UNIT-III

TRANSPORTATION ENGINEERING

Transport Engineering is the application of scientific and technological principles in the planning, functional design, operation and facilities management for any means of transport (road, rail, water and air) in order to provide a safe, fast, comfortable, convenient, economic travel for people and goods. Transport Engineering is connected to similar disciplines such as: Electrical Engineering, Mechanical Engineering, Aerospace and Marine Engineering.

The main branches of Transport Engineering are: traffic engineering, highway engineering, port and harbour engineering, airport engineering, infrastructure engineering. Academic study programmes include topics such as Transportation Safety and Design, Urban Planning, Traffic Engineering and Simulation, Highway Traffic Operations, Public Transportation Systems.

Transportation Engineering offer technological knowledge as well as an understanding of the economic, political, and social factors. It ensures that transportation systems contribute to the quality of life of the community. Transport Engineering students will obtain fundamental theoretical and practical knowledge to perform engineering calculations, demonstrations and applications using specialised transport engineering software. They will assess interdependencies between transport, urban and regional planning following requirements of sustainable mobility.

Forms of Transport:

There is not just a single mode of transport for people to travel; there are many. Let's have a look at different forms.The transport system has many forms like roads, railways, air, and water.

Road Transport:

Road transport is the oldest form of transport and comprises cars, hand-pulled rickshaws, bullock carts, auto, tempo, buses, etc. This is the transport where you need to use the roads. Short distances can be easily covered by using road transport, but only for long traveling, you will require other modes of transport like that of rail or air or water. Like if you want to travel overseas it is a fact that for the whole journey, you can not use road transport, you need to change your mode of transport.

Rail Transport:

In India, the central government owns and manages the railway system. This system has numerous benefits, as outlined below:

- It can be used for transporting bulky goods. Often the bulky goods can not be traveled through roads and for that, you are required to use this mode of transport only.
- Rail transport is less polluted. As compared to other modes of transport, trains cause very less pollution.
- It is economical for traveling longer distances. If you want to travel long distances then the road or air mode of transport is going to cost you a lot so you can say this is the cheapest means of transportation.

Water Transport:

India has a long coastline as it is surrounded by water with the Bay of Bengal, the Indian Ocean, and the Arabian sea bordering the country. Water transport in the form of the movement of goods and people on waterways is common in India. Water transport carries people and goods within, as well as outside of the country. Although it doesn't sound that interesting, traveling through water is the kind of experience that you should go for.

Air Transport:

Air transport is the fastest means of transportation and in India is a relatively recent development. Air transport is also the costliest means of transportation in general. The Indian air transport now ranks amongst the fastest growing aviation sectors in the entire world. If you want to reach a place a bit early or even if you are looking for an adventurous ride you should go for air transport. It provides you with a safe journey over long distances.

Importance of Transportation in Nation's economic Development:

When you are defining a transport system, you can define it as a set of relationships that occurs between sets, networks and demand. All the components of transport are designed in such a way so that the movement of passengers, freight and information can be facilitated either as a separate component or as joint components.
First let's get information about what the basics of this transport system is, then we will move towards its relationship with economic growth.

Firstly the Transport System Includes the:

- **Demand:** This you can say is the derived function that ensures the mobility of people, information and a variety of activity
- **Nodes:** These are the points where the movements are basically generated, transmitted or ended, that is it is the exit or entering point in a transport system. There is variation in them according to the geographical systems
- **Network:** It talks about linkage that is connecting the places with the capacity to hold the passengers or information
- **Locations:** These are the nodes where demands are expressed as origin, destination or they are expressed as a point of transit. In simple language, it defines demands and where it is taking place
- **Flows:** This is basically the amount of traffic over a network that is composed of different nodes and linkages
- **Infrastructure:** It is basically the reality of a network. The conveyance such as roads and terminals can be mentioned in this infrastructure

Here we get to know about the transport system in brief and the details will show up further in this article. Now let's look at its role in economic development.

Transport System and Economic Development:

The Transport System and Economic Development are tightly coupled with each other. A well-knit transport system that is well-coordinated contributes to the sustained growth of any country. One can say that it is the transport routes that govern the basic arteries of the economic system of a country. It is the link between production and consumption; hence a transport system can also be deemed as the controller of the national economy. A country is progressing if there is transport moving in and out of it. This article will look closely into the elements of a transport system and see how the Transport System and Economic Development in India are interrelated.

If a product is produced at a place it is necessary for the producer to make that product to reach its consumer. For that this transport system will work. Let's take an example: if you have ordered anything online from an app, your producer will produce the product and this app will have its own delivery people who will transport your product to your doorstep. This provides them with the money and you with the thing of your necessity, it is as simple as that. Thus, it will only play a role in increasing the economic growth of the country also.

Role of the Transport System in Daily Life:

A transport system plays a vital role in providing and improving access to different parts of a geographical region which is important for businesses as well as individuals. A transport system supports both freight and personal movements. In the business sector, the business and supplier or the business and the market need an efficient transport system to work smoothly. In the household sector transport is used as the means to go to offices, schools, shops, etc. The transport system is used widely by individuals for personal and leisure activities as it connects them to recreational, social, and medical facilities.

Even for the people who are required to travel or for normal people who are going to their work daily, they use the method of transport to travel to their workplace and this transport can be anything: a bike, a car, a bus or anything that will make the person reach their destination.

The transport system is the main thing that connects people all around the world. If you want to meet someone, then also you are going to take help from the transport system. All the things in this world now seem to be impossible without a transport system. Thus, it is the basic necessity of all people across the world.

The Economic Importance of the Transport System in India:

In a country like India, which is the size of a continent, the importance of efficient, dependable, affordable, and safe transport facilities is very high. The commercial markets in India and the economic resources are dotted across the length and breadth of the nation. Below are mentioned some of the important roles that the transport system plays in the economic development of India:

- **Moving Inputs and Outputs**

The entire production system of India depends on the seamless movement of inputs like raw materials, machinery, fuels, etc. In a similar manner, the output from various sectors needs the transport system to bring them to the market. Thus, the transport system in India is key in raising the volume of production of different sectors of this country.

- **Mobilizes Labor**

Labor can move smoothly between different regions of the country, which helps in the expansion of industries. It also provides jobs to workers and opens up gainful employment opportunities for the unemployed laborers of India.

- **Enhances Specializations**

Concerning production, the transport system is clearly promoting geographical specialization. By developing the market for a variety of products in distant parts of the country, transport increases the extent of the market, thereby facilitating specializations.

