 Gradients for drainage :

A gradient is normally represented by the distance travelled for a rise or fall of one unit. Sometimes the gradient is indicated as per cent rise or fall. For example, if there is a rise of 1 m in 400 m, the gradient is 1 in 400 or 0.25 per cent. Gradients are provided to meet the following objectives:-

a) To reach various stations at different elevations.
b) To follow the natural contours of the ground to the extent possible.
c) To reduce the cost of earthwork.
d) Allow drainage of surface and sub surface water.

The following types of gradients are used on the railways:
(a) Ruling gradient
(b) Pusher or helper gradient

(c) Momentum gradient
(d) Gradients in station yards

Ruling Gradient :

The ruling gradient is the steepest gradient that exists in a section. It determines the maximum load that can be hauled by a locomotive on that section. While deciding the ruling gradient of a section, it is not only the severity of the gradient, but also its length as well as its position with respect to the gradients on both sides that have to be taken into consideration. The power of the locomotive to be put into service on the track also plays an important role in taking this decision, as the locomotive should have adequate power to haul the entire load over the ruling gradient at the maximum permissible speed. In plain terrain: 1 in 150 to 1 in 250 In hilly terrain: 1 in 100 to 1 in 150 Once a ruling gradient has been specified for a section, all other gradients provided in that section should be flatter than the ruling gradient after making due compensation for curvature

Pusher or Helper Gradient:

In hilly areas, the rate of rise of the terrain becomes very important when trying to reduce the length of the railway line and, therefore, sometimes, gradients steeper than the ruling gradient are provided to reduce the overall cost. In such situations, one locomotive is not adequate to pull the entire load, and an extra locomotive is required. When the gradient of the ensuing section is so steep as to necessitate the use of an extra engine for pushing the train, it is known as a pusher or helper gradient. Examples of pusher gradients are the Budni-Barkhera section of Central Railway and the Darjeeling Himalayan Railway section.

Momentum Gradient:

The momentum gradient is also steeper than the ruling gradient and can be overcome by a train because of the momentum it gathers while running on the section. In valleys, a falling gradient is sometimes followed by a rising gradient. In such a situation, a train coming down a falling gradient acquires good speed and momentum, which gives additional kinetic energy to the train and allows it to negotiate gradients steeper than the ruling gradient. In sections with momentum gradients there are no obstacles provided in the form of signals, etc., which may bring the train to a critical juncture.

Gradients in Station Yards:

The gradients in station yards are quite flat due to the following reasons: (a) It prevents standing vehicles from rolling and moving away from the yard due to the combined effect of gravity and strong winds. (b) It reduces the additional resistive forces required to start a locomotive to the extent possible. It may be mentioned here that generally, yards are not levelled completely and certain flat gradients are provided in order to ensure good drainage. The maximum gradient prescribed in station yards on Indian Railways is 1 in 400, while the recommended gradient is 1 in 1000.

A good track drainage system should essentially ensure that no water percolates into the track at either the surface or the sub-surface levels, and the arrangements for the drainage of sub-surface water should be good and effective. Track drainage should be handled in two distinctive phases.

1. Surface drainage Surface water due to rain or snow, or from adjacent areas should be drained off properly by designing well-planned and effective surface drains.
2. Sub-surface drainage In case water percolates into the formation due to bad soil or such other reasons, the formation gets adversely affected and this has a bearing on the safety and stability of the track.

4.4 Super elevation – necessity & limiting valued :

Superelevation or cant (C_a) :

It is the difference in height between the outer and the inner rail on a curve. It is provided by gradually raising the outer rail above the level of the inner rail. The main functions of superelevation are the following:

a. To ensure a better distribution of load on both rails.
b. To reduce the wear and tear of the rails and rolling stock.
c. To neutralize the effect of lateral forces.
d. To provide comfort to passengers.

Equilibrium speed :

When the speed of a vehicle negotiating a curved track is such that the resultant force of the weight of the vehicle and of radial acceleration is perpendicular to the plane of the rails, the vehicle is not subjected to any unbalanced radial acceleration and is said to be in equilibrium. This particular speed is called the equilibrium speed.

Maximum permissible speed :

This is the highest speed permitted to a train on a curve taking into consideration the radius of curvature, actual cant, cant deficiency, cant excess, and the length of transition. On curves where the maximum permissible speed is less than the maximum sectional speed of the section of the line, permanent speed restriction becomes necessary.

Cant deficiency (Cd):

It 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 high speeds and the actual cant provided.

Cant excess (Ce):

It occurs when a train travels around a curve at a speed lower than the equilibrium speed. It is the difference between the actual cant provided and the theoretical cant required for such a low speed.

Centrifugal force on a curved track :

A vehicle has a tendency to travel in a straight direction, which is tangential to the curve, even when it moves on a circular curve. As a result, the vehicle is subjected to a constant radial acceleration.

Radial acceleration = $a = V^2/R$

where V is the velocity (metres per second) and R is the radius of curve (metres).

This radial acceleration produces a centrifugal force which acts in a radial direction away from the centre.

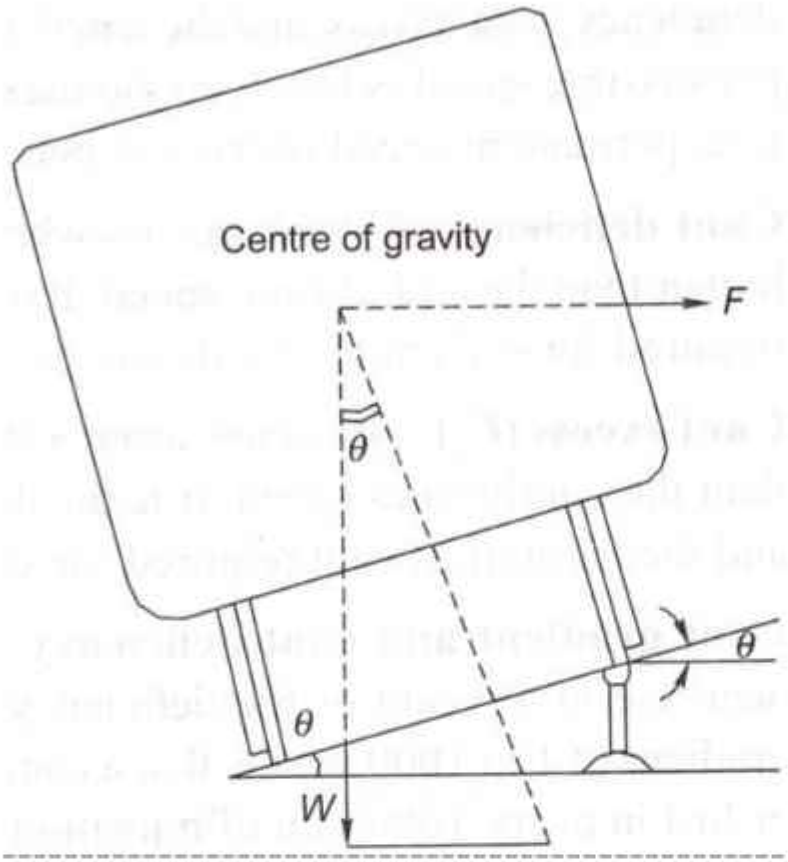
The value of the centrifugal force is given by the formula:

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

where F is the centrifugal force (Kilo newton), W is the weight of the vehicle (tonnes), V is the speed (m/s), g is the acceleration due to gravity (m/s2), and R is the radius of the curve in metres.

To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the superelevation. A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the superelevation is enough to bring the resultant of

the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve is known as equilibrium superelevation.



Equilibrium Superelevation:

If θ *is* the angle that the inclined plane makes with the horizontal line and e is the

Superelevation than,

$\tan\theta$ = Superelevation / Gauge = e/ G

Again, $\tan\theta$ = Centrifugal force/weight = F/W

From these equations

=> e/ G = F/W

=> e = F x G/W

=> e = W/g x V^2/R x G/W = GV^2 / gR

Here, e is the equilibrium superelevation in meter, G is the gauge, V is the velocity m/s, g is the acceleration due to gravity, and R is the radius of the curve in meter.

=>e =GV^2/127 R

Where e is in meter, velocity in kmph, G is in meter and R in meter.

Maximum value of superelevation :

The maximum value of superelevation has been laid down based on experiments carried out in Europe on a standard gauge for the overturning velocity, taking into consideration the track maintenance standards. The maximum value of superelevation generally adopted on on many railways around the world is one-tenth to one-twelfth of the gauge.

Gauge	*Group*	*Limiting value of cant (mm)*	
		Under normal conditions	*With special permission*
BG	*A*	165	185
BG	B and C	165	-
BG	D and E	140	-
MG	All routes	90	100
NG	-	65	75

Chapter-05

Points and Crossings

Topics to be covered n this chapter….

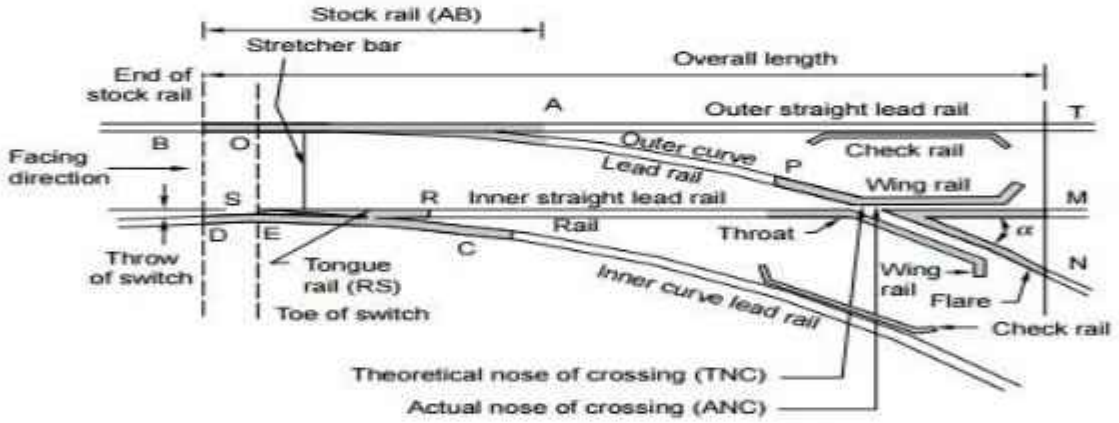
5.1 Definition, necessity of Points and crossings

5.2 Types of points & crossings with tie diagrams

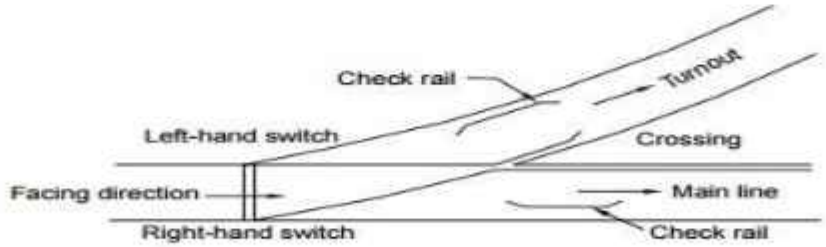
5.1 Definition, necessity of Points and crossings:

Definition:

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



Constituents of a turnout



Left-hand turnout

Important Terms:

Turnout:

It is an arrangement of points and crossings with lead rails by means of which the rolling stock may be diverted from one track to another.

Direction of a turnout:

A turnout is designated as a right-hand or a left-hand turnout depending on whether it diverts the traffic to the right or to the left. The direction of a point (or turnout) is known as the facing direction if a vehicle approaching the turnout or a point has to first face the thin end of the switch. The direction is trailing direction if the vehicle has to negotiate a switch in the trailing direction i.e., the vehicle first negotiates the crossing and then finally traverses on the switch from its thick end to its thin end. Therefore, when standing at the toe of a switch, if one looks in the direction of the crossing, it is called the facing direction and the opposite direction is called the trailing direction.

Tongue rail:

It is a tapered movable rail, made of high-carbon or -manganese steel to withstand wear. At its thicker end, it is attached to a running rail. A tongue rail is also called a *switch rail*.

Stock rail:

It is the running rail against which a tongue rail operates.

Points or switch:

A pair of tongue and stock rails with the necessary connections and fittings forms a switch.

Crossing:

A crossing is a device introduced at the junction where two rails cross each other to permit the wheel flange of a railway vehicle to pass from one track to another.

Necessity of Points and Crossings:

a. Points and crossing are provided to help divert railway vehicles from one track to another.
b. Giving precedence to the faster vehicles in the same direction, giving passage to a train moving in the opposite direction.
c. To diverge or converge the tracks.

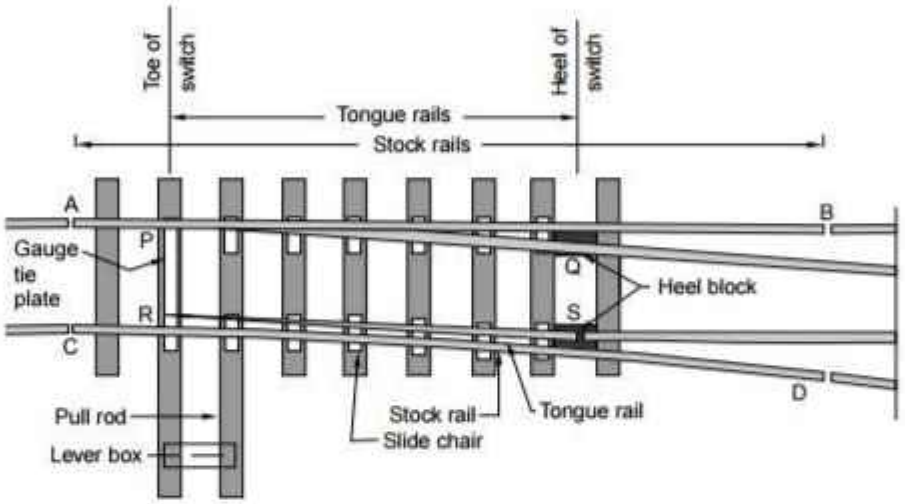
5.2 Types of points & crossings with tie diagrams:

Points or Switches: A switch consists of a stock rail and a tongue rail. A set of switches or points consists of a left-hand switch and a right-hand switch. Switches are tapered rails with the thicker end known as the heel fixed to the main track and thinner end known as the toe moveable by means of which the flanged wheels of the train are diverted from one route to another.

A set of points or switches consists of the following main constituents:-

a. A pair of stock rails, AB and CD, made of medium-manganese steel.

b. A pair of tongue rails, PQ and RS, also known as switch rails, made of medium-manganese steel to withstand wear. The tongue rails are machined to a very thin section to obtain a snug fit with the stock rail. The tapered end of the tongue rail is called the toe and the thicker end is called the heel.
c. A pair of heel blocks which hold the heel of the tongue rails is held at the standard clearance or distance from the stock rails.
d. A number of slide chairs to support the tongue rail and enable its movement towards or away from the stock rail.
e. 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.
f. A gauge tie plate to fix gauges and ensure correct gauge at the points.



Details of a switch

Important Terms Pertaining to Switches or points:

Switch angle: This is the angle between the gauge face of the stock rail and that of the tongue rail at the theoretical toe of the switch in its closed position. It is a function of the heel divergence and the length of the tongue rail.

Flangeway clearance: This is the distance between the adjoining faces of the running rail and the check rail/wing rail at the nose of the crossing. It is meant for providing a free passage to wheel flanges. The minimum and maximum values of flangeway clearance for BG and MG tracks.

Flangeway clearance

	Flangeway clearance	
Gauge	*Maximum value (mm)*	*Minimum value (mm)*
BG	48	44
MG	44	41

Heel divergence: This is the distance between the gauge faces of the stock rail and the tongue rail at the heel of the switch. It is made up of the flangeway clearance and the width of the tongue rail head that lies at the heel.

Throw of the switch: This is the distance through which the tongue rail moves laterally at the toe of the switch to allow movement of the trains. Its limiting values are 95-115 mm for BG routes and 89-100 mm for MG routes.

Flangeway width: It is the vertical distance between the top surfaces of the running rail to the top surface of heel block used between the stock rail and the check rail.

Types of Switches:

Switches are of two type:-

A. Stub switch: In a stud type of switch, no separate tongue rail is provided and some portion of the track is moved from one side to the other side. Stud switches are no more in use on Indian Railways. They have been replaced by split switches.
B. Split switch: These consist of a pair of stock rails and a pair of tongue rails. Split switches may again be of two types-**loose heel type and fixed heel type** based on fixation at heel. Again on the basis Toe of switches split switches are:-
    1. **Under cut switches**
    2. **Overriding switches**
    3. **Straight cut switches**

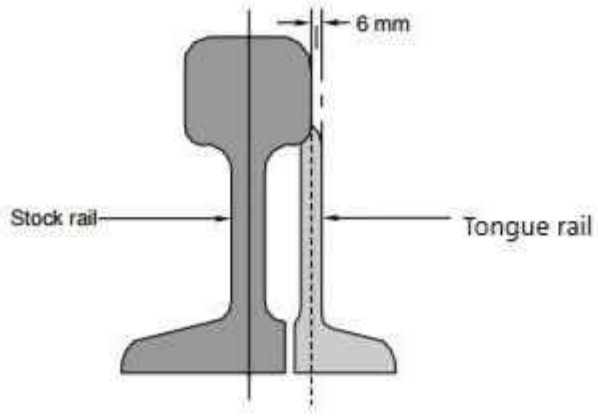
Loose heel type switches:

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 slightly 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 is not preferred.

Fixed heel type switches:

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 the flexibility of the tongue rail.

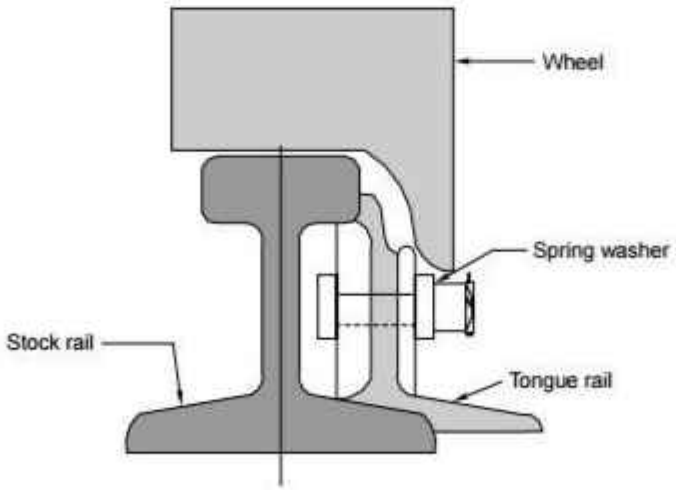
Under cut switch: In this case the height of stock rail and tongue rail is same, it is desirable to cut out a portion of flange at the foot of the stock rail so that the toe of the tongue rail is accommodated under the head of the stock rail. Such types of switches are called under cut switches.



Over riding switch:

In this case, the stock rail occupies the full section and the tongue rail is planed to a 6-mm (0.25") -thick edge, which overrides the foot of the stock rail. The switch rail is kept 6 mm (0.25") higher than the stock rail from the heel to the point towards the toe where the planning starts. This is done to eliminate the possibility of splitting caused by any false flange moving in the trailing direction. Overriding switches have been standardized on the Indian Railways. This design is considered to be an economical and superior design due to the reasons given below.

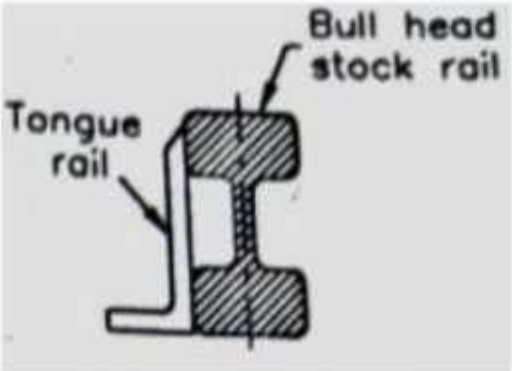
a. Since the stock rail is uncut, it is much stronger.
b. Manufacturing work is confined only to the tongue rail, which is very economical.
c. Although the tongue rail has a thin edge of only 6 mm (0.25"), it is supported by the stock rail for the entire weakened portion of its length. As such, the combined strength of the rails between the sleepers is greater than that of the tongue rail alone in the undercut switch.



Overriding switch

Straight cut switches: In this type the tongue rail is cut straight in the line with the stock rail and hence termed as straight cut switches. This is done to increase the thickness of toe of

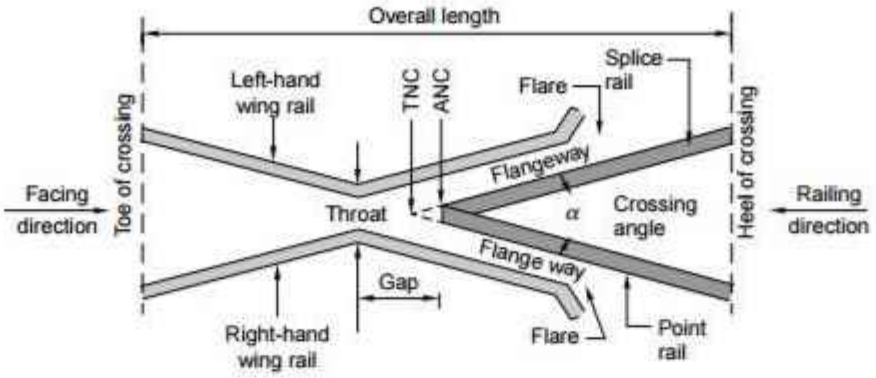
tongue rail, which as a result, increase the strength. This type of switch is suitable for B.H rails.



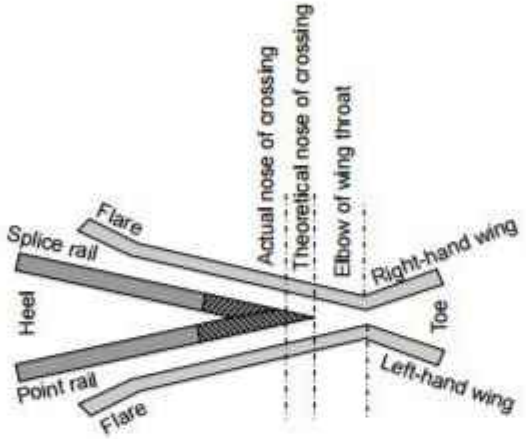
Straight cut switch

Crossing:

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



Details of a crossing



Point rail and splice rail

a. Two rails, the point rail and splice rail, 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's rail should end in a point and be made as thin as possible, but such a knife edge of the point rail would break off under the movement of traffic. The point rail, therefore, has its fine end slightly cut off to form a blunt nose, with a thickness of 6 mm (1/4"). The toe of the blunt nose is called the actual nose of crossing (ANC) and the theoretical point where gauge faces from both sides intersect is called the theoretical nose of crossing (TNC). The 'V' rail is planed to a depth of 6 mm (1/4") at the nose and runs out in 89 mm to stop a wheel running in the facing direction from hitting the nose.
b. 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.
c. A pair of check rails to guide the wheel flanges and provide a path for them, thereby preventing them from moving sideways, which would otherwise may result in the wheel hitting the nose of the crossing as it moves in the facing direction.

Types of Crossings:

Crossings can be classified as:-

A. On the basis of shape of crossing.

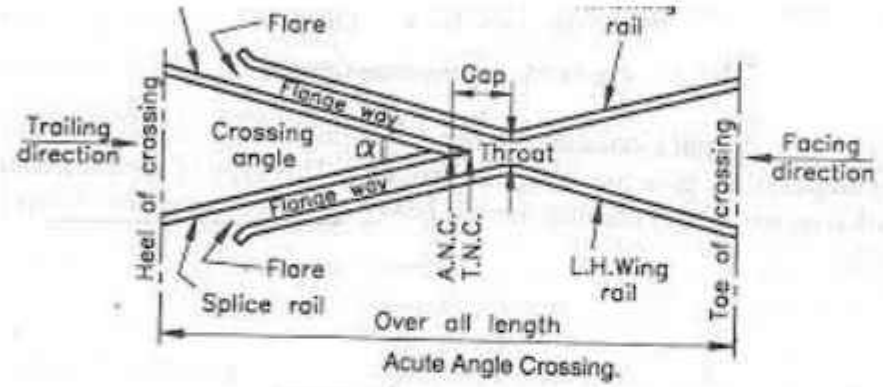
1. Acute angle crossing or V crossing
2. Obtuse angle crossing or Diamond crossing.
3. Square Crossing.

B. On the basis of Assembly of crossing.

1. Spring or movable wing crossing
2. Ramped crossing.

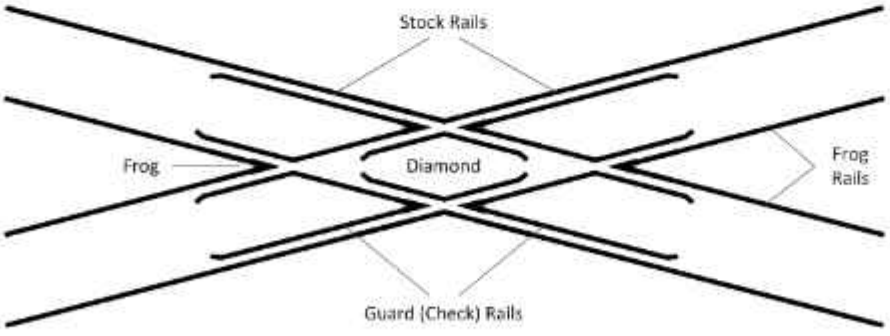
Acute angle crossing or V crossing:

An acute angle crossing or 'V' crossing is one in which the intersection of the two gauge faces forms an acute angle. For example, when a right rail crosses a left rail, it makes an acute crossing.



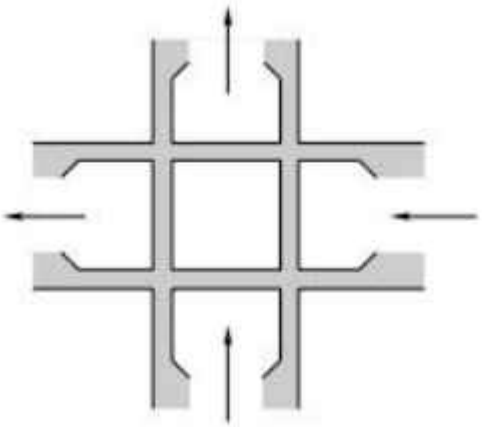
Obtuse angle crossing or Diamond crossing:

An obtuse or diamond crossing is one in which the two gauge faces meet at an obtuse angle. When a right or left rail crosses a similar rail at an obtuse angle, it makes an obtuse crossing.



Square Crossing:

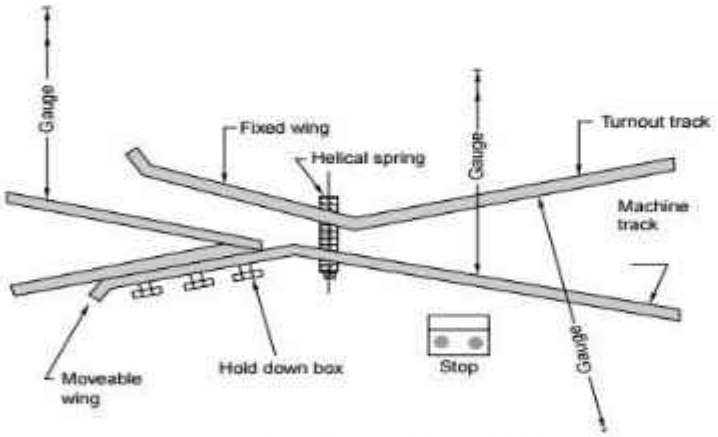
When two straight tracks cross each other at right angles, they formed square crossing. This type of crossing must be avoided on main lines because there is heavy wear due to dynamic loads.



Square crossing

Spring or movable wing crossing:

In a spring crossing, one wing rail is movable and is held against the V of the crossing with a strong helical spring while the other wing rail is fixed. When a vehicle passes on the main track, the movable wing rail is snug with the 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 a 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.



Spring or movable crossing

Ramped crossing:

In case of complicated yard layout with heavy but slow speed traffic, the throat to nose clearance is negotiated by use of special manganese steel blocks over long distance. The wheel flanges roll over this distance extending from a little beyond the throat to little beyond the nose. The top level of these special blocks is so arranged that the thread of wheel is taken off the table by the wheel flange riding the blocks. So the entire wheel load comes on the flange and this type of crossing may be used with safety for slow speeds.

Terms in connection with Crossings:

Theoretical and actual nose of crossing (T.N.C and A.N.C):

The toe of the blunt nose is called the actual nose of crossing (ANC) and the theoretical point where gauge faces from both sides intersect is called the theoretical nose of crossing (T.N.C). The difference between T.N.C and A.N.C is given by:-

$T.N.C - A.N.C = N \times t$

Where N = Number of crossings t = Thickness of the nose crossing.

Number and Angle of Crossing:

A crossing is designated either by the angle the gauge faces make with each other or, more commonly, by the number of the crossing, represented by N.

$$N = \frac{The\ spread\ at\ the\ leg\ of\ crossing}{The\ length\ of\ crossing\ T.N.C}$$

There are three methods of measuring the number of a crossing, and the value of N also depends upon the method adopted.

1. Right angle method:

This method is used on Indian Railways. In this method, N is measured along the base of a right-angled triangle. This method is also called Coles method.

$$\cot\alpha = \frac{N}{1}$$

or

$$N = \cot\alpha$$

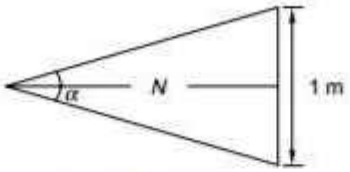
2. Centre line method:

This method is used in Britain and the USA. In this method, N is measured along the centre line of the crossing.

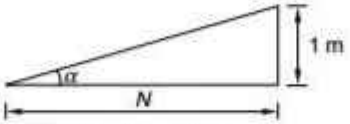
$$\cot\frac{\alpha}{2} = N \div \frac{1}{2}$$

or

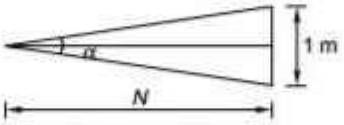
$$N = \frac{1}{2}\cot\frac{\alpha}{2}$$



Centre line method



Right angle method



Isosceles triangle method

Different methods of measuring number (*N*) and angle of crossing

3. Isosceles triangle method:

In this method, N is taken as one of the equal sides of an isosceles triangle.

$$\sin\frac{\alpha}{2} = \frac{1/2}{N} = \frac{1}{2N}$$

or

$$\operatorname{cosec}\frac{\alpha}{2} = 2N$$

$$N = \frac{1}{2}\operatorname{cosec}\frac{\alpha}{2}$$

The right angle method used by Indian Railways, in which N is the cotangent of the angle formed by two gauge faces, gives the smallest angle for the same value of N.

Chapter-06

Laying & Maintenance of Track

Topics to be covered in this chapter…
6.1 Methods of Laying & maintenance of track
6.2 Duties of a permanent way inspector

6.1 Methods of Laying & maintenance of track:

The operation of laying out and connecting sleepers and connecting rail and sleepers is known as Plate laying. The point of commencement of the new track to be laid is the existing rail head. In new track sleepers are laid directly over the formation, after compaction the track is then lifted and ballast is packed around the sleeper.

There are three distinct methods of Plate laying in railway track. These are:-

1. **Telescopic Method**
2. **Tramline/ Side Method**
3. **Mechanical/American Method**

1. Telescopic Method of Construction of Railway Track:

This method is used very widely in India. A large central depot is constructed near the junction of the existing railway or highway and the proposed railway line. The manual force is divided in to (i) Material gang (ii) Linking-in-gangs (iii) Packing-in-gangs.

i. Material gangs: These gangs unload the materials from the trains. They carry the materials to the rail head and supply them to the linking-in-gangs. These gangs distribute sleepers, rails, fishplates, bolts etc. to the required places.
ii. Linking-in-gangs: These gangs mark the centre line of the proposed track and place the sleepers at required place. Rails are placed on the sleepers. Successive rails are joined together by fishplates, bolts with expansion joints. After joining the rails are fixed to the sleepers.
iii. Packing-in-gangs: These gangs correct the rails to the required level and gradients by packing earth or ballast below and around the sleepers.

2. Tramline Method Railway Track Construction:

This method is used where tram carrier are installed for carrying earthwork or in rainy season due to difficulty in movement of cart.. The basic difference between this and telescopic method lies in the conveyance and spreading of the sleepers. The track can be assembled at more than one point simultaneously, which is the great advantage of this method. Sometimes an additional track is laid on the side of existing track for which this method is best.

3. Mechanical Method Railway Track Construction:

This method involves all mechanical work. This method consists of fixing rails to the sleepers and lifting the whole unit by heavy cranes. First one is linked with the rail head, then the train moves

ahead by one rail length and the same procedure is repeated. This method is un-economical one and is not used in India.

Plasser Quick Relaying System (PQRS method): This is a mechanical method of laying railway track in Indian Railways. This method is used for relaying existing track under traffic condition without interrupting the flow of traffic. Following equipments are used for PQRS method of plate laying.

a. Sleeper layer
b. 5 tonne portal crane
c. Track jacks
d. Hand gantries
e. Engine
f. B.F.R (open wagon for carrying long rails)
g. B.F.R for carrying sleep
h. B.F.R for old materials



An auxiliary track is laid with a gauge length of 3.4m. This is to carry the required equipments and materials for laying new work. The auxiliary track is laid over wooden blocks on cast iron posts at two metres interval. The level of auxiliary track is laid with the same level of track. The portal crane moves on the auxiliary track and it is used to lift and carry the rail panels. Sleeper's layers is a machine which is used for laying sleepers with required spacing and alignment. The jacks are used to support the track laying at uniform level. Hand gantries are used for moving the rails in longitudinal direction at lifted position.

Maintenance of Track:

Necessity of Maintenance of track:

a) Increases the life of track.
b) Provides comfortable ride to the passenger.
c) Provides safety to goods.
d) Increase the life of rolling stock.

e) Operating cost is reduced.
f) Safety to passengers.

Maintenance of railway track consists of:-

(i) Daily maintenance.

(ii) Periodic Maintenance.

(i) Daily maintenance:

a) For daily maintenance the track is divided into sections of 5 to 8 kms lengths.
b) Each section is look after by a gangs.
c) The daily maintenance consists of:- General inspection of the track, Checking up of all fastenings and fittings, Tightening of bolts wherever required, Reporting by unusual occurrence.

(ii) Periodic Maintenance: The periodic maintenance consists of detailed inspection of the track to detect defects in the track which may not be detected during daily maintenance. The various aspects of periodic maintenance are:-

a) Maintenance of track alignment
b) Maintenance of track drainage
c) Maintenance of track components
d) Maintenance of level crossing

Maintenance of track materials:

a) The top surface of the rails should be kept at the same level
b) Ballast under sleepers should be regularly packed
c) Defective sleepers should be replaced immediately
d) Worn-out rails should be replaced
e) Kink or fracture rails should be replaced
f) Fastening should be tightened and oiled
g) Gauge should be checked and corrected
h) Ensure that both the rails are at same level
i) Maintain track drainage properly
j) Oiling and greasing of fishplates regularly
k) Flanges and check rails should be kept free from dust

Maintenance of track on Bridges:

a) Proper embankment should be provided near the bridge
b) Avoid scouring near abutments and piers
c) Flood control measures should be taken near the bridges
d) Riveted joints should be inspected periodically
e) Bed blocks should be checked regularly
f) Steel bridges should be painted regularly
g) Bearings of the girders should be oiled regularly
h) Masonry works should be inspected regularly

Maintenance of rolling stock:

a) Lubrication of all reciprocating parts and bearings
b) Worn-out parts should be replaced the rolling stock

c) It is necessary to clean the different parts every day
d) All axles which have run 3,22,000Km should be Replaced
e) A passenger vehicle used for 30years should be dismantled and re-assembled
f) The locomotive boilers have to be carefully maintained and removed every 15 years

6.2 Duties of a permanent way inspector(P.W.I):

The duties of permanent way inspector (P.W.I) can be divided into 3 heads:-

a. Duties in the field work
b. Duties in the office work
c. Miscellaneous duties

Duties in the field work:

1) The P.W.I is personally responsible for maintain the track in a safe condition for passage of trains.
2) He inspects track of his section at least 2 to 3 times in a week, notes down the defects with distance and kilometrage from telegraph posts by using different symbols for different defects and rectifies them to keep track in best condition for continuous service of track.
3) He inspects track by push trolley or by travelling on an engine or brake van.
4) He keeps all the records of programme of work to rectify the defects and make renewals, progress of maintenance work and relay of track.
5) He imparts instructions to Gang mate, keyman,gateman at level crossing and A.P.W.I.
6) At the time of accidents, he should make the track safe in shortest possible time and should make enquiries for the cause of accidents.

Duties in the office work:

1) He takes care of the labour and materials, and also maintains the accounts of gangman, keyman and gang mate as well as of materials.
2) He controls the workshops such as smithy, carpentry, welding, etc.
3) He prepares the estimates of the maintenance work and makes report of works.

Miscellaneous duties:

1) He attends all the monthly meetings of P.W.Is, usually at divisional Engineer's office.
2) He has to attend the inspection if made by divisional Engineer or Assistant Engineer.
3) He also attends trhe inspection of Government Inspector for Railways with all the relevant drawings and reports of work.
4) He officiates as Assistant Engineer in his absence as and when required.

Chapter - 01

=: Introduction to Bridges:-

Topics to be covered in this chapter.

1.1: Definitions
1.2: Components of a bridge
1.3: Classification of bridges.
1.4: Requirements of an ideal bridge.

Introduction:

A bridge is a structural construction made for facilitating a communication route for carrying the road traffic or other moving loads in order to pass through an obstacle or other constructions. The required passage may be for pedestrians, a road, a railway, a canal, a pipeline etc.. obstacle can be rivers, valleys, sea channels, and and other constructions such as bridges themselves, buildings, railways or roads etc..

Bridges are important structures in modern highway and railway transportation systems, and generally serving as lifelines in the social infrastructure systems.

1.1: Definitions:

The definitions of certain important terms are used in bridge engineering are:-

(1) Bridge:

A structure 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 streamway, a roadway, a footpath, a cycle track or a combination of them.

(2) High level bridge/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 Culvert:

When a small stream crosses a road with linear waterway less than about 6 metres, the cross drainage structures so provided is called culvert.

⑤ Foot Bridge:

The foot bridge is a bridge exclusively used for carrying pedestrians cycles & animals.

(6) Deck Bridges:

These are the bridges whose floorings are supported at top of the superstructures.

(7) Through Bridges:

These are the bridges whose floorings are supported or suspended at the bottom of the superstructures.

(8) Semi-Through Bridges:

These are the bridges whose floorings are supported at some intermediate level of the superstructure.

(9) Cantilever Bridges:

Bridges which are more or less fixed at one end and free at the other. It can be used for spans varying from 18 metres to 30 metres.

(10) Continuous Bridges:

Bridges which continue over two or more spans. They are used for large

spans and where unyielding foundations are available.

(11) **Arch Bridges:**

These are the bridges which produce inclined pressures on supports under vertical loads. These bridges can be economically used up to spans of about 20 metres.

(12) **Square Bridges:-**

These are the bridges at right angles to the axis of the river.

(13) **Skew Bridges:-**

The bridges which are not at right angles to the axis of the river.

(14) **Suspension Bridges:-**

These are the bridges suspended on cables anchored at ends.

(15) **class 'A' Bridges:**

These are the permanent bridges designed for I.R.C. class A loading.

(16) Class 'B' Bridges:-

These are the temporary bridges designed for I.R.C. class 'B' loading.

(17) Class 'AA' bridges:-

These are bridges designed for I.R.C. class 'AA' loading and checked for class 'A' loading.

(18) Viaduct:

It is a long continous structure which carries a road or railways like a bridge over a dry valley composed of series of spans over trestle bents instead of solid piers.

(19) Apron:

It is a layer of concrete, masonry stone etc. placed like flooring at the entrance or outlet of a culvert to prevent scour.

(20) **Piers:**

They are the intermediate supports of a bridge superstructure and may be of solid or open type.

(21) **Abutments:**

They are the end supports of the superstructure.

(22) **Effective span:**

The centre to centre distance between any two adjacent supports is called as the effective span of a bridge.

(23) **Clear span:**

The clear distance between any two adjacent supports of a bridge is called clear span.

(24) **Economic span:**

The span for which the total cost of bridge structure is minimum is known as economic span.

(25) **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.

(26) **Free Board:**

Free board at any point is the difference between the highest flood level after allowing for afflux, if any and the formation level of road embankment on the approaches or top level of guide bunds at that point.

(27) **Low water level (LWL):**

The low water level is the level of water surface obtained generally in the dry season.

(28) Ordinary Flood Level (O.F.L):

It is the average level of a high flood which is expected to occur normally every year.

(29) Highest Flood level (H.F.L):

It is the level of the highest flood every recorded or the calculated level for the highest possible flood.

1.2: Components of a Bridge:

Broadly a bridge can be divided into two major parts:

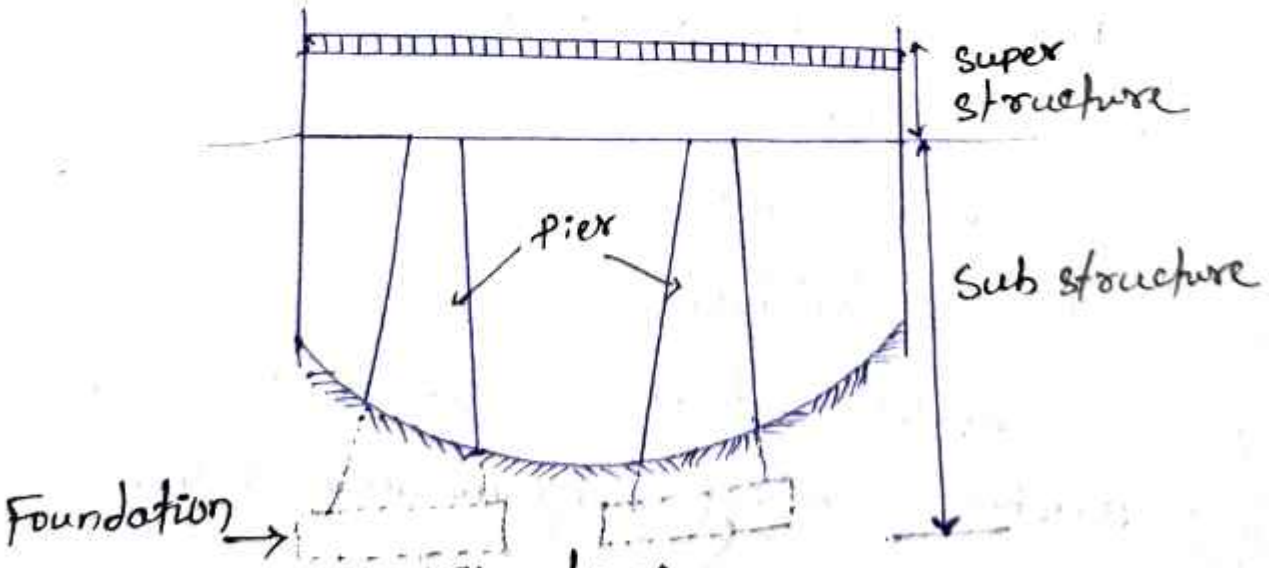
- Super structure.
- Sub structure.

Superstructure consists of structural members carrying a communication route. Thus handrails, guard stones and flooring supported by any structural system such as beams, girders, arches and cables above the level of bearings constitutes the superstructure.

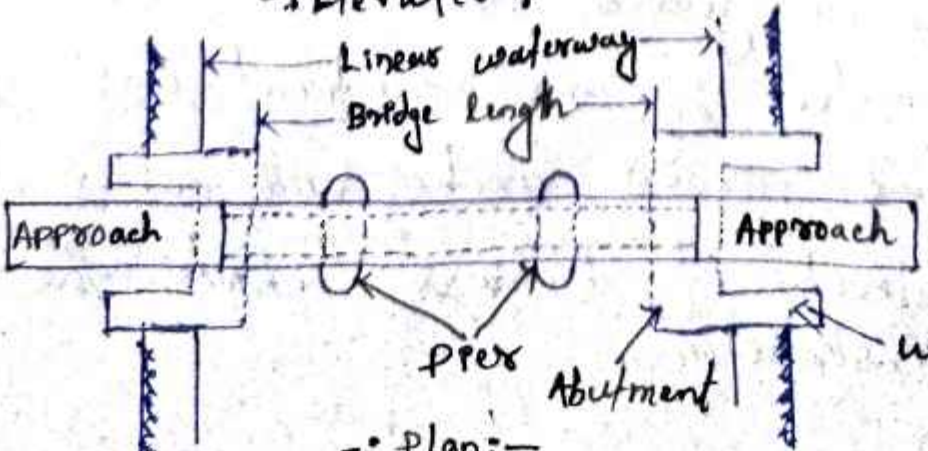
Substructure is a supporting system for superstructure. It consists of the following:

(i) Abutments
(ii) piers and Abutment piers.
(iii) Wing walls
(iv) Foundations for the piers and abutments.

The other main parts of a bridge structure are approaches, bearings and river training works, like aprons, revetment for slopes at abutments etc.



-: Elevation :-



-: Plan :-

1.3: classification of Bridges:

Bridges can be classified into various types depending upon the following factors:-

① Materials used for construction:

under this category, bridges may be classified as timber bridges, masonry bridges, steel bridges, reinforced cement concrete bridges, pre-stressed bridges and composite bridges.

(2) Alignment:

Under this the bridge can be classified as straight or a skew bridge.

(3) Location of Bridge Floor:

Under this category, bridge can be classified as deck, semi-through or through bridges.

(4) Purpose:

Under this the bridge can be classified as an aqueduct, viaduct, highway bridge and foot bridge etc.

(5) Nature of superstructure Action:-

Under this the bridges may be classified as portal frame bridges, truss bridges, balanced cantilever bridges and suspension bridges.

(6) Position of High Flood level:-

Under this the bridges may be classified as submersible and non-submersible bridges.

(7) Life:

Under this the bridges may be classified as permanent and temporary bridges.

(8) Loadings:

Road bridges and culverts have been classified by Indian Road congress into class AA, class A & class B bridges according to the loadings they are designed to carry.

(9) Fixed or Moveable:

For navigable channels where permanent and sufficient clear waterway cannot be provided, the following movable bridges are used.

- Swinging bridges.
- Bascule bridges.
- Lift bridges.

(10) ~~Span Length~~ Degree of Redundancy:

Under this category the bridges can be classified as determinate bridges and indeterminate bridges.

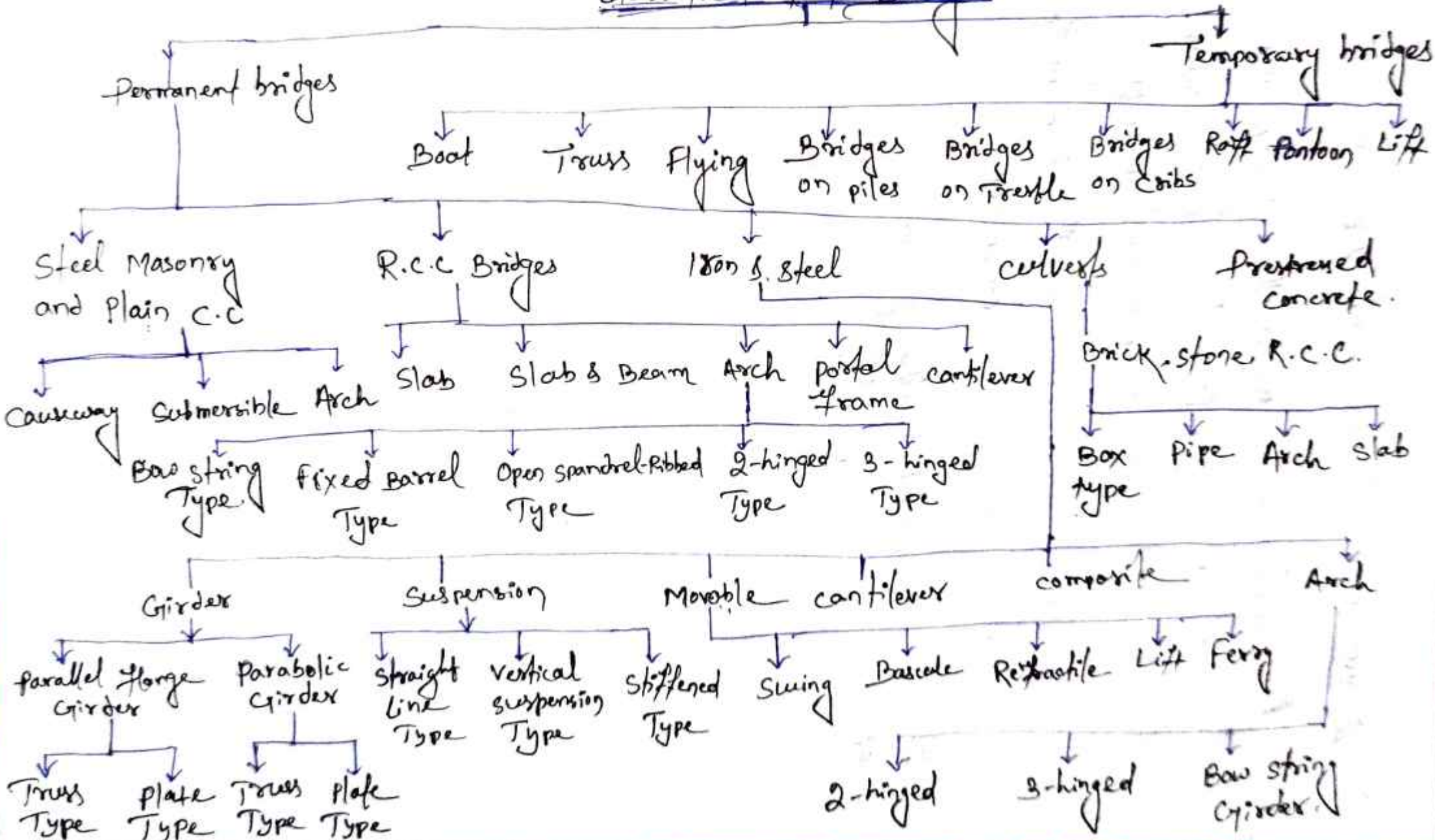
(11) Span length:

Under this category the bridges can be classified as culverts (span less than 8m) minor bridges (span 8 to 30m), major bridges (span above 30m) and long span bridges (span above 120m).

(12) Types of connection:-

Under this category the steel bridges can be classified as connected riveted or welded bridges.

Classification of Bridges



1.4: Requirements of an ideal Bridges:

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

i. It serves the intended function with utmost safety and convenience.

ii. It is aesthetically sound.

iii. It is economical.

Chapter-02

Bridge site Investigation, hydrology and planning:

Topics to be covered in this chapter...

2.1: Selection of bridge site, Alignment.

2.2: Determination of flood discharge.

2.3: Waterway and Economy span.

2.4: Afflux, clearance and free board.

2.1: Selection of Bridge site:

Detailed ground reconnaissance, collection of adequate hydraulic/ground data and sub soil investigation form an important part of engineering survey for deciding the best possible location and type of bridge. The site for a bridge is usually governed by engineering, economic, social and aesthetic considerations. In order to get ideal site, the Bridge site should have following characteristics.

① Suitable, unyielding and non-erodable material for foundation should be available at a short depth for the abutments and piers of a bridge.

② The stream at the bridge site should be well defined and as narrow as possible.

③ There should be a straight reach of stream at bridge site.

④ The site should have firm, permanent, straight and high banks.

⑤ There should be no confluence of large tributaries in the vicinity of bridge site.

⑥ There should be minimum obstruction of natural waterway so as to have minimum afflux.

⑦ In order to achieve economy there should be easy availability of labour, construction material and transport facility in the ~~vicat~~ vicinity of bridge site.

(8) There should be no adverse environmental conflict.

(9) The bridge site should be such that adequate vertical height and waterway is available underneath the bridge for navigational use.

(10) At the bridge site it should be possible to provide secure and economical approaches.

Bridge Alignment:

Depending upon the angle which the bridges makes with the axis of the river, the alignment can be of two types.

i) **Square Alignment:**
On this the bridge is at right angle to the axis of the river.

ii) **Skew Alignment:**
On this the bridges is at some angle to the axis of river which is not a right angle.

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 a skew bridge is more susceptible to scour action.

2.2: Determination of Flood Discharge:

One of the essential data for the bridge ~~des~~ 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 Indian Roads congress has recommended that the maximum discharge which a bridge on a natural stream should be designed to pass should be determined by a consideration of at least two of the following methods :-

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

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

(ii) By a rational method, provided if 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 in its vicinity.

Empirical Methods:

Some of the commonly used empirical methods ~~used~~ for flood estimation in India are:-

1. Dicken's formula.
2. Ryve's formula.
3. Inglis formula.
4. Nawab Jang Bahadur's formula
5. Creager's formula.
6. Khosla's formula.
7. Benon's formula.

1. Dicken's Formula:

It was formerly adopted in Northern India but now it can be used in most of the states in India after proper modification of the constant.

$$Q = C \cdot M^{3/4}$$

where, Q = discharge in m^3/sec.

M = area of catchment in km^2.

C = constant.

According to the catchment area and amount of rainfall. c varies from 11.02 to 22.04.

Region	value of c
Norther India	11.37
central India	13.77 - 19.28
western India	22.04.

(2) Ryve's formula:

This formula is used only in southern India.

$$Q = C \cdot M^{2/3}$$

Here, C = 6.74 → Area within 24 km from coast.

= 8.45 → Area within 24-161 km from coast.

= 10.1 → hilly areas.

(3) English formula:-

This formula is used only in the state of Maharashtra. Here three different cases are taken into consideration.

(a) For small areas only. (Fan shaped catchment)

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

(b) For areas between 160 to 1000 km^2.

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

(c) For all types of catchments.

$$Q = \frac{123.2\,M}{\sqrt{M + 10.36}}$$

(4) Nawab Jang Bahadur's formula:-

$$Q = C\left(\frac{M}{2.59}\right)(a - b.\log A)$$

where a, b, & C are constant.

$a = 0.993$

$b = \frac{1}{14}$

$C = 59.5$ for North India.

$= 48.1$ for South India.

(5) Creager's formula:-

$$Q = 46.C\,M^{(0.894M^{-0.048})}$$

where: Q = discharge in m^3/sec.

M = area of catchment in km^2.

(6) Khosla's formula:

It is a rational formula. It is based on the equation

$$P = R + L$$

$$R = P - L$$

where,

R = Runoff.

P = Rainfall

L = Losses.

According to Khosla factor influencing losses is temperature. He expressed losses in mean temperature, T_m in fahrenheit. The formula in c.g.s. system becomes:-

$$\boxed{R = P - 4.82 T_m}$$

where $L = 4.82 T_m$

(7) Benson's formula:-

This formula is rational & can be used in any case.

$$\boxed{Q_m = \frac{P_m \times Q_r}{P_r}}$$

Where, Q_m = Peak flow expected.

Q_r = some observed peak flow

P_r = observed rainfall

P_m = expected rainfall.

Rational Method:

The size of the flood depends upon the following factors.

i) Climate or Rainfall factors: This includes
   a) intensity
   b) Distribution
   c) Duration of rainfall.

ii) Catchment Area factors: This includes.
   a) catchment area
   b) its shape
   c) its slope
   d) porosity of the soil
   e) vegetable cover
   f) Initial state of wetness

Let. for an individual stream.

F = Total rainfall in cm.

T = duration of rainfall in hours.

I_o : mean intensity of rainfall in cm/hr during rainfall duration T hrs.

Then $$I_o = \frac{F}{2}\left(1 + \frac{1}{T}\right)$$

Time of concentration: (T_c)

It is defined as the time taken by runoff to reach the site of the bridge or culvert from the farthest point on the periphery of the catchment. This farthest point is known as the critical point. T_c depends on:-

i) Length of catchment area

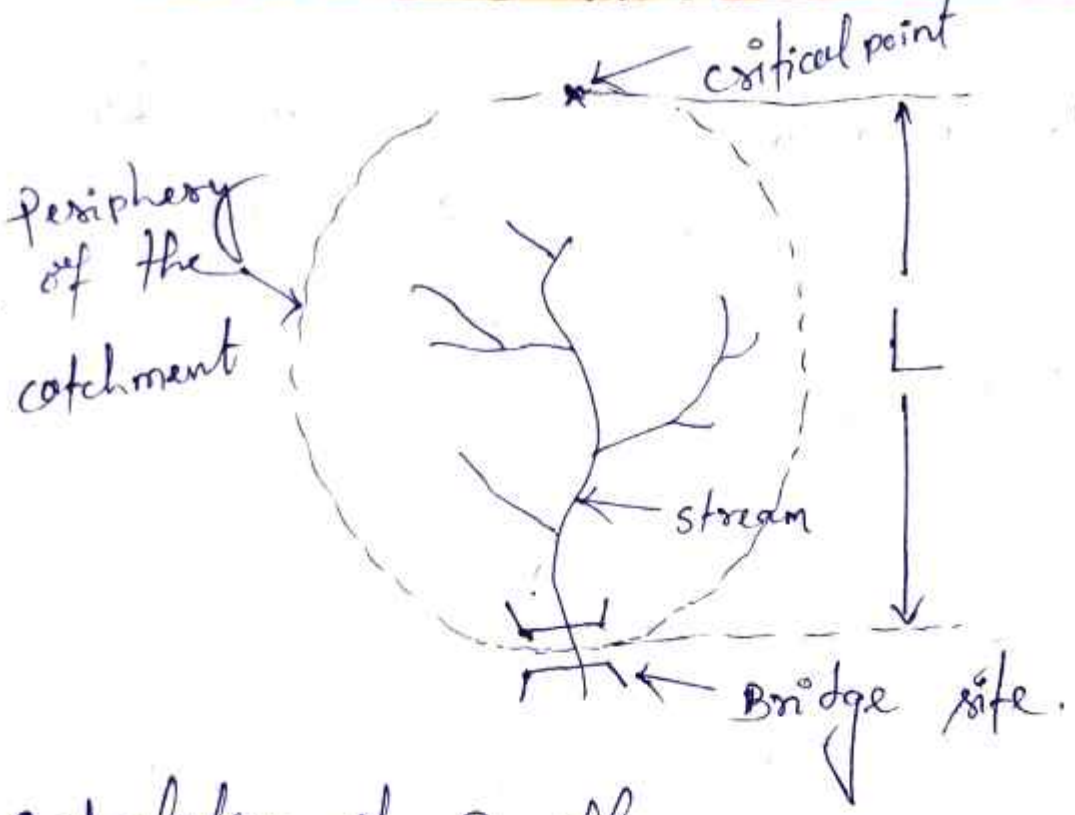
ii) Slope, roughness and depth of flow.

$$T_c = \left(0.89 \times \frac{L^3}{H}\right)^{0.385}$$

where, T_c = the concentration time in hours.

L = distance from critical point to the site of bridge in KM.

H = fall in level from the critical point to the bridge site in metres.



Calculation of Runoff:

$$Q = 100\ P\ I_c\ A \quad m^3/h.$$

where Q = Discharge in m^3/hr.

$$I_c = \frac{F}{T}\left(\frac{T+1}{T_c+1}\right)$$

T_c = Time of concentration.

P = constant, depends on type of soil.

2.3: Waterway and Economy Span:

Waterway: The 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. The natural waterway is the unobstructed area of the river or stream through which the water flows at the bridge site.

While fixing the waterway of a bridge the following points must be kept in mind to ensure the safety of the structure.

i) The increased velocity due to afflux should not exceed the permissible velocity under the bridge.

ii) There should not be too much heading up of water surface above the bridge, when it is necessary to restrict the waterway to such an extent that the resultant afflux will cause the stream to discharge at erosive velocities, protection against damage by scour should be afforded by deep foundation.

curtain or cut of walls, rip cap. stream bed pavement, bearing piles, sheet piles or other suitable means.

(iii) The freeboard for high level bridges should not be less than 600mm.

(iv) clearance should be allowed according to navigational requirements.

Discharge	Minimum vertical clearance in mm
$< 0.3\ m^3/s$	150
$0.3 - 3.0\ m^3/s$	450
$3.1 - 30.0\ m^3/s$	600
$31 - 300\ m^3/s$	900
$301 - 3000\ m^3/s$	1200
$> 3000\ m^3/s$	1500

Methods for fixing the waterway:

(1) Waterway for stream with Rigid Boundaries:

The artificial irrigation, navigation and drainage channels where boundaries remain the same during and after the

flood the effective linear waterway should generally be equal to the width of channel at mid-depth.

(2) Waterway for Quasi-Alluvial Streams:

For non-meandering natural streams not wider than 30m in alluvial beds but with well defined banks and for all natural channels in beds with rigid & erodible boundaries, the linner-waterway should be the distance between banks of the high flood level water surface.

(3) Waterway for Alluvial streams:

For large natural streams in alluvial beds and having undefined banks, the linear waterway should be determined from the designed discharge using the following formula proposed by Lacey for Regime condition.

$$L = c\sqrt{Q}$$

L = Linear waterway in metres.
Q = Design discharge m^3/sec.
c = const.

Economic Span :→

The economic span of a bridge is the one which reduces the overall cost of a bridge to be a minimum. The overall cost of a bridge depends upon :

(i) cost of material and its nature.
(ii) Availability of skilled labour.
(iii) span length.
(iv) Nature of stream to be bridged.
(v) Climate and other conditions.

→ For most economic span length,

cost of the super-structure
= cost of the sub-structure.

→ During derivation of economic span following assumptions are made :-

(i) The bridge has equal span lengths.
(ii) The cost of the supporting system of super-structure varies as the square of the span length.
(iii) cost of flooring and parapets varies

directly as the span.

(ii) cost of one pier and its foundation is constant.

(iii) cost of the abutments and their foundations is also constant.

∴ General equation for Economic span.

∴ Economic span = $l = \sqrt{\frac{P}{a}}$

∴ P = cost of one pier with its foundation.

a = const.

∴ For small bridges economic spans are determined as:

Types of Bridge	Economic span (l) / height of pier from bottom of its foundation (H)
Masonry arch type bridge	2
R.C.C Slab bridge	1.50
Steel Girder bridge	1.75
steel truss bridge	2.0

2.4: Afflux, clearance, Freeboard:

Afflux:

When a bridge is constructed, the structures such as abutment and piers cause the reduction of the natural waterway area. The contraction of the stream is desirable because it leads to saving in the cost. Therefore to carry the maximum flood discharge, the velocity under a bridge increases. This increased velocity gives rise to a sudden heading up of water on the upstream side of the stream. This phenomenon of heading up of water on the upstream side of the stream is known as afflux.

→ Afflux can be calculated by:

(a) Mansiman's formula

(2) Molesworth's formula

(a) Marriman's formula:

$$h_a = \frac{V^2}{2g}\left[\left(\frac{A}{Ca}\right)^2 - \left(\frac{A}{A_1}\right)\right]$$

$\therefore h_a$ = Afflux in metres.

V = velocity of approach in metres/second.

A = Natural waterway Area.

a = contracted area in m^2.

A_1 = Enlarged area of upstream in m^2.

C = coefficient of discharge

$= 0.75 + 0.35\left(\frac{a}{A}\right) - 0.1\left(\frac{a}{A}\right)^2$

(b) Molesworth's formula:

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

Clearance:

To avoid any possibility of traffic striking structural part clearance diagrams are specified. The horizontal clearance should be the clear width and the vertical clearance the clear height, available for

the passage of vehicular traffic.

Free board:

Free board is the vertical distance between the designed high flood level allowing for afflux, and the 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.

(i) Free board is required to allow floating debris, fallen tree trunks and approach waves to pass under the bridge.

(ii) Free board is also required to allow for the afflux during the maximum flood discharge due to contraction of waterway.

(iii) Free board is required to allow the vessels to cross the bridge in case of navigable rivers.

Type of Bridge	Free board
High level bridges	600mm.
Arch bridges	300 mm
Girder bridges	600 - 900mm.
Navigable streams	2400 - 3000mm.

Ch-03

: Bridge Foundations :

Topics to be covered in this chapter--

3.1: Scour depth, Minimum depth of foundation.

3.2: Types of bridge foundations - Spread foundation, pile foundation, well foundation. Sinking of wells caission foundation.

3.3: coffer dams.

3.1: Scour depth. Minimum depth of foundation:-

Scour depth:

When the velocity of stream exceeds the limiting velocity which the erodable particle of bed material can stand the scour occurs. The normal scour depth is the depth of water in the middle of the stream when it is carrying the peak flood discharge.

The scour pattern of a bridge depends upon factors like flood discharge, bed slope, direction of flow, bed material, alignment of piers, pier geometry i.e. its shape & size.

For a safe and sound design of a bridge it is important to estimate the correct scour depth.

① Scour depth of Alluvial Streams:

The alluvial stream when comes to regime it requires a regime wetted perimeter 'P', a regime slope "S", and a hydraulic mean depth "d". Lacy developed equations for regime characteristics of an alluvial channel carrying a discharge of "Q" m^3/s.

wetted perimeter $P = 4.8\sqrt{Q}$.

scour depth, $d = 0.473\left(\frac{Q}{f}\right)^{1/3}$

Bed slope, $S = \frac{0.0003\, f^{5/3}}{Q^{1/6}}$

flow velocity, $V = 0.44\, Q^{1/6} f^{1/3}$

flow Area, $A = \frac{2.3\, Q^{5/6}}{f^{1/3}}$

Case-I

Linear waterway of the Bridge is not less than the Regime width:

Normal scour depth = $d = 0.473\left(\frac{Q}{f}\right)^{1/3}$

$\therefore d$ = Normal depth of scour below H.F.L for regime conditions in a stable channel in metres.

Q = Designed discharge in m^3/s.

f = Lacey's silt factor.

$= 1.76\sqrt{m}$.

m = mead diameter of the bed material in mm.

Case-II:

Linear waterway less than the Regime width:

$$d_1 = d\left(\frac{W}{L}\right)^{0.61}$$

$\therefore W$ = Regime width of the stream.

L = width of waterway provided under the bridge.

d = Normal scour depth when, $L = W$

d_1 = Normal scour depth with contracted waterway.

(2) Scour depth for Quasi-Alluvial streams:

In Quasi-alluvial streams which have got rigid banks and erodable beds, the normal scour depth when the stream width is large as compared to depth can be computed as:-

i) when ~~velocity~~ velocity is known:-

$$d = \frac{Q}{W \times V}$$

∴ d = scour depth
W = surface width of stream.
Q = Discharge in m^3/s
v = velocity of flood.

ii) when Slope is known

$$Q = \frac{1}{n} \times W \times d^{5/3} \times S^{1/2}$$

∴ n = Manning's coefficient
S = Slope.

(iii) When both velocity and slope are not known:

$$d = \frac{1.2\, Q^{0.60}}{f^{0.33} \times W^{0.60}}$$

f = silt factor.

Maximum scour depth should not exceed the value

$$d_m = d\left(\frac{W}{L}\right)^{1.56}$$

d_m = Maximum scour depth.

Minimum depth of foundation:

The depth of bridge foundation is determined by consideration of the safe bearing capacity of the soil after taking into account the effect of scour.

The minimum depth of foundation can be calculated as:-

$$D_{min} = \frac{q}{\gamma}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

$\therefore D_{min}$ = Min. depth of foundation in metres.

q = Bearing capacity of soil in kg/m^2

γ = unit weight of soil in kg/m^2

ϕ = angle of internal friction of the soil.

3.2: Types of Bridge foundations:

The selection of the foundation type suitable for a particular site depends on

(i) Nature of subsoil.

(ii) Nature and extent of difficulties likely to be met. i.e. presebence of boulder etc.

(iii) Availability of expertise and equipment.

Depending upon the nature & depth foundations have been categorised as:-

(a) open or shallow foundations.

(b) Raft foundations.

(c) pile foundations

(d) well foundations.

(a)

Shallow foundations:

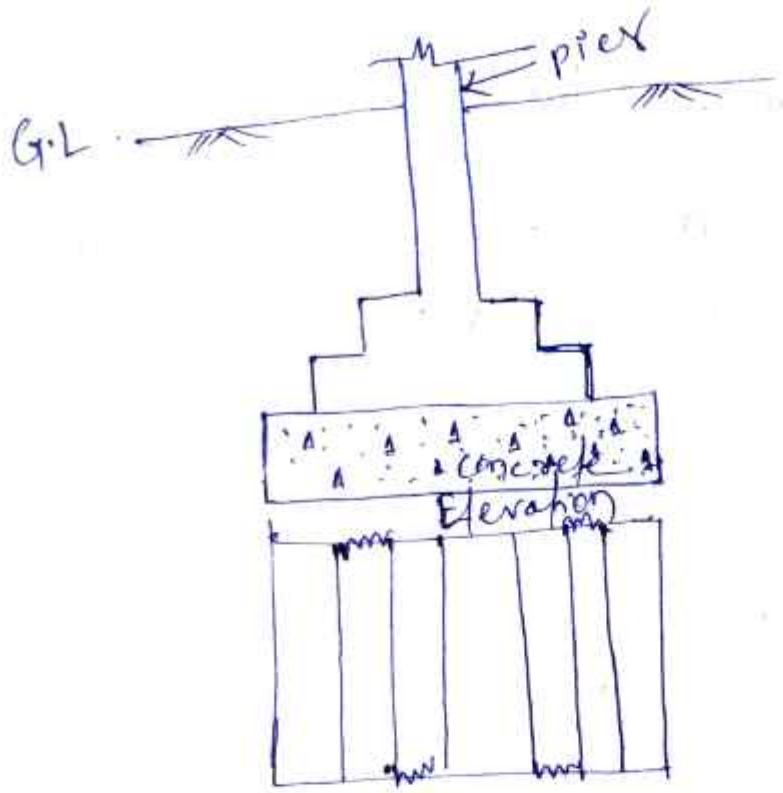
When the depth of foundation is less than the width, then it is termed as shallow foundation.

The various types of shallow foundations are:-

(a) Open foundations:

An open foundation or a spread foundation is a type of shallow foundation. This is the most common type of foundation and can be laid using open excavation by allowing natural slopes on all sides and is practicable for depth upto 5m.

- The base of the pier or abutment is enlarged or spread to provide individual support.
- This type of foundation is provided for bridges of moderate height built on sufficiently Hard ground.

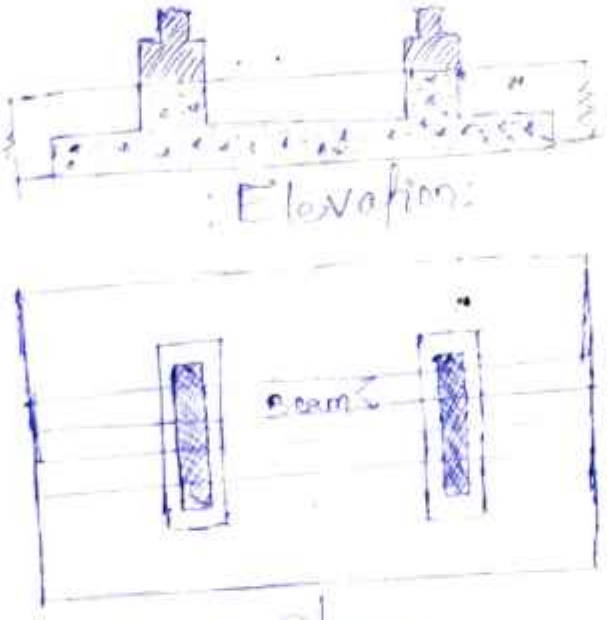


(b) Raft Foundation in bridge:

A raft or mat is a combined footing that covers the entire area beneath a bridge and support all the piers and abutments. when the allowable soil pressure is low, or bridge loads are heavy, the use of spread footings would cover more than ~~half~~ one-half of the area and it may prove more economical to use raft foundation in that situation.

→ Raft foundation is used to reduce the settlement above highly compressible

soils by making the weight of bridge and raft approximately equal to the weight of soil excavated.



(c) Pile Foundations in Bridge:

The pile foundation is a construction for the foundation of a bridge pier or abutment supported on the piles. A pile is an element of construction composed of timber, concrete or steel or a combination of them.

Pile foundation may be defined as a column support type of foundation

which may be cast-in-situ or precast.

- This type of construction is adopted when the loose soil extends to great depth.
- 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:-

1. classification based on the function.
2. classification based on materials and composition.

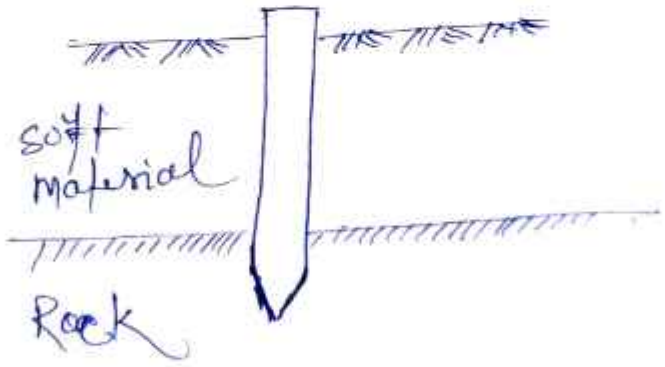
1. classification Based on Foundation:
   - (a) Bearing pile
   - (b) Friction pile
   - (c) Screw pile
   - (d) compaction pile
   - (e) uplift pile

(f) Batter pile

(g) Sheet pile.

(a) **Bearing pile:**

These piles penetrate through the soft soil and their bottoms rest on a hard stratum. The soft ground through which the piles pass also gives some lateral support and this increases the load carrying capacity of the bearing piles.



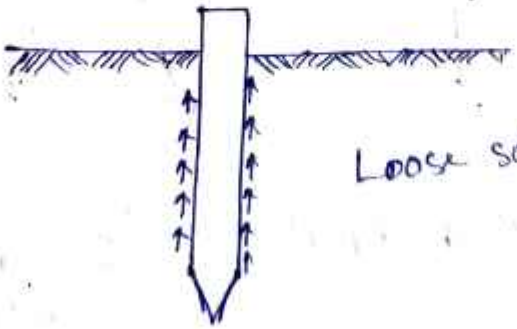
(b) **Friction Piles:**

When loose soil extends to a great depth, piles are driven up to such a depth that frictional resistance developed at the sides of the piles equals the load coming on the piles.

The total frictional resistance of piles is obtained by multiplying frictional resistance of soil with the area of pile in contact with the soil.

The total frictional resistance can be increased by

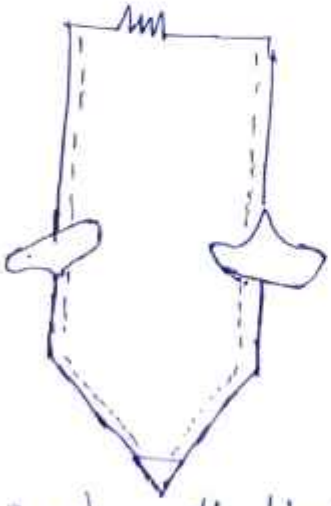
(i) increasing the diameter of the pile.
(ii) driving the pile to a great depth.
(iii) Making the surface of the pile rough.
(iv) Placing the piles closely.
(v) grouping the piles.



(c) Screw piles:

A screw pile consists of a shallow cast-iron or steel cylinder with one or more blades at the bottom. The blades are generally made of cast-iron.

The bottom end of the screw pile with blunt point is useful when ground to be penetrated consists of sand and clay. Screw piles when provided with gimlet point, hollow conical point and serrated point are used for gravelly ground, sand mixed gravel ground and soft rock.



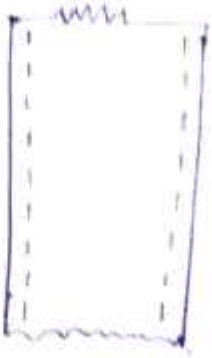
Screw pile with blunt point



Screw pile with gimlet point



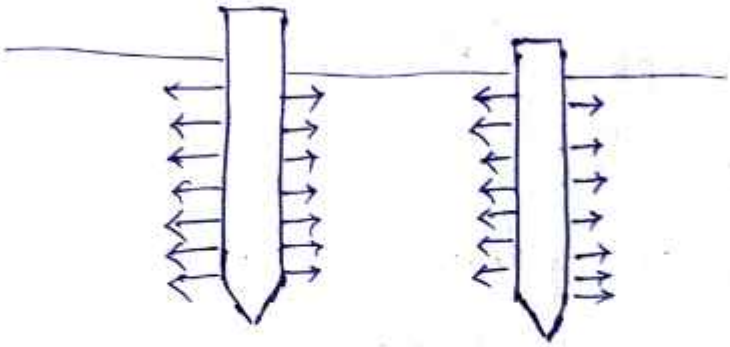
Screw pile with ~~shallow~~ hollow conical point



Screw pile with serrated point.

(d) Compaction piles:

They are used to compact loose granular soils in order to increase their bearing capacity. These piles themselves do not carry any load.



(e) Uplift piles:

These piles anchor down the structure subjected to uplift due to hydrostatic pressure or due to overturning moment.

(f) Batter piles:

They are used to resist large horizontal or inclined forces.

(g) Sheet piles:

They are used as bulk heads or as

impervious cut off to reduce seepage and uplift.

(2) Classification Based on Materials and composition:

1. cement concrete piles.
2. Timber piles.
3. steel piles.
4. Sand piles.
5. composite piles.

(1) cement concrete piles:

Cement concrete piles possess excellent compressive strength. These piles can be reinforced or prestressed. They are divided into two groups.

i) pre-cast concrete piles.

ii) cast in-situ concrete piles.

i) Pre-cast concrete piles:-

These piles manufactured in factory. They may be tapered or parallel sided. They may be square, octagonal or round in shape. These pile possess high resistance to biological and chemical actions of the ground. The concrete in the piles should controlled concrete and should correspond to M200 grade. They require space for casting and storage, more time to set and cure before installation and heavy equipment for handling and driving.

ii) cast-in-situ concrete piles:

In this type a bore is dug into the ground by inserting a casing. This bore is then filled with cement concrete after placing reinforcement.

The common types of cast in-site concrete piles used are. Raymond piles, Mac-Arthur piles, Monotube piles. BSP base-driven piles, Buffon bottom piles, Simplex piles, Franki piles etc.

Cast in-site concrete piles are easy to handle and to drive in the ground. They do not require any extra reinforcement to resist the stresses developed during handling or driving operations. There is no wastage of material as pile of required length only constructed and extra cost of transporting pile is eliminated.

(2) Timber piles:

Timber piles are prepared from trunks of tree. They may be circular or square. They are 30 to 50 cm in diameter with a length not exceeding 20 times

its top width. At the bottom, a cast-iron shoe is provided and at the top, a steel plate is fixed. If a group of timber piles is driven, the top of each member of the group is brought at the same level and then a concrete cap is provided to have a common platform. It is very difficult or even impossible to drive these piles into hard stratum or boulders. Where timber is available easily these piles prove to be economical.

(5) Steel piles:

Steel piles are used in following three different forms:-

(i) H-piles
(ii) Box piles
(iii) Tube piles

(i) H-piles:

These piles are usually of wide flange section. They are suitable for trestle type piers in which the piles extend above ground level and work also as columns. They are used as long piles with high bearing capacity.

(ii) Box piles:

They are rectangular or octagonal in form filled with concrete. These piles are used when it is not possible to drive H piles up to hard strata.

(iii) Tube piles:

In this type tubes or pipes of steel are driven into the ground. Concrete is filled inside the tube piles. Because of their circular cross-section these piles are easy to handle and easy to drive.

(4) Sand piles:

These piles are formed by making holes in the ground and then filling them by sand. The top of the sand piles is filled with concrete to prevent the sand to come upwards due to lateral pressure. Sand piles are spaced at 2 to 3m. Its length is kept about 12 times its diameter. They are not suitable for loose or wet soils or where is a danger of scour and at places subjected to frequent earthquakes.

(5) Composite piles:

A composite pile is formed when it is a combination either of a bored pile and a driven piles of two different materials. They are economical and easy to construct.

(d) Well foundations in Bridges:

The caisson is a structure used for the purpose of placing a 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 may be of:-

i) Box caissons.
ii) Open caissons or wells.

(i) Box caissons:

A box caisson is a strong watertight vessel open at top and close at the bottom. They are generally built of timber, reinforced concrete and steel. This type of caisson is suitable

where bearing stratum is available at shallow depth, and where loads are not very heavy.

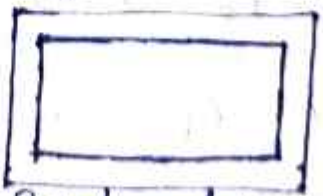
(ii) Open caissons or wells:

The open caissons are open both at the top and the bottom. They are used on sandy or soft bearing stratum liable to scour.

The shapes of wells may be circular, rectangular, Double-D rectangular with D-shaped ends, twin hexagonal and twin octagonal.



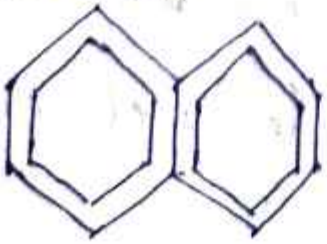
Circular



Rectangular



Rectangular with D-shaped

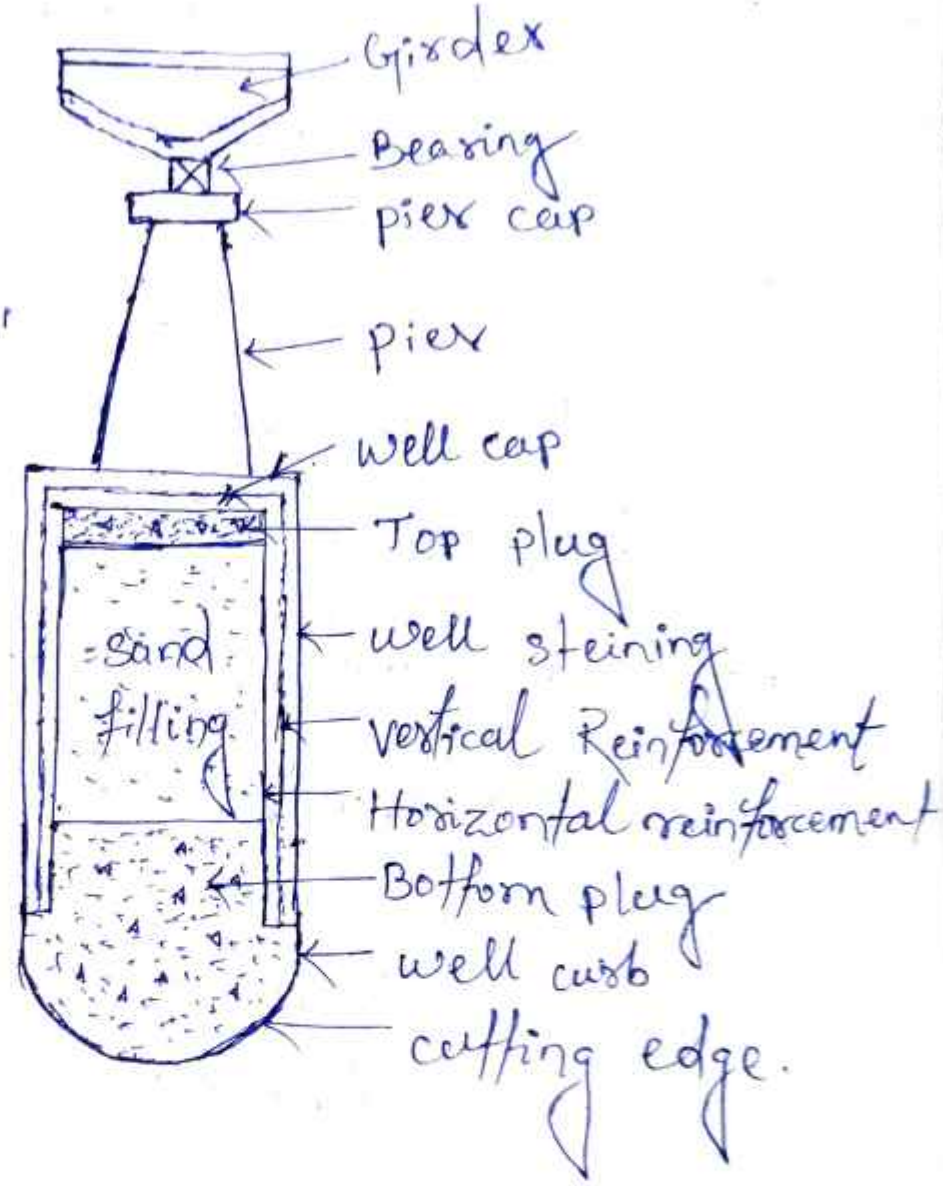


Twin hexagonal



Double-D

Components of well foundation:



Sinking of wells:

In case of well sinking on dry grounds, an open excavation up to half a metre above subsoil water level is carried out and the well curb is laid.

In case the wells to be sunk midstream, a suitable cofferdam is constructed around the site of the well and islands are made.

The well is sunk by excavating material from inside under the curb. Great care should be exercised during well sinking in the initial stages because the well is very unstable. Excavation of soil inside can be done by sending down workers inside the wells. When the depth of water inside the well becomes more than 1 metre, then excavation is carried out by Tham or dredger.

Pumping out the water from the inside of well is effective when the well has gone deep enough or has passed through a clayey strata so that chances of lifts and shifts are

minimised during this process. when the well has been sunk to about 10m. depth, sinking thereafter should be done by grabbing, chiselling and applying Kentledge.

In case the well being sunk in Sandy strata is struck up and normal method of Kentledge and gredging failed to sink it further, in such a case frictional resistance developed on its outer periphery is reduced considerable by forcing jet of water on the outer face of the well all around.

3.3: coffer dams:

A cofferdam is a temporary structure which is built to remove water from an area and make it

possible to carry on the construction work under reasonably dry conditions. cofferdams are usually required for Project such as dams, locks and construction of bridge piers and abutments.

Requirements of a cofferdam:

i) The cofferdam should be reasonably water tight.

ii) The design and layout of a cofferdam should be such that the total cost of construction, maintenance and pumping is minimum.

iii) It should be sufficiently stable against bursting, over turning and sliding, under the floods, waves and anticipated loads.

(iv) It should be constructed at site of work.

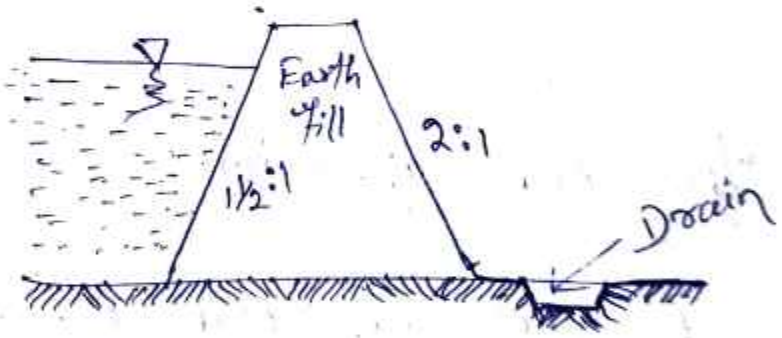
(v) It should be so planned as to facilitate easy dismantling and reuse of materials.

Types of cofferdam:

1. Earth fill cofferdam.
2. Rock fill cofferdam.
3. Rock fill crib cofferdam.
4. Single wall cofferdam.
5. Double wall cofferdam.
6. cellular cofferdam.

(1) Earth fill cofferdam:

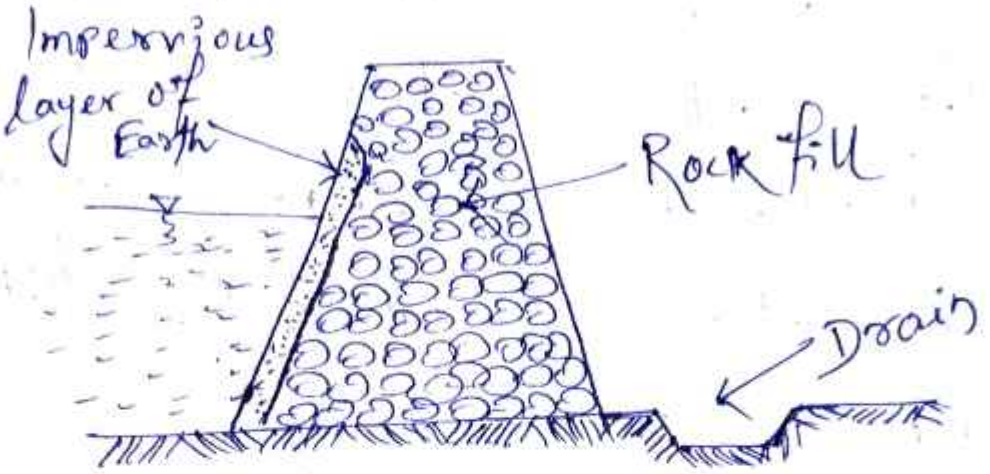
This is the simplest form of cofferdam. Its use is limited to the vicinity where impervious earth is available and water depth is shallow with low velocity of flow. It should never be used where there is danger of over-topping by water.



(2) Rock fill cofferdam:

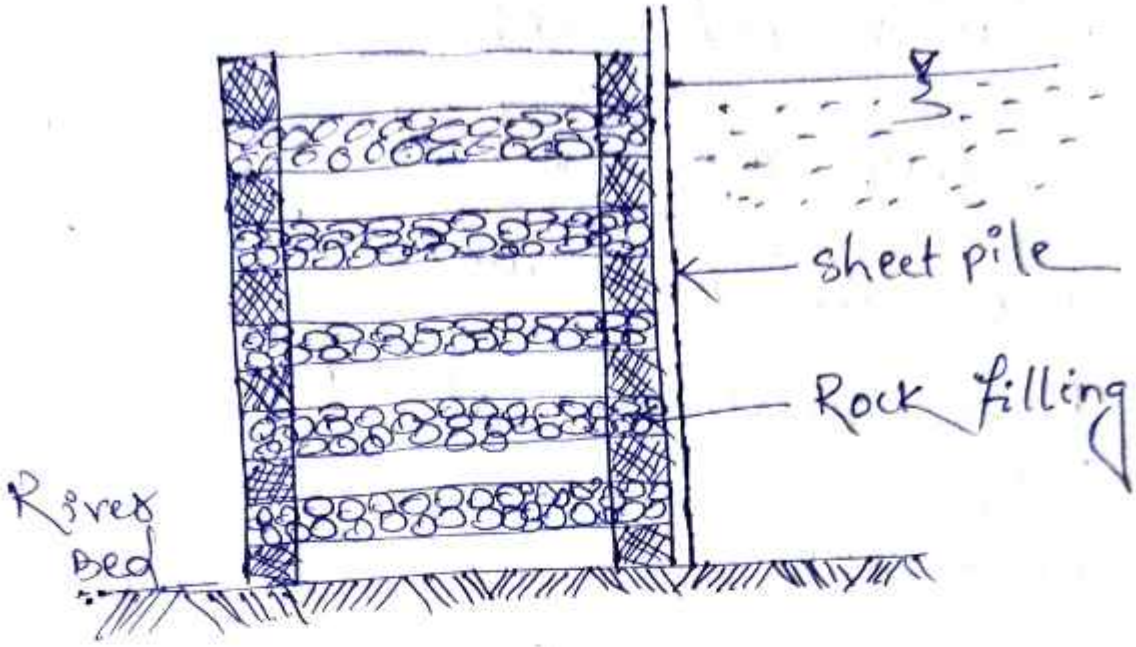
They are constructed by placing rock along stream. They can be used for depths of water up to about 3m and are suitable even in case of swift water. They are economical at places where rock is available in plenty.

An impervious layer of earth is laid on the outer face of the cofferdam, which makes it impervious.



(3) Rock fill crib cofferdam:

A rock fill crib cofferdam is comprised of timber cribs, A crib is a framework of wooden horizontal and cross beams laid in alternate courses. The cribs are open at the bottom and are filled with rock or gravel or earth.



(4) Single wall cofferdam:

This type of cofferdam is suitable when available working space is limited and area to be enclosed is small. It may be used upto the maximum depth of water of 25 m. The walls of cofferdam are normally made up of steel sheet pile.

(5) Double wall cofferdam:

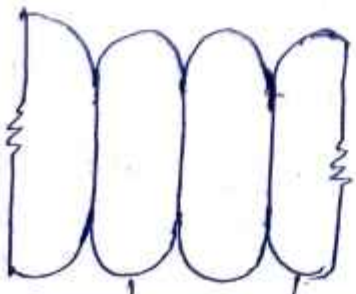
Double wall cofferdams are provided to enclose a large area; the double wall gives stability to the cofferdam.

⑥ cellular cofferdam:

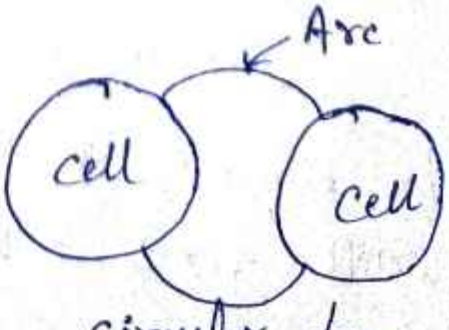
They are made of steel sheet piles and are suitable for dewatering large areas. ~~In case of cellular cofferdams~~ ..

They are comprised of diaphragm cells or circular cells or modified cells. In case of cellular cofferdams with diaphragm cells series of arcs are connected to straight cross walls and they can withstand overtopping of water.

The circular cellular cofferdam is comprised of series of complete circles connected by short arcs. and they require more material than diaphragm.



Diaphragm type



circular type.

Ch - 04

Bridge Substructure and Approaches

The bridge substructure is one of its most significant components in regard to design and layout and greatly influences its economy. Its design is significant because of the many possible load variants that can exercise control. The substructure design process therefore is the most demanding in bridge construction. The bridge layout is designated by the proper spacing of substructure units and is often the most significant factor in producing the most economical design. Placement and location of the substructure also will influence the aesthetics of the structure.

The bridge substructure consists of the following elements:

i) Piers
ii) Abutment piers
iii) Abutments
iv) Wing walls

4.1 Bridge Piers

They are the intermediate supports of the superstructure. They may have many different configurations. Normally they are required to withstand not only high vertical loads but lateral loads as well because of the various possible loading effects. When cast-in-place concrete structures are used it is common practice to cast the pier and superstructure monolithically with adequate reinforcement to make framed corners. These efficient rigid frames have a number of redundancies that give them added reserve strength not accounted for in the design calculations. Precast concrete superstructures are normally placed on bearings that sit on pier caps in which the bearings can transmit longitudinal and transverse lateral loads. Broadly, piers are classified under the following two categories:

I. Solid Piers

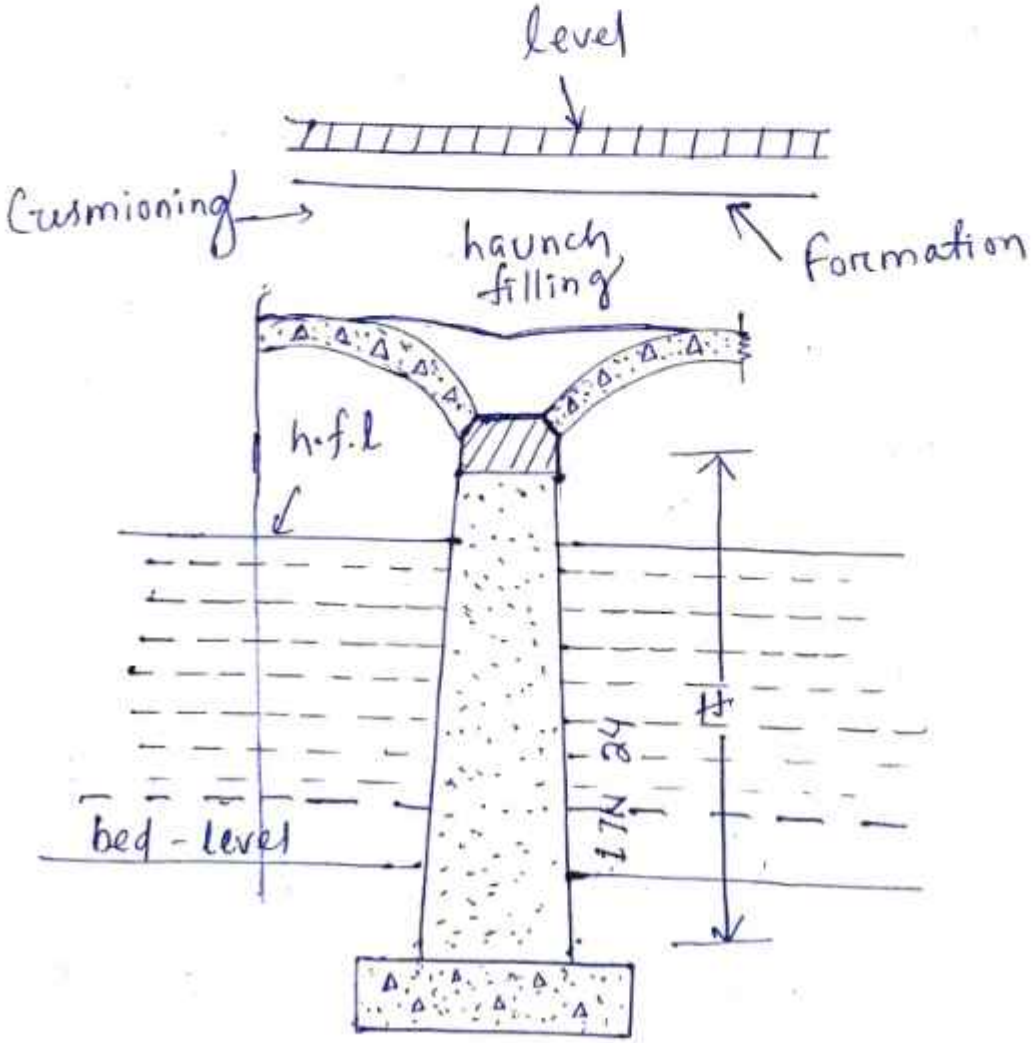
II. Open Piers

I Solid piers :-

They may be constructed either of masonry or mass concrete. The salient features of solid bridge piers are :

(a) Height :-

The height of a pier is measured up to the support level of girders or the springing point of the arch. The pier top is kept 1 to 1.5 m above the H.F.L of the river or stream as free board.



(b) Pier Batter :-

The sides of a masonry pier may be either vertical or battered. Generally a batter of 1 in 12 to 1 in 24 is provided. Short piers have vertical sides.

(C) Pier Width :-

The top width of the pier should be sufficient to accommodate the seats of two bearings with a clearance of about 15 cm in between. According to Bligh, the top width should be equal to $\sqrt{\text{span length}}$ and Rankine 1/6 to 1/2 of the span length. The width of the pier at bottom is generally about 1/3 of its total height. The top surface of the pier should be flat for a girder or semi-circular arch, and provided with skewback if the arch is segmental or elliptical.

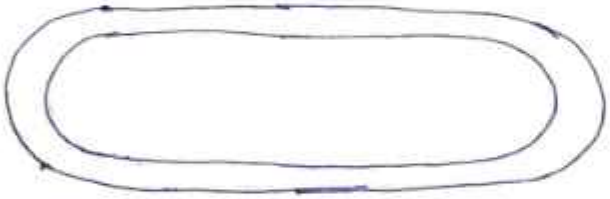
(d) Length of Pier :-

Generally the length of pier is kept 1-1/2 times the top width beyond the centre line of the outer trusses or girders

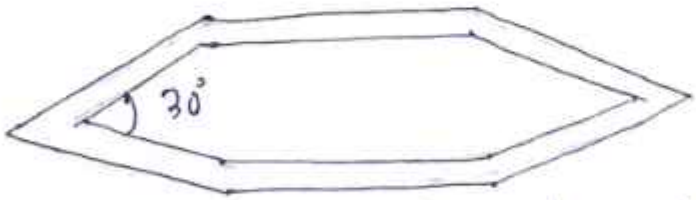
Plus length of cut-waters and ease-waters. This is to prevent diagonal shearing at the ends.

(e) Cut and Ease Waters :-

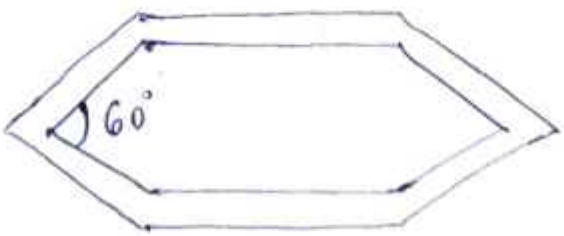
The pier ends are shaped for easy passage of water. The end on the upstream side is known as cut water and that on the down stream side is known as ease water. They prevent the formation of eddies and the consequent scouring effects.



Piers with semi-circular ends.



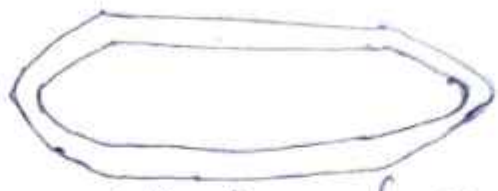
Piers with included angle between the faces 30° or less.



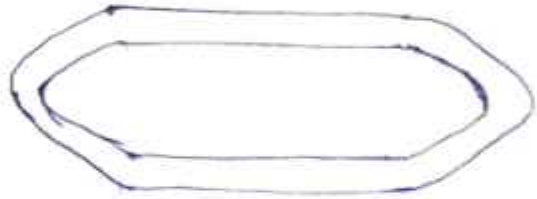
Piers with included angle between the face 30° to 60°



Piers with included angle between the faces 60° to 90°



Piers with faces of equilateral arcs of circles



Piers with faces intersecting at 90°

(f) Pier Cap :-

The top of the pier provides the immediate bearing surface for the support of the superstructure. It distributes the loads from the bearings to the pier more uniformly. The pier cap covers the entire area of the top of the pier and projects 7.5 cm beyond the pier dimension. This 7.5 cm projection not only improves the pier appearance but also protects it from rain water.

dripping down the sides. The pier cap is built of reinforced concrete which corresponds to M 150 grade concrete.

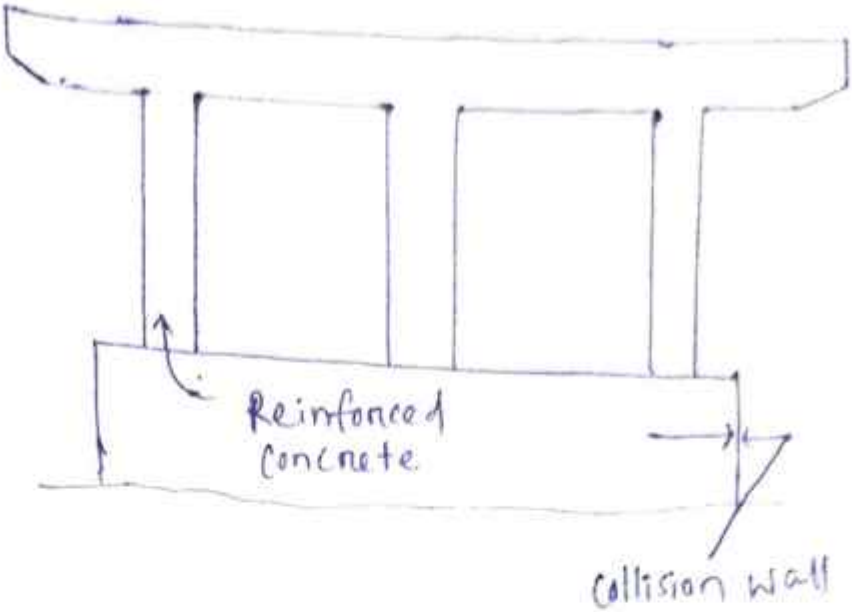
II Open piers :-

They are classified as:

1. Multiple bent or Multiple-Column.
2. Pile bent.
3. Cylindrical piers.
4. Trestle piers.

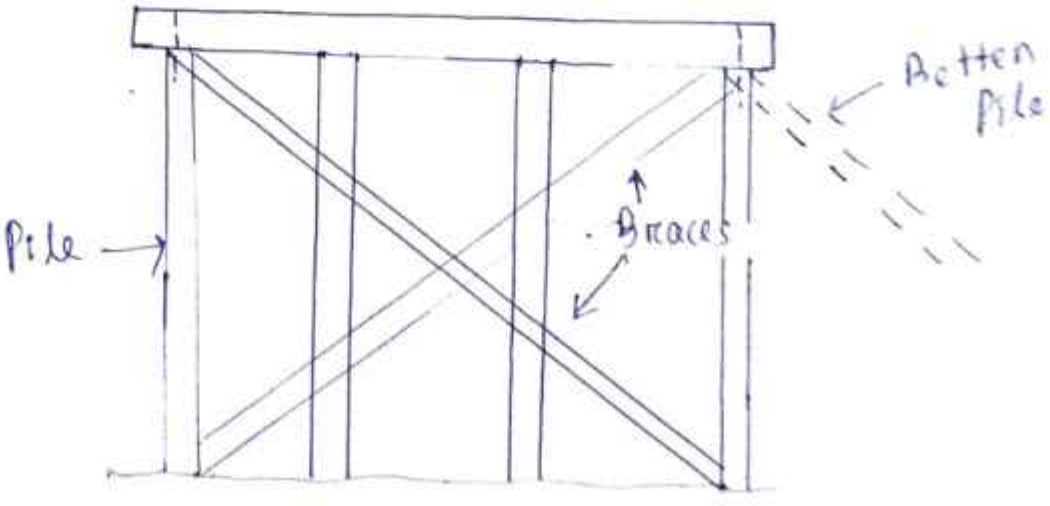
① Multiple Bent :-

They are often used on ground. The section of wall at the bottom may or may not be used. It is needed in overpass work where traffic runs parallel close to the bent to reduce damage to the columns in case of accident. It is lighter and may be more economical than the solid pier; but it requires more formwork and material.



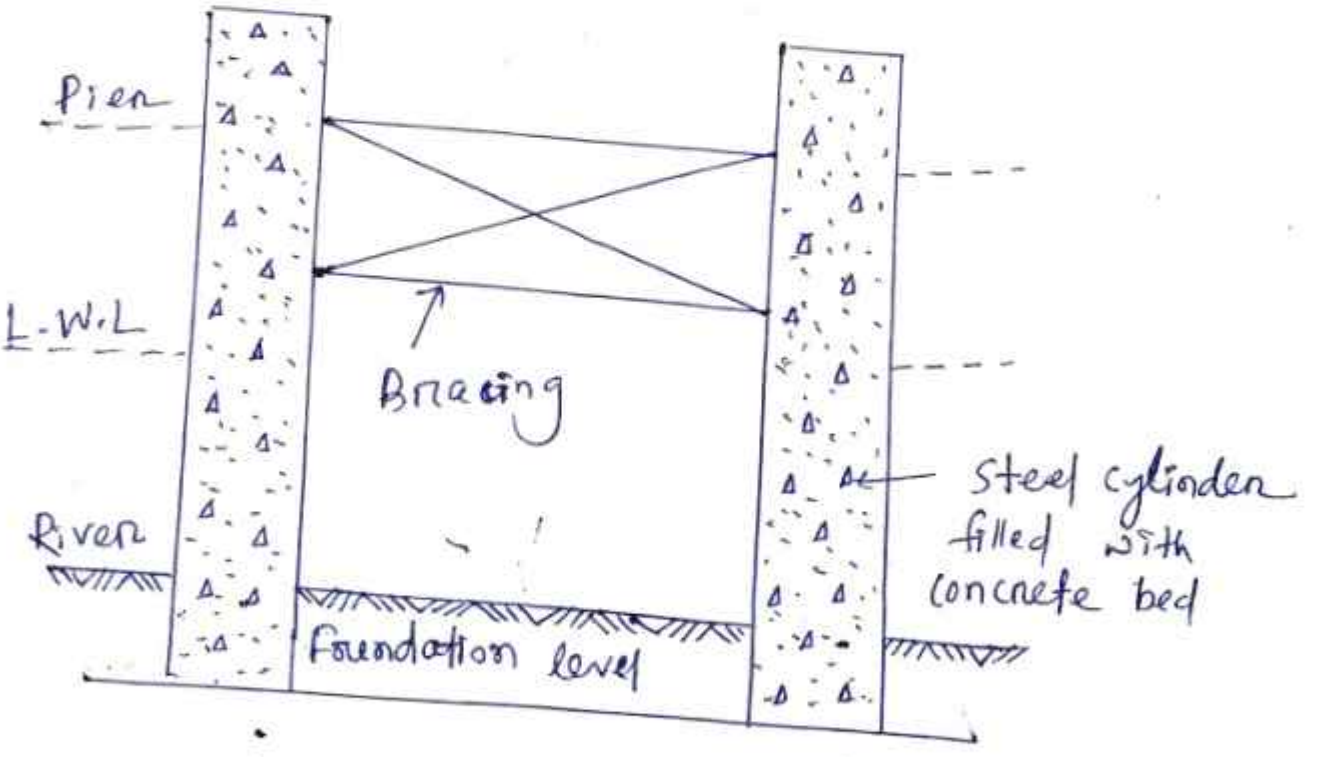
② Pile Bent :—

The Pile bent is used for low piers over unstable ground. They consist of reinforced concrete or steel piles driven into the ground, provided with a capping at their top to support the main girders. They are laterally connected by reinforced concrete or steel braces. The pile is used both for a support by driving to resistance and for a column by projecting above ground. The outside piles are usually battered.



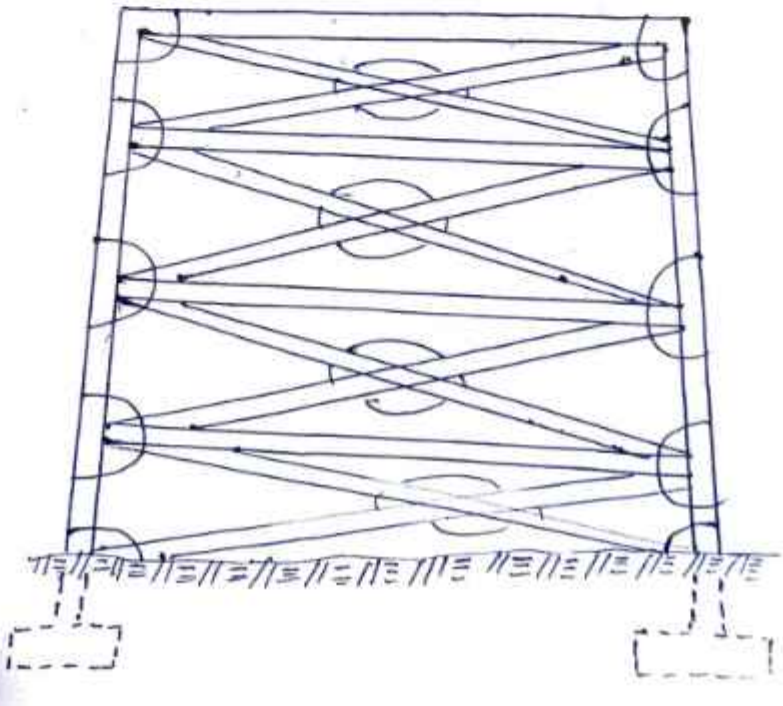
(3) Cylindrical Piers :-

They consist of mild steel or cast iron cylinders which are filled with concrete. when cylinders are used for bridges of greater widths two cylinders are sunk a slight distance apart and suitable bracing is provided.



(4) Trestle ~~Cylindrical~~ Piers

They are used for temporary work and for timber work. They are made up of R.C.C. or steel vertical, horizontal and diagonal members. The connections in steel trestle may be either riveted or welded. R.C.C trestle type pier consists of circular columns with a bent cap at the top. In order to avoid moments being transferred from deck to the columns concrete hinges are introduced between the top of the columns and the bent cap. In case of flyovers and elevated roads where trestle piers are used, it is desirable to provide connecting diaphragms between the columns.

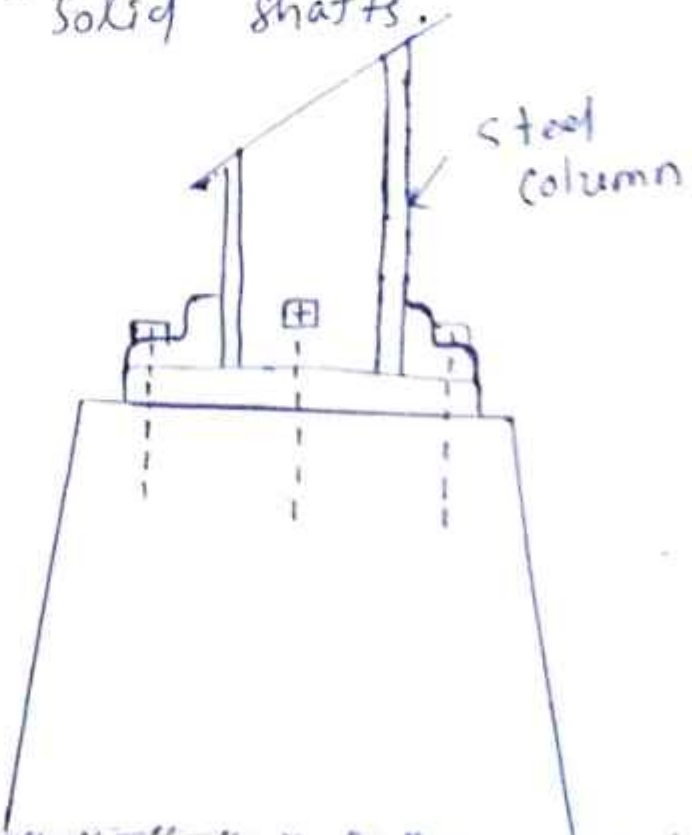


The following are some of the special piers:

1. Separate piers
2. Abutment piers
3. Cellular piers
4. Framed piers.

(1) Separate Piers:-

They are sometimes used for high bridges. These may be low piers with steel columns above on concrete piers up to the bridge level. In water, they may be combined with a solid shaft below up to flood water level. They may have the advantage of lower cost than solid shafts.

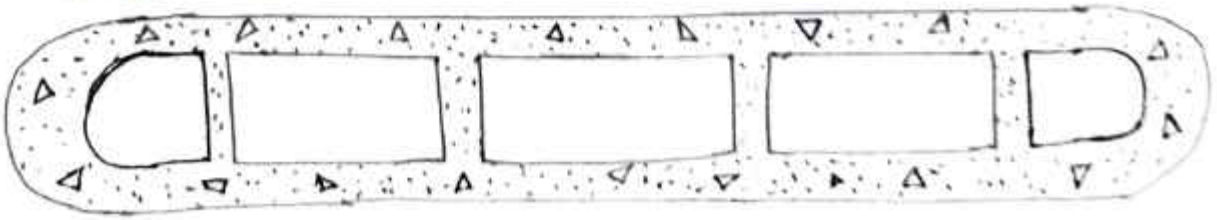


(2) Abutment piers :-

In the case of multiple span arch bridges, every third or fourth pier is designed as an abutment to receive the thrust from either side. Such a pier is thicker in section and is known as abutment pier.

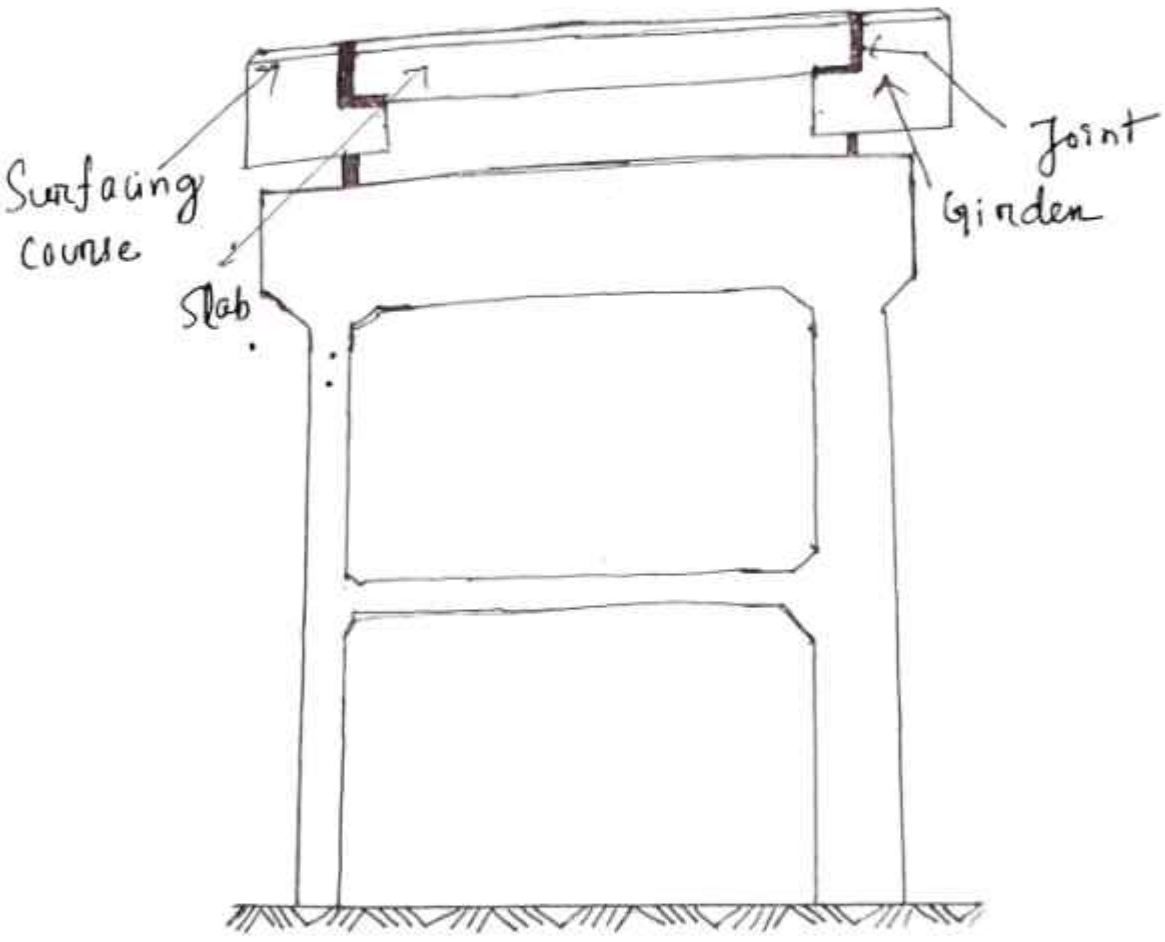
(3) Cellular piers :-

The cellular pier consists of two concentric R.C.C. shells connected by radial ribs and horizontal bands at suitable intervals. The intermediate space between the shells is filled with some filler material. This will result in saving of cement concrete which is a costly material. This type of piers usually require difficult shuttering and additional labour in placing reinforcements.



④ Framed Piers :-

This type of piers result in reduced effective span lengths for girders on either side of the centre line of the pier leading to economy in the cost of Super-structure.



Such type of piers if used in rivers subjected to sudden floods near hills and forests would be subjected to floating debris, e.g. floating tree trunk, etc.

4.2 Abutments :-

They are the end supports of the superstructure, retaining earth on their back. They are built either with masonry, stone or brick work or ordinary mass concrete or reinforced concrete. The top surface of the abutment is made flat when the superstructure is of trusses or girders or semi-circular arch. In case of ~~se~~ segmental or elliptical arch type of superstructure, the abutment top is made skew. Weepholes are provided at different levels through the body of the abutment to drain of the ~~salient~~ retained earth.

The salient features of bridge abutments are :-

(a) Height. :-

The height of the abutment is kept equal to that of the piers.

(b) Abutment Batter :-

The water face of the abutment is usually kept vertical or could be given

a batter of 1 in 12 to 1 in 24 as for piers. The face retaining earth is given a batter of 1 in 6 or may be stepped down.

(C) Abutment Width :—

The top width of the abutment should provide enough space for the bridge seat and for the construction of a dwarf wall to retain earth up to the approach level.

(d) Length of Abutment :—

The length of abutment is kept at least equal to the width of the bridge.

(e) Abutment Cap :—

The design is similar to that of pier cap.

Broadly, abutments are classified under the following two categories :—

1. Abutments with wing walls.
2. Abutments without wing walls.

(1). Abutment with Wing Walls :—

In this category, the abutments are provided with wing walls which may be

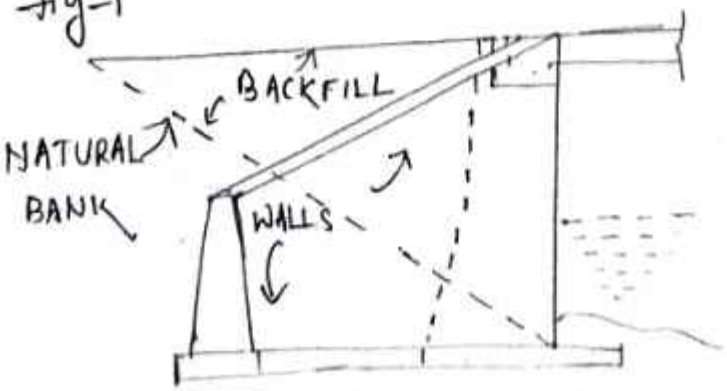
(a) Straight wing walls, or

(b) Splayed wing walls, or

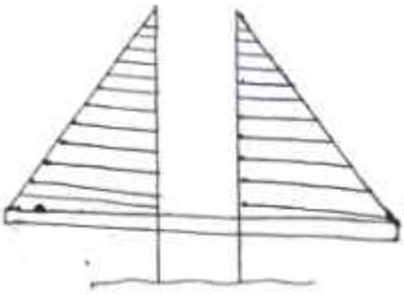
(c) Return wing walls.

The details of a standard gravity abutment with wing walls are shown in fig-1. In this type of abutment the wing walls can be either straight or splayed. The abutments wing splayed with walls are used across a river to provided smooth entry and exit for the water. The wing walls not only withstand the earth pressure but also the impact of live load over them.

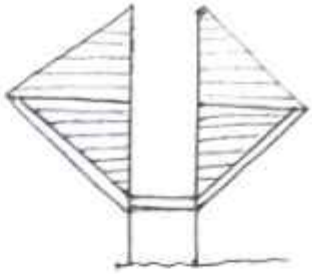
fig-1



(a) Standard Gravity Abutment

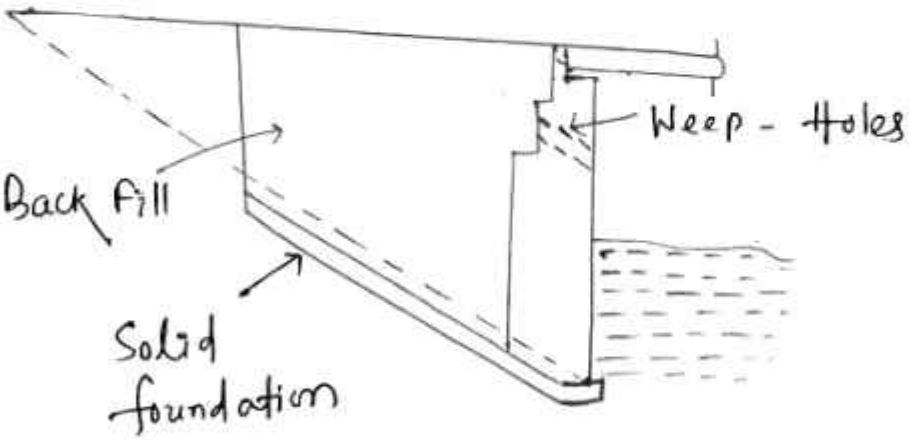


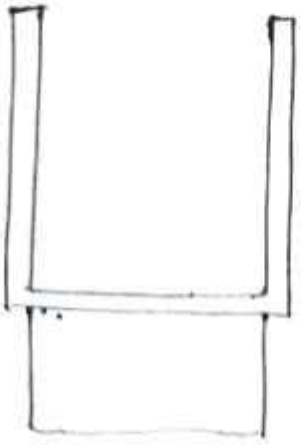
(b) Plan Straight wing wall



(c) Plan Splayed Wing Wall

The abutments with return wing walls are known as U-abutments. In this type abutment is extended at right angles on both the ends to some distance to protect the earth work. These are used where banks are steep and rocky.





Plan

The abutments with wing walls suffer from the following disadvantages:

(a) They tend to restrict the flood prism and hence increase scour and raise upstream flood level.

(b) The scour may require deeper foundations.

(c) Foundations may have to be built in the wet. These types are indicated for small heights. Special attention must be paid to the junction of the wing and abutment walls to prevent cracks.

(2) Abutments Without Wing Walls :—

In this category, the following types of abutments are in general use:

(a) Buried abutments.

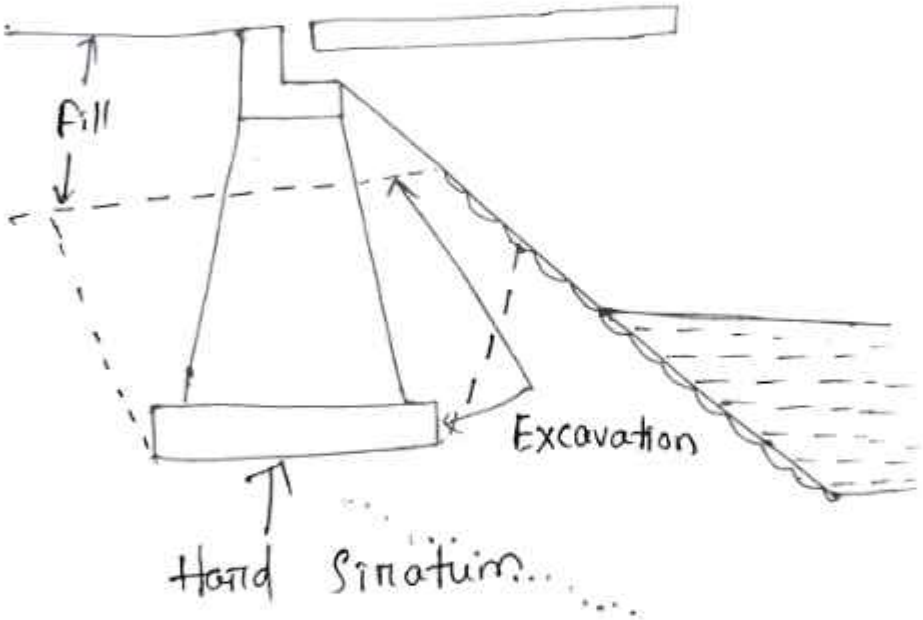
(b) Box abutments.

(c) Tee abutments.

(d) Arch abutments.

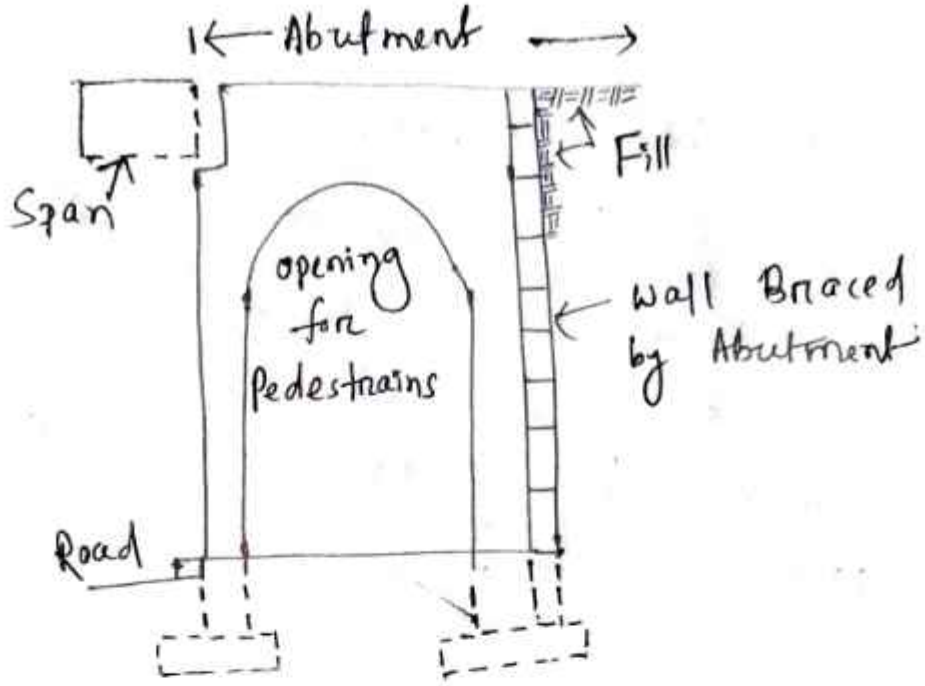
(a) Buried Abutments :—

This type of abutment is generally built prior to the placing of the fill. Since it is filled on both sides the earth pressure is low. Superstructure erection can begin before placement of fill.



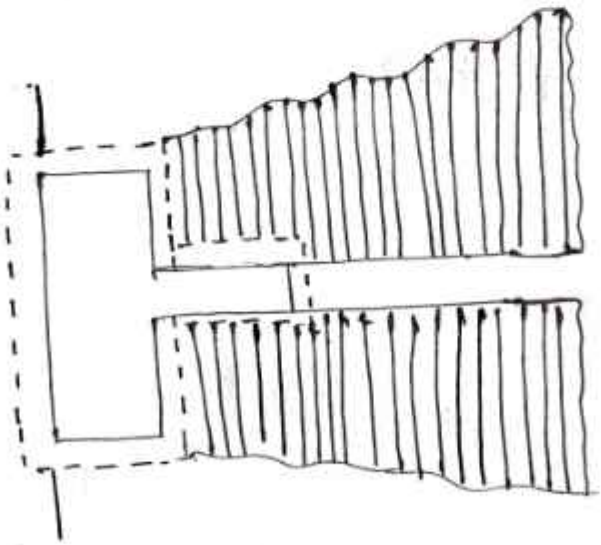
(b) Box abutments :—

This employs a short span of bridge built integral with columns to act as a frame and resist earth pressure of the approaches. It is most often used for overpass work where the short span may be employed for pedestrain passage.



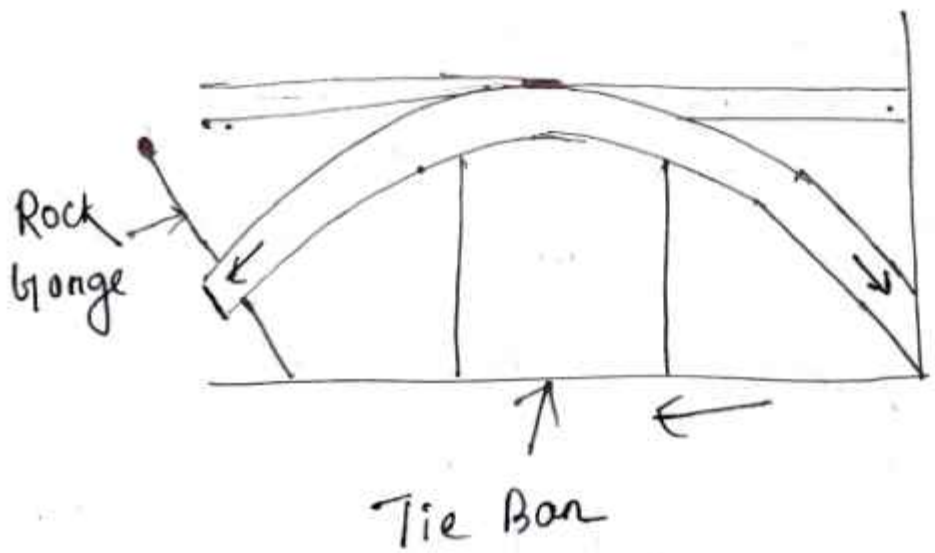
(c) Tee Abutments :-

This type looks like T in plan and has now become obsolete.



(d) Arch Abutments :-

This type of abutment is used where arches are employed because of their economy in certain conditions. The high inclined skewback thrusts are difficult to handle unless the abutment can be seated in rock. Therefore, they are often used for span over gorges.



4.3 Wing Walls :—

These are the walls provided at both ends of the abutments to retain the earth filling of the approach road. They are constructed of the same material as those of the main abutment. The design of the wing wall depends upon the nature of banks.

Depending upon the type of material used, the wing walls are categorised as follows:

(a) Masonry wing walls.

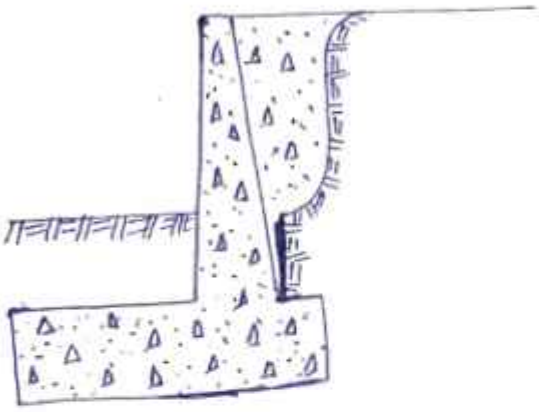
(b) Reinforced concrete wing walls.

(a) Masonry wing walls :—

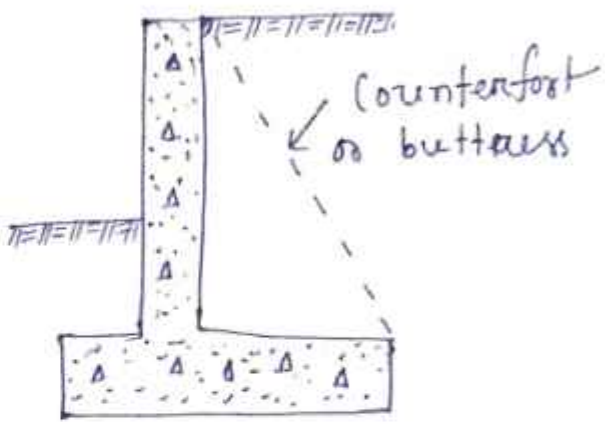
The masonry wing walls either end abruptly or form a small return wall constructed parallel to the road-way with horizontal top. Their water face is kept either vertical or battered. In order to drain off the retained filling, weepholes are provided through the body of the wall. Generally, the top of wing wall is either kept horizontal or sloping downwards.

(b) Reinforced Concrete Wing Walls:-

Generally, cantilever type or counterfort type retaining walls are used as the R.C.C wing walls. The top of these wing walls is also either kept as horizontal or sloping downwards.



(a) Cantilever Type.



(b) Counterfort Type.

As per their layout on plan, wing walls are classified as follows:

1. Straight wing walls.
2. Splayed wing walls.
3. Return wing walls.

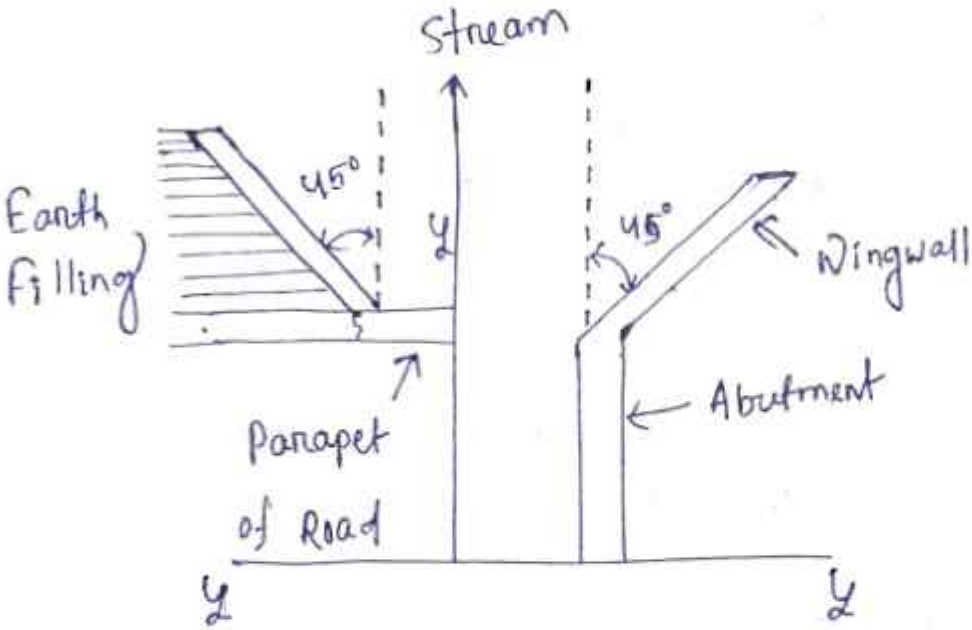
(1) Straight Wing Walls :-

They are suitable for small bridges constructed across drains with low banks. Generally, they are built for a railway bridge specially in cities, where the cost of the land is high. In case of hard and rocky foundation, the wing walls may be constructed in steps. When the soil is loose, the foundation should be taken to a uniform depth. Stepped foundations when provided must be built with vertical joint, as otherwise there will be a crack formed due to unequal settlement.

(2) Splayed Wing Walls :-

They are constructed generally at 45° with abutment and are straight or curved in plan. Their top is 0.5 m thick and their face batter is 1 in 12 and back batter is 1 in 6. They provide a smooth entry and exit to the flowing water.

They are best suited for the crossing of a river. They are also adopted when the road has to narrow on crossing the bridge, or when two or more roads meet at the approach.



(3) Return Wing Walls :—

These are walls built at right angles to the abutment at its both ends. They are designed to retain the earth filling of the approach road. Their top width is 1.5 m, face is Vertical, and the back is given either a batter of 1 in 4 or stepping if the abutment has a stepped back. They are suitable where the banks are high and rocky. They are best fitted where the cost of the land is high.

Ch-05

CULVERT AND APPROACHES

5.1 Culvert :-

A culvert is a small bridge for carrying water beneath a road railway. It is used when the linear waterways does not exceed 12 m. The waterway is provided in 1 to 3 spans, as required. In case of road culvert, span is limited to 5m in length, whereas in case of railway the span can be as high as 6 m.

Types of culverts are :-

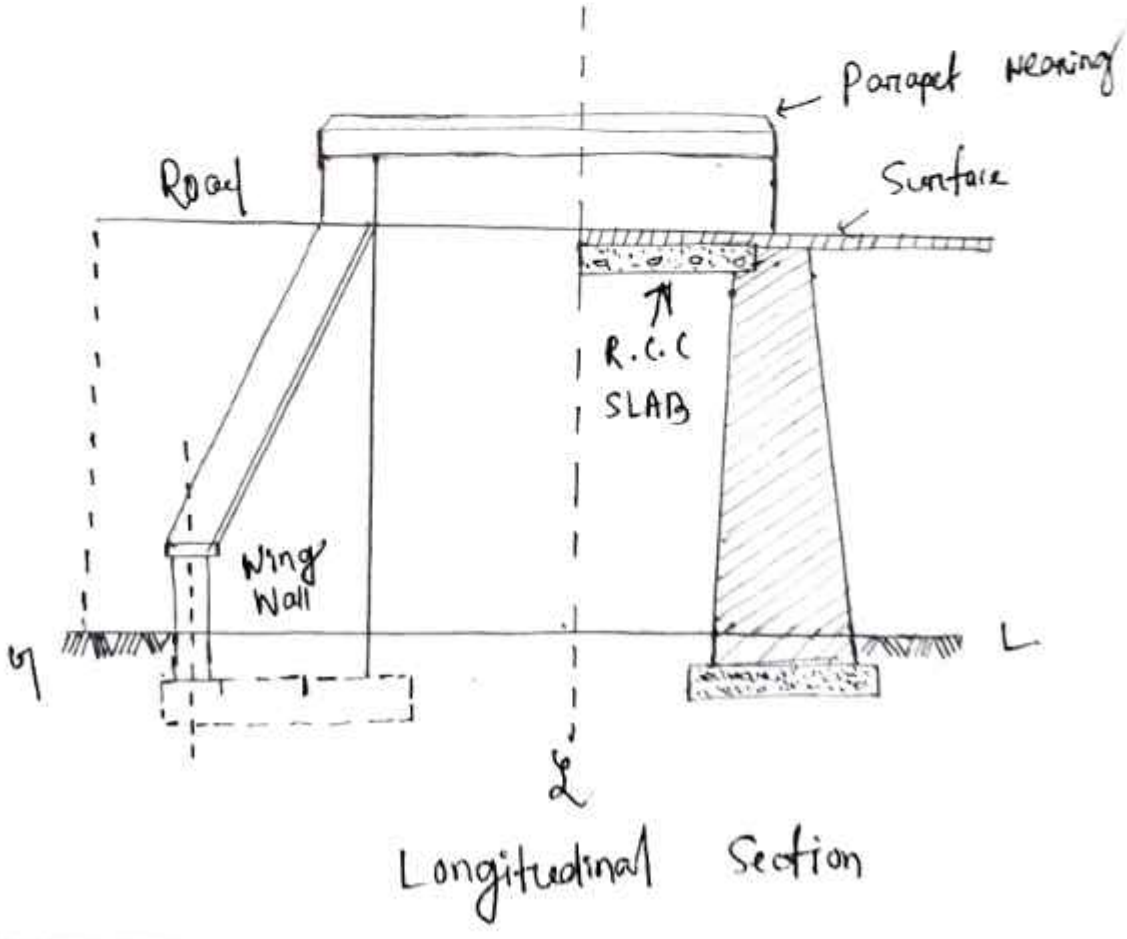
(i) Arch Culvert.
(ii) Slab Culvert.
(iii) Pipe Culvert.
(iv) Box Culvert.

(i) Arch Culvert :-

An arch culvert consists of abutments, wing walls arch, parapets and the foundations. The construction materials commonly used are brick work or concrete. Floor and Curtain wall may or may not be provided depending upon the nature of foundation soil and velocity of flow.

(ii) Slab Culvert :-

A slab Culvert consist of R.C.C. slab with or without beams or a stone slab, with or without steel girders to cover the span across the abutments and piers. The other details like parapets, wingwalls and the necessary foundations are provided.



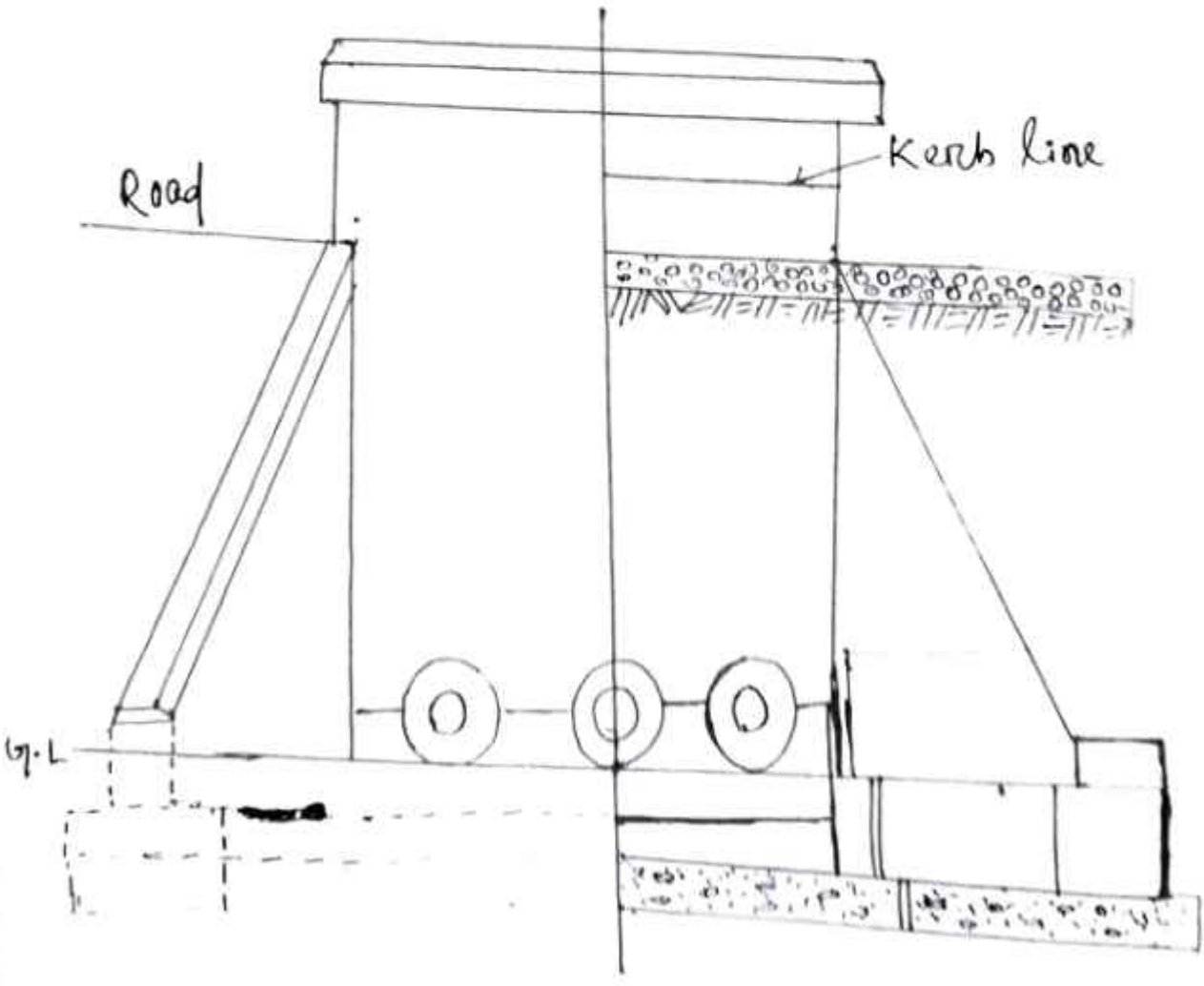
Longitudinal Section

The deck slab should be designed as oneway slab. ~~des~~ The culverts on important highways should be designed for the worst effect either one-lane of IRC class 'AA' track vehicle, or one-lane of IRC class 'AA' wheeled loading, or two-lanes of class 'A' loading.

(iii) Pipe Culvert :-

They are provided when discharge of stream is small or when suffient headway is not available. Usually one or more pipes of diameter not less than 60 cm are placed side by side. Their exact number and diameter depend upon the discharge and height of bank. For easy approach of water splayed type wing walls are provided. These pipes can be built of masonry, stone ware, cement concrete, cast iron, or steel. A concrete bedding should also be given below the

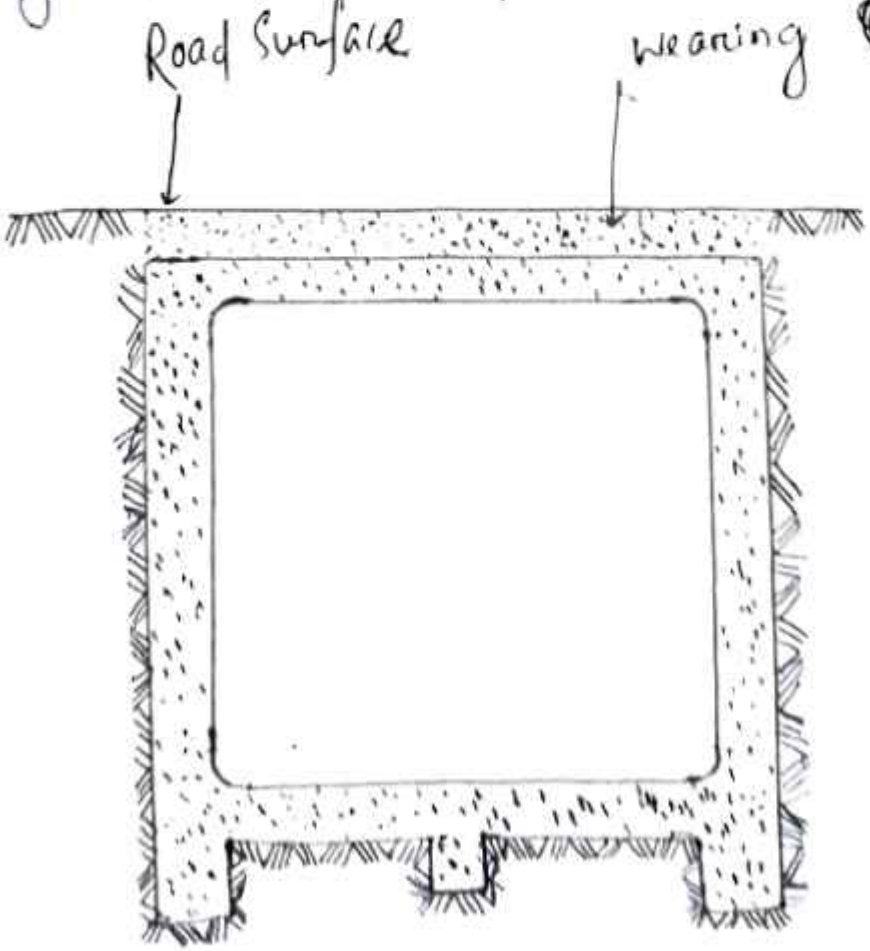
pipes and earth cushion of sufficient thickness on the top to protect the pipe and their joints. For economic reasons road culverts should have non-pressure heavy duty pipes of type ISI class NP3 conforming to IS:458-1961. As far as possible the gradient of the pipe should not be less than 1 in 1000.



Longitudinal Section

(iv) Box Culvert :-

They comprise one or more number of rectangular or square openings. These are provided if soil is soft and the load has to be spread over a wider foundation area. An R.C box culvert is a cheapest alternative if a pipe cannot be cast. The abutments, top and bottom slabs are all made into a monolithic rigid frame. They can be used for a single span of 3m and a double span of 6 m.



5.2 Causeways

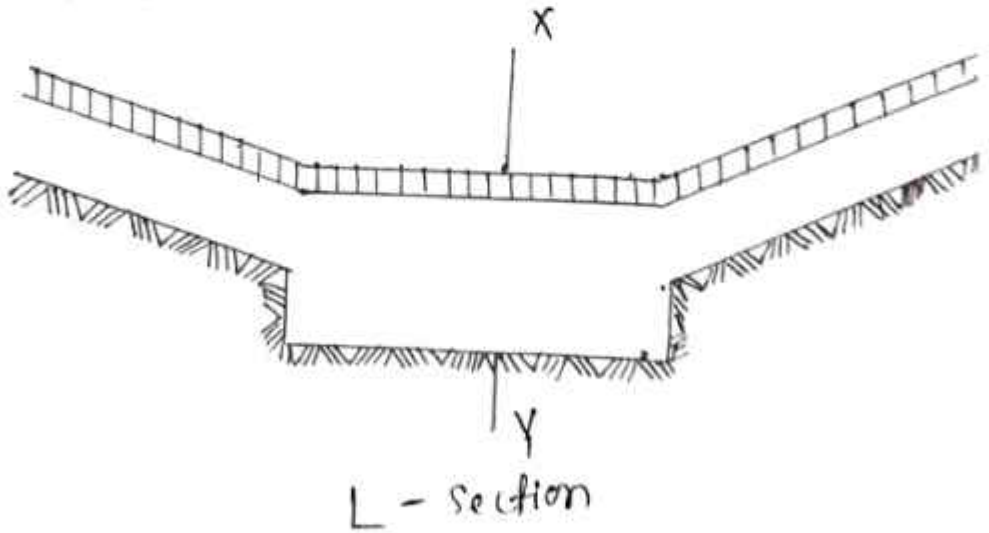
A road causeway is a pucca dip which allows floods to pass over it. It may or may not have opening or vents for low water to flow. If it has vents for low water to flow then it is known as high level causeway or submersible bridge; otherwise a low level causeway.

Types of causeways :-

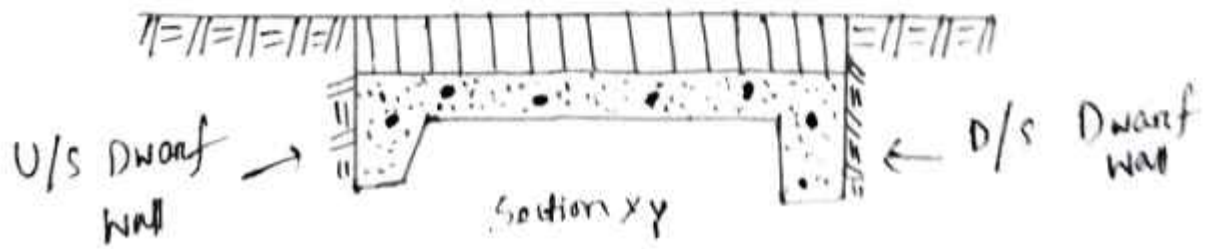
(1) Low Level Causeway :-

It is also known as Irish bridge. The beds of small rivers or streams, which remain dry for most part of the year, are generally passable without a bridge. This involves heavy earth work in cutting for bridge approaches. Banks of such types of streams are cut down at an easy slop. For streams or rivers in plains having sandy beds, it is often sufficient to lay bundles of grass over and across the sandy track. The bundles may be of 20 to 25 cm in diameter whose ends are secured by longitudinal fascines pegged down by stakes.

For crossings important from traffic point of view it is essential to lay a metal or pucca paving of stone or brick set in lime mortar on a substantial bed of concrete. To prevent against possible scour and undermining a cut off or dwarf wall usually 60 cm deep on the upstream side and 120 to 150 cm on downstream side is provided. The low level causeway could be provided with openings formed by concrete lime pipes if there is a continuous flow stream during the Monsoon periods.

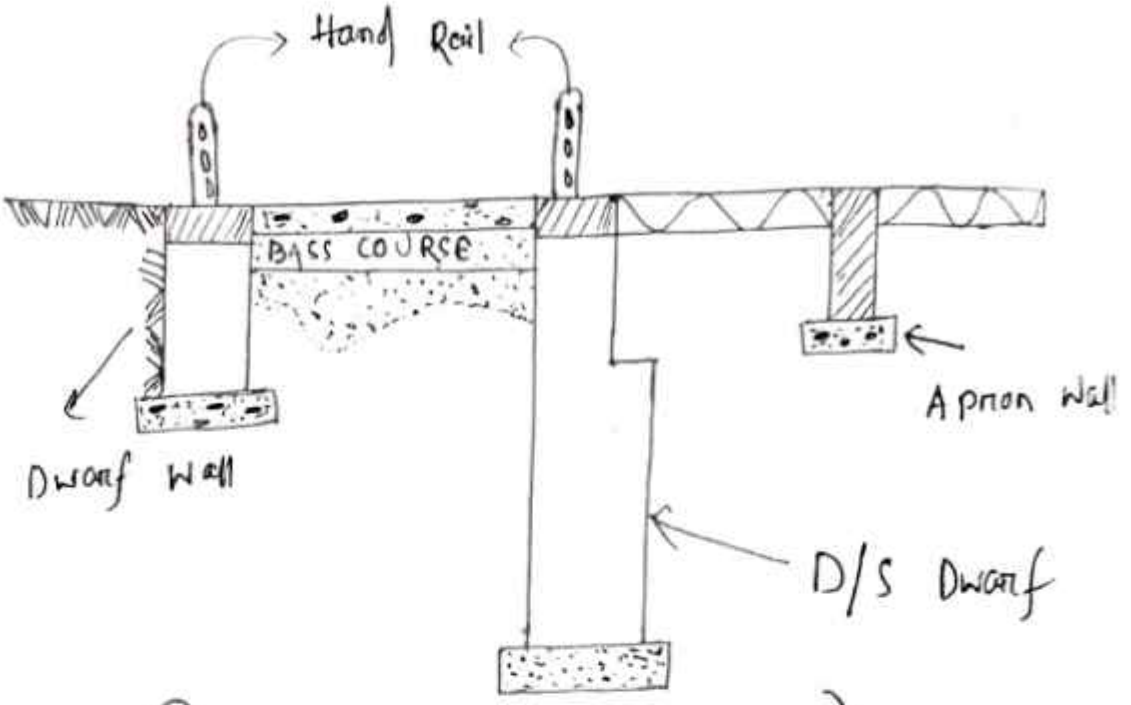


L - Section



Section XY

(Low levels causeway)



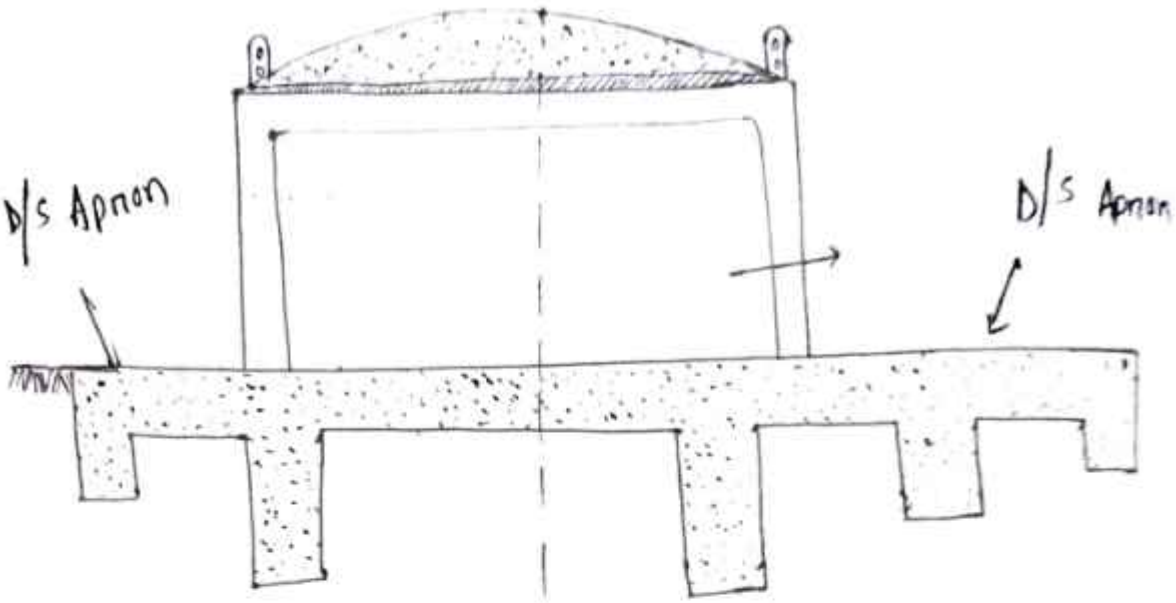
(Paved Low Level Causeway)

② High Level Causeway :-

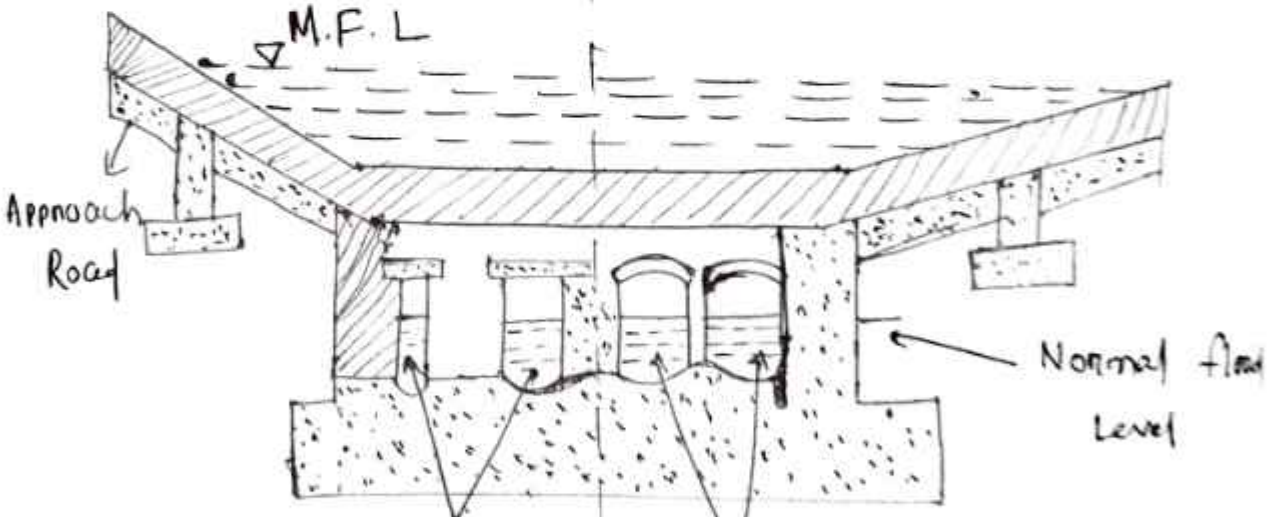
A high level causeway is submersible road bridge designed to be overtopped in floods. Its formation level is fixed in such a way as not to cause interruption to traffic during floods for more than three days at a time not for more than six times in a year.

A sufficient number of openings are provided to allow the normal flood discharge to pass through them with the

required clearance. They are provided with abutments and piers, floors and slabs or arches to form the required number of openings. The slope of the approaches is kept as 1 in 20. When the velocity is high and stream bed is soft the aprons could be of concrete or harder masonry up to a certain distance. Similarly, the road can be formed of a cement concrete slab or stone blocks set in cement mortar. A typical type of high level causeway is shown below. If railing are provided on the bridge, they should be of collapsible type.



Cross - sectional Elevation



Longitudinal . Section

(High Level . Causeway)