RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

Civil Engineering, IV-Semester

CE404 TRANSPORTATION ENGINEERING –I

Unit–I: Introduction, Tractive resistances & Permanent way : Principles of Transportation, transportation by Roads, railways, Airways, Waterways, their importance and limitations. Route Surveys and alignment, railway track, development and gauges. Hauling capacity and tractive effort.

1. Rails: types, welding of rails, wear and tear of rails, rail creep.
2. Sleepers: types and comparison, requirement of a good sleeper, sleeper density.
3. Rail fastenings: types, Fish plates, fish bolts, spikes, bearing plates, chain keys, check and guard rails.
4. Ballast: Requirement of good ballast, various materials used as ballast, quantity of ballast.

Different methods of plate laying, material trains, and calculation of materials required, relaying of track

Unit –II : Geometric Design ; Station & Yards; Points and Crossings & Signaling and interlocking : Formation, cross sections, Super elevation, Equilibrium, Cant and cant deficiency, various curves, speed on curves. Types locations, general equipments, layouts, marshalling yards. Definition, layout details, design of simple turnouts. Types of signals in stations and yards, principles of signaling and inter-locking.

Unit – III : Bridge Site Investigation and Planning ; Loading Standards & Component parts: Selection of site, alignment, collection of bridge design data : essential surveys, hydraulic design, scour depth of bridge foundation, Economical span, clearance, afflux, type of road & railway bridges : Design loads and forces, Impact factor, Indian loading standards for Railways Bridges and Highway Bridges. Bridge super structure and sub-structures, abutments, piers, wing walls, return walls, approaches, floors & flooring system, choice of super structure.

Unit – IV: Bridge Foundations, Construction, Testing and Strengthening of Bridges: Different types of foundation: piles and wells, sinking of wells, coffer-dams. Choice of bridges and choice of materials, details of construction underwater and above water, sheet piles coffer dams, Erection of bridges, girders, equipments and plants, inspection and data collection, strengthening of bridges, Bridge failure.

Unit – V: Tunnels:

1. Selection of route, Engineering surveys, alignment, shape and size of tunnel, bridge action, pressure relief phenomenon, Tunnel approaches, Shafts, pilot shafts.
2. Construction of tunnels in soft soil, hard soil and rock. Different types of lining, methods of lining. Mucking operation, Drainage and ventilation. Examples of existing important tunnels in India and abroad.

References:-

1.Chakraborty and Das; Principles of transportation engineering; PHI
2.Rangwala SC; Railway Engineering; Charotar Publication House, Anand
3.Rangwala SC; Bridge Engineering; Charotar Publication House, Anand
4.Ponnuswamy; Bridge Engineering; TMH
5.Railway Engineering by Arora & Saxena - Dhanpat Rai & Sons
6.Railway Track by K.F. Antia
7.Principles and Practice of Bridge Engineering S.P. Bindra - Dhanpat Rai & Sons
8.Bridge Engineering - J.S. Alagia - Charotar Publication House, Anand
9.Railway, Bridges & Tunnels by Dr. S.C. Saxena
10.Harbour, Docks & Tunnel Engineering - R. Srinivasan
11.Essentials of Bridge Engg. By I.J. Victor; Relevant IS & IRS codes

Transpotation Engineering Lab - I

1. Collection of different types of photographs showing
   a. Various bridge types
   b. Rail tracks
   c. Tunnels
2. Hydraulic design of bridges.
3. Various modern large span bridges: Pre stressed bridges and launching process.
4. Visit of Railway bridges for rehabilitation.
5. Visit of Railway Over Bridges and Under Bridges.

Unit-1Railways:

Introduction, Tractive resistances & Permanent way: Principles of Transportation, transportation by Roads, railways, Airways, Waterways, their importance and limitations, Route surveys and alignment, railway track, development and gauges, Hauling capacity and tractive effort.
i) Rails: types, welding of rails, wear and tear of rails, rail creep.
ii) Sleepers: types and comparison, requirement of a good sleeper, sleeper density.
iii) Rail fastenings: types, Fish plates, fish bolts, spikes, bearing plates, chain keys, check and guard rails.
iv) Ballast: Requirement of good ballast, various materials used as ballast, quantity of ballast, different methods of plate laying, material trains, calculation of materials required, relaying of track.

INTRODUCTION

One of the most important modes of transportation is the railway. With the development of civilization mankind developed various modes of transport for carrying people and goods from one place to another. Of these modes, the railway network of any country, especially of a developing country like India, has come to be considered as the most important asset in achieving all-round progress- economic, social, cultural, industrial, commercial and political. Various forces offer resistance to the movement of a train on the track. These resistances may be the result of movement of the various parts of the locomotives as well as the friction between them, the irregularities in the track profile, or the atmospheric resistance to a train moving at great speed. The tractive power of a locomotive should be adequate enough to overcome these resistances and haul the train at a specified speed.

RESISTANCE DUE TO FRICTION-Resistance due to friction is the resistance offered by the friction between the internal parts of locomotives and wagons as well as between the metal surface of the rail and the wheel to a train moving at a constant speed. This resistance is independent of speed and can be further broken down into the following parts.
Journal friction-This is dependent on the type of bearing, the lubricant used, the temperature and condition of the bearing, etc. In the case of roll bearings, it varies from 0.5 to 1.0 kg per tones. Internal resistance-This resistance is consequential to the movement of the various parts of the locomotive and wagons. Rolling resistance-This occurs due to rail-wheel interaction on account of the movement of steel wheels on a steel rail. The total frictional resistance is given by the empirical formula $R1= 0.0016$ W Where R1 is the frictional resistance independent of speed and W is the weight of the train in tones.

RESISTANCE DUE TO WAVE ACTION-When a train moves with speed a certain resistance develops due to the wave action in the rail. Similarly, track irregularities such as longitudinal unevenness and differences in cross levels also offer resistance to a moving train. Such resistances are different for different speeds. There is no * Under revision method for the precise calculation of these resistances but the following formula has been evolved based on experience:
$R2 = 0.00008$ WV Where R2 is the resistance (in tones) due to wave action and track irregularities on account of the speed of the train, W is the weight of the train in tones, and V is the speed of the train in kmph.

RESISTANCE DUE TO WIND-When a vehicle moves with speed, a certain resistance develops, as the

vehicle has to move forward against the wind. Wind resistance consists of side resistance, head resistance, and tail resistance, but its exact magnitude depends upon the size and shape of the vehicle, its speed, and the wind direction as well as its velocity. Wind resistance depends upon the exposed area of the vehicle and the velocity and direction of the wind. In Fig. below, V is the velocity of wind at an angle θ. The horizontal component of wind, V COSθ, opposes the movement of the train. Wind normally exerts maximum pressure when it acts at an angle of 60° to the direction of movement of the train. Wind resistance can be obtained by the following formula:

$R3 = 0.000017AV^2$ Where A is the exposed area of vehicle (m^2) and V is the velocity of wind (k-mph).

$R3 = 0.0000006 \, W \, V^2$

Where R3 is the wind resistance in tones, Vis the velocity of the train in km per hour, and W is the weight of the train in tones.

Track or permanent way

Track or permanent way is the single costliest asset of Indian Railways. It consists of rails, sleepers, fittings and fastenings, ballast, and formation.

Traction

The traction mix has significantly changed in the last two decades and Railways have been progressively switching over to diesel and electric traction. Though Steam locomotion involves the least initial costs, it is technologically inferior to Diesel and electric traction in many respects. On the other hand, diesel and electric Locomotives have superior performance capabilities, the electric locomotive being the more powerful one of the two. Electric traction is also the most capital intensive and, therefore, requires a certain minimum level of traffic density for its economic use. In broad terms, the traction policy on Indian Railways envisages the extension of the electrification of high-density routes as dictated by economic and resource considerations and the dieselization of the remaining services.

GAUGE

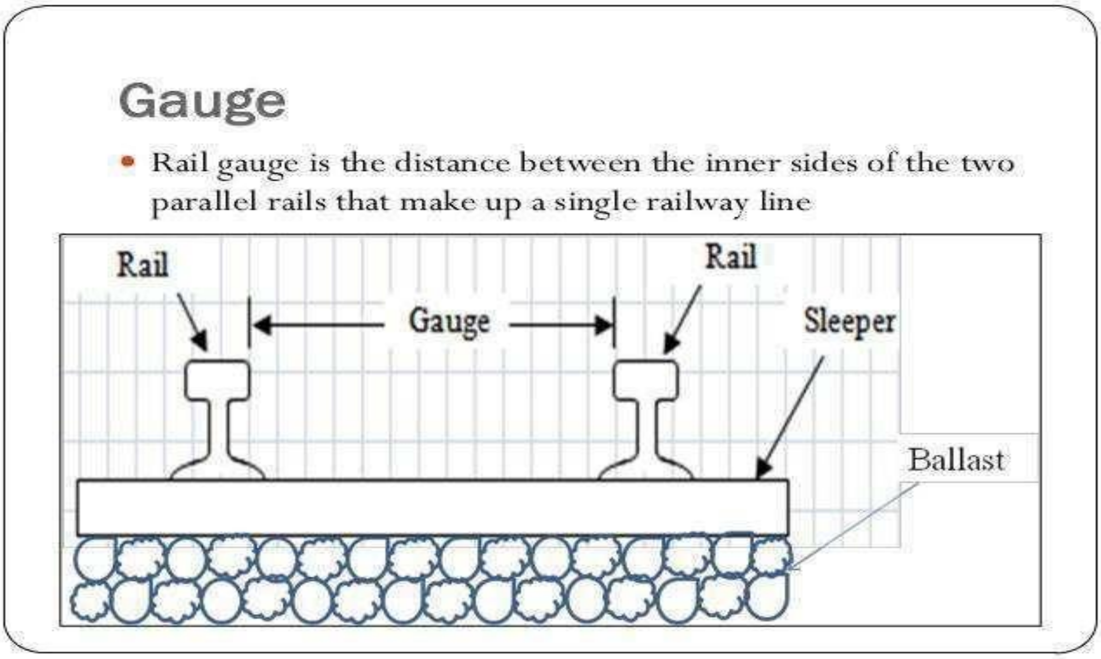
Gauge is defined as the minimum distance between two rails. Indian Railways follows this standard practice and the gauge is measured as the clear minimum distance between the running faces of the two rails.

Name of gauge Width (mm) Width (feet) Route % of route

Broad gauge (BG) 1676

Meter gauge (MG) 1000

Narrow gauge (NG) 762



Alignment of railway line-

Alignment of railway line refers to the direction and position given to the center line of the railway track on the ground in the horizontal and vertical planes. Horizontal alignment means the direction of the railway track in the plan including the straight path and the curves it follows. Vertical alignment means the direction it follows in a vertical plane including the level track, gradients, and vertical curves.

HAULING POWER OF A LOCOMOTIVE-

Hauling power of a locomotive depends upon the weight exerted on the driving s and the friction between the driving wheel and the rail. The coefficient of friction depends upon the speed of the locomotive and the condition of the rail surface. The higher the speed of the locomotive, the lower will be the coefficient of friction, which is about 0.1 for high speeds and 0.2 for low speeds. The condition of the rail surface, whether wet or dry, smooth or rough, etc., also plays an important role in deciding the value of the coefficient of function. If the surface is very smooth, the coefficient of friction will be very low.

Hauling power = number of pairs of driving wheels x weight exerted on each driving axle X coefficient of friction.

Thus, for a locomotive with three pairs of driving wheels, an axle load of 20 tones, and a coefficient of friction equal to 0.2, the hauling power will be equal to 3 x 20 x 0.2 tones, i.e., 12 tones.

Importance of Good Alignment-

A new railway line should be aligned carefully after proper considerations, as improper alignment may ultimately prove to be more costly and may not be able to fulfill the desired objectives. Railway line constructions are capital-intensive projects, once constructed, it is very difficult to change the alignment of a railway line because of the costly structures involved, difficulty in getting additional land for the new alignment, and such other considerations.

Basic Requirements of an Ideal Alignment-

The ideal alignment of a railway line should meet the following requirements.

Purpose of the New Railway Line

The alignment of a new railway line should serve the basic purpose for which the railway line is being

constructed. As brought out earlier, the purpose may include strategic considerations, political considerations, developing of backward areas, connecting new trade centers, and shortening existing rail lines.

Integrated Development

The new railway line should fit in with the general planning and form a part of the integrated development of the country.

Economic Considerations-

The construction of the railway line should be as economical as possible. The following aspects require special attention. Shortest route it is desirable to have the shortest and most direct route between the connecting points. The shorter the length of the railway line, the lower the cost of its construction, maintenance, and operation. There can, however, be other practical considerations that can lead to deviation from the shortest route. Construction and maintenance cost the alignment of the line should be so chosen that the construction cost is minimum. This can be achieved by a balanced cut and fill of earthwork, minimizing rock cutting and drainage crossings by locating the alignment on watershed lines, and such other technical considerations. Maintenance costs can be reduced by avoiding steep gradients and sharp curves, which cause heavy wear and tear of rails and rolling stock.Minimum operational expenses the alignment should be such that the operational or transportation expenses are minimum. This can be done by maximizing the haulage of goods with the given power of the locomotive and traction mix. This can be achieved by providing easy gradients, avoiding sharp curves, and adopting a direct route.

Maximum Safety and Comfort-

The alignment should be such that it provides maximum safety and comfort to the travelling public. This can be achieved by designing curves with proper transition lengths, providing vertical curves for gradients, and incorporating other such technical features.

Aesthetic Considerations-

While deciding the alignment, aesthetic aspects should also be given due weightage. A journey by rail should be visually pleasing. This can be done by avoiding views of borrow pits and passing the alignment through natural and beautiful surroundings with scenic beauty.

Selection of a Good Alignment

Normally, a direct straight route connecting two points is the shortest and most economical route for a railway line, but there are practical problems and other compulsions which necessitate deviation from this route. The various factors involved is the selection of a good alignment for a railway line are given below.

Choice of Gauge-

The gauge can be a BG (1676 mm), an MG (1000 mm), or even an NG (762 mm).

Obligatory or Controlling Points

These are the points through which the railway line must pass due to political, strategic, and commercial reasons as well as due to technical considerations. The following are obligatory or controlling points. Important cities and towns these are mostly intermediate important towns, cities, or places which of

commercial, strategic, or political importance. Major bridge sites and river crossings The construction of major bridges for large rivers is very expensive and suitable bridge sites become obligatory points for a good alignment. Existing passes and saddles in hilly terrain Existing passes and saddles should be identified for crossing a hilly terrain in order to avoid deep cuttings and high banks.Sites for tunnels The option of a tunnel in place of a deep cut in a hilly terrain is better from the economical viewpoint. The exact site of such a tunnel becomes an obligatory point.

Requirements of a Good Track-

A permanent way or track should provide a comfortable and safe ride at the maximum permissible speed with minimum maintenance cost. To achieve these objectives, a sound permanent way should have the following characteristics.

(a) The gauge should be correct and uniform.

(b) The rails should have perfect cross levels. In curves, the outer rail should have a proper super elevation to take into account the centrifugal force.

(c) The alignment should be straight and free of kinks. In the case of curves, a proper transition should be provided between the straight track and the curve.

(d) The gradient should be uniform and as gentle as possible. The change of gradient should be followed by a proper vertical curve to provide a smooth ride.

(e) The track should be resilient and elastic in order to absorb the shocks and vibrations of running trains.

(f) The track should have a good drainage system so that the stability of the track is not affected by water logging.

(g) The track should have good lateral strength so that it can maintain its stability despite variations in temperature and other such factors.

(h) There should be provisions for easy replacement and renewal of the various track components.

(i) The track should have such a structure that not only is its initial cost low, but also its maintenance cost is minimum.

Introduction to rails-

Rails are the members of the track laid in two parallel lines to provide an unchanging, continuous, and level surface for the movement of trains. To be able to withstand stresses, they are made of high-carbon steel. Standard rail sections, their specifications, and various types of rail defects are discussed in this chapter.

Function of Rails

Rails are similar to steel girders. These are provided to perform the following functions in a track.

(a) Rails provide a continuous and level surface for the movement of trains.

(b) Rails provide a pathway which is smooth and has very little friction. The friction between the steel wheel and the steel rail is about one-fifth of the friction between the pneumatic tire and a metaled road.

(c) Rails serve as a lateral guide for the wheels.

(d) Rails bear the stresses developed due to vertical loads transmitted to them through axles and wheels of rolling stock as well as due to braking and thermal forces.

(e) Rails carry out the function of transmitting the load to a large area of the formation through sleepers and the ballast.

Types of Rails

A flat-footed rail, also called a Vignola rail with an inverted T-type cross section of inverted T- type was, therefore, developed, which could be fixed directly to the sleepers with the help of spikes.

Weight of rails

Though the weights of a rail and its section depend upon various considerations, the heaviest axle load that the rail has to carry plays the most important role. The following is the thumb rule for defining the maximum axle load with relation to the rail section:

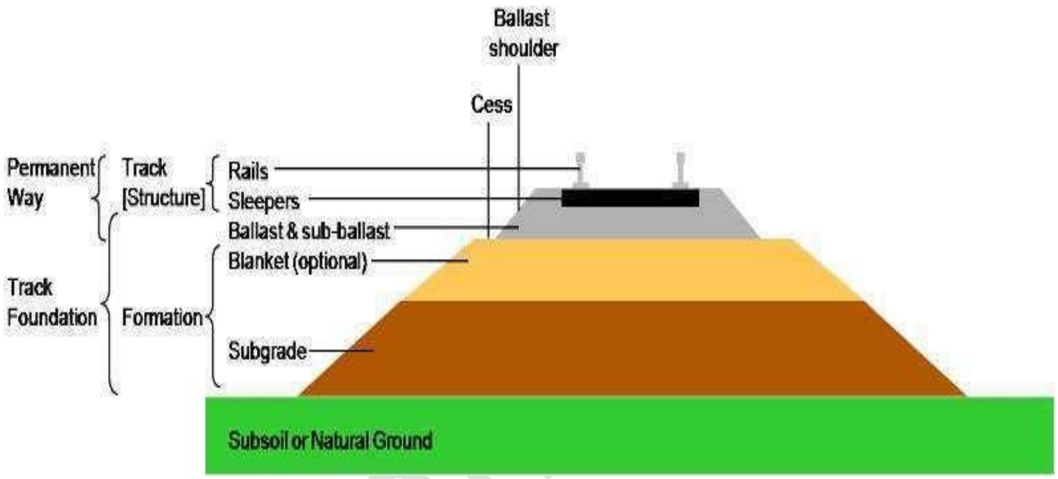
Maximum axle load = 560 × sectional weight of rail in lbs. per yard or kg per meter

For rails of 90 lbs. per yard,

Maximum axle load = 560 × 90 lbs. = 50,400 lbs. or 22.5 t

For rails of 52 kg per m,

Maximum axle load = 560 × 52 kg = 29.12 t



Rail Wear

Due to the passage of moving loads and friction between the rail and the wheel, the rail head gets worn out in the course of service. The impact of moving loads, the effect of the forces of acceleration, deceleration, and braking of wheels, the abrasion due to rail–wheel interaction, the effects of weather conditions such as changes in temperature, snow, and rains, the presence of materials such as sand, the standard of maintenance of the track, and such allied factors cause considerable wear and tear of the vertical and lateral planes of the rail head. Lateral wear occurs more on curves because of the lateral thrust exerted on the outer rail by centrifugal force. A lot of the metal of the rail head gets worn out, causing the weight of the rail to decrease. This loss of weight of the rail section should not be such that the Rails stresses exceed their permissible values. When such a stage is reached, rail renewal is called for.

In addition, the rail head should not wear to such an extent that there is the possibility of a worn flange of the wheel hitting the fish plate.

Type of Wear on Rails

A rail may face wear and tear in the following positions:

(A) On top of the rail head (vertical wear)
(a) On the sides of the rail head (lateral wear)
(b) The ends of the rail (battering of rail ends) wear is more prominent at some special locations of the track.

These locations are normally the following:

(a) On sharp curves, due to centrifugal forces
(b) On steep gradients, due to the extra force applied by the engine
(c) On approaches to railway stations, possibly due to acceleration and deceleration
(d) In tunnels and coastal areas, due to humidity and weather effects causes of rail failures.

The main causes for the failure of rails are as follows.

Inherent defects in the rail manufacturing defects in the rail, such as faulty chemical composition, harmful segregation, piping, seams, laps, and guide marks. Defects due to fault of the rolling stock and abnormal traffic effects Flat spots in tires, engine burns, skidding of wheels, severe braking, etc. Excessive corrosion of rails Excessive corrosion in the rail generally takes place due to weather conditions, the presence of corrosive salts such as chlorides and constant exposure of the rails to moisture and humidity in locations near water columns, ash pits, tunnels, etc. Corrosion normally leads to the development of cracks in regions with a high concentration of stresses. Badly maintained joints Poor maintenance of joints such as improper packing of joint sleepers and loose fittings.

Defects in welding of joints-These defects arise either because of improper composition of the termite weld metal or because of a defective welding technique. Improper maintenance of track Ineffective or careless maintenance of the track or delayed renewal of the track. Derailments Damages caused to the rails during derailment.

- Creep of Rails

Introduction

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

Theories for the Development of Creep

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

Wave Motion Theory

According to wave motion theory, wave motion is set up in the resilient track because of moving loads, causing a deflection in the rail under the load. The portion of the rail immediately under the wheel gets slightly depressed due to the wheel load. Therefore, the rails generally have a wavy formation. As the wheels of the train move forward, the depressions also move with them and the previously depressed portion springs back to the original level. This wave motion tends to move the rail forward with the train. The ironing effect of the moving wheels on the wave formed in the rail causes a longitudinal

movement of the rail in the direction of traffic resulting in the creep of the rail.

Percussion Theory

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

Drag Theory

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

Causes of Creep

The main factors responsible for the development of creep are as follows. Ironing effect of the wheel the ironing effect of moving wheels on the waves formed in the rail tends to cause the rail to move in the direction of traffic, resulting in creep. Starting and stopping operations when a train starts or accelerates, the backward thrust of its wheels tends to push the rail backwards. Similarly, when the train slows down or comes to a halt, the effect of the applied brakes tends to push the rail forward. This in turn causes creep in one direction or the other.

- **Effects of Creep**

The following are the common effects of creep.

Sleepers out of square the sleepers move out of their position as a result of creep and become out of square. This in turn affects the gauge and alignment of the track, which finally results in unpleasant rides. Disturbance in gaps get disturbed Due to creep, the expansion gaps widen at some places and close at others. This results in the joints getting jammed. Undue stresses are created in the fish plates and bolts, which affects the smooth working of the switch expansion joints in the case of long welded rails. Distortion of points and crossings Due to excessive creep, it becomes difficult to maintain the correct gauge and alignment of the rails at points and crossings. Difficulty in changing rails If, due to operational reasons, it is required that the rail be changed, the same becomes difficult as the new rail is found to be either too short or too long because of creep.

- **Effect on interlocking**

The interlocking mechanism of the points and crossings gets disturbed by creep. Possible buckling of track if the creep is excessive and there is negligence in the maintenance of the track, the possibility of buckling of the track cannot be ruled out.

- **Sleepers**

Introduction

Sleepers are the transverse ties that are laid to support the rails. They have an important role in the

track as they transmit the wheel load from the rails to the ballast. Several types of sleepers are in use on Indian Railways. Functions and Requirements of Sleepers

The main functions of sleepers are as follows.

(a) Holding the rails in their correct gauge and alignment
(b) Giving a firm and even support to the rails
(c) Transferring the load evenly from the rails to a wider area of the ballast
(d) Acting as an elastic medium between the rails and the ballast to absorb the blows and vibrations caused by moving loads
(e) Providing longitudinal and lateral stability to the permanent way
(f) Providing the means to rectify the track geometry during their service life.

Apart from performing these functions the ideal sleeper should normally fulfill the following requirements.

(a) The initial as well as maintenance cost should be minimum.
(b) The weight of the sleeper should be moderate so that it is convenient to handle.
(c) The designs of the sleeper and the fastenings should be such that it is possible to fix and remove the rails easily.
(d) The sleeper should have sufficient bearing area so that the ballast under it is not crushed.
(e) The sleeper should be such that it is possible to maintain and adjust the gauge properly.
(f) The material of the sleeper and its design should be such that it does not break or get damaged during packing.
(g) The design of the sleeper should be such that it is possible to have track Circuiting.

- SLEEPER DENSITY AND SPACING OF SLEEPERS

Sleeper density is the number of sleepers per rail length. It is specified as M + x or N + x, where M or N is the length of the rail in meters and x is a number that varies according to factors such as

(a) Axle load and speed,
(b) Type and section of rails,
(c) Type and strength of the sleepers,
(d) Type of ballast and ballast cushion, and
(e) Nature of formation. If the sleeper density is M + 7 on a broad gauge route and the length of the rail is 13 m, it means that 13 + 7 = 20 sleepers will be used per rail on that route.

The number of sleepers in a track can also be specified by indicating the number of sleepers per kilometer of the track. For example, 1540 sleepers/km. This specification becomes more relevant particularly in cases where rails are welded and the length of the rail does not have much bearing on the number of sleepers required. This system of specifying the number of sleepers per kilometer exists in many foreign countries and is now being adopted by Indian Railways as well. The spacing of sleepers is fixed depending upon the sleeper density. Spacing is not kept uniform throughout the rail length. It is closer near the joints because of the weakness of the joints and impact of moving loads on them. There is, however, a limitation to the close spacing of the sleepers, as enough space is required for working the beaters that are used to pack the joint sleepers.

Types of Sleepers

The sleepers mostly used on Indian Railways are

(h) Wooden sleepers,
(a) Cast iron sleepers,
(b) Steel sleepers, and
(c) Concrete sleepers

Wooden Sleepers

The wooden sleeper is the most ideal type of sleeper, and its utility has not decreased with the passage of time. The wooden sleeper has the following features. Specifications the size of a wooden sleeper should be economical. It should provide the desired strength to the sleeper as a beam as well as adequate bearing area. The depth of a sleeper governs its stiffness as a beam and its length and width control the necessary bearing area. The bearing length under each rail seat is 92 cm (3 ft.) for a BG wooden sleeper, thereby giving an area of 2325 cm2 under each rail seat.

Advantages

(a) Cheap and easy to manufacture
(b) Absorbs shocks and bears a good capacity to dampen vibrations; therefore,retains the packing well
(c) Easy handling without damage
(d) Suitable for track-circuited sections
(e) Suitable for areas with yielding formations
(f) Alignment can be easily corrected
(g) More suitable for modern methods of maintenance
(h) Can be used with or without stone ballast
(i) Can be used on bridges and ash pits also
(j) Can be used for gauntleted track

Disadvantages

(a) Lesser life due to wear, decay, and attack by vermin
(b) Liable to mechanical wear due to beater packing
(c) Difficult to maintain the gauge
(d) Susceptible to fire hazards
(e) Negligible scrap value

- Durable and Non-durable Types of Sleepers

Wooden sleepers may be classified into two categories, durable and non-durable.

- Durable type

Durable sleepers do not require any treatment and can be laid directly on the track. The Indian Railway Board has classified particular categories of sleepers as the durable type. These are sleepers produced from timbers such as teak, sal, nahor, rosewood, anjan, kongu, crumbogamkong, vengai, padauk, lakooch, wonta, milla, andcrul.

- Non-durable type

Non-durable sleepers require treatment before being put on the track. Non-durable sleepers are made of wood of trees such as chir, deodar, kail, gunjan, and jamun.

- **Treated and Untreated Sleepers**

Wooden sleepers are also sometimes classified as hard wood and soft wood sleepers depending upon the origin or species of the wood of which these are made. Broadly speaking, timber produced from trees with broad leaves is known as hard wood and that obtained from trees bearing long leaves is considered soft wood. Some of the hard wood varieties also require treatment before being used in the track. As per the recommendations of the committee, the use of the terms 'durable' and 'non-durable' as well as 'hard' and 'soft' should be done away with to avoid confusion.The committee recommended that for simplification and rationalization, wooden sleepers should be classified in two categories:
(a) 'U' or Untreated sleepers comprising of all the sleepers made of wood from naturally durable species.
(b) 'T' or Treated sleepers consisting of the rest of the sleepers

- **Seasoning of sleepers**

Wooden sleepers are seasoned to reduce the moisture content so that their treatment is effective. The Indian Standard code of practice for preservation of timber lays down that the moisture content in the case of sleepers to be treated by pressure treatment should not be more than 25%. The seasoning of sleepers can be done by any one of the following processes. Artificial seasoning in kiln This is a controlled method of seasoning the timber, normally used in the USA and other advanced countries, under conditions of temperature and relative humidity, which are in the range of natural air seasoning. Bolton or boiling under vacuum process this is a process in which unseasoned wood is treated with hot preservative to remove the moisture content. This is adopted in the Naharkatia depot. Air seasoning This is the method adopted extensively for the seasoning of wooden sleepers in India. The sleepers are stacked in the timber yard and a provision is made for enough space for the circulation of air in between the sleepers.

- **Concrete Sleepers**

The need for concrete sleepers has been felt mainly due to economic considerations coupled with changing traffic patterns. In the early days of Indian Railways, wood was the only material used for making sleepers in Europe. Even in those days, the occasional shortage of wooden sleepers and their increasing price posed certain problems and this gave a fillip to the quest for an alternative material for sleepers.

- **Advantages and disadvantages**

Concrete sleepers have the following advantages and disadvantages.

Advantages

(a) Concrete sleepers, being heavy, lend more strength and stability to the track and are specially suited to LWR due to their great resistance to buckling of the track.
(b) Concrete sleepers with elastic fastenings allow a track to maintain better gauge, cross level, and alignment. They also retain packing very well.
(c) Concrete sleepers, because of their flat bottom, are best suited for modern methods of track maintenance such as MSP and mechanical maintenance, which have their own advantages.

(d) Concrete sleepers can be used in track-circuited areas, as they are poor conductors of electricity.
(e) Concrete sleepers are neither inflammable nor subjected to damage by pests or corrosion under normal circumstances.
(f) Concrete sleepers have a very long lifespan, probably 40–50 years. As such rail and sleeper renewals can be matched, which is a major economic advantage.
(g) Concrete sleepers can generally be mass produced using local resources.

Disadvantages

(a) Handling and laying concrete sleepers is difficult due to their large weights. Mechanical methods, which involve considerable initial expenditure, have to be adopted for handling them.
(b) Concrete sleepers are heavily damaged at the time of derailment.
(c) Concrete sleepers have no scrap value.
(d) Concrete sleepers are not suitable for beater packing.
(e) Concrete sleepers should preferably be maintained by heavy 'on track' Tamper.

Ballast

Introduction

The ballast is a layer of broken stones, gravel, moored, or any other granular
Material placed and packed below and around sleepers for distributing load fromthe sleepers to the formation. It provides drainage as well as longitudinal and lateralstability to the track.

Functions of Ballast

The ballast serves the following functions in a railway track. Provides a level and hard bed for the sleepers to rest on. Holds the sleepers in position during the passage of trains. Transfers and distributes load from the sleepers to a large area of the formation. Provides elasticity and resilience to the track for proper riding comfort. Provides the necessary resistance to the track for longitudinal and lateral stability. Provides effective drainage to the track. Provides an effective means of maintaining the level and alignment of the track.

Types of Ballast

The different types of ballast used on Indian Railways are described in the following.

Sand ballast

Sand ballast is used primarily for cast iron (CI) pots. It is also used with wooden and steel trough sleepers in areas where traffic density is very low. Coarse sand is preferred in comparison to fine sand. It has good drainage properties, but has the drawback of blowing off because of being light. It also causes excessive wear of the rail top and the moving parts of the rolling stock.

Morum ballast

The decomposition of lateritic results in the formation of moor. It is red, and sometimes yellow, in color. The moored ballast is normally used as the initial ballast in new constructions and also as sub-ballast. As it prevents water from percolating into the formation, it is also used as a blanketing material for black cotton soil.

Coal ash or cinder

This type of ballast is normally used in yards and sidings or as the initial ballast in new constructions since it is very cheap and easily available. It is harmful for steel sleepers and fittings because of its corrosive action.

Broken stone ballast

This type of ballast is used the most on Indian Railways. A good stone ballast is generally procured from hard stones such as granite, quartzite, and hard trap. The quality of stone should be such that neither is it porous nor does it flake off due to the vagaries of weather. Good quality hard stone is normally used for high-speed tracks. This type of ballast works out to be economical in the long run.

Sizes of Ballast

Previously, 50-mm (2") ballasts were specified for flat bottom sleepers such as concrete and wooden sleepers and 40-mm (1.5") ballasts were specified for metal sleepers such as CST-9 and trough sleepers. Now, to ensure uniformity, (2") ballasts have been adopted universally for all type of sleepers. As far as points and crossings are concerned, these are subjected to heavy blows of moving loads and are maintained to a higher degree of precision. A small sized, 25-mm (1") ballast is, therefore, preferable because of its fineness for slight adjustments, better compaction, and increased frictional area of the ballast.

- **Requirements of a Good Ballast**

Ballast material should possess the following properties.

(a) It should be tough and wear resistant.
(b) It should be hard so that it does not get crushed under the moving loads.
(c) It should be generally cubical with sharp edges.
(d) It should be non-porous and should not absorb water.
(e) It should resist both attrition and abrasion.
(f) It should be durable and should not get pulverized or disintegrated under adverse weather conditions.
(g) It should be cheap and economical.

Plate Laying methods or Track Linking –

Once the formation is ready, plate laying or track linking is required. It consists of laying rails, sleepers, and fastenings.

The following methodology is adopted for plate laying.

Tram Line Method In this method, a temporary line known as the 'tram line' is laid by the side of the proposed track for taking track materials to the site. This method is useful in flat terrain, where laying the tram line on natural ground may be comparatively easier. This method is, however, seldom used in practice. A modification of the above method is the side method. This method is used where track and bridge material is carried to the site on trucks on a service road parallel to the track. The material is then unloaded near the work site. This method is used only in cases where comparatively flat gradients are available.

American Method- in the American method, rails and sleepers are first assembled in the base depot and pre-assembled track panels are then taken to the site along with the necessary cranes, etc. The track panels are unloaded at the work site either manually or with the help of cranes and are then laid in the final position. This procedure is used in many developed countries, particularly those where concrete sleepers are laid, since these sleepers are quite heavy and it is not easy to handle them manually.

Telescopic Method- This method is widely used on Indian Railways. In this method, the rails, sleepers, and other fittings are taken to the base depot and unloaded. The track material is then taken to the rail head and the track is linked and packed. The rail head is then advanced up to the extent of laid track. The track material is then taken up to the advanced rail head with the help of a dip lorry and the track is again linked and packed. In this way, the rail head goes on advancing till the full track is linked.

The main operations involved are as follows.

Unloading of materials-The track material is taken to the base depot and unloaded with the help of material gangs. The first base depot is the junction of the existing line and the new line to be constructed. All track material is taken from the base depot with the help of a dip lorry (a special type of trolley) to the rail head. The rail head goes on advancing till the track is sufficiently linked. After that, a subsidiary depot is established at a distance of about 5 km where the track material is taken with the help of a material train. Alternatively, the track material is moved from the base depot with the help of dip lorry only up to a distance of about 2 km and by material train beyond this distance. In the base depot, advance arrangements such as adzing and boring of the sleeper and arrangement of matching materials are made so that the track is linked as soon as possible to the site.

TRACK FITTINGS AND FASTENINGS

INTRODUCTION TO FASTENINGS

The purpose of providing fittings and fastenings in railway tracks is to hold the rails in their proper position in order to ensure the smooth running of trains. These fittings and fastenings are used for joining rails together as well as fixing them to the sleepers, and they serve their purpose so well that the level, alignment, and gauge of the railway track are maintained within permissible limits even during the passage of trains.

Rail-to-Rail Fastenings-

Rail-to-rail fastenings involve the use of fish plates and bolts for joining rails in series. Detailed descriptions of these are given in the following sections.

- **Fish Plates**

The name 'fish plate' derives from the fish-shaped section of this fitting. The function of a fish plate is to hold two rails together in both the horizontal and vertical planes. Fish plates are manufactured using a special type of steel (Indian Railways specification T-1/57) with composition given below:
Carbon: 0.30–0.42%
Manganese: not more than 0.6%
Silicon: not more than 0.15%
Sulfur and phosphorous: not more than 0.06%.

- **Dog Spikes**

This fastening is named dog spike because the head of this spike looks like the ear of a dog. Dog spikes are used for fixing rails to wooden sleepers. The number of dog spikes normally used is as follows:

- **Location Number of dog spikes**

On straight track 2 (1 on either side and duly staggered)
On curved track 3 (2 outside and 1 inside)
Joint sleepers, bridges 4 (2 outside and 2 inside)

- **Round Spikes**

Round spikes (Fig. 10.5) are used along with anti-creep bearing plates for fixing rails to sleepers. These are also used for fixing assemblies of switches onto wooden sleepers. The round spike has a round section of a diameter of 18 mm, and its length depends upon the purpose it serves. Round spikes have become obsolete now.

- **Screw Spikes**

Indian Railways has developed screw spikes with diameters of 20 mm and 22 mm to be used on high-speed, main, and trunk routes in order to increase the lifespan of wooden sleepers. Screw spikes with a diameter of 20 mm are called 'plate screws' and are used in place of round spikes for fixing rails to sleepers with the help of anti-creep bearing plates while screw spikes with a diameter of 22 mm are called 'rail screws' and are used to directly fasten the rails to the sleepers with or without the use of bearing plates. They are also used on bridges and platform lines. Plate and rail screws should be preferred to round and dog spike in order to conserve the life of wooden sleepers.

- **Bearing Plates**

Bearing plates are used for fixing wooden sleepers to rails. The different types of bearing plates in use on Indian Railways are described below. Mild steel canted bearing plates Mild steel canted bearing plates are used on all joints and curves to provide a better bearing area to the rails. They have a cant of 1 in 20 and a groove in the center to prevent rocking. Mild steel (MS) canted bearing plates with only round holes are sanctioned for use on the Railways. The normal size of this kind of bearing plate is 260 mm × 220 mm × 18 mm for 52 kg and 90 R rail

- **Flat MS bearing plates**

Flat MS bearing plates are used at points and crossings in the lead portion of a turnout. No cant is

provided in these bearing plates. The size of this bearing plate is 260 mm × 220 mm × 19 mm for 52 kg and 90 R rails Cast iron anticreep bearing plate's Cast iron (CI) anticreep bearing plates are provided with wooden sleepers at locations where the rails are likely to develop creep. These bearing plates have a cant of 1 in 20 and can be fixed using normal round spikes. The size of this bearing plate is 285 mm × 205 mm for BG tracks Special CI bearing plates for BH rails Special cast iron bearing plates are used for fixing bull headed (BH) rails. The rail is held in position with the help of a spring key.

Unit-II

Geometric Design; Station & Yards; Points and Crossings & Signaling and interlocking: Formation, cross sections, Super elevation, Equilibrium, Cant and cant deficiency, various curves, speed on curves. Types locations, general equipment's, layouts, and marshalling yards. Definition, layout details, design of simple turnouts. Types of signals in stations and yards, principles of signaling and inter-locking.

Introduction

The geometric design of a railway track includes all those parameters which determine or affect the geometry of the track. These parameters are as follows.

1. **Gradients in the track including grade compensation, rising gradient, and falling gradient.**
2. **Curvature of the track, including horizontal and vertical curves, transition curves, sharpness of the curve in terms of radius or degree of the curve, cant or super elevation on curves, etc.**
3. **Alignment of the track, including straight as well as curved alignment. It is very important for tracks to have proper geometric design in order to ensure the safe and smooth running of trains at**

maximum permissible speeds, carrying the heaviest axle loads. The speed and axle load of the train are very important and sometimes are also included as parameters to be considered while arriving at the geometric design of the track.

Necessity for Geometric Design

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

(a) To ensure the smooth and safe running of trains

(b) To achieve maximum speeds

(c) To carry heavy axle loads

(d) To avoid accidents and derailments due to a defective permanent way

(e) To ensure that the track requires least maintenance.

(f) For good aesthetics

- 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. The extra force P required by a locomotive to pull a train of weight W on a gradient with an angle of inclination θ is

$P = W \sin\theta$

$= W \tan\theta$ (approximately, as θ is very small)

$= W \times$ gradient

Curves and Super elevation

CIRCULAR CURVES

Curves are introduced in the horizontal alignment when there is a need to change in the direction of the track, either to connect obligatory points or to avoid undesirable locations in the terrain. A curve facilitates a gradual change in direction in horizontal plane. Curves are either circular or non-circular (Transitional)

TYPES OF CIRCULAR CURVES

The basic types of circular curves are-

(a) Simple curves

(b) Compound curves

(c) Reverse curves

SIMPLE CURVES-A simple curves is a single circular arc connecting two straights or tangents.

COMPOUND CURVES- A compound curve consists of two circular arcs of different radii, curving in same directions. It can be visualized as connecting three straights. The middle one being the common tangent for both the arcs.

REVERSE CURVES-A reverse curve has two circular arcs of the same or different radii curving in opposite directions. This too can visualized as connecting three straights. The middle one is again the common tangent for both the arcs.

SPEED ON CURVES

For all practical purposes safe speed means a speed which protects a carriage from the danger of overturning and derailment and provides a certain margin of safety. Earlier it was calculated empirically by applying Martin's formula:

For BG and MG

Transitioned curves

$$V = 4.4\sqrt{R - 70} \qquad (13.7)$$

where V is the speed in km/h and R is the radius in metres.

Non-transitioned curves Safe speed = four-fifths of the speed calculated using Eqn (13.7).

For NG

Transitioned curves

$$V = 3.65\sqrt{R - 6} \qquad (13.8)$$

(subject to a maximum of 50 km/h).

Non-transitioned curves

$$V = 2.92\sqrt{R - 6} \qquad (13.9)$$

(subject to a maximum of 40 km/h).

Indian Railways no longer follows this concept of safe speed on curves or the stipulations given here.

1. New Formula for Determining Maximum Permissible Speed on Transitioned Curves

Earlier, Martin's formula was used to work out the maximum permissible speed or safe speed on curves. This empirical formula has been changed by applying a formula based on theoretical considerations as per the recommendations of the committee of directors, chief engineers, and the ACRS. The maximum speed for transitioned curves is now determined as per the revised formulae given below.

On Broad Gauge

$$V = \sqrt{\frac{(C_a + C_d) \times R}{13.76}} = 0.27\sqrt{(C_a + C_d) \times R} \qquad (13.10)$$

Where V is the maximum speed in km/h, Ca is the actual cant in mm, Cd is the permitted cant deficiency in mm, and R is the radius in m. This equation is derived from Eqn (13.6) for equilibrium super elevation and is based on the assumption that G = 1750 mm, which is the centre-to-centre distance between the rail heads of a BG track with 52-kg rails.

On Meter Gauge

$$V = 0.347\sqrt{(C_a + C_d)R}$$

This is based on the assumption that the center-to-center (c/c) distance between the rail heads of an MG track is 1058 mm. Narrow Gauge (762 min.)

$$V = 3.65\sqrt{R - 6} \text{ (subject to a maximum of 50 km/h)}$$

2.New Criteria for Determining Maximum Speed on Curves Without Transition-As per the procedure being followed at present, the determination of the maximum permissible speed on curves without transitions involves the concept of *virtual transitions*. The linear velocity of a train moving with uniform velocity on a straight track begins to change into angular velocity as soon as the first bogie reaches the tangent point. This change continues till the rear bogie reaches the tangent point, at which moment the train acquires full angular velocity. The change in the motion of the train from a straight line to a curve takes place over the shortest distance between the bogie centers and is considered a *virtual transition.* Normally, this distance is l4.6 m on BG, 13.7 m on MG, and 10.3 m on NG, commencing on a straight line at half the distance before the tangent point and terminating on the curve at half the distance beyond the tangent point. The deficiency of cant is considered as being gained over the length of the virtual transition and the cant has to be gained in a similar manner. The cant gradient must not be steeper than 1 in 360 on BG and 1 in 720 on MG and NG under any circumstance. The safe speed should be worked out on the basis of the cant that can be practically provided based on these criteria, and increased by the permissible amount of cant deficiency. In the case of non-transitioned curves, where no cant is provided, the safe speed for the curve can be worked out by calculating the permissible cant deficiency after taking into consideration the rate at which the cant deficiency is gained or lost over the virtual transition.

3. Maximum Permissible Speed on a Curve-The maximum permissible speed on a curve is the minimum value of the speed that is calculated after determining the four different speed limits mentioned here. The first three speed limits are taken into account for the calculation of maximum permissible speed, particularly if the length of the transition curve can be increased. For high-speed routes, however, the fourth speed limit is also very important, as cases may arise when the length of the transition curve cannot be altered easily.

(i) Maximum sanctioned speed of the section this is the maximum permissible speed authorized by the commissioner of railway safety. This is determined after an analysis of the condition of the track, the standard of interlocking, the type of locomotive and rolling stock used, and other such factors.

(ii) Maximum speed of the section taking into consideration cant deficiency-the equilibrium speed is decided after taking various factors into consideration and the equilibrium super elevation (*C*a) calculated. The cant deficiency (*C*d) is then added to the equilibrium super elevation and the maximum speed is calculated as per this increased superelevation (*C*a + *C*d).

INTRODUCTION TO SUPERELEVATION

Curves are introduced on a railway track to bypass obstacles, to provide longer and easily traversed gradients, and to pass a railway line through obligatory or desirable locations. Horizontal curves are provided when a change in the direction of the track is required and vertical curves are provided at

points where two gradients meet or where a gradient meets level ground. To provide a comfortable ride on a horizontal curve, the level of the outer rail is raised above the level of the inner rail. This is known as superelevation.

Cant deficiency is the difference between the equilibrium cant that is necessary for the maximum permissible speed on a curve and the actual cant provided. Cant deficiency is limited due to two considerations:

(a) Higher cant deficiency causes greater discomfort to passengers and Curves and Super elevation

(b) Higher cant deficiency leads to greater unbalanced centrifugal forces, which in turn lead to the requirement of stronger tracks and fastenings to withstand the resultant greater lateral forces.

Negative Super elevation-When the main line lies on a curve and has a turnout of contrary flexure leading to a branch line, the super elevation necessary for the average speed of trains running over the main line curve cannot be provided. Branch line the provision of negative super elevation for the branch line and the reduction in speed over the main line can be calculated as follows. The equilibrium super elevation e is reduced by the permissible cant deficiency Cd and the resultant super elevation to be provided is $x = e - Cd$, where, x is the super elevation, e is the equilibrium super elevation, and Cd is 75 mm for BG and 50 mm for MG. The value of Cd is generally higher than that of e, and, therefore, x is normally negative. The branch line thus has a negative super elevation of x. The maximum permissible speed on the main line, which has a super elevation of x, is then calculated by adding the allowable cant deficiency (x + Cd). The safe speed is also calculated and smaller of the two values is taken as the maximum permissible speed on the main line curve.

Introduction Points and crossings

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.

Important Terms

The following terms are often used in the design of points and crossings.

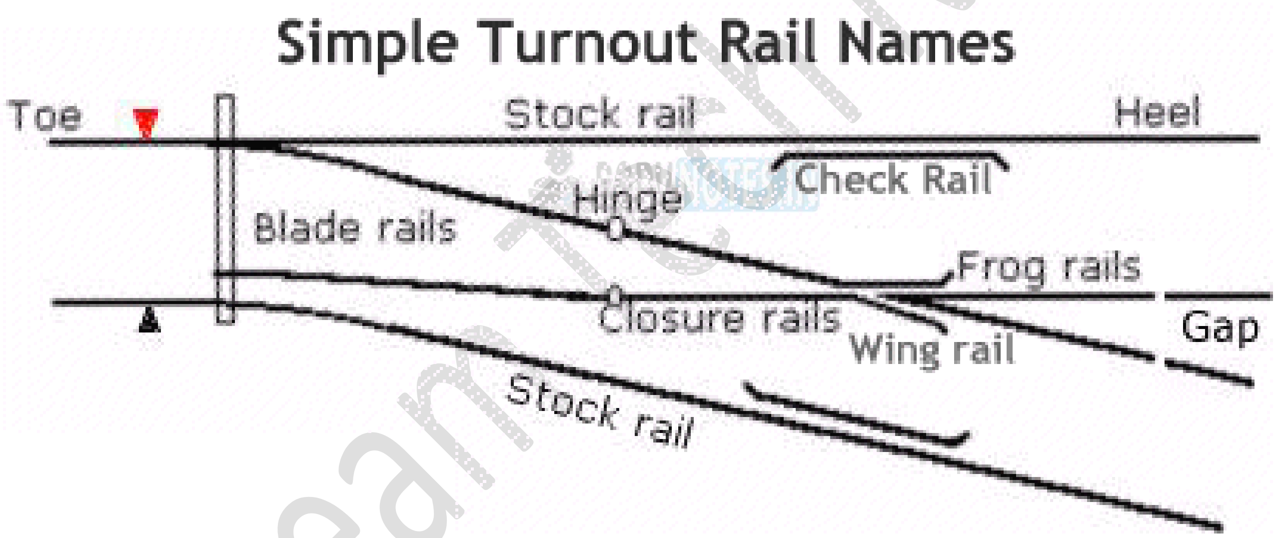
Turnout -It is an arrangement of points and crossings with lead rails by means of which the rolling stock may be diverted from one track to another. A turnout is designated as a right-hand or a left-hand turnout depending on whether it diverts the traffic to the right or to the left. In the turnout is a right-hand turn out because it diverts as the traffic towards the right side shows a left-hand turnout. 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.

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

Turnouts-The simplest arrangement of points and crossing can be found on a turnout taking off from a straight track. There are two standard methods prevalent for designing a turnout. These are the (a) Coles method and the (b) IRS method.These methods are described in detail in the following sections .The important terms used in describing the design of turnouts are defined as follows.

Curve lead (CL) this is the distance from the tangent point (T) to the theoretical nose of crossing (TNC) measured along the length of the main track.



Switch lead (SL) This is the distance from the tangent point (T) to the heel of the switch (TL) measured along the length of the main track.Lead of crossing (L) This is the distance measured along the length of the main track as follows:Lead of crossing (L) = curve lead (CL) – switch lead (SL),Gauge (G) This is the gauge of the track.,Heel divergence (D) This is the distance between the main line and the turnout side at the heel.Angle of crossing ( ) α This is the angle between the main line and the tangent of the turnout line. Radius of turnout (R) This is the radius of the turnout. It may be clarified that the radius of the turnout is equal to the radius of the centre line of the turnout (R1) plus half the gauge width.

R = R1 + 0.5G

As the radius of a curve is quite large, for practical purposes, R may be taken to be equal to R1.

Special fittings with turnouts

Some of the special fittings required for use with turnouts are enumerated below. Distance blocks Special types of distance blocks with fishing fit surfaces are provided at the nose of the crossing to prevent any vertical movement between the wing rail and the nose of the crossing. Flat bearing plates as turnouts do not have any cant, flat bearing plates are provided under the sleepers. Spherical washers these are special types of washers and consist of two pieces with a spherical point of contact between them. This permits the two surfaces to lie at any angle to each other. These washers are used for connecting two surfaces that are not parallel to one another. Normally, tapered washers are necessary for connecting such surfaces. Spherical washers can adjust to the uneven bearings of the head or nut of a bolt and so are used on all bolts in the heel and the distance blocks behind the heel on the left-hand side of the track. Slide chairs, these are provided under tongue rails to allow them to move laterally.

These are different for ordinary switches and overriding switches.

Grade off chair- These are special chairs provided behind the heel of the switches to give a suitable ramp to the tongue rail, which is raised by 6 mm at the heel.

Gauge tie plates-These are provided over the sleepers directly under the toe of the switches, and under the nose of the crossing to ensure proper gauge at these locations.

Stretcher bars-These are provided to maintain the two tongue rails at an exact distance.

Train Resistance and Tractive Power

Introduction-Various forces offer resistance to the movement of a train on the track. These resistances may be a result of the movement of the various parts of the locomotives as well as the friction between them, the irregularities in the track profile, or the atmospheric resistance to a train moving at great speed. The tractive power of a locomotive should be adequate enough to overcome these resistances and haul the train at a specified speed.

Resistance Due to Friction-

Resistance due to friction is the resistance offered by the friction between the internal parts of locomotives and wagons as well as between the metal surface of the rail and the wheel to a train moving at a constant speed. This resistance is independent of speed and can be further broken down into the following parts. Journal friction this is dependent on the type of bearing, the lubricant used, the temperature and condition of the bearing, etc. In the case of roll bearings, it varies from 0.5 to 1.0 kg per ton. Internal resistance this resistance is consequential to the movement of the various parts of the locomotive and wagons.

Rolling resistance-This occurs due to rail-wheel interaction on account of the movement of steel wheels on a steel rail. The total frictional resistance is given by the empirical formula

$R1 = 0.0016W$, where R1 is the frictional resistance independent of speed and W is the weight of the train in tones.

Tractive Effort of a Locomotive

The tractive effort of a locomotive is the force that the locomotive can generate for hauling the load. The tractive effort of a locomotive should be enough for it to haul a train at the maximum permissible speed. There are various tractive effort curves available for different locomotives for different speeds, which enable the computation of the value of tractive effort. Tractive effort is generally equal to or a little greater than the hauling capacity of the locomotive. If the tractive effort is much greater than what is required to haul the train, the wheels of the locomotive may slip.

Hauling Power of a Locomotive-The hauling power of a locomotive depends upon the weight exerted on the driving wheels and the friction between the driving wheel and the rail. The coefficient of friction depends upon the speed of the locomotive and the condition of the rail surface. The higher the speed of the locomotive, the lower the coefficient of friction, which is about 0.1 for high speeds and 0.2 for low speeds. The condition of the rail surface, whether wet or dry, smooth or rough, etc., also plays an important role in deciding the value of the coefficient of function. If the surface is very smooth, the coefficient of friction will be very low.

Hauling power = number of pairs of driving wheels × weight exerted on

The driving wheels × coefficient of friction Thus, for a locomotive with three pairs of driving wheels, an axle load of 20 t, and a coefficient of friction equal to 0.2, the hauling power will be equal to 3 ×20 × 0.2 t, i.e., 12 t.

Example 25.4 Calculate the maximum permissible train load that can be pulled by a locomotive with four pairs of driving wheels with an axle load of 28.42 t each on a BG track with a ruling gradient of 1 in 200 and a maximum curvature of 3°, travelling at a speed of 48.3 km/h. Take the coefficient of friction to be 0.2.

Solution (a) Hauling capacity of locomotive

= no. of pairs of driving wheels × axle load × coefficient of friction

= 4 × 28.42 × 0.2 = 22.736 t

(b) Total resistance of train = resistance due to friction + resistance due to speed+ resistance due to wind + resistance due to gradient + resistance due to curve= 0.0016W + 0.00008WV + 0.0000006WV2+ W(1/g) + 0.0004WD = 0.0016W + 0.00008W × 48.3 + 0.0000006W × (48.3)2 + W ×(1/200) × 0.0004 × W × 3

(c) Hauling capacity = total resistance

22.73 = 0.01306W or W = 1740 t

Therefore, the maximum weight of the train is 1740 t.

Railway Stations and Yards

Introduction

A railway station is that place on a railway line where traffic is booked and dealt with and where trains are given the authority to proceed forward. Sometimes only one of these functions is carried out at a station and accordingly it is classified as a flag station or a block station. In the case of a flag station, there are arrangements for dealing with traffic but none for controlling the movement of the trains. In the case of a block station, a train cannot proceed further without obtaining permission from the next station and traffic may or may not be dealt with. However, most railway stations perform both the functions indicated above.

Purpose of a Railway Station

A railway station is provided for one or more of the following purposes.

(a) To entrain or detrain passengers

(b) To load or unload goods or parcels

(c) To control the movement of trains

(d) To enable trains to cross each other in the case of a single-line section

(e) To enable faster trains to overtake slower ones

(f) To enable locomotives to refuel, whether it be diesel, water, or coal

(g) To attach or detach coaches or wagons to trains

(h) To collect food and water for passengers

(i) To provide facilities for change of engines and crew/staff

(j) To enable sorting out of wagons and bogies to form new trains

(k) To provide facilities and give shelter to passengers in the case of emergencies

Such as floods and accidents, which disrupt traffic

- Selection of Site for a Railway Station

The following factors are considered when selecting a site for a railway station.

Adequate land-There should be adequate land available for the station building, not only for the proposed line but also for any future expansion. The proposed area should also be without any religious buildings. Level area with good drainage. The proposed site should preferably be on a fairly level ground with good drainage arrangements. It should be possible to provide the maximum permissible gradient in the yard. In India, the maximum permissible gradient adopted is 1 in 400, but a gradient of 1 in 1000 is desirable. Alignment The station site should preferably have a straight alignment so that the various signals are clearly visible. The proximity of the station site to a curve presents a number of operational problems. Easy accessibility. The station site should be easily accessible. The site should be near villages and towns. Nearby villages should be connected to the station by means of approach roads for the convenience of passengers.

Types of Yards

A yard is a system of tracks laid out to deal with the passenger as well as goods traffic being handled by the railways. This includes receipt and dispatch of trains apart from stabling, sorting, marshalling, and other such functions. Yards are normally classified into the following categories.

Coaching yard

The main function of a coaching yard is to deal with the reception and dispatch of passenger trains. Depending upon the volume of traffic, this yard provides facilities such as watering and fuelling of engines, washing of rakes, examination of coaches, charging of batteries, and trans-shipment of passengers.

Goods yard-

A goods yard provides facilities for the reception, stabling, loading, unloading, and dispatch of goods wagons. Most goods yards deal with a full train load of wagons. No sorting, marshalling, and reforming is done at goods yards except in the case of 'sick' wagons or a few wagons booked for that particular station. Separate goods sidings are provided with the platforms for the loading and unloading of the goods being handled at that station.

Marshalling yard-

A goods yard which deals with the sorting of goods wagons to form new goods trains is called a marshalling yard.

Locomotive yard-

This is the yard which houses the locomotive. Facilities for watering, fuelling, examining locomotives, repairing, etc., are provided in this yard. The yard layout is designed depending upon the number of locomotives required to be housed in the locomotive shed. The facilities are so arranged that a requisite number of locomotives are serviced simultaneously and are readily available for hauling the trains. Such yards should have adequate space for storing fuel. The water supply should be adequate for washing the locomotives and servicing them. Sick line yard .Whenever a wagon or coach becomes defective, it is marked 'sick' and taken to sick lines. This yard deals with such sick wagons. Adequate facilities are provided for the repair of coaches and wagons, which include examination pits, crane arrangements, train examiner's office and workshop, etc. A good stock of spare parts should also be available with the TXR (train examiner) for repairing defective rolling stock.

Marshalling Yard

The marshalling yard (Fig. 26.14) is a yard where goods trains are received and sorted out, and new trains are formed and finally dispatched to various destinations.

Principles of design

A marshalling yard should be so designed that there is minimum detention of wagons in the yard and as such sorting can be done as quickly as possible. These yards should be provided with the necessary facilities such as a long shunting neck, properly designed hump, braking arrangement in the shape of mechanical retarders, etc., depending upon the volume of traffic. The following points should be kept in mind when designing a marshalling yard.

(a) Through traffic should be received and dispatched as expeditiously as possible. Any idle time should be avoided.

(b) There should be a unidirectional movement of the wagons as far as possible.

(c) There should be no conflicting movement of wagons and engines in the various parts of the yard.

(d) The leads that permit the movement of wagons and train engines should be kept as short as possible.

(e) The marshalling yard should be well lighted.

(f) There should be adequate scope for the further expansion of the marshalling Yard

Types of Marshalling yards -

Marshalling yards can be classified into three main categories, namely, flat yards, gravitation yards, and hump yards. This classification is based on the method of shunting used in the marshalling yard.

Flat yard-In this type of yard, all the tracks are laid almost level and the wagons are relocated for sorting, etc., with the help of an engine. This method is costly, as it involves frequent shunting, which requires the constant use of locomotive power. The time required is also more as the engine has to traverse the same distance twice,Railway Stations and Yards 469 first to carry the wagons to the place where they are to be sorted and then to return idle to the yard. This arrangement, therefore, is adopted when

(a) There is limitation of space,

(b) There is a severe limitation of funds, or

(c) The number of wagons dealt with by the marshalling yard is very low.

Gravitation yard- In this yard, the level of the natural ground is such that it is possible to lay some tracks at a gradient. The tracks are so laid that the wagons move to the siding assigned for the purpose of sorting by the action of gravity. Sometimes, shunting is done with the help of gravity assisted by engine power. However, it is very seldom that natural ground levels are so well suited for gravitation yards. Hump yard in this yard, an artificial hump is created by means of proper earthwork. The wagons are pushed up to the summit of the hump with the help of an engine from where they slide down and reach the sidings under the effect of gravity. A hump yard, therefore, can be said to be a gravitation yard as shunting is done under the effect of gravity. These are, however, only recommended gradients and the final gradient for a particular yard is decided after a test run of the trains over the humps, taking into consideration the rolling quality of different types of wagons and the spacing between successive groups of wagons. The topography of the location of the yard also plays an important role in deciding the gradient.

Signaling and Interlocking

Introduction

The purpose of signaling and interlocking is primarily to control and regulate the movement of trains safely and efficiently. Signaling includes the use and working of signals, points, block instruments, and other allied equipment in a predetermined manner for the safe and efficient running of trains. Signaling enables the movement of trains to be controlled in such a way that the existing tracks are utilized to the maximum. In fact in railway terminology signaling is a medium of communication between the station master or the controller sitting in a remote place in the office and the driver of the train. The history of signaling goes back to the olden days when two policemen on horseback were sent ahead of the train to ensure that the tracks were clear and to regulate the movement of the trains. In later years, policemen in uniform were placed at regular intervals to regulate the movement of trains. Railway signaling in its present form was introduced for the first time in England in 1842, whereas interlocking was developed subsequently in 1867.

Objectives of Signaling

The objectives of signaling are as follows.

(a) To regulate the movement of trains so that they run safely at maximum permissible speeds.

(b) To

The safety of two or more trains that have to cross or approach each other.

(d) To provide maintain a safe distance between trains that are running on the same line in the same direction.

(c) To ensure facilities for safe and efficient shunting.

(e) To regulate the arrival and departure of trains from the station yard.

(f) To guide the trains to run at restricted speeds during the maintenance and repair of tracks.

(g) To ensure the safety of the train when it comes in contact with road traffic at level crossing.

Types of signals

Railway signals may be classifies based on different criteria,they are

OPERATION-

1.Audible or detonating signals

2.Visible signals

FUNCTION-

1.Stop signals

2.Permission or caution signals

3.Shunting signals

LOCATION

1.Reception signalsOuter,router,home

2.Departure signals:Starter,advance starter

CONSTRUCTION-

1.Semaphore signals

2.Colored light signals

SPECIAL PURPOSE-

1.Repeater signal

2.Co-acting signal

3.Router signal

4.Calling-on signal

5.Home and Warner combination signal

6.Temporary signal

Interlocking

Interlocking is a device or a system meant to ensure the safety of trains. With the increase in the number of points and the signals and introduction of high speeds, it has become necessary to eliminate human error, which would otherwise lead to massive losses of life and property. The points and signals are set in such a way568 Railway Engineering that the cabin man cannot lower the signal for the reception of a train unless the corresponding points have been set and locked. The signal is thus interlocked with the points in a way that no conflicting movement is possible and the safety of trains is ensured. Interlocking can, therefore, be defined as an arrangement of signals, points, and other apparatus so interconnected by means of mechanical or electrical locking that they can be operated in a predetermined sequence to ensure that there is no conflicting movement of signals and points and trains run safely. The signal and interlocking system is so designed that the failure of any equipment results in the turning on of the signal, thus ensuring train safety.

Unit – 3

BRIDGES

Bridges: Site Investigation and Planning; Loading Standards & Component parts: Selection of site, alignment, collection of bridge design data: essential surveys, hydraulic design, and scour, depth of bridge foundation, Economical span, clearance, afflux, and type of road & railway bridges. : Design loads and forces, Impact factor, Indian loading standards for Railways Bridges and Highway Bridges, Bridge super-structure and sub-structures, abutments, piers, wing walls, return walls, approaches, floors & flooring system, choice of super structure.

BRIDGES: SITE INVESTIGATION AND PLANNING

Selection Criteria For Bridge Site

1. The choice of the right site is a crucial decision in the planning and designing of a bridge.

2. It may not be possible always to have a wide choice of sites for a bridge.

3. This is particularly so in case of bridges in urban areas and flyovers.

4. For river bridges in rural areas, usually a wider choice may be available.

Selection Criteria For Bridge Site

1. For selecting a suitable site for a major bridge, the investigating engineer should make a reconnaissance survey to get impression of the landscape and to decide on the type of the structure to the site.

2. Care should be taken to investigate a number of probable alternative sites and then decide on the site which is likely to serve the needs of the bridge at the least cost.

3. A brief description of the reasons for the selection of a particular site should be furnished in the investigation report along with salient details of alternative sites investigated and rejected

Different studies perform during PRELIMINARY SURVEY are:

- Topography
- Catchment area
- Hydrology
- Geo-technical data
- Seismology
- Navigation

- Construction resources
- Nearby bridges
- Traffic data

Loads and Load combinations

Loads on bridges : The following are the various loads to be considered for the purpose of computing stresses, wherever they are applicable.

- Dead load
- Live load
- Impact load
- Longitudinal force
- Thermal force
- Wind load
- Seismic load
- Racking force

· Forces due to curvature. · Forces on parapets · Frictional resistance of expansion bearings

· Erection forces

Dead load – The dead load is the weight of the structure and any permanent load fixed thereon. The dead load is initially assumed and checked after design is completed.

Live load – Bridge design standards specify the design loads, which are meant to reflect the worst loading that can be caused on the bridge by traffic, permitted and expected to pass over it. In India, the Railway Board specifies the standard design loadings for railway bridges in bridge rules.

ALIGNMENT OF BRIDGES-The alignment of a bridge along its centre line is governed by the following factors:

1. RECTANGULAR OR SQUARE CROSSING-The angle of crossing should be near to 90º as possible, that is, centre-line of the bridge should be at right angles to the direction of water flow.

2. STRAIGHT ALIGNMENT-The centre-line of the bridge should be straight and not curved, alternatively, it can also be a series of straight lines. In mountains or hilly terrain it may become inevitable to align the bridge on a curve.

3. ALIGNMENT OF APROACHES-Sometimes, approaches to the bridge may be aligned on curves in order to avoid skew crossing and achieve square crossing for the bridge.

4. SILTING AND SCOURING-The alignment should be protected from the effects of silting and scouring on the abutments, piers and embankments near approaches.

HYDRAULIC DESIGN-The hydraulics designer should identify the types of data that will be required prior to conducting the hydraulic analysis. The effort necessary for data collection and compilation should be tailored to the importance of the project. Data collection for a specific project should be appropriate for the project scope and be tailored to:

• site conditions; • scope of the hydraulic analysis; • social, economic, environmental and archaeological requirements; • unique project requirements; and • regulatory requirements.

TYPES OF DATA NEEDED

The hydraulics designer should compile the data that are specific to the subject site. Following are the major types of data that may be required:

• Permit requirements;

• Watershed characteristics;

• Stream-reach data;

• Other physical data within the vicinity of the facility (e.g., utilities, easements);

• Hydrologic and meteorological data (e.g., stream-flow and rainfall data related to maximum or historical peak and low-flow discharges and hydrographs applicable to the site);

• Existing and proposed land-use data in the subject drainage area and in the general vicinity of the facility;

• Anticipated changes in land-use and/or watershed characteristics; and

• Floodplain limits, environmental regulations and archaeological data. Watershed, stream-reach and site characteristic data and data on other physical characteristics can be obtained from a field reconnaissance of the site. Examination of available maps and aerial photographs of the watershed are also excellent methods of defining physical characteristics of the watershed.

Scour Potential Scour potential is an important consideration relative to the stability of the structure over time. Scour potential will be determined by a combination of the stability of the natural materials at the facility site, tractive shear force exerted by the stream and sediment transport characteristics of the stream.

DEPTH OF BRIDGE FOUNDATION

Foundation types depend primarily on the depth and safe bearing pressures of the bearing stratum, also restrictions placed on differential settlement due to the type of bridge deck. Generally in the case of simply supported bridge decks differential settlements of about 20 to 25 mm can be tolerated, whereas multi-span continuous decks 10 mm is usually considered as a maximum. Bridge foundations generally fall into two categories:

1. Strip footings, one for each pier and abutment. However, it is sometimes convenient to split the deck into two halves longitudinally along the centre line, this is then continued to the footing.
2. Piled foundations.

It is possible to have a combination of both (i.e. piers being piled with abutments on strip footings).

<u>Design Considerations</u>

The design of foundations comprise of the following stages :

1. From the site investigation report decide upon which stratum to impose the structure load and its safe bearing pressure.
2. Select the type of foundation, possibly comparing the suitability of several types.

3. Design the foundation to transfer and distribute the loads from the structure to the ground. Ensure that the factor of safety against shear failure in the soil is not reached and settlement is within the allowable limits.

Piled Foundations

The type of piles generally used for bridge foundations are :

1. Driven Piles; preformed piles of concrete or steel driven by blows of a power hammer or jacked into the ground.
2. Preformed Driven Cast In-Situ Piles; formed by driving a hollow steel tube with a closed end and filling the tube with concrete.
3. Driven Cast In-Situ Piles; formed by driving a hollow steel tube with a closed end and filling the tube with concrete, simultaneously withdrawing the tube.
4. Bored and Cast In-Situ Piles; formed by boring a hole and filling it with concrete.

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

Dmin = Minimum depth of foundation in m

y= Density of unit weight of soil in kN/m3

Ø = Angle of repose in Degrees

q = Intensity of load or Safe bearing capacity of soil in kN/m2

ECONOMICAL SPAN OF BRIDGE

Fixing length of typical span in design of bridges across river/elevated road/metro project is very important structural design decision. The cost of building one typical span can be broadly divided into following two components

1. Cost of Substructure
2. Cost of Superstructure

The cost of substructure is covers cost of bridge bearing, pier cap/pier head, pier and foundation (Open/Pile/Casino). To take decision on most economical length of typical span, initial design and cost estimate is done for four to five different span lengths.

CLEARANCE - This is the vertical distance between the high flood level inclusive of afflux and the bottom most part of bridge super structure like slab girder etc.

AFFLUX - It is the rise in the flood level of the river upstream of the bridge as a result of obstruction to natural flow caused by the construction of the bridge.

Types of Bridges-Bridges are classified into so many types based on different criteria's. They are explained below.

Types of Bridges based on Type of Super Structure

- **Arch bridge**
- **Girder bridge**
- **Truss bridge**
- **Suspension bridge**

Arch Bridge-Arch bridge is curve shaped bridge, in which horizontal thrust is developed and is restrained by the abutments at each end of the bridge. There are many types of arch bridges are there. In some cases, the arch may be under the deck slab also.

Arch Bridge

In case of Girder Bridge, the deck slab is supported by means of girders. The girder may be of rolled steel girder or plate girder or box girder. Load coming from the deck are taken by girder and transferred them to the piers and abutments.

Girder Bridge

Truss is member consisting connected elements to form triangular units. In case of truss bridge the super structure is provided with trusses. Generally, trusses are made of steel. There are several types of trusses are available.

Truss Bridge

In case of Suspension bridge, deck slab is suspended with the help of cables and suspenders. These will give good appearance. For long span bridges, this type of suspension is suitable.

Suspension bridge

Types of Bridges based on Materials

- Timber bridge
- Masonry bridge
- Steel bridge
- R.C.C bridge
- Pre stressed concrete bridge

Timber Bridge

Bridges constructed using timber are called timber bridges. These are generally constructed for short spans or as temporary bridges. They are not useful for heavy loads.

Masonry Bridge

Masonry Bridge constructed by using bricks or stones. These are generally constructed for short spans and in low depth canals.

Steel Bridge: Steel bridges are constructed using steel bars or trusses or steel cables. These are more durable and bear heavy loads.

R.C.C Bridge: R.C.C bridges are constructed using reinforced cement concrete. These are more stable and durable. They can bear heavy loads and are widely using nowadays.

Pre--stressed Concrete Bridge: If concrete material is placed under compression before applying the loads, then it is called as pre-stressed concrete. To construct pre stressed concrete bridge, pre-stressed concrete blocks are arranged as deck slab with the help of girders. These blocks are suitable for shorter span to longer span bridges.

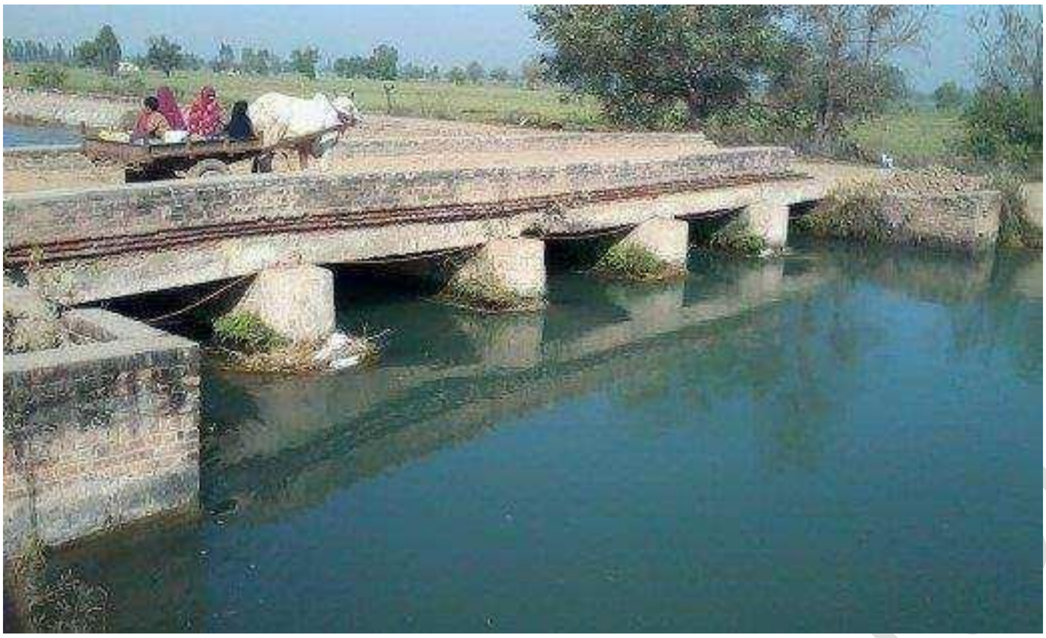
Types of Bridges based on Span

- Culvert bridge
- Minor bridge
- Major bridge
- Long span bridge

Culvert Bridge

When the bridge span length is below 6meters then it is called as Culvert Bridge.

Minor Bridge: If the bridge span length is in between 8 to 30 meters, then it is called minor bridge.



Major Bridge: For major bridge, the span is generally about 30 to 120 meters.

Long Span Bridge: When the span of bridge is more than 120 meters then it is termed as long span bridge.

Types of Bridges based on Level of Crossing

- **Over bridge**
- **Under bridge**

Over Bridge

To pass over another route (railway or highway), a bridge is constructed to allow traffic. This is called over bridge or flies over bridge.

Under Bridge: If over bridge is not possible, an underground type bridge is constructed to pass another route. This is called under bridge.

Types of Bridges based on Function

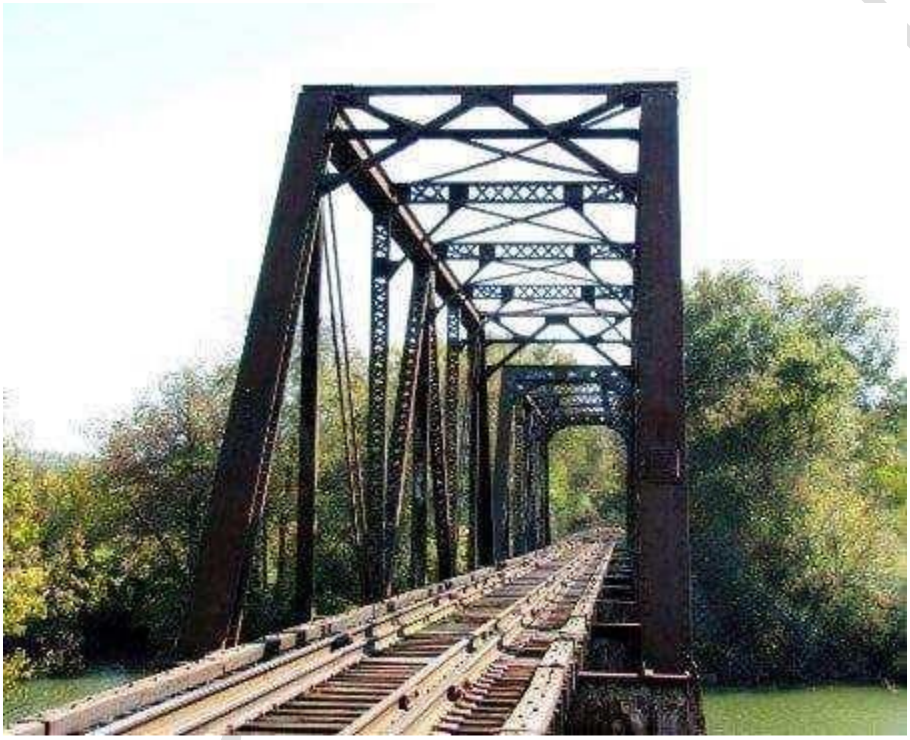
- **Foot bridge**
- **Highway bridge**
- **Rail way bridge**
- **Aqueduct bridge**
- **Road cum railway bridge**

Foot Bridge-Foot Bridge is generally constructed for humans to cross the roads or rail route or any canal by foot. Vehicles are not allowed in this bridge.

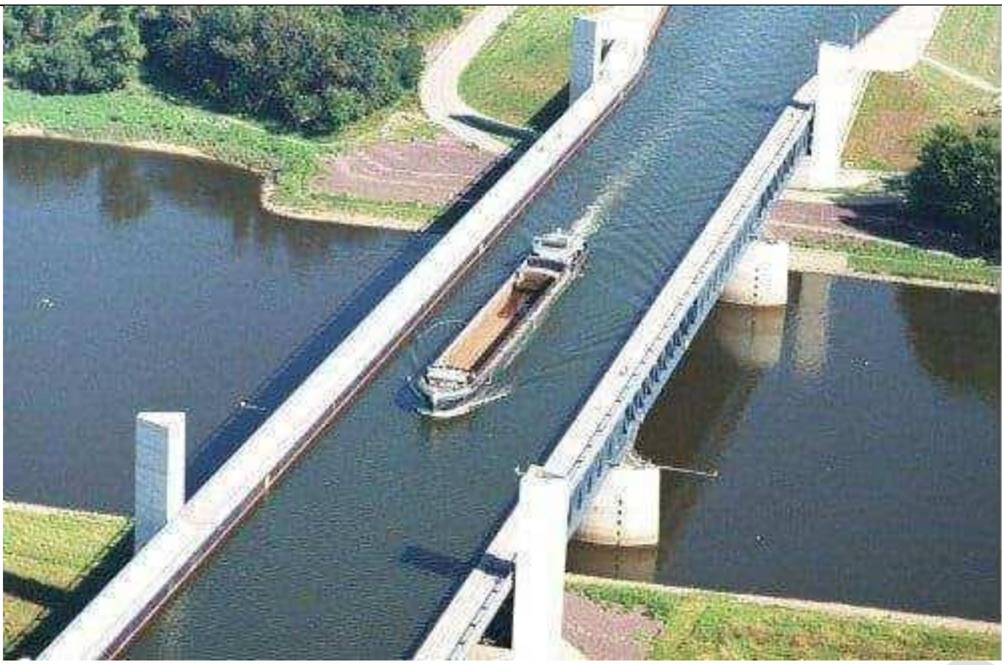
Highway Bridge: High way or road Way Bridge is used for road transportation. These are constructed over rivers or another routes to allow road way traffic. Girder type bridges are used as highway

bridges over rivers or canals.

Railway Bridge: Rail bridges are constructed for rail transportation. Truss type bridges are preferred for railways but however R.C.C bridges are also used.



Aqueduct Bridge: Aqueduct bridges are nothing but water carrying bridges which are constructed to0 transport water from source to system.



Road cum Railway Bridge: This type of bridge is useful for both road way and railway transport. It may be of one floor or two floors. If one floor is there then, rail and road way are arranged side by side. Otherwise roadway on top deck and railway in bottom deck is preferred.

DESIGN LOADS AND FORCES

Live load and dead load-

The primary function of a bridge is to carry traffic loads: heavy trucks, cars, and trains. Engineers must estimate the traffic loading. On short spans, it is possible that the maximum conceivable load will be achieved—that is to say, on spans of less than 30 meters (100 feet), four heavy trucks may cross at the same time, two in each direction. On longer spans of a thousand meters or more, the maximum conceivable load is such a remote possibility (imagine the Golden Gate Bridge with only heavy trucks crossing bumper-to-bumper in each direction at the same time) that the cost of designing for it is unreasonable. Therefore, engineers use probable loads as a basis for design. In order to carry traffic, the structure must have some weight, and on short spans this dead load weight is usually less than the live loads. On longer spans, however, the dead load is greater than live loads, and, as spans get longer, it becomes more important to design forms that minimize dead load. In general, shorter spans are built with beams, hollow boxes, trusses, arches, and continuous versions of the same, while longer spans use cantilever, cable-stay, and suspension forms. As spans get longer, questions of shape, materials, and form become increasingly important. New forms have evolved to provide longer spans with more strength from less material.

Forces of nature-Dead and live weight are essentially vertical loads, whereas forces from nature may be either vertical or horizontal. Wind causes two important loads, one called static and the other dynamic. Static wind load is the horizontal pressure that tries to push a bridge sideways. Dynamic wind load gives rise to vertical motion, creating oscillations in any direction. Like the breaking of an overused violin string, oscillations are vibrations that can cause a bridge to fail. If a deck is thin and not properly shaped and supported, it may experience dangerous vertical or torsional (twisting) movements.

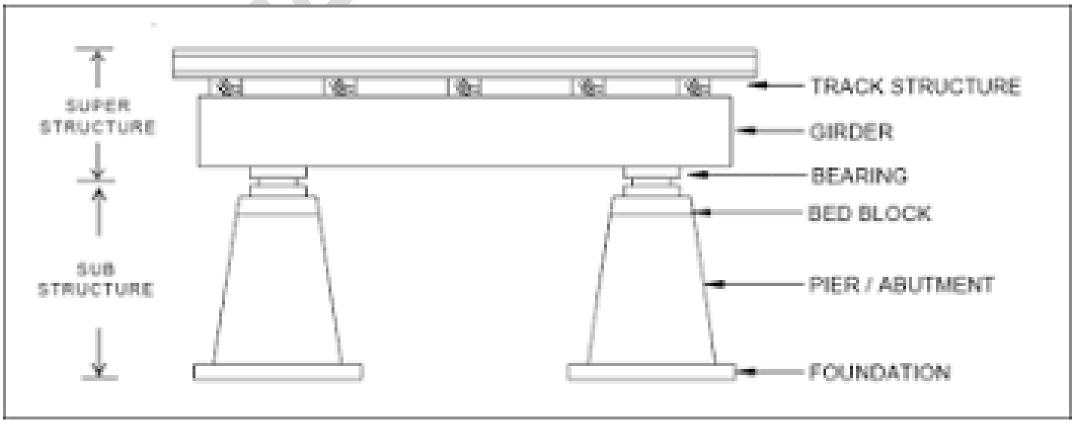
COMPONENTS OF BRIDGES-Every bridge can be divided broadly into three parts-

1. Superstructure
2. Substructure
3. Foundation

Superstructure-Superstructure is that part of the structure which supports traffic and includes deck, slab and girders. All the parts of the bridge which is mounted on a supporting system can be classified as a Super structure. Super-structure is that part of the structure which is above ground level, and which serves the purpose of its intended use. A part of the super-structure, located between the ground level and (he floor level is known as plinth.

Substructure-Substructure is that part of the structure, i.e. piers and abutments, which supports the superstructure and which transfers the structural load to the foundations. Sub-structure or Foundation is the lower portion of the building, usually located below the ground level, which transmits the loads of the super-structure to the supporting soil. A foundation is therefore that part of the structure which is in direct contact with the ground to which the loads are transmitted.

Plinth is therefore defined as the portion of the structure between the surface of the surrounding ground and surface of the floor, immediately above the ground. The level of the floor is usually



ABUTMENTS

Choice of Abutment

The objective is to avoid the use of joints over abutments and piers. Expansion joints are prone to leak and allow the ingress of de-icing salts into the bridge deck and substructure. In general all bridges are made continuous over intermediate supports, and decks under 60 meters long with skews not exceeding 30° are made integral with their abutments. Full height integral abutments are generally used for the shorter spans (< about 20m).

Integral abutments with piled foundations usually incorporate steel H piles in a single row; the H piles are orientated so that bending occurs about their weaker axis. These abutments are suitable for the larger span decks.Integral abutments with spread footings (DfT BA 42/96 call Bank Pad Abutments) should only be used where settlement due to consolidation of founding strata is minimal. Where decks exceed 60 meters long or have skews exceeding 30° then movement joints and bearings usually need to be provide.

GeometriConsiderations

1. Open Side Span with Bank Seats
2. Solid Side Span with Full Height Abutments.

Usually the narrow bridge is cheaper in the open abutment form and the wide bridge is cheaper in the solid abutment form. The exact transition point between the two types depends very much on the geometry and the site of the particular bridge. In most cases the open abutment solution has a better appearance and is less intrusive on the general flow of the ground contours and for these reasons is to be preferred. It is the cost of the wing walls when related to the deck costs which swings the balance of cost in favor of the solid abutment solution for wider bridges. However the wider bridges with solid abutments produce a tunneling effect and costs have to be considered in conjunction with the proper functioning of the structure where fast traffic is passing beneath. Solid abutments for narrow bridges should only be adopted where the open abutment solution is not possible. In the case of wide bridges the open abutment solution is to be preferred, but there are many cases where economy must be the overriding consideration.

Design Considerations

Loads transmitted by the bridge deck onto the abutment are :

1. Vertical loads from self weight of deck.
2. Vertical loads from live loading conditions.
3. Horizontal loads from temperature, creep movements etc and wind.
4. Horizontal loads from braking and skidding effects of vehicles.

These loads are carried by the bearings which are seated on the abutment bearing platform. The horizontal loads may be reduced by depending on the coefficient of friction of the bearings at the movement joint in the structure.However, the full braking effect is to be taken, in either direction, on top of the abutment at carriageway level.In addition to the structure loads, horizontal pressures exerted by the fill material against the abutment walls is to be considered. Also a vertical loading from the weight of the fill acts on the footing.

Vehicle loads at the rear of the abutments are considered by applying a surcharge load on the rear of the wall. For certain short single span structures it is possible to use the bridge deck to prop the two abutments apart. This entails the abutment wall being designed as a propped cantilever.

TYPES OF ABUTMENTS-

1. ABUTMENT WITHOUT WINGWALLS

2. STAIGHT ABUTMENTS

3. T-ABUTMENTS

4. ABUTMENTS WITH WINGWALLS

5. ABUTMENT WITH STRAIGHT WINGS

6. ABUTMENT WITH SPLAYED WINGS

7. ABUTMENTS WITH RETURN WINGS.

PIERS-The intermediate supports of a bridge superstructure are known as piers.

Normal piers are of following types:

1. Solid piers
2. Column Bents
3. Cylindrical piers
4. Dumb-bell piers
5. Pile bents
6. Trestle bents

WING WALLS-

Choice of Wing Wall

Wing walls are essentially retaining walls adjacent to the abutment. The walls can be independent or integral with the abutment wall.Providing the bridge skew angle is small (less than 20°), and the cutting/embankment slopes are reasonably steep then the wing wall cantilevering from the abutment wall is likely to give the most economical solution.

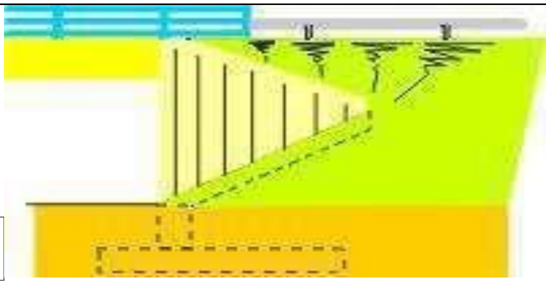
Splayed wing walls can provide even more of an economy in material costs but the detailing and fixing of the steel reinforcement is more complicated than the conventional wall.

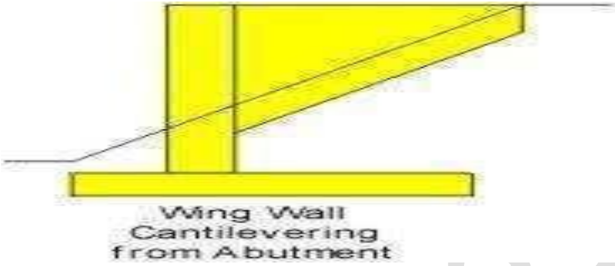
Design Considerations

Loads effects to be considered on the rear of the wall are:

1. Earth pressures from the backfill material.
2. Surcharge from live loading or compacting plant.
3. Hydraulic loads from saturated soil conditions.

The stability of the wall is generally designed to resist 'active' earth pressures (Ka); whilst the structural elements are designed to resist 'at rest' earth pressures (Co). The concept is that 'at rest' pressures are developed initially and the structural elements should be designed to accommodate these loads without failure. The loads will however reduce to 'active' pressure when the wall moves, either by rotating or sliding. Consequently the wall will stabilize if it moves under 'at rest' pressures providing it is designed to resist 'active' earth pressures.





RETURN WALLS- A wall that makes a decided angle with and is approximately the same height as an outer wall of a building and that is distinguished from a partition or a low wall carrying a partition

APPROACHES-Bridge approaches typically experience two types of settlement, global and local. Global settlement consists of a consolidation of the underlying natural foundation soils, and is evidence of possible long-term differential settlement between the bridge structure and the bridge embankment. Local settlement consists of compression of fill materials directly beneath the approach pavement, and is evidence of possible embankment consolidation within the upper 10 to 20 feet of the bridge embankment. It is the combination of global and local settlements adjacent to the bridge end piers that forms the characteristic “bump” in the pavement at the bridge ends. The purpose of the bridge approach slab is to significantly reduce local settlement and to accommodate global settlement by providing a gradual transition between the roadway and the bridge deck.

Bridge approach slabs are required for all new and widened bridges, except when concurrence is reached between the Materials Laboratory Geotechnical Branch, the Region

Design Project Engineer Office, and the Bridge and Structures Office, that approach slabs are not appropriate for a particular site. In accordance with WSDOT Design Manual Chapter 1120, the State Geotechnical Engineer will include a recommendation in the geotechnical report for a bridge on whether or not bridge approach slabs should be used at the bridge site. Factors considered while evaluating the need for bridge approach slabs include the amount of expected settlement and the type of bridge structure.

The foundations of a bridge are particularly critical because they must support the entire weight of the bridge and the traffic loads that it will carry.

Foundation types depend primarily on the depth and safe bearing pressures of the bearing stratum, also restrictions placed on differential settlement due to the type of bridge deck. Generally in the case of simply supported bridge decks differential settlements of about 20 to 25 mm can be tolerated, whereas multi-span continuous decks 10 mm is usually considered as a maximum. Bridge foundations generally fall into two categories:

i. Strip footings, one for each pier and abutment. However, it is sometimes convenient to split the deck into two halves longitudinally along the centre line, this is then continued to the footing.

ii. Piled foundations.

It is possible to have a combination of both (i.e. piers being piled with abutments on strip footings).

Design Considerations

The design of foundations comprise of the following stages :

i. From the site investigation report decide upon which stratum to impose the structure load and its safe bearing pressure.

ii. Select the type of foundation, possibly comparing the suitability of several types.

iii. Design the foundation to transfer and distribute the loads from the structure to the ground. Ensure that the factor of safety against shear failure in the soil is not reached and settlement is within the allowable limits.

Strip Footings

The overall size of strip footings is determined by considering the effects of vertical and rotational loads. The combination of these two must neither exceed the safe bearing capacity of the stratum nor produce uplift. The thickness of the footings is generally about 0.8 to 1.0 m but must be capable of withstanding moments and shears produced by piers or abutments. The critical shearing stress may be assumed to occur on a plane at a distance equal to the effective depth of the base from the face of the column. Cover to reinforcement should never be less than values given in BS 5400: Part 4: Table 13, and crack control calculation must be carried out to ensure the crack width is less than 0.25mm (Table 1). Cover to reinforcement will need to be increased to comply with BS 8500 requirements.

Piled Foundations

The type of piles generally used for bridge foundations are :

a. Driven Piles; preformed piles of concrete or steel driven by blows of a power hammer or jacked into the ground.

b. Preformed Driven Cast In-Situ Piles; formed by driving a hollow steel tube with a closed end and filling the tube with concrete.

c. **Driven Cast In-Situ Piles; formed by driving a hollow steel tube with a closed end and filling the tube with concrete, simultaneously withdrawing the tube.**

d. **Bored and Cast In-Situ Piles; formed by boring a hole and filling it with concrete.**

Pile foundations

Suitability of Pile Foundation:

Pile foundations are used under the following conditions:

(i) When the soil near the ground surface or at a reasonable depth is too soft or loose.

(ii) When the loads are so high that there is not enough plan area to accommodate the size of foundation required.

(iii) When large lateral loads act on the foundation.

(iv) Pile foundations are used when the structure is expected to carry large uplift loads in transmission towers and underground structures below water table.

(v) Pile foundation is used when the foundation is subjected to inclined loads, eccentric loads and moments.

Classification of Piles:

Piles are classified as follows:

(a) Classification based on materials and composition:

(i) Timber piles:

Timber piles are made from tree trunks and are well seasoned, straight and free from all defects. In India, timber piles mostly made up of sal tree trunks. These piles are available in length between 4 to 6 m. Timber piles are used where good bearing stratum is available at a relatively shallow depth.

(ii) Concrete piles:

Concrete piles are either precast or cast in situ. Precast piles are cast and cured at the casting site and then transported to the site for installation. These piles are adequately reinforced to with stand handling stresses along with working stresses. Precast piles are normally suitable for short lengths. Cast-in-situ piles are constructed by drilling hole in the ground and then filling the hole by concrete after placing the reinforcement.

(iii) Steel piles:

Steel piles are usually of rolled H-sections or thick pipe sections. These piles are used to withstand large impact stresses and where less distributance from driving is desired. Steel sheet piles and H-piles are generally used to support the open excavation and to provide seepage barrier.

(iv) Composite piles:

A pile which is made up of two materials like concrete and timber or concrete and steel is called composite pile. Composite piles are used in situations where a part of the pile is permanently under water. The part of the pile which will be under water can be made of untreated timber and the other part can be of concrete.

(b) Classification based on method of installation:

(i) Bored piles:Bored piles are constructed in pre-bored holes either using a casing or by circulating stabilizing agent like betonies slurry. The borehole is then filled with concrete after placing the reinforcement. The advantage of board pile is that there is no damage due to handling and driving which is common in driven piles.

Board piles are of following types:

(i) Small diameter piles-up to 600 mm diameter; large diameter piles-diameter greater than 600 mm; under reamed piles.

(ii) Driven piles:Driven piles may be of concrete, steel or timber. These piles are driven into the soil by the impact of hammer. Boring is not required for this type of piles. When a pile is driven into granular soils it densities the soil and increases strength of soil. But when a pile is driven in saturated clay, the soil instead of being compacted gets remolded with reduction in strength.

(iii) Driven and cast-in-situ piles:It is a type of driven pile. They are constructed by driving a steel casing in to the ground. The hole is then filled with concrete by placing the reinforcement and the casing is gradually lifted.

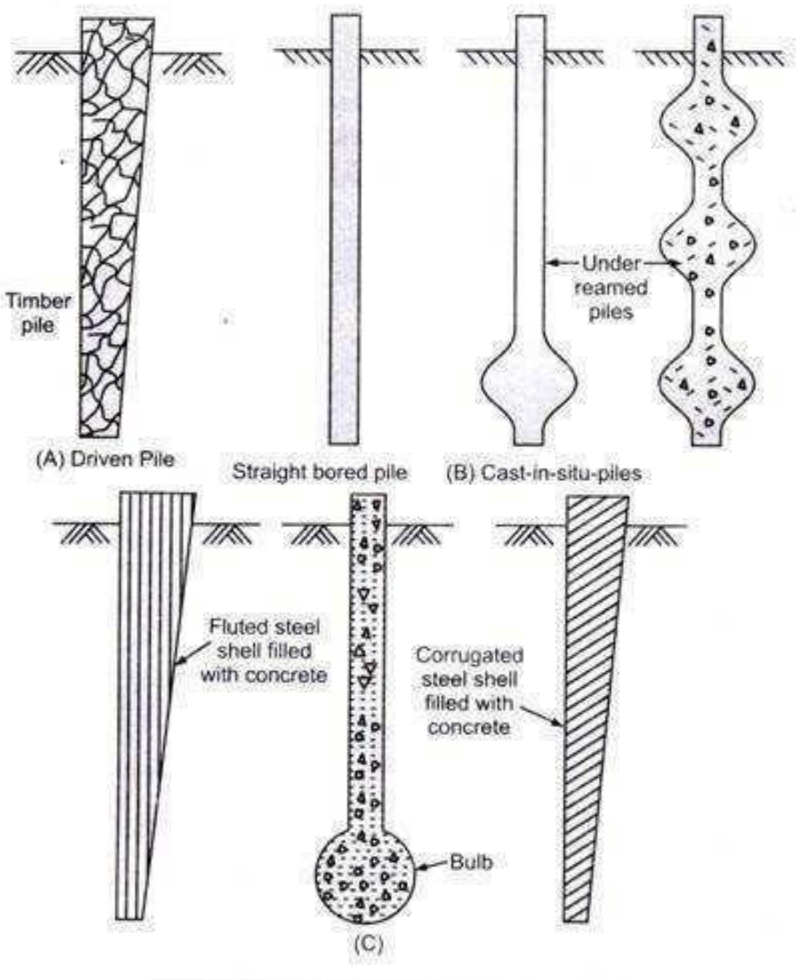


FIG. 11.14 Driven and cast in situ piles

(c) Classification based on the function: Piles are of following types based on its use:

(i) End bearing piles: The piles which transfer its load to a hard and relatively incompressible stratum like rock or dense sand are called end bearing piles. These piles derive its bearing capacity from end bearing at the pile tip.

(ii) Friction piles: The piles which do not rest on hard stratum but derives its carrying capacity from skim friction or adhesion between the pile surface and surrounding soil are called friction piles.

(iii) Tension pile: Tension piles are also called uplift piles. These piles are used to anchor down the structures subjected to uplift due to hydrostatic pressure.

(iv) Compaction piles: These piles are used to compact loose granular soil to increase its bearing capacity. Compaction piles do not carry load and hence they can be of weaker material. Sand piles can be used as compaction piles.

(v) Anchor piles: piles are used to provide anchorage against horizontal pull from sheet piling.

(vi) Fender piles and dolphins: Fender piles and dolphins are used to protect water front structure from impact of any floating object or ship.

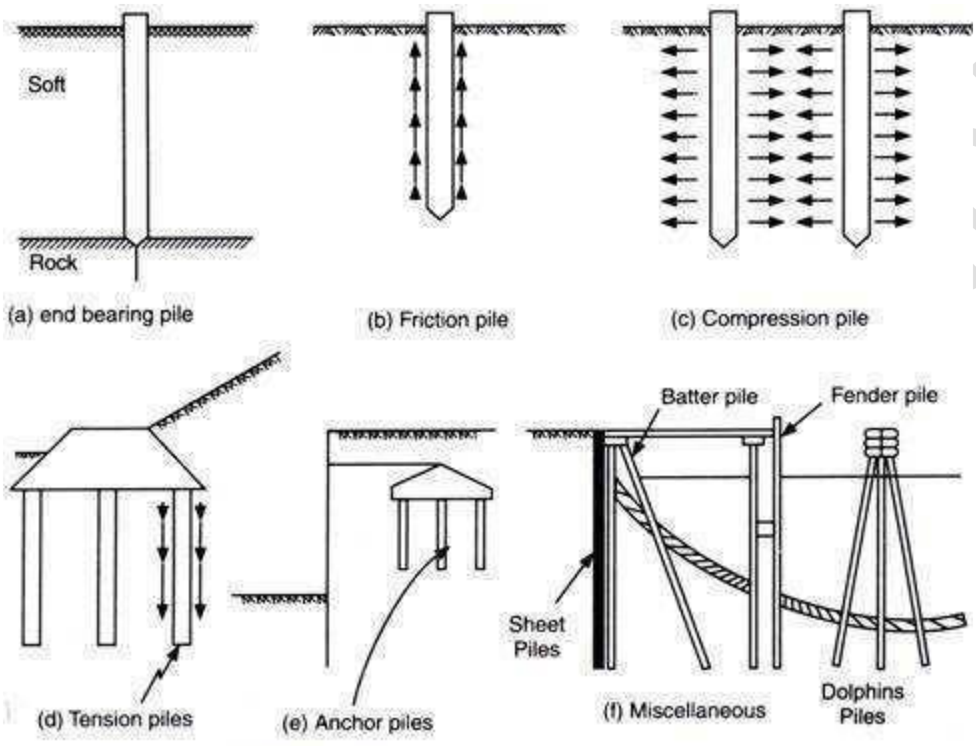


FIG. 11.15 Classification based on function

Well Foundations-Well foundation is a type of deep foundation which is generally provided below the water level for bridges. Caissons or well have been in use for foundations of bridges and other structures since ʻoman and Munhall periods. The term 'caisson' is derived from the French word cuisse which means box or chest. Hence caisson means a box like structure, round or rectangular, which is sunk from the surface of either land or water to some desired depth.

The caissons are of three types :(i) Box casino:It is open at the top and closed at the bottom and is made of timber, reinforced concrete or steel. This type of caisson is used where bearing stratum is available at shallow depth.

(ii) Open caisson (wells): Open caisson is a box opened both at top and bottom. It is made up to timber, concrete or steel. The open caisson is called well. Well foundation is the most common type of deep foundation used for bridges in India.

(iii) Pneumatic caissons has its lower end designed as a working chamber in which compressed air is forced to prevent the entry of water and thus excavation can be done in dry conditions.

Shapes of Wells:

The common types of well shapes are:

(i) Single circular

(ii) Twin circular

(iii) Dumb well

(iv)Double-d

(v)Twin hexagonal

(vi)Twin octagonal

(vii) Rectangular.

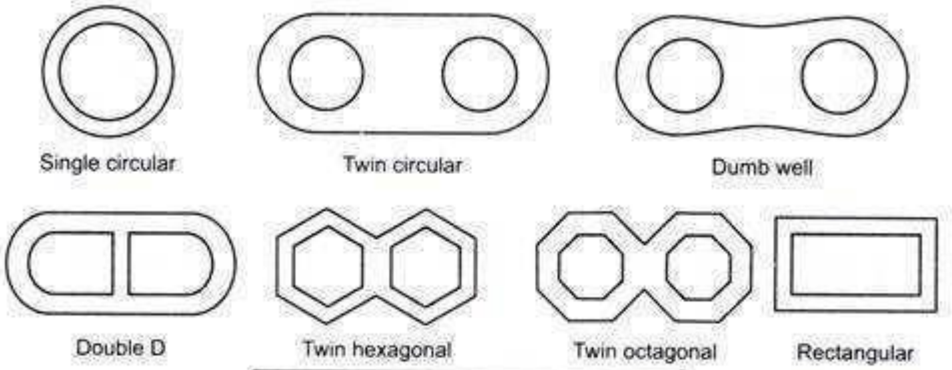


FIG. 11.30 Different shapes of wells

The choice of a particular shape of well depends upon the size of the pier, the care and cost of sinking, the considerations of tilt and shift during sinking and the vertical and horizontal forces to which well is subjected.

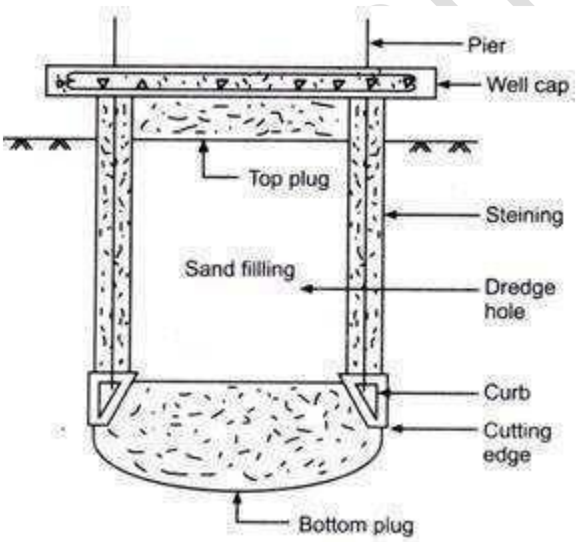


FIG. 11.31 Section of well foundation

A circular well has the minimum perimeter of a given dredge area. Since the perimeter is equidistant at the points from the center of dredge hole, the sinking is more uniform than the other shapes.

However, the circular well is that in the direction parallel to the span of bridge, the diameter of the well is much more than required to accommodate minimum size of pier and hence circular well obstruct water way much in comparison to other shapes.

Forces Acting On a Well Foundation:

In addition to the self-weight and buoyancy, it carries the dead load of superstructure, bearing and piers and subjected to the following horizontal forces:

(i) Braking effort of the moving vehicle.

(ii) Force due to the resistance of bearings against movement due to temperature variations.(iii) Force of water current(iv) Seismic forces(v) Wind force.(vi) Earth pressure.

Description of Parts (Elements) of Well:

1. Staining: It is the wall or shall of the well, made of R.C.C. and which transfer the load to the curb. It acts as an enclosure for excavating the soil for the penetration of well.

2. Curb: It is a R.C.C. ring beam with steel cutting edge below. The cross- section of the curb is wedge shaped which facilitates the sinking of the well. The curb supports well stewing. The curb is kept slightly projected from the stoning to reduce the skin friction.

3. Cutting edge:It is the lowest part of the well curb which cuts the soil during sinking.

4. Bottom plug:After completion of well sinking the bottom of well is plunged with concrete. The bottom plug which is confined by the well curb acts as a raft against soil pressure from below.

5. Back fill:The well is dewatered after setting of the bottom plug and it is backfilled by sand or excavated material.

6. Top plug:It is a concrete plug provided over the filling inside the well.

7. Well cap:It is a R.C.C. slab provided at the top of stewing to transmit the load of superstructure to the stewing and over which pier is laid. The minimum thickness of the slab is about 750 mm.

COFFER DAMS

INTRODUCTION

Cofferdams are temporary enclosures to keep out water and soil so as to permit dewatering and construction of the permanent facility (structure) in the dry.

• A cofferdam involves the interaction of the structure, soil, and water. The loads imposed include the hydrostatic forces of the water, as well as the dynamic forces due to currents and waves.

• In construction of cofferdams maintaining close tolerances is difficult since cofferdams are usually constructed offshore and sometimes under severe weather conditions. Under these circumstances, significant deformations of cofferdam elements may happen during the course of construction, and therefore it may be necessary to deviate from the design dimensions in order to complete the project according to plan.

• The loads imposed on the cofferdam structure by construction equipment and operations must be considered, both during installation of the cofferdam and during construction of the structure itself.

• Removal of the cofferdam must be planned and executed with the same degree of care as its installation, on a stage-by-stage basis. The effect of the removal on the permanent structure must also be considered. For this reason, sheet piles extending below the permanent structure are often cut off and left in place, since their removal may damage the foundation soils adjacent to the structure.

• In cofferdam construction, safety is a paramount concern, since workers will be exposed to the hazard of flooding and collapse.

• Safety requires that every cofferdam and every part thereof shall be of suitable design and construction, of suitable and sound material and of sufficient strength and capacity for the purpose for which it is used, proper construction, verification that the structure is being constructed as planned, monitoring the behavior of the cofferdam and surrounding area, provision of adequate access, light and ventilation, and attention to safe practices on the part of all workers and supervisors, and shall be properly maintained.

Types of cofferdam:

1. Braced: It is formed from a single wall of sheet piling which is driven into the ground to form a "box" around the excavation site. The box is then braced on the inside and the interior is dewatered. It is primarily used for bridge piers in shallow water (30 - 35 ft depth)

2. Earth-Type: It is the simplest type of cofferdam. It consists of an earth bank with a clay core or vertical sheet piling enclosing the excavation. It is used for low-level waters with low velocity and easily scoured by water rising over the top.

3. Timber Crib: Constructed on land and floated into place. Lower portion of each cell is matched with contour of river bed. It uses rock ballast and soil to decrease seepage and sink into place, also known as "Gravity Dam". It usually consists of 12'x12' cells and is used in rapid currents or on rocky river beds. It must be properly designed to resist lateral forces such as tipping / overturning and sliding.

4. Double-Walled Sheet Pile: They are double wall cofferdams comprising two parallel rows of sheet piles driven into the ground and connected together by a system of tie rods at one or more levels. The space between the walls is generally filled with granular material such as sand, gravel or broken rock.

5. Cellular: Cellular cofferdams are used only in those circumstances where the excavation size precludes the use of cross-excavation bracing. In this case, the cofferdam must be stable by virtue of its own resistance to lateral forces. Advantages of Cofferdam Performing work over water has always been more difficult and costly than performing the same work on land. And when the work is performed below water, the difficulties and cost difference can increase geometrically with the depth at which the work is performed.

COFFERDAM COMPONENTS:

• Sheet piling Sheet piling is a manufactured construction product with a mechanical connection "interlock" at both ends of the section. These mechanical connections interlock with one another to form a continuous wall of sheeting. Sheet pile applications are typically designed to create a rigid barrier for earth and water, while resisting the lateral pressures of those bending forces. The shape or geometry of a section lends to the structural strength. In addition, the soil in which the section is driven has numerous mechanical properties that can affect the performance.

• Bracing frame

• Concrete seal the typical cofferdam, such as a bridge pier, consists of sheet piles set around a bracing frame and driven into the soil sufficiently far to develop vertical and lateral support and to cut off the flow of soil and, in some cases the flow of water.

CHOICE OF MATERIALS FOR BRIDGE CONSTRUCTION

FOR SUPERSTRUCTURE-

1.Stone masonry arches-For road bridges of moderate spans Brick masonry arches- For culverts

2.Timber structures-For temporary bridges near forest areas and military bridges of small spans

3.Reinforced cement concrete-Slabs for small spans up to 8m.

4.For girders and T-beams-For spans in the range of 10 to 20m.

5.Hollow grids- For spans from 25 to 30m

6.Balanced cantilevers-For spans of 30 to 60m

7.Continuous Girders-For spans up to 40m

8.RCC arches-For span up to 200mm

9.RCC rigid frames -For spans up to 20m

10.Pre-stressed concrete girders-For major bridges with spans of 30 to 120m.

FOR SUBSTRUCTURE

1.Masonry-This can be of brick or stone

2.Steel-This can be used for piers formed by trestle bents

3.Cement concrete-Usually M20 is adopted for piers and abutments.

FOR FOUNDATION

1.Masonry-Coursed rubble masonry is used for spread footings in building of piers,Sometimes it is used for well foundation also.

2.Timber- For sheet-piling for temporary structure like cofferdams, and bracings for excavations

3.Steel- For grillage foundations consisting of steel girders and joists placed in both directions in the form of open structure.

4.Cement concrete- Used in spread foundations,either for footings,as also for the bottom bed, cast-in-situ piles,under-reamed piles.

TESTING AND STRENGTHENING OF BRIDGES:

The following list of strengthening methods

1. Replace existing deck with a lighter weight deck.

2. Provide composite action between deck and supporting members.

3. Increase transverse stiffness of bridge deck.

4. Replace deficient members.

5. Replace structurally significant portions of deficient members. Increase cross section of deficient members.

6. Add supplemental members.

7. Post-stress members.

8. Add supplemental spanning mechanisms.

9. Strengthen critical connections.

10. Add supplemental supports to reduce span length.

11. Convert a series of simple spans to a continuous span.

TESTING OF BRIDGES-

Testing of bridges becomes necessary if old bridges that have been in operation for sometime are affected to such an extent that the deficiencies are seen even on visual inspectionTesting is also essential in the case of newly constructed bridges in which new materials and /or new techniques of construction have been used.

TYPES OF TESTS-

1. BEHAVIOUR TEST
2. PROOF LOAD TEST
3. STRESS HISTORY TEST
4. ULTIMATE LOAD TEST
5. DIAGNOSTIC TESTS.

BRIDGE FAILURE-

Although absolute safety is not attainable for any structure including a bridge,every possible care should be taken in the design and construction of a bridge structure.This is because the failure of bridges,especially of major ones,entails interruption to traffic and failure of vital communication links and loss of human life and property.

CAUSES OF BRIDGE FAILURE

The failure of bridge is normally due to combination of several causes,defects and deficiencies.

1.Floods,scour and foundation movements.

2.Unsuitable or defective material or poor workmanship

3.Over loading and accidents

4.Inadequate temporary works during construction or improper erection procedure

5.Earthquake effects

6.Inadequate design procedures

7.Wind forces

8.Fatigue under traffic

9.Corrosion of steel components

INDIAN LOADING STANDARD FOR RAILWAY BRIDGES

The loads specified herein shall be taken into consideration in calculating the strength of all bridges, including turntable girders and foot-bridges but excluding road bridges in which case, the loads to be considered shall be in accordance with the Standard Specifications and Codes of Practice for Road Bridges (IRC Codes). The details of design shall be controlled by the appropriate Codes of Practice as given below:

(a) The design of steel bridges shall be in accordance with the Indian Railway Standard Code of Practice for the Design of Steel or Wrought Iron Bridges carrying Rail, Road or Pedestrian Traffic (Steel Bridge Code).

(b) The design of concrete bridges shall be in accordance with the Indian Railway Standard Code of Practice for Plain, Reinforced and Pre-stressed Concrete for General Bridge Construction (Concrete Bridge Code).

(c) The design of masonry and plain concrete arch bridges shall be in accordance with the Indian Railway Standard Code of Practice for the Design and Construction of Masonry and Plain Cement Concrete Arch Bridges (Arch Bridge Code).

(d) The design of sub-structures of bridges shall be in accordance with the Indian Railway Standard Code of Practice for the design of Substructures of Bridges (Bridge SubStructure Code). (e) The design of sub-structures and super-structures of road bridges shall be in accordance with Standard Specification and Codes of Practice for Road Bridges and other codes as specified by the appropriate authorities.

(f) The design of sub-structures and super-structures of rail-cum-road bridges shall be in accordance with the relevant Indian Railway Standard Codes of Practice except that the Standard Specifications and Codes of Practice for Road Bridges issued by the Indian Roads Congress may apply for the design of such members as are subjected to loads from road traffic alone.

NOTE: (1) Unless otherwise specified the word „Span‟ shall mean effective span.

(2) SI and Metric system of units are given in all cases, but only one system of unit is to be adopted for the design.

(3) Attention is drawn to the fact that equations in the text, for which no units are specified, are applicable in any system of units - SI or Metric provided the unit of length and the unit of force used in an equation are the same throughout. 1.2 Any revision or addition or deletion of the provisions of the Bridge Rules shall be issued only through the correction slip to these Bridge Rules. No cognizance shall be given to any policy directives issued through other means.

LOADS

For the purpose of computing stresses, the following items shall, where applicable, be taken into account:

(a) Dead load

(b) Live load

(c) Dynamic effects.

(d) Forces due to curvature or eccentricity of track

(e) Temperature effect

(f) Frictional resistance of expansion bearings

(g) Longitudinal force

(h) Racking force

(i) Forces on parapets

(j) Wind pressure effect

(k) Forces and effects due to earthquake

(l) Erection forces and effects

(m) Derailment loads

(n) Load due to Passer's Quick ʻelay System (PQʻS)

ERECTION OF BRIDGE GIRDERS

Erection of concrete bridge generally means erection of pre-stressed concrete bridges as erection of reinforced concrete bridges is rarely done. However, one reinforced concrete arch bridge was erected in Japan by means of a new construction method unprecedented in the world as claimed. A cantilever construction method was adopted in this bridge in which the segments formed of an arch rib, struts and floor slab were supported by pre-stressing steel bars and the over hanged bodies extended their length in stages from both the banks towards the center until the last segment is placed at the center .Erection of PSC beams can be done by the use of gantry. This method is suitable for land spans or in river bed, where the dry weather flow is small and is limited to a very small width of the bed. The height of erection is about 10 meters.The erection of PSC beams in the approach viaduct of the second Hooghly Bridge, Calcutta was done by the use of tilting derricks. Two derricks were used, one at each and of the girder, to lift the girder over the pier. These derricks were then tilted by releasing one of the guy ropes and tightening the other very slowly and carefully keeping both the guy ropes taut. The girder was then placed over the pier cap and side-shifted to its actual position by usual process. The pre-stressed concrete girders, 46.0 meters in length between centerlines of bearings were cast and stressed on the approaches, placed over two trolleys at two ends. The trolleys were than run over rail lines and the girders were brought near the abutments where a launching truss as shown in Fig. 24.6a was standing. Both ends of the girder were lifted from the trolley simultaneously and suspended from the bottom boom of the launching truss. The suspenders had a pair of wheel at top resting on the bottom boom through which the girders could be moved longitudinally. In this way, the girders were brought over the first span and lowered one by one by the use of sand jacks and side-shifted to their actual position.

EQUIPMENT'S AND PLANTS

1. Pneumatic/Hydraulic
2. Tools
3. Air Compressor/ Hydraulic Pump
4. Rock Drill/Jack Hammer/Other Drills
5. Concrete Breaker
6. Asphalt Cutter
7. Impact Wrenches/Nail Driver
8. Grinder
9. Concrete Vibrator
10. Circular saw/ Chain Saw
11. Road Broom
12. Aggregate Producer
13. Rock Crushers, Screen, and Conveyors
14. Central Mix Plant (Asphalt), (Batch Plant/Continuous Mix Plant)
15. Bitumen Decanter, Bitumen Heater
16. Bitumen Distributor
17. Portable Mix Plant
18. Pavers (Asphalt/Concrete)
19. Aggregate Spreader
20. Concrete Mixers/Concrete Batch Plant
21. Concrete Vibrator.

INSPECTION AND DATA COLLECTION

When they arrive at the project site, examine the beams/girders carefully for the following defects and report significant ones to the Project Administrator:

KINKS: Sharp bends in flange or web plates that do not reveal warps. Kinks are occasionally required by the design so check the plans before you report a kink as a defect.

WARPS: Wavy sections in flange or web plates that are an indication of buckling or excessive temperature effects caused by welding.

BENDS: Gradual curves in plates that are not indicated as being part of the design.

CRACKS: These are very serious defects when in a steel beam because they can grow and eventually cause sudden failure of a plate, which can cause collapse of the beam or even the entire superstructure.

PLUMBNESS: Using a Plumb Bob or square, check to see that flange plates are perpendicular to the web plate and that stiffener plates are perpendicular to top and bottom flange plates.

WELDED AND BOLTED CONNECTIONS: Examine all welds that join plates together, such as flange to web connections, for obvious welding defects and make sure that any bolted connections are properly assembled and that bolts appear to be snug. A loose bolt can be revealed by the sound it makes when lightly taped with a hammer.

HANDLING AND STORAGE: When the beams/girders arrive at the project site very often they are lifted from a truck or barge and are placed directly in their permanent position. You must make sure that the proper lifting devices are used and placed at the proper locations so that lifting stresses will not cause damage to the girder. These devices are usually special clamps that attach to the top flange. If they are used improperly, there can be damage structurally or to the beam's protective coating. Pay particular attention to box girders and curved girders since they can be larger, heavier, or far more unstable then single straight beams and are; therefore, more difficult to handle property. If the beams/girders are placed in a temporary storage site prior to permanent placement, they must be supported at least at the points of bearing shown in the plans and they must be high enough off the ground to avoid being submerged in, or being splashed by, water. The beams should also be kept free of dirt, oil, or any other detrimental contaminant

INTRODUCTION

Tunnels are underground constructions used for transportations. The tunnel engineering is one of the most interesting disciplines in engineering. The work is complex and difficult throughout its course, even though it is interesting.

The tunnels are defined as the underground passages that are used for the transportation purposes. These permit the transmission of passengers and freights, or it may be for the transportation of utilities like water, sewage or gas etc.

The operations and the constructions are carried out underground without disturbing the ground surface. This operation is called as the tunneling.

Selection of Tunneling Route

1. The two main factors that help in the efficient route of the tunnel are the alignment restraints and the environmental considerations.

2. The underground, as we know is heterogeneous in nature.

3. A proper inspection on the nature of soil, rock, the water table level, and all the alignment restraints had to be made before fixing the route.

4. The site chosen for tunneling is such a way that the inconvenience and difficulty that is caused to the environment in that area including living is minimum.

5. The tunneling method chosen depends on the ground conditions, the water table level, the tunnel drive length and the diameter, the tunnel depth, final utility requirements, the shape of the tunnel and the risk of construction.

Advantages of Tunneling

The tunneling method gain certain advantages compared with other methods, which are mentioned below:

- The tunneling procedure is more economical in nature, compared to open cut trench method when the depth is beyond a limit
- The surface life or ground activities like transportation are not disturbed when tunneling is undergone.
- The method ensures high-speed construction with low power consumption
- Reduces Noise Pollution
- These methods have freedom from snow and iceberg hazards, in areas of high altitudes
- Surface and air interference is restricted for tunnels
- Provision of tunnels with easy gradients, help in reducing the cost of hauling
- For the transportation of public utilities, tunneling method has a remarkable advantage

compared to the bridge.

- The dangerous open cut to a nearby structure, when it is needed, is solved by the tunneling method
- The tunneling grant greater protection in aerial warfare and bombing conditions

Tunneling Disadvantages

The tunneling method gains certain disadvantages, which is due to its complexity and difficulty. Some of them are:

- The initial investment cost for commencing the tunnel is high compared to the open cut method.
- Highly skilled and experienced designers and engineer team only will work best for this operation.
- Higher and constant supervision from the start to the end of the tunneling project is necessary without any compromise
- Highly sophisticated and specialized equipment are necessary to perform the tunneling operations.

Engineering surveys

Surveying Steps in Tunnels:

1. Surface Survey
2. Transferring the alignment under ground
3. Transferring levels under ground

1. Surface Survey:

This includes

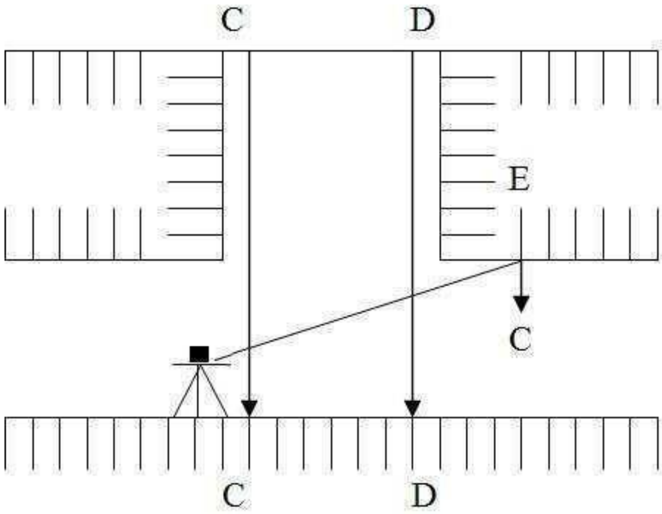
1. A preliminary survey by transit and staid for 2-3miles (3-4km) on either side of the proposed alignment.
2. A plan (map) with a scale of say 1 in with contours drawn at 5m (20) intervals.
3. Final alignment is selected form this plan.
4. A detail survey of the geological information of strata as the cost of tunneling depends upon the nature of materials to be encountered.

The proposed route having been decided upon, the following points require consideration.

1. Alignment of the center line of the tunnel.
2. Gradient to be adopted.
3. Determination of the exact length of tunnel.
4. Establishment of permanent stations marking the line.

2. Transferring the alignment underground

This is the most difficult and important operation in setting out a tunnel.



- Fix two timber beams C and D as shown in figure two across the top of the shaft near its edges perpendicular to the direction of tunnel and as far apart as possible.
- A threadlike is set up at a ground at a prêt ermined station on a center. Line mark one ground surface and another stations is again on the center line itself.
- The center line is very carefully set up on the beams preferably on the plates fixed on a beam and drilled with hole for suspending wires by repetition observing and averaging the result.
- From these pts. two long penal wire with heavy plumb hobs 10 to 15 kg attacked to their lower edges or suspended down the shaft.
- At the bottom these plumb bobs are immured in bucket of water, oil etc. to eliminate oscillation.
- Great care must be taken that wires and plumb bobs are hanging free. As a check the dist. b/w the wires at the top and at the bottom of the shaft is to be measured and this should be the same.
- The line joining the two wires gives the dir. of alignment underground.
- The-theologize is transfer to the bottom of shaft and through the no of trails suspended wires.
- Now the alignment is marked on marks driven into the whole i.e., E drilled on the roof.

3. Transferring levels underground-Leveling on the surface is done in the usual way and the levels are transfer underground at the ends of the tunnel from the nearest bench mark. In case of transfer of levels underground at the shaft. The steps involve are

- A fine steel wire loaded with weight of 5 to 15 kg is passed over a pulley (w) at the top of the shaft and is lowered into the shaft as shown in fig.3
- Tow fine wire AA and BB horizontally stretched at the top and bottom of the shaft rasp.
- The steel wired lowered into the shaft is so adjusted that it is in contact with both the wires AA and BB.
- The pts. of contact are marked on a still wire by a piece of chalk or by some other marker.

- The wire is withdrawn from the shaft and is stretched on the ground.
- The dist. b/t the two marks on the wire is measured using the measuring tape and this gives the level of the bottom of the shaft.

Alignment and Grade in Tunneling Process

Certain factors that must kept in mind in the tunneling procedures are:

- The best and economical alignment was chosen must be straight in nature
- Tunnel should have a grade, which is less than the outside. It is observed that in the railway tunnels, constant slipping of the wheels takes place due to the wetness of the rails. This reduces the hauling capacity of the locomotives.
- 0.2% gradient must be provided to ensure proper drainage.
- When it comes to long tunnels, two grades at the either ends must be provided (That rise from each end then towards the center as shown in figure-3).

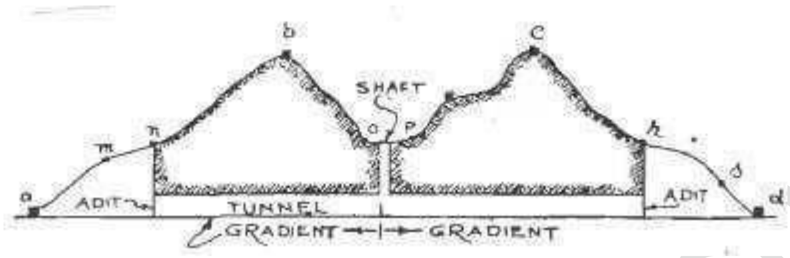


Fig.3: Surface Alignment and the provision of grade for the tunnel

- If the grade is provided on one side, instead of either side, the effectiveness of ventilation can be increased.

Size and Shape of a Tunnel

The size and shape of a tunnel depend upon the nature and type of ground it passes through and also on whether it is designed to carry a single or a double railway line. The shape of a tunnel should be such that the lining is able to resist the pressures exerted by the unsupported walls of the tunnel excavation.

If the ground is made up of solid rock, then the tunnel can be given any shape. Tunnels in rocky terrains are generally designed with a semicircular arch with vertical sidewalls. In the case of soft ground such as that consisting of soft clay or sand, the pressure from the sides and the top must be resisted. A circular tunnel is generally best suited for resisting both internal and external forces regardless of the purpose for which the tunnel is used. Theoretically, a circular section provides the largest cross-sectional area for the smallest diameter, which provides greater resistance to external pressure. But this type of cross section is more useful for drains carrying sewage and fluids and for aqueducts built for irrigation purposes. For railway track, the circular portion at the bottom of the tunnel has to be leveled in order to lay the track and facilitate the easy removal of muck and placing of concrete. The typical cross section of a tunnel is shown in Fig. 30.1.

Table 30.1 Shape and purpose of tunnels

Shape	*Purpose*
Circular	Water and sewage
Elliptical	Water and sewage mains
Horseshoe	Roads and railways
Arched roof with vertical walls	Roads and railways
Polycentric cross section	Roads and railways

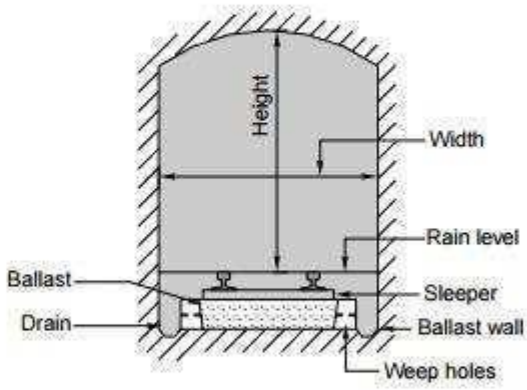
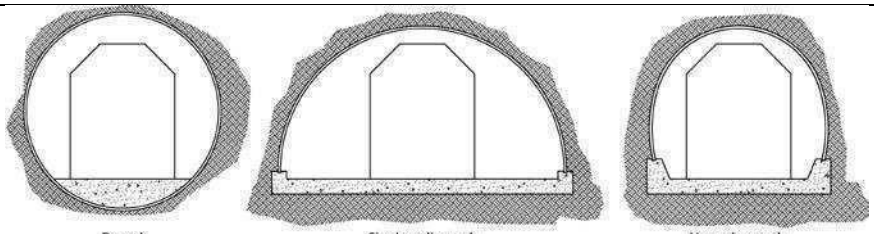


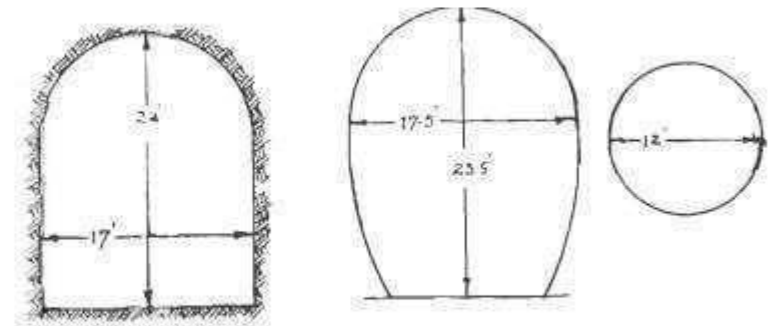
Fig. 30.1 A typical cross section of a tunnel

The shapes of tunnel linings are usually determined by their purpose, ground conditions, construction method and/or lining materials.

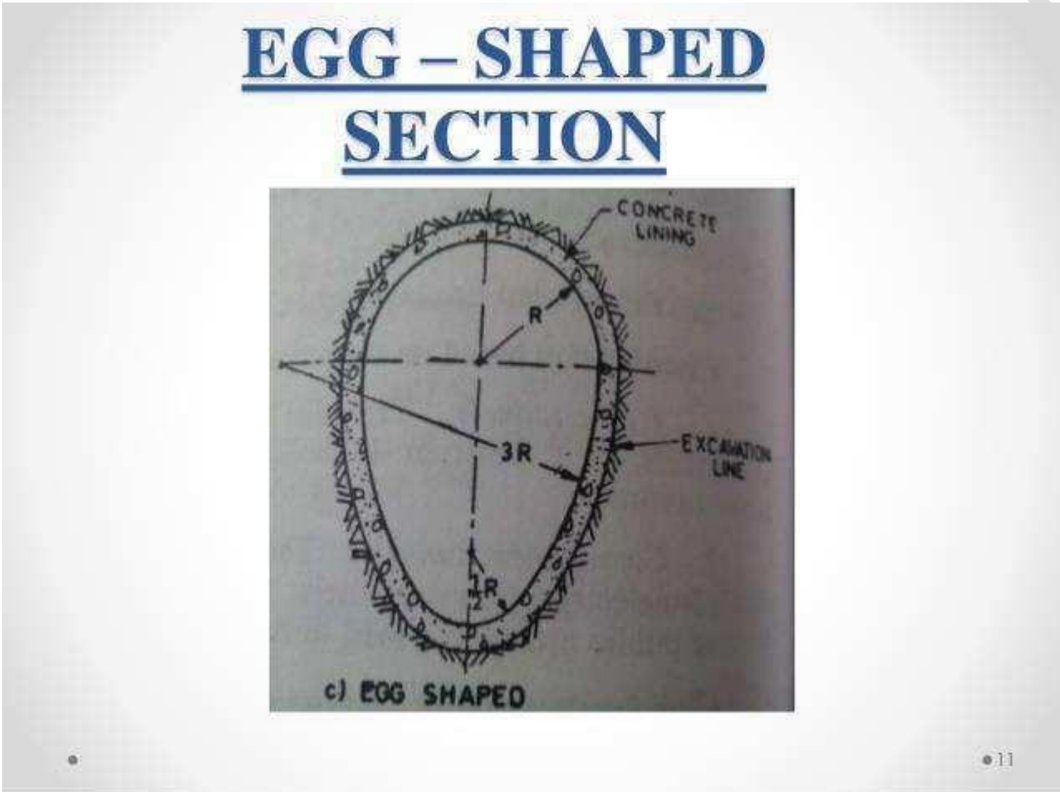
1. **Rectangular shape Rectangular shaped tunnels are usually adopted by the cut and cover method. It is particular suitable for pedestrian and highway tunnels. On the other hand, multi-lane submerged highway tunnels are often in rectangular shape.**
2. **Elliptical shape / Egg shape Elliptical shape tunnels have the advantages for the transportation of sewer. The smaller cross section at the bottom maintains the flow at the required self-cleaning velocity. However, due to the difficulty in construction, circular shape ones are more common.**
3. **Circular shape a circular shape tunnel has the greatest cross-sectional area to perimeter ratio. They are often associated with TBM or the shield tunneling methods.**
4. **Horseshoe / segmental shape they are commonly used for rock tunneling. It has the advantages of utilizing the compressive strength of concrete in resisting the loading by means of arch action and the base is wide enough for traffic.**



Round Single radius arch Horseshoe arch



Arch with straight sides. Horse shoe section. Circular section.



Approaches in Tunneling Method

There are two approaches based on the open cuts on the either ends of a slope. They are short approach and long approach. The approach is said to be short, when the hill slope is very steep in nature, as shown in figure.1.

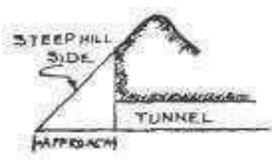


Fig.1: Short Approach in Tunneling

The approach is said to be very long, when the slope of the hill is very flat, as shown in figure.2. The cost of this mainly depends upon the topography of the considered area. In high altitudes, these approaches will be bounded with snow or may be blocked by the heavy landslides. These are the factors that would cause the decision of open cut or tunnel method.

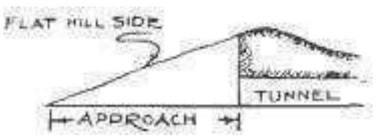


Fig.2: Short Approach in Tunneling

Shaft, Pilot Tunnel:

Shafts are the vertical tunnels, generally circular in section. In case of the hydro projects you have to construct the surge shafts to prevent the water hemorrhage. In the highway projects surge shafts are constructed from the top to reach down to the main tunnel and provides the access path to the main tunnels.

A numbers of shafts may be constructed at places more than one in a long tunnel project, and work may be started from those numbers of places. Diameter of a shaft depends upon the purpose of the shaft, if a TBM is to be lowered to the main tunnel than it is necessary to make the shaft of the required size.

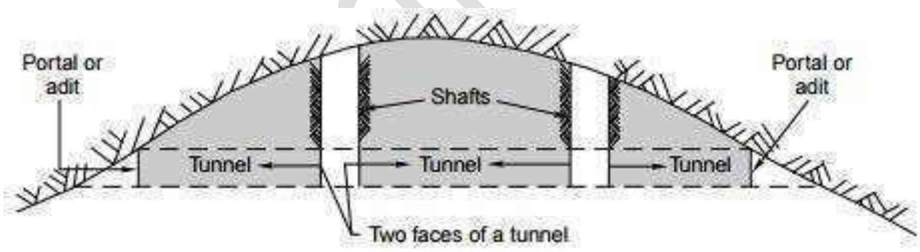


Fig. 30.11 Tunnel shafts

Definition of pilot tunnel

A small tunnel or shaft excavated in the center, and in advance of the main drivage, to gain information about the ground and create a free face, thus simplifying the blasting operations.

Similar to a shaft, Pilot tunnels serves as the access tunnels to the main tunnels. The cross section of a pilot tunnel is usually 240 cm or a little bigger and are driven parallel to the main tunnel. The pilot tunnel is first driven to the full length of the tunnel and is connected to the center line of the main tunnel at many points. From these points, the work of the main tunnel may be started and also they make is easy to take out the muck. Uses of the pilot tunnels may be summarized in the following points:

1. It helps in providing proper ventilation to the main tunnel.
2. It helps in removing the muck from the main tunnel quickly.
3. It helps in providing proper lighting in the main tunnel.

Pilot tunnels also offer a path to reach to the main tunnel so that you can access it to go for the further construction. Pilot tunnels are constructed generally parallel to the main tunnel, and when in connects to the main tunnel path, you get two faces/two directions to excavate your main tunnel.

Construction of tunnels in soft soil- Driving tunnels in soft ground

While tunneling in soft grounds, explosives are not used and tunneling is done with the hand tools such as pick-axes, shovels etc. During excavation operation supports for soil are required immediately depending upon the type of soil. In the old days, timber was the only material used for supporting soft ground till the introduction of the steel liner plates few years ago. As heavy supporting system is needed to support the roof and sides, there is more obstruction in the movement inside the tunnel, which reduces the progress of the work. Care should taken to ensure that all struts should be sufficiently strong to bear the pressure coming on them. The method to be adopted in the soft ground tunneling depends upon the type of ground.

- Needle beam method, sequence of construction operations

This method is useful for tunneling in the soft ground whose roof soil can stand without support for few minutes. In this method 5 to 6 meters long R.S. joist or timber beams are required in addition to other timber boards and struts. This method requires large number of jacks which cause obstruction in the efficient working of the laborers. For tunneling in soft ground it is more economical than other methods.

- Sequence of Working:

1. First of all a small drift of size of about 1*1 m is prepared on the working face of the tunnel.
2. The needle beam consisting of two I girders, bolted together with a wooden block at the center, is inserted in the drift and its roof is supported on lagging carried on the wooden segment as shown in the figure below. These segments are supported by jacks resting on the needle beam.

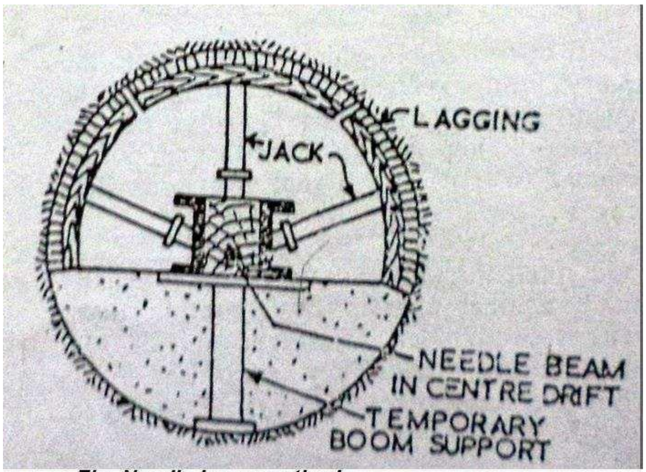


Fig. Needle beam method

Needle beam method- 1

3. As shown in the figure below, the needle beam is placed horizontally, whose front end rests on the drift itself and the rear end is supported on the vertical stout post, resting on the lining of the tunnel.

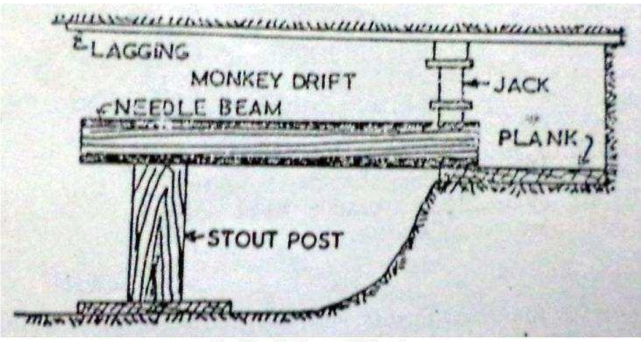


Fig. Needle Beam Method

Needle beam -2

4. The jack is placed on the top of the beam(Needle Beam) to support the roof with lagging and then drift is widened sideways and the whole section is excavated. After excavating lining may be provided.

- Compressed Air Tunneling Method:

This method is considered as most modern method of tunneling in soft grounds having water bearing stratum. A compressed air is forced into the enclosed space to prevent the collapse of the roof and sides of the tunnel.

Usually air is used in conjunction with a shield and air-tight locks. However, numerous small tunnels have been driven using only linear plates or wood cants only. This method can be safely adopted if the air pressure is approximately 1 kg/cm^2. If the pressure is more than 1 kg/cm^2, the working hours should be reduced considerably which will increase the cost of tunneling.

Application of the air pressure to the tunneling is not so simple due to the following reasons:

1. The earth pressure varies from the top of the tunnel to the bottom of the tunnel.

2. As the pressure in the floor of the tunnel depends upon the nature of the strata, it is difficult to ascertain it theoretically.
3. The value of pressure varies with the moisture content in different strata, which is difficult to ascertain.
4. The compressed air will escape through the pores of the soil, hence air pressure will diminish continuously. Thus the value of air pressure will have to vary from time to time to get a balanced value and the determination of this value depends more on experience than theoretical considerations.

This method is ideally suitable for clay formations which do not contain large number of pores and the pressure does not vary much from top of the tunnel to its bottom.

Construction of tunnels hard soil and rock- Tunneling in hard rock's is carried by one the following methods:

1. Full face method
2. Heading and benching method
3. Drift Method
4. Pilot tunnel method
5. Perimeter method

Here we will discuss the first three methods in details.

- **Full Face Method**

This method of tunneling is adopted when the length of the tunnel is more than 3 meters. Large sized tunnels in rocks are always driven by this method. With the development of drill carriage this method is becoming more and more popular. In this method vertical columns are fixed to the face of the tunnel to which a large number of drills may be mounted or fixed at any suitable height as shown in the figure below. A series of drill holes are drilled at about 120 cm center to center in any number of desired rows, preferably in two rows. The size of the holes may vary from 10 to 40 mm. These holes are then charged with explosives and ignited. The muck is removed before the next operation of drilling holes.

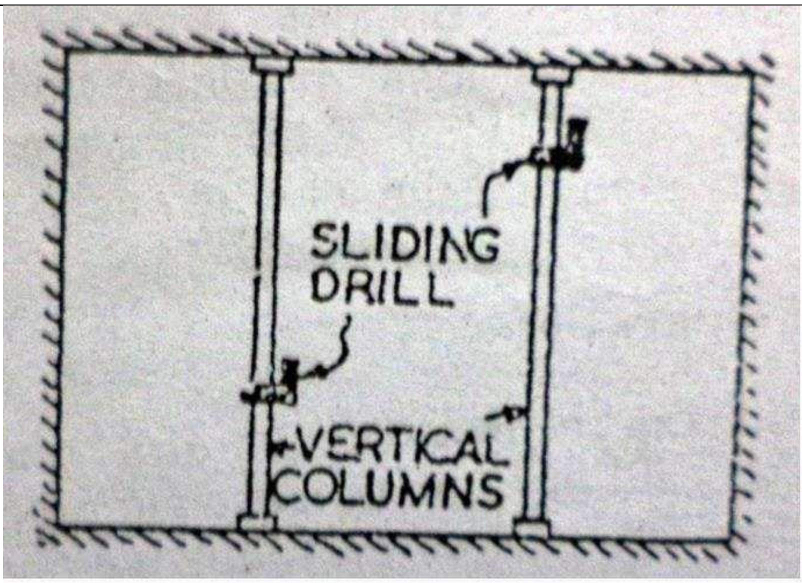


Fig. Full Face Method of Tunneling

- **Heading and Benching Method**

Tunnel cross section is divided into two parts, the top portion of the tunnel is known as the heading and the bottom portion as *bench.* Usually this method is adopted for railway tunnels. In this method of tunneling, top portion or heading will be about 3.70 to 9.6 m ahead of the bottom portion as shown in the figure below. In hard rock which may permit the roof to withstand without supports, the top heading generally is advanced by one round of bottom portion. If the rock is broken then heading may be driven well ahead of the bottom portion and after giving proper support to the roof, the bottom portion is completed. In hard rock the heading is bored first and the holes are driven for the bench portion at the same time as the removal of the muck. This required less explosive than the full face method, but due to the development of the drill carriage or jumbo, the use of this method is decreasing.

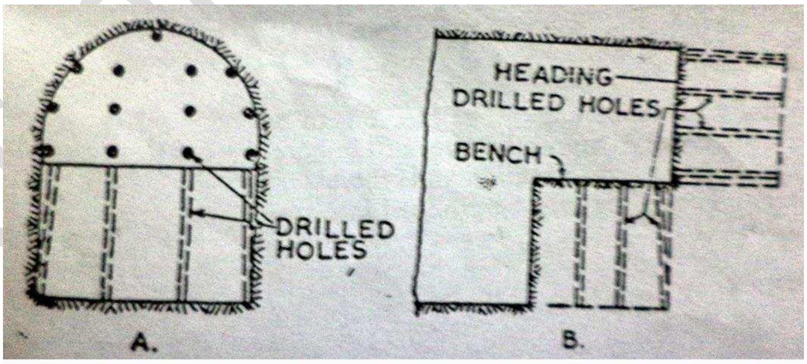


Fig. Heading and Benching (Tunneling)

Heading and Benching Method (Tunneling)

- **Drift Method:**

Drift is a small tunnel, usually its size is 3m*3m. In driving a large tunnel it has been found advantageous to drive a drift first through the full length or in a portion of the length of the tunnel prior to the excavating the full bore.

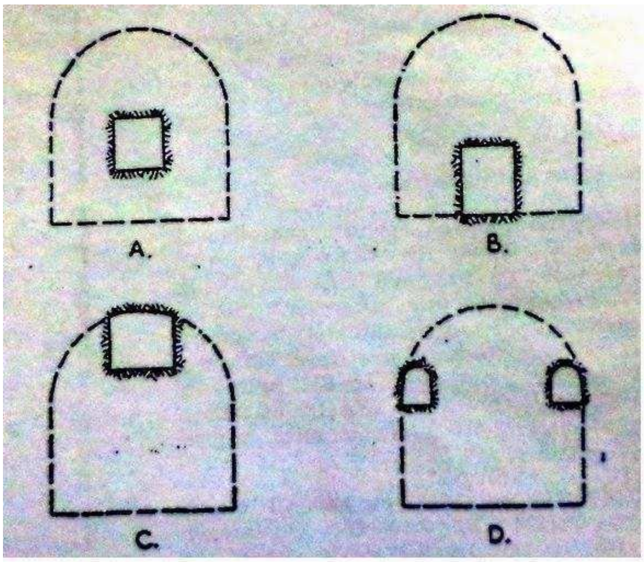


Fig. Drift Method of Tunneling

Drift Method (tunneling)

The drift may be provided at the center, sides, bottom or top as desired. In this method after driving the drift, the drill holes are drilled all-round the drift in the entire cross section of the tunnel, filled with explosives and ignited. The rock shatters, the muck removed and the tunnel expanded to the full cross section.

Different types of lining-

Lining of Tunnels

Tunnels in loose rock and soft soils are liable to disintegrate and, therefore, a lining is provided to strengthen their sides and roofs so as to prevent them from collapsing. The objectives of a lining are as follows.

(a) Strengthening the sides and roofs to withstand pressure and prevent the tunnel from collapsing.

(b) Providing the correct shape and cross section to the tunnel.

(c) Checking the leakage of water from the sides and the top.

(d) Binding loose rock and providing stability to the tunnel.

(e) Reducing the maintenance cost of the tunnel.

1 Sequence of Lining

The lining of a tunnel is done in the following steps.

1. In the first stage guniting is done to seal the water in rock tunnels.

2. Concrete lining is done either in one attempt as in the case of circular tunnels or by separately tackling the vest, the sidewall, and the arch. For small tunnels that measure 1.2 to 3.0 m in diameter, the concrete lining can be provided by the hand placing method. In the case of bigger tunnels, concrete pumps or pneumatic placers are used for placing the concrete.

3. The concrete is cured to its maximum strength. If the humidity inside the tunnel is not sufficient, curing can be done by spraying water through perforated pipes.

4. The different types of lining practices adopted by Indian Railways depending upon ground conditions are depicted in Fig. 30.12.

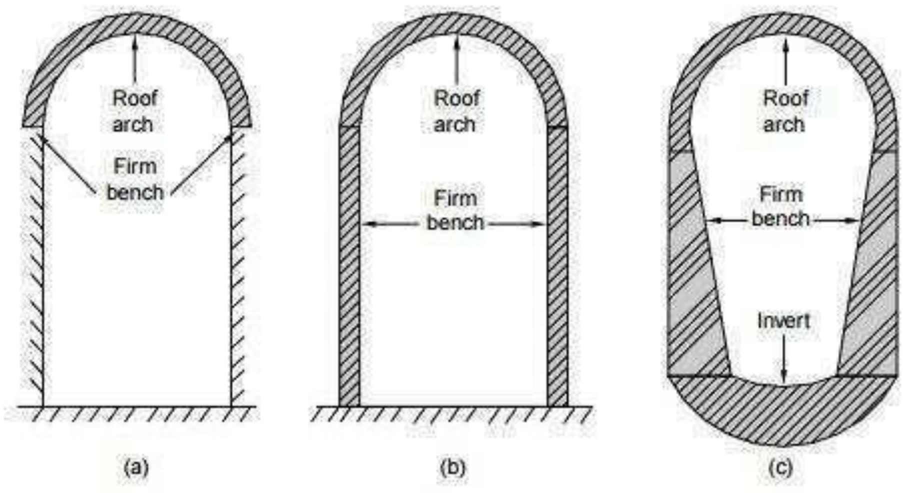


Fig. 30.12 Linings of tunnels

2 Types and Thickness of Lining

Theoretically, the lining provided inside tunnels may be of timber, iron, steel, brick, or any other construction material but in practical terms the lining provided most commonly is that of reinforced concrete or concrete surface. Concrete lining is provided in tunnels because of (a) its superiority in structural strength, (b) ease of placement, (c) its durability, and (d) lower maintenance cost.

The thickness of concrete lining depends upon various factors such as conditions of the ground, size and shape of the tunnel, soil pressure, and the method of concreting. The thickness of concrete is calculated by the following empirical formula:

$T = 0.083D$ (30.1) where T is the thickness of the lining in centimeters and D is the diameter of the tunnel in meters.

Drainage of Tunnels

Good drainage of the tunnels is very essential in order for them to operate safely and smoothly during the construction period as well as afterwards. The sources of water for this purpose include ground water and water collected from the washing of bore holes. Water seeping in up through the ground as well as from the washing of bore holes is collected in sump wells and pumped out. If the tunnel is long, a number of sump wells are provided for the collection of water.

After the construction is over, drainage ditches are provided along the length of the portion of the tunnel that slop from the portal towards the sump well and are used for pumping the water out.

Ventilation of Tunnels-The objectives of ventilation of tunnels are-

1. Removal of foul gases in tunnel which primarily evolve on blasting of explosives.

2. Removal of duct caused by drilling blasting and mucking operations.

3. Supply of fresh air to the tunnel workers who may be engaged in different construction activities.

Methods of ventilation –

1. Natural Ventilation

2. Artificial or Mechanical Ventilation.

Mucking operation-Mucking is the removal of debris from the blasting/excavation site in the tunnel to places outside. This is major element of tunnel construction, especially in the case of large tunnels. Hence efficient and quick removal of muck leads to overall economy. Initially, muck removal was done manually. Later on, various types of machines that run on compressed air or electric power were developed for this purpose.

Emico loader & Conway shovel are two such machines, which are fitted with a bucket/shovel at the leading end and are actuated by a jib crane.

Examples of existing important tunnels in India and abroad-

S.no.	Tunnel	Length in	Location	Purpose	Year

		KM			
1	Jawahar	2.50	Banihal J&K	Roadway	1956
2	Bhatan	1.05	Mumbai-Pune	Roadway	2000
3	Malabar	3.60	Expressway	Roadway	2014
4	Kmashet	1.00	Mumbai	Roadway	2000
5	Banihal	8.45	Mumbai-Pune	Roadway	2015
6	Patnitop	9.20	Jammu & Kashmir	Roadway	2016
7	Rohtang	8.80	Himachal pradesh	Roadway	2017
8	Parsik	1.60	Maharashtra	Railway	1916
9.	Saranda	2.00	Goikera-Jharkhand	Railway	1900
10.	Monkey hill	2.16	Karjal-Maharashtra	Railway	1982
11.	Karbude	6.50	Ukshi-Mahrashtra	Railway	1997
12.	Tike	4.30	Natuwadi	Railway	1997
13.	Ratnagiri	4.08	Ratnagiri	Railway	1997
14.	Panvel	2.83	Chowk	Railway	2006
15.	Khowai	2.48	Munigiabam	Railway	2008

Tunnels in other countries-

S.no.	Tunnel	Length in KM	Location	Purpose	Year
1	Laerdal	24.51	Norway	Roadway	2000

2	Zhongnaushan	18.04	China	Roadway	2007
3	St. gatthard	16.94	Switzerland	Roadway	1980
4	Ariberg	15.52	Austria	Roadway	1978
5	Mount Ovit	14.70	Turkey	Roadway	2015
6	Frejus	12.90	France-Italy	Roadway	1980
7	Mont blanc	11.60	France-Italy	Roadway	1965
8	Kan-etsu	11.00	Japan	Roadway	1991
9.	Duplex A-86	10.00	France	Roadway	2011
10.	Seikan Tunnel	53.85	Japan	Railway	1988
11.	Channel tunnel	50.50	UK France	Railway	1994
12.	lotschberg	34.60	Switzerland	Railway	2007
13.	Guadarrama	28.40	Spain	Railway	2007
14.	Taihong	27.80	China	Railway	2007
15.	Hakkoda	26.45	Japan	Railway	2005