- **Opening Inaccessible Regions**

The vast and unexplored resources of our country (forest, mineral, agricultural wealth) lie in many remote regions. Roads and railways are making it possible to venture into these areas and tap into their potential.

- **Enriching the Outlook of People**

The cultural, political, and social outlook of people is getting widened by the transport system. It helps in removing superstitions, conservative attitudes, and ignorance amongst various sections of society.

What is a pavement?

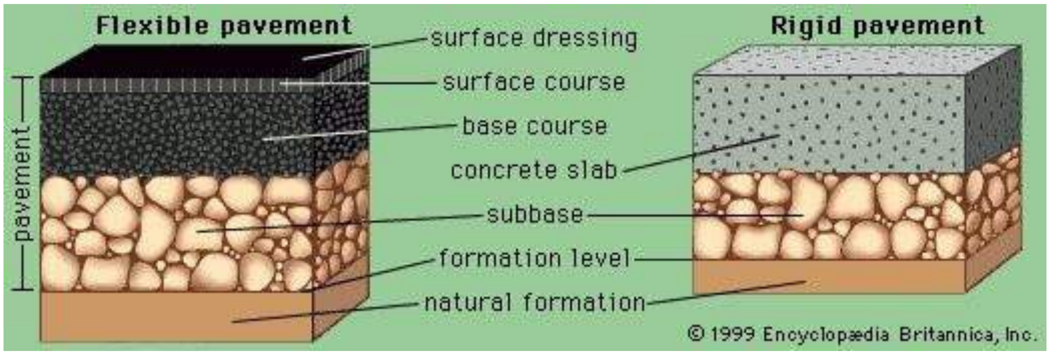
The pavement is the part of the road that carries the traffic (not to be confused with the footpath), and has a set of layers or material placed over the natural ground (subgrade). The pavement layers spread the load of the vehicles so that it does not exceed the strength capacity of the subgrade.

The challenge for the pavement engineer designing the road is to select the right material and layer thicknesses so that the pavement will be serviceable for the full design life. When discussing the strength of road paving, we usually measure this in the number of vehicles they can support.

Once we know the requirements of the road paving in terms of supporting traffic and how long it should ideally last, the next step is to set out the specifications for construction. In addition to the materials and layer thickness, the type of pavement (rigid or flexible) is also a key design choice.

Types of pavement in road construction:

There are two main types of road surfaces and pavement construction methods: **rigid pavement** (consisting of one layer) and **flexible pavement** (typically made up of multiple layers). Pavements are often made of materials such as asphalt or concrete. But they can also be constructed from artificial stone, flagstone, cobblestone, bricks, tiles or even timber.



Cross section of modern pavements.

(Left) Flexible asphalt-based pavement.

(Right) Rigid Portland cement concrete pavement.

Rigid pavements:

When rigid pavements are constructed, a reinforced or unreinforced in-situ concrete slab is laid over a granular subbase. Loads are supported by the flexural strength of the pavement, which acts like a stiff plate, transferring the load over a wider area of subgrade. Concrete roads are a rigid road paving type, and there will usually be joints in the concrete to control cracking.

Much of the US Interstate network and European highway network use concrete construction, although it has been much less popular in the UK. Concrete road pavements can handle very heavy traffic flows and high axle loads. They are now more common in urban areas, ports and locations, where heavy trucks travel slowly. The design life of rigid pavement is typically 40 years, with failure usually occurring due to cracking of the slabs, or degradation at the joints.

Advantages of Rigid Pavement:

- Longer lifespan
- Maintenance costs are low
- Allows for future asphalt resurfacing
- Allows for wider load distribution with fewer base and sub base requirements
- Can be installed on low- and high-quality soils
- Strong edges that don't require additional edging work or curbs
- Resistant to damage from oil spills and chemicals

Disadvantages of Rigid Pavement:

- Initial installation fee is expensive
- Cost of repairs is expensive
- Low and very rough riding quality
- Support joints are required for concrete contraction and expansion in various conditions

Flexible pavements:

Flexible pavements are the most commonly used pavement type in road construction in the world. They typically have multiple layers, often with road asphalt making up surface layers. With flexible pavements, wheel loads are transferred by particle-to-particle contact of the aggregate through the unbound granular layers. The pavement is supported by and protects the subgrade below the pavement.

Asphalt roads are constructed using flexible pavement. Also included within the flexible pavement type are gravel roads, which are common across the globe in rural areas, farm-to-market roads, quarries and access roads.

Flexible road construction:

In flexible road construction, one or more layers of selected granular material are laid and compacted over the subgrade. As-dug, naturally occurring materials are often used, but greater performance is gained by using manufactured, crushed aggregates.

With crushed aggregate (unpaved) roads, one or more layers of manufactured, crushed aggregate will form the pavement, with the crushed rock having angular particle shape with a defined range and mix of particle size. The layers are wetted to aid compaction, allowing the particles to interlock and densify. Where multiple layers are used, the lower layer is of a coarser grading, while the upper layer is finer textured granular material.

Bituminous pavements are flexible. Bitumen is used to bind aggregate particles together to form a flexible, strong, and waterproof layer. The mixture of aggregate and bitumen is called asphalt concrete (or asphalt or tarmac for short). Aggregate roads can be given a thin, flexible surface of bitumen-bound stone that will prevent dust, provide waterproofing, reduce maintenance, and provide a safer driving surface. Bitumen is sprayed on and stone chippings spread over the surface and bound in place by the bitumen.

By far the most commonly adopted construction type for urban and network roads is the layered flexible bituminous pavement. The pavement is built up with one or more unbound aggregate layers, the subbase, followed by either an unbound granular base or road asphalt base layer. Above this is the asphalt binder course and finally the asphalt surface course. The base course and binder course provide most of the structural support while the surfacing provides a smooth waterproof riding surface with high skid resistance.

The design life of bituminous flexible pavements is normally 20 years. Failure sometimes occurs due rutting, cracking, or ageing of the asphalt layers or failure of the subgrade leading to deep rutting. Regular maintenance of the surfacing layer can greatly prolong pavement life.

Advantages of Flexible Pavement

- Can be applied during pre-construction stage
- Repairs are easy and it can be opened and patched
- Materials are inexpensive

- Frost heave and settlement can be easily repaired
- Resists ice glaze formation
- Short curation time means short traffic and business disruptions
- No joints required during installation

Disadvantages of Flexible Pavement

- Shorter lifespan than rigid pavement
- Frequent maintenance required, which drives up the cost
- Susceptible to oil stains and damage from other chemicals
- Edges are weak and therefore require curb structures or edging

Earthworks in road construction:

Earthworks refers to any activity or work that is done to create a space where the roads can be built. Adequate earthworks ensure the longevity of the road being built and help to prevent the need for maintenance and repairs in the future.

The ‘cut-and-fill’ process is typically used for earthworks in road construction. First, the material is excavated from the site. It is then transported nearby and used to create embankments. The cut-and-fill method minimises the amount of construction labour and conserves the excess material reducing soil disposal.

Road excavation method:

Road or highway excavation involves the removal of topsoil and vegetation to expose the desired ‘formation level’. Excavation in road construction is typically done using a bulldozer or tractor shovel. The strength of the subgrade below the formation level will then be tested and stabilised if deemed unstable.

Soil or rock that was removed from its natural location is transported to the fill locations to either create a level surface or to create embankments.

Difference Between Flexible Pavement And Rigid Pavement

Flexible Pavement	Rigid Pavement
Low initial cost.	High initial cost.
The wheel load is transferred by grain to grain mechanism.	The load is distributed by the slab action mechanism.
Have low flexural strength.	Have sufficient flexural Strength.
Less durable.	More durable.
Short service life, usually 15 years.	Long service life, more than 30 years.
Joints are not required.	Essentially require joints.

Have many layers of materials.	Have only one layer.
Require frequent repairing.	Do not require frequent repairing.
High repairing and maintenance costs.	Low repairing and maintenance costs.
Damaged by oil and chemicals.	No damage by oil and other chemicals like greece.
Design based on subgrade strength.	Design based on flexural strength.
Temperature variations do not produce stresses.	Temperature variations produce heavy stresses.
Deformation in the sub-grade is transferred to the upper layers.	Deformation in the sub-grade is transferred to the subsequence Layers
The thickness is more.	The thickness is less.
Constructed using bituminous materials like asphalt.	Constructed using portland cement.
Can be opened to traffic shortly after construction.	Require curing, which delays the opening to traffic.
Provides poor night visibility due to the color of asphalt.	Concrete offers good night visibility.
More resilient to vehicle loads.	Less resilient to vehicle loads.
Suitable for all types of traffic.	Noisy under iron-wheeled traffic.
Corrugations are developed.	No corrugations are developed.
Provides more tractive resistance.	Less tractive resistance than flexible pavement.
Easy to lay, locate or repair underground pipes below flexible pavements.	Difficult to repair underground pipes below rigid pavements.
No glare due to sunlight.	Glare due to reflected sunlight.
Stage development is practicable.	Stage development is not practicable.
Require good subgrade.	Good subgrade is not necessary.
Normal skill and less supervision are required.	Skilled workers are required.

Airport:

An **airport** is an aerodrome with extended facilities, mostly for commercial air transport. Airports usually consist of a landing area, which comprises an aerially accessible open space including at least one operationally active surface such as a runway for a plane to take off and to land or a helipad, and often includes adjacent utility buildings such as control towers, hangars and terminals, to maintain and monitor aircraft. Larger airports may have airport aprons, taxiway bridges, air traffic control centres, passenger facilities such as restaurants and lounges, and emergency services. In some countries, the US in particular, airports also typically have one or more fixed-base operators, serving general aviation.

Operating airports is extremely complicated, with a complex system of aircraft support services, passenger services, and aircraft control services contained within the operation. Thus airports can be major employers, as well as important hubs for tourism and other kinds of transit. Because they are sites of operation for heavy machinery, a number of regulations and safety measures have been implemented in airports, in order to reduce hazards. Additionally, airports have major local environmental impacts, as both large sources of air pollution, noise pollution and other environmental impacts, making them sites that acutely experience the environmental effects of aviation. Airports are also vulnerable infrastructure to extreme weather, climate change caused sea level rise and other disasters.

Classification of Airports of India - List of Domestic and International Airports In India

There are four different types of airports in India and they are classified as International airports, custom airports, domestic airports, airports in India list, and civil Enclaves in Defence airports.

International airports: These are declared international airports and are available for scheduled international operations by India and foreign carriers. There are 34 International airports in India.

Custom airports: These airports have custom and immigration facilities for limited international operations by national carriers and for foreign tourist and cargo charter flights. It is an airport notified by the appropriate customs authority of the country as an airport for the uploading of imported goods and the loading of exported goods or any class of such goods. This place shall be an inland container of depots for the unloading of imported goods and the loading or clearance of exported goods or any such class of goods. There are 10 custom airports in India.

Domestic airports: Domestic airports are airports that are available only for the handling of domestic flights. Domestic flights are the ones that fly within the country. There are 103 domestic airports within the country.

Civil Enclaves in Defence airports: There are 26 civil enclaves in Defence Airfields. A civil enclave is an area at a military airbase allotted for the usage of civil aviation. Air traffic control at civil enclaves is usually entrusted to the armed forces or it may be a joint civilian-military crew.

CHAPTER I

HARBOURS

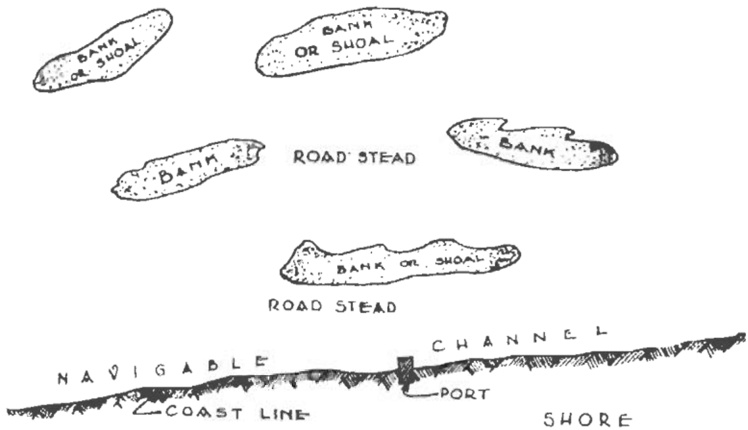
As navigation developed, ships felt the necessity to find shelter during their cruise and thus arose the creation of havens, where ships could take in and discharge, passengers and cargo, under protected conditions. Such a place of refuge is called a *Harbour*. As methods of navigation improved, these vessels gradually increased in size, number and importance; then arose the imperative need for providing suitable and commodious accomodation. Harbours are broadly classified as: (1) Natural and (2) Artificial.

Natural harbour: Natural formations affording safe discharge facilities for ships on sea coasts, in the form of creeks and basins are called *Natural harbours*. With the rapid development of navies engaged either in commerce, or war, improved accommodation and facilities for repairs, storage of cargo and connected amenities had to be provided in natural harbours.

Artificial harbours: Where such natural facilities are not available, countries having a sea board had to create or construct such shelters making use of engineering skill and methods and such harbours are called *Artificial harbours*.

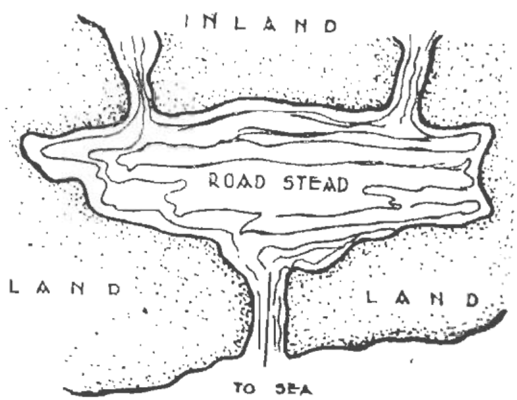
Thus, a naval vessel could obtain shelter during bad weather within a tract or area of water close to the shore, providing a good hold for anchoring, protected by natural or artificial harbour walls against the fury of storms — such good berthing conditions constitute a *roadstead*. Such roadsteads could be naturally available or artificially created.

Natural roadsteads: (i) A deep navigable channel with a protective natural bank or shoal to seaward is a good example of a *natural roadstead* as shown in fig. 1.



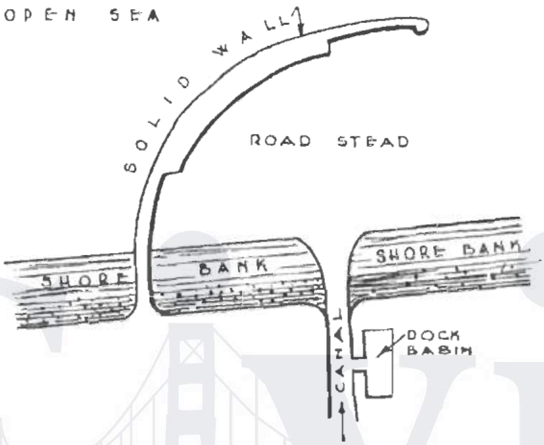
Natural roadstead.
FIG. 1

(ii) A confined area naturally enclosed by islands as in a creek if available is known as a *circumscribed natural roadstead* (fig. 2).



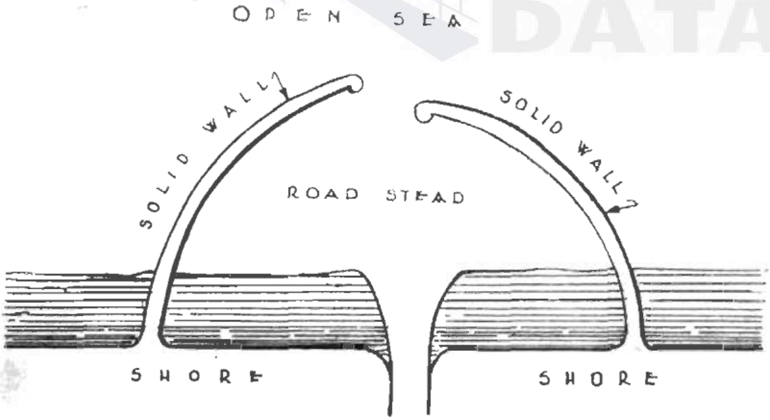
Naturally circumscribed roadstead.
FIG. 2

Artificial roadsteads: (i) These may be created suitably by constructing a break water or wall parallel to the coast or curvilinear from the coast (fig. 3). As an alternative a *circumscribed*



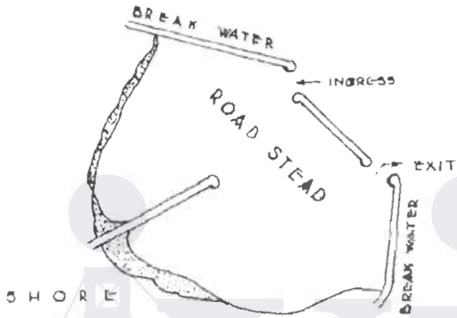
Artificial roadstead.
FIG. 3

artificial roadstead could be formed by enclosing a tract providing good anchorage, by projecting solid walls called jetties, from the shore (fig. 4).



Artificially circumscribed roadstead.
FIG. 4

(ii) Another method is to create a *confined basin* of small area having a narrow entrance and exit for ships. Such roadsteads with smaller inner enclosures and wharf and with loading and unloading facilities are commonly provided for fishing vessels (fig. 5).



Confined basin.
FIG. 5

From their utility and situation harbours are further classified into three major types, viz,

(i) Harbours of refuge including Naval bases.
(ii) Commercial harbours, connected with ports.
(iii) Fishery harbours:

It is necessary to study the requirements of these types and provide for them.

Requirements of harbour of refuge:

(i) Ready ascessibility.
(ii) Safe and commodious anchorage.
(iii) Facilities for obtaining supplies and repairs.

On dangerous coast-lines, disabled or damaged ships, under stress of weather conditions will need quick shelter and immediate repairs. All types of naval craft, small and big will need refuge in an emergency and hence such refuge harbours should provide commodious accommodation. Modern big ships will require a lot of elbow room for purposes of manouvering or turning about.

Requirements of commercial harbour:

(i) Spacious accommodation for the mercantile marine.
(ii) Ample quay space and facilities for transporting, loading and unloading cargo.
(iii) Storage sheds for cargo.
(iv) Good and quick repair facilities to avoid delay.
(v) More sheltered conditions as loading and unloading could be done with advantage in calmer waters.

Commercial harbours could be situated on coasts or estuaries of big rivers or even on inland river coasts. They do not normally have any emergency demand like a harbour of refuge and practically the size and number of ships using such harbours are known factors.

Requirements of fishing harbour:

(i) Harbour should be constantly open for departure and arrival of fishing ships.
(ii) Loading and unloading facilities and quick despatch facilities for the perishable fish catch like railway sidings and roads.
(iii) Refreigerated stores with ample storing space for preserving the catch.

Accessibility and size of harbours: Accessibility depends on the location of the harbour. The harbour entrance should be designed and located for quick easy negotiation by ships, overtaken by storms. At the same time, it should be narrow enough not to expose the harbour to the effects of the stormy sea. Maximum dimensions up to 600′ have been adopted. The entrance is generally placed to receive the ship direct from the worst storm affected part of the sea, with a passage to the interior of the harbour so arranged to minimise the effect of rough seas.

Size of harbour depends upon the number and size of ships likely to use the harbour at one time. Some of the biggest modern ships are 900′ to 1000′ long and about a 100′ wide and there should be sufficient area to manoeuvring them, without collision. Thus, the size is determined by,

(i) Accomodation required.
(ii) Convenience for manoeuvring and navigation.
(iii) Adaptability to natural features.

Regarding the entrance width the narrower the entrance the better is the interior portected, consistent with easy and quick entry or exit of the biggest vessel using the harbour. Even when the break waters are high enough to protect the harbour, waves from outside the harbour, set up diminutive waves inside the harbour depending on the entrance widths. The following empirical formula with a limited application is sometimes used in the design of entrances.

$$h = H \left\{ \tfrac{1}{2} - \cdot 02^4 \sqrt{D} \left(1 + \sqrt{\tfrac{l}{L}}\right) \right\}$$

Where H is the height in feet of unrestricted wave at the entrance mouth of width l feet, h the reduced height of the diminitive wave inside the harbour at a distance D' from the mouth and where the harbour is L feet wide. This formula is applicable to a distance of 50 feet from the entrance and where the harbour is well protected by a vertical sea wall.

Tides during ebb cause scour in a narrow entrance, likely to undermine foundations of sea walls and this factor has also to be considered in the design.

CHAPTER III

BREAK WATERS

Break water: The protective barrier constructed to enclose harbours, and to keep the harbour waters undisturbed by the effect of heavy and strong seas are called break waters. Such a construction makes it possible to use the area thus enclosed as a safe anchorage for ships and to facilitate loading of cargo in comparatively calm waters.

Sometimes the inner side of a break water is constructed as a Quay for cargo handling and is known as a Mole.

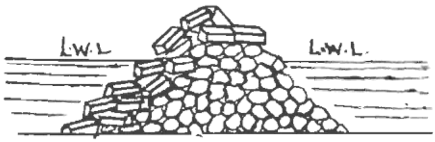
Classification of break waters: Break waters are classified mainly into: (i) heap or mound break water, (ii mound with superstructure and (iii) upright wall break water.

(1) *Heap or mound break water* is a hetrogeneous assemblage of natural rubble, undressed stone blocks, rip rap, supplemented in many cases by artificial blocks of huge bulk and weight, the whole being deposited without any regard to bond or bedding. This is the simplest type and is constructed by tipping or dumping of rubble stones into the sea till the heap or mound emerges out of the water, the mound being consolidated and its side slopes regulated by the action of the waves. The quantity of rubble depends upon the depth, rise of tides and waves and exposure. On exposed sites the waves gradually drag down the mound, giving it a flat slope on the sea face. As far as possible such flattening has to be protected.

The disturbing action of the waves is most between the high and low water levels. Consequently, all protective methods are adopted above the low water level. Protection is also very necessary to the top of the mound and outer, or exposed face.

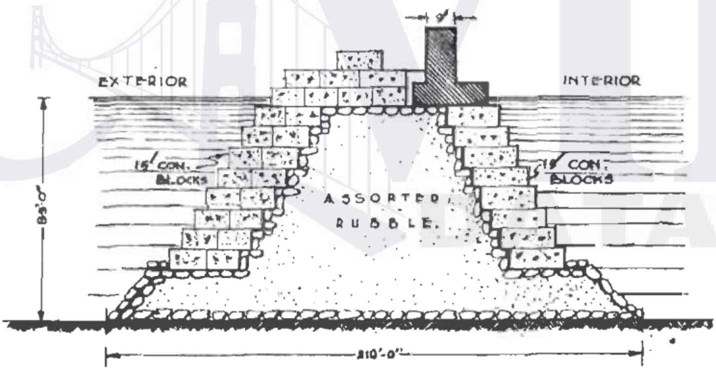
Methods of protection:

(a) Dumping heavy blocks of concrete on top and on front face. This to a great extent resists



Concrete blocks on top and frot face.
Fig. 13

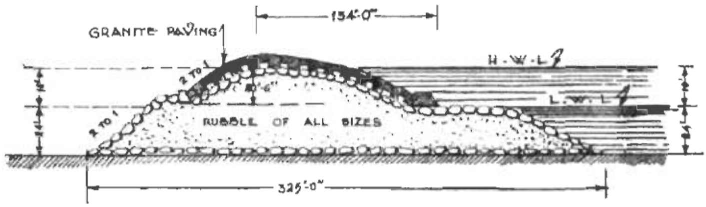
the flattening action of the waves, by sheer weight. These blocks weigh 25 tons to 30 tons and are either deposited at random fig. 13 or laid in courses as shown in fig. 14. These blocks are prepared as



Concrete blocks laid in regular courses.
Fig. 14

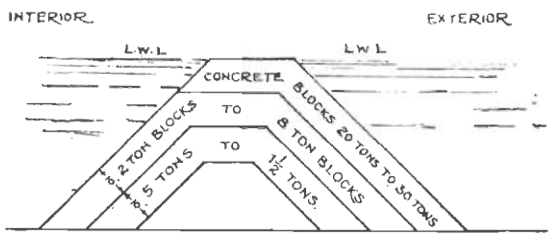
rectangular solids and laid with ends towards the waves. This provides minimum area and maximum mass against impact or overturning.

(b) Paving the upper part up to the low water level by deep granite blocks (fig. 15) is another method to protect the top and face. Granite paving blocks set in cement mortar reduces the erosive action of the waves.



Top protection by granite paving.
FIG. 15

Mound formation: Rubble mounds are formed using rubble of assorted weights, placed according to sizes; the smallest and lightest materials constituting the core. The sizes are increased gradually outwards. This arrangement is logical, exposing the bigger sizes to the action of the waves, while the smaller sizes forming the core are protected (see fig. 16).

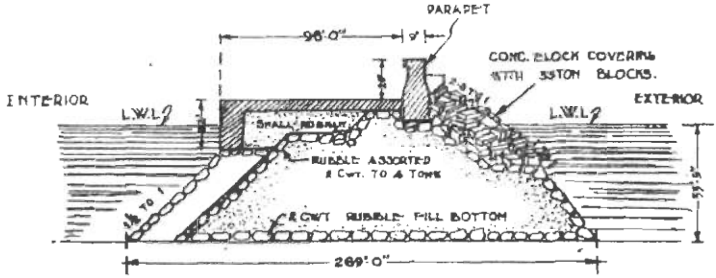


Mound formation.
FIG. 16

Where rubble is difficult to get concrete blocks have been used to form the mound. Concrete blocks have the advantage that they could be heaped at a steeper slope than rubble, economising in space and material. Also the size of blocks could be controlled to suit the exposure condition.

(2) (i) *Mound with superstructure founded at low water:*

A solid superstructure consisting of a Quay protected by a parapet on the sea face is constructed on top of the rubble mound (fig. 17). Such a construction is founded about low water level. The advantages of such a construction are,



Mound with solid superstructure
and concrete block potection.
FIG. 17

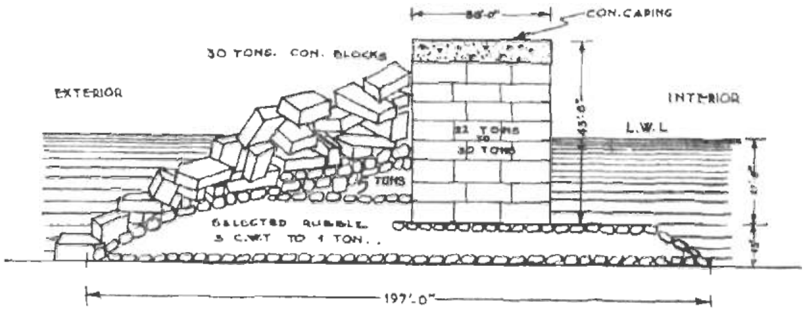
(a) It provides a platform for handling cargo.
(b) It protects the top of the mound.
(c) It reduces the mass of rubble required for the mound in proportion to the depth at which it is founded.

Unlike the ordinary or plain mound break water, this type of construction makes it possible for ships to come close to the break water wall on the inner or harbourside for loading and unloading cargo.

Heavy concrete blocks are used on the sea face for protection. The front batter changes from 2·8 to 1, abruptly to 1 to 1 in order to provide a sharp edge to cut the waves on impact.

(ii) *Mound with superstructure founded below L.W. level:*

This type of construction affords the advantage of founding the superstructure well below the level of disturbance, the waves having practically no disturbing effect at such low levels. In deep waters this type, is very economical in mound material (fig. 18).



Mound with superstructure founded below L.W L.

FIG. 18

Stability of mounds: Mounds lack quality of permanence in shape and section specially the upper portions. They stand in equilibrium, below levels of wave effect at slopes of 45° to 50°. The maximum wave effect and disturbance of the mound is felt between H.W.L. and L.W.L. Hence large and bigger blocks of 30 tons each or more are deposited at a slope of 1 to 1 in this region. The concrete blocks are made in ~~large~~ rectangular blocks and laid as headers, offering minimum face area and maximum resistance to overturning.

different

MOUND CONSTRUCTION:

Size of material and arrangement: Mounds are formed in assorted layers, the smaller sized material being disposed at the base and the larger at the top and sides, particularly between the High and Low water levels, which region is the worst affected (fig. 16).

Methods of construction:

Mound construction is carried out by any one of the following three methods.

(i) Barge method.
(ii) Staging method.
(iii) Low level method.

(1) *Barge method:* Special barges with flat bottoms and hoppers with vertical sides and doors at the bottom opening outwards are used. The hoppers are loaded with rubble, and the barge is adjusted and aligned in position along the line of construction and the load is discharged by opening the hopper doors (fig. 19). Rubble should be evenly distributed over the entire width of base of the break water mound. The layers are trimmed and rectified to the correct section by divers.

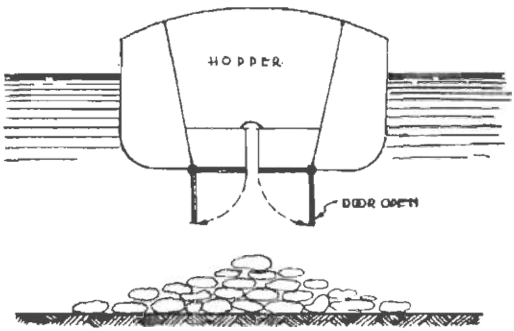
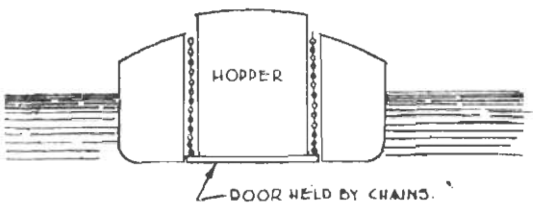


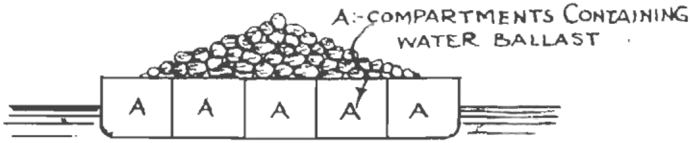
FIG. 19 (*a*)



Discharge from hopper barge.
FIG. 19 (*b*)

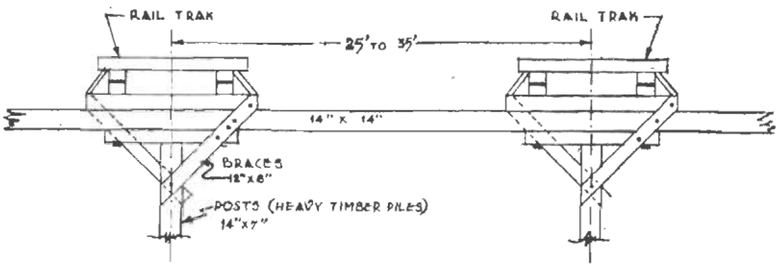
When the mound rises up sufficiently high that hopper barges cannot be used, decked barges (fig. 20) are resorted to. These are loaded and brought to the site and slightly canted by flooding compartments on one side, causing a tilt which dislodges the material.

This method has the advantage of offering the opportunity for a uniform depositing, simultaneously over a large area.



Decked barge.
FIG. 20.

(2) *Staging method:* A series of piles are driven at regular intervals of 15′ to 20′ and connected by longitudinal runners, struts and braces (fig. 21) forming a number of parallel tracks for tipping waggons to move on rails. These tracks are well above the high sea level and at 25′ to 35′ centres. The material is hauled on this staging and is tipped at the ends and sides. As work in one section is completed the staging is removed and re-erected in a forward position to continue the work. Very heavy and powerful tackle arrangement is necessary to withdraw the staging piles from the areas where the mound has been completed.



Cross-section of staging.
FIG. 21

(3) *Low level method:* This consists in forming a length of mound from the shore, well above the high sea level and using this for laying tracks and running tipping waggons on this solid break water structure as it advances. This method naturally restricts the scope of a multi-section attack, but has the advantage of consolidating the mound formed, by the traffic of loaded waggons.

ECTION II

TUNNEL ENGINEERING

CHAPTER I

GENERAL ASPECTS

Tunnels are underground passages used for transportation. They could be used for carrying freights and passengers, water, sewage, gas etc. The methods involved are underground operations known as Tunnel driving and the ground surface is not disturbed.

Advantages of tunneling: There are many factors that make a tunnel more advantageous than other means, viz.,

(i) Tunnels are more economical than open cuts beyond certain depths.

(ii) Tunnels avoid disturbing or interfering surface life and traffic during construction.

Economics of tunneling: This is a very broad question and in general depends on the relative cost of open cut *vs* tunneling. The following aspects of the problem are instructive:

(a) Nature of soil, particularly in deep cutting, with the consequent side slopes and volume of excavation, will greatly influence the cost of open cuts.

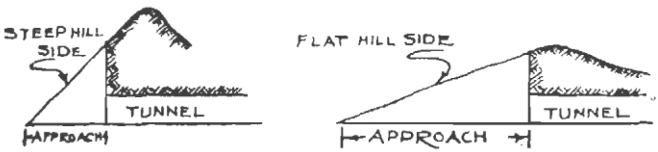
A tunnel may be comparatively cheaper and easier.

(b) If the soil is hard rock, the open cut could be of steep side slope, involving much less volume of excavation and may prove cheaper; whereas a tunnel through the same, though may require little or no timbering may be very difficult to blast out.

(c) The requirements of fill in the neighbourhood also largely influence the choice. If a large amount of material is needed for the nearby fill, an open cut may be justified, though a tunnel may be comparatively more economical.

Generally when depth of cut is over 60 feet tunneling is advisable.

Tunnel approaches: These are open cuts at either ends. The cost depends on the topography. The approach is very short (see fig. 1) in case of



Short approach Long approach.

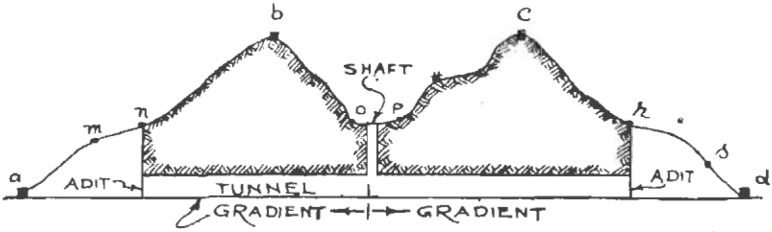
FIG. 1

steep hill slopes and very long, when the hill slope is very flat. At very high altitudes the approaches are likely to get snow bound in winter or may get blocked by heavy land slides. These factors may carry weight in deciding the choice of 'cut' or 'tunnel'.

Alignment and grade: The several points for consideration could be summarised as follows:

(1) Straight alignment is best and economical.

(2) Grades in a tunnel should be appreciably less than that outside; the tendency to continue the maximum grades, of approach open cuts into the tunnel should be checked. In a railway tunnel,



Surfac calignment and grade for tunnel.

FIG. 1 (*a*)

there will be constant wetness of rails causing slipping of the wheels and increased atmospheric resistance. These tend to reduce the hauling capacity of locomotives.

(3) As nearly level as 0·2% gradient may be given to provide effective drainage in the tunnel.

(4) In long tunnels it is better to give two grades rising from each end towards the centre. [see fig. 1(*a*)].

(5) But, ventilation will be more effective if the grade is all in one direction.

Tunnel surveying: A brief description of the type of survey and the instruments usually used will be given. Mainly the work consists of alignment of the centre line on the surface, its transfer into the tunnel and good levelling work on the surface and inside the tunnel.

(1) First a preliminary location survey is done, followed by a very precise resurvey of the line on the surface.

(2) As tunnel excavation is carried out from each end face, as also from several intermediate shaft faces, minute accuracy in the survey of the centre line is essential; the centre line will have to be carried forward by prominently marking on each fresh face after excavation. When adjacent headings carried from opposite faces meet, there should be no appreciable shifting of the centre line laterally or vertically.

(3) When the tunnel is short, ordinary engineers transit, properly handled gives close and satisfactory result.

(4) When the tunnel is very long it is very necessary to have a Tunnel Transit, which is large, powerful, invertible in the wyes and is fitted with a striding level, by which the transverse axis can be made truly horizontal.

(5) These instruments must be frequently tested and maintained in adjustment.

(6) Levelling work is carried on in the standard way except for the fact, that where steep slopes are

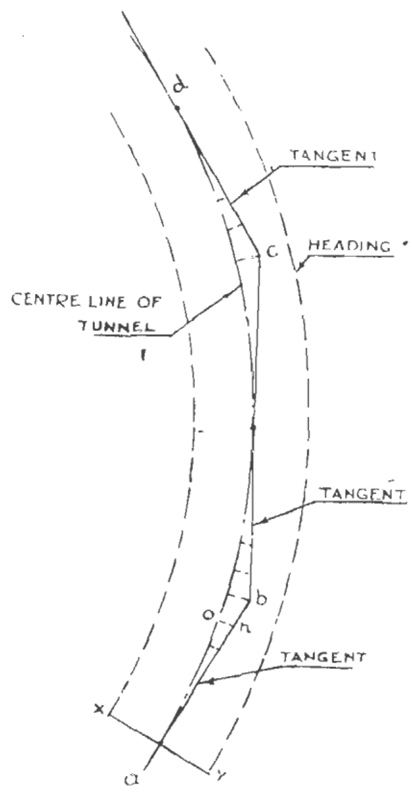
encountered extra care is necessary to avoid errors. The practice is to make back sights and foresights equal as far as possible to neutralise and minimise errors due to mal-adjustments of the instrument.

(7) Horizontal distances are measured by:

(i) Stepping or (ii) inclined sights.

Cumulative errors are avoided by applying necessary checks and corrections to the steel tapes, for tension and temperature.

Curved line survey and alignment (see fig. 2):



Centre line on curve..
FIG. 2

(1) The heading contains short tangents to the curved line like *ab*, *bc*, *cd* etc.,

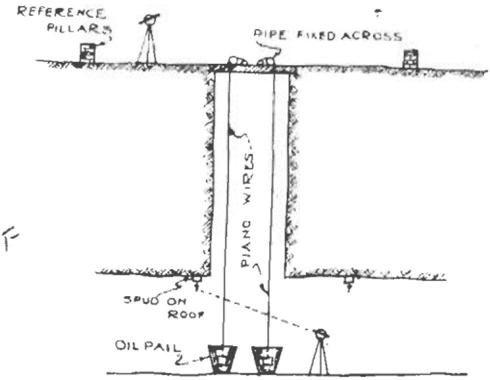
(2) To locate the centre line offsets from these tangents are set off.

(3) When heading has proceeded upto *x y*, align points like *n* on the tangents. Set off the calculated offset *n o* to intersect the centre line at *o*, on the heading.

(4) Centre line has to be transferred thus after each blasting of the heading face.

Transfering centre line into the tunnel: This is a work needing the utmost care and accuracy in execution, as otherwise the centre line worked from opposite faces will not meet, and deviations in the centre line will cause overbreaking and additional expenditure, especially, when the material tunnelled through happens to be hard rock.

Elaborate equipment is necessary for the purpose: Initially plumb bobs, weighing 22 lbs. are lowered into the tunnel shafts from the surface from



Transfer of centre line into the tunnel.
FIG. 3

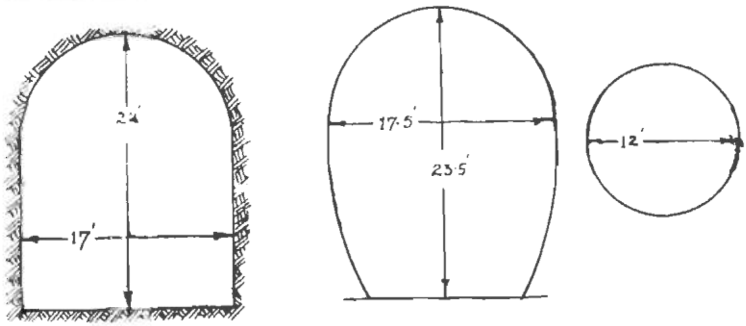
opposite faces of the shaft, to transfer two points from the centre line on the surface, vertically down. The plumb bobs are suspended by piano wire, passing over grooves cut on pipes fixed, across the mouth of the shaft. The wire of each plumb bob is wound over a reel and released to the required length to the bottom of the shaft. Once the bottom is reached, these plumb bobs are replaced by a pair of extra heavy ones made of angle iron, to keep the wires steady. As a further precaution against the wires oscillating or vibrating, the heavy plumb bobs are kept *immersed* in a pail of oil (fig. 3) placed on the shaft floor. The line joining these two piano wires is fixed and extended by a theodolite placed in the shaft (as shown in the figure) on to a point on the roof of the heading and indicated on spuds or dogs fixed to the roof. A corresponding point is similarly located on the roof of the opposite face. The centre line is then marked on the floor of the shaft with reference to the roof points and is extended through the tunnel.

Transfer of tunnel grade: Grade levels from tunnel portals are carried into the tunnel in the ordinary way, but transferring levels from the surface to the shaft bottom, the same *piano wire* and plumb bob equipment is used. Two marks are made on the wire one at the top and the other below, 5 feet above the intended springing level of the arch roof. The R.L. of the top mark is first determined with respect to a bench mark at the top near the shaft mouth and the corresponding R.L. of the other mark is obtained. With this as reference a permanent B.M. is established on the side wall of the tunnel and the floor levels are then transferred and continued from this B.M.

Design of shape and size: The shape of tunnel cross-section is governed by the nature and type of ground penetrated while size is largely controlled by the use to which the tunnel is put.

Theoretically, the circular tunnel section is the best for resisting either internal or external pressures;

and at the same time provides the greatest cross-sectional area for the least diameter. But this section



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

Shapes for tunnel cross-sections.

FIG. 4

though ideal has other disadvantages from the engineers' point of view. The curved invert makes it difficult to carry railway tracks without considerable filling and levelling of the invert. The curved bottom also makes it difficult for placing the concrete lining of the invert. General practice is to design tunnels in rock with a semicircular arch and vertical side walls. Tunnels in soft soils or ground, are usually circular or horse-shoe shaped as they have to withstand horizontal pressures. The horse-shoe shape is a compromise section to minimise the inconvenience of lining the invert of a circular section. Fig. 4 shows typical sections in common use.

Procedure of work: In the wake of driving, tunnels are lined, with timber, masonry, or concrete with suitable outlets to let out enclosed sub-soil water behind the lining. Other items of work including provision of ventilation during and after construction, drainage and lighting if necessary, are carried out to complete the construction of tunnels.

CHAPTER VII

TUNNEL LINING

The objects of providing a tunnel with permanent lining are manifold.

(1) It gives correct section to the tunnel.

(2) It withstands soil pressure when driven in soft soils.

(3) It reduces losses in friction and erosive action, and ensures stream line motion, when the tunnel has to carry water by providing a smooth passage at good velocity, free from turbulance.

(4) It forms a good protective covering to certain types of rocks prone to air slaking.

(5) It keeps the inside of the tunnel free from water percolation.

(6) It supports large slabs of rock which might have become loosened during blasting.

Materials for lining:

Masonry: Brick masonry was the standard material for tunnel lining, but is now rapidly going out of use, except in the case of underground sewers, as bricks are more acid resisting and suitable to carry sewage. A great disadvantage in using brick lining is the difficulty in back packing the space between the tunnel roof and the extrodas of the arch which at best has to be handpacked and is imperfect. At a later stage this may cause uneven pressures on the arch lining. The packing material employed is usually spalls, sand and brick bats, well rammed. On account of so many indeterminate factors in design, a very heavy section may be necessary the construction of which becomes cumbersome and costly.

Stone masonry: It has more or less the same disadvantages as brick lining and in addition is very heavy necessitating very strong centres. But is still used for lining the sides.

Cement concrete has become the standard material for tunnel lining in both rock and soft soils. Its main advantage lies in its plasticity which allows it to be well packed between the form and the soil. The waterproof qualities of cement concrete, makes for a first class watertight lining. It could be used to form an unbroken ring right round, forming a shell. If unusual soil pressures have to be reckoned with, the thickness could be controlled and reinforced, suitably.

Timber: is one of the oldest lining materials though of late, it is slowly yielding place to concrete. It is used both as a temporary support during construction and as a permanent support later.

Modern practice is to use either timber for semi-permanent lining and cement concrete as a standard practice. An attempt will be made to describe these two types of linings in detail. Masonry linings more or less follow the same modus operandi as concrete, like erection of centring, construction of the arch, easing of centres etc., except that the material is different.

Design of thickness of lining: Stresses in tunnel lining primarily originate in earth pressure. The laws of action of earth pressures at least are only approximate and involve indeterminate factors. The designer is therefore well advised to primarily depend on judgement and precedent, guided by theoretical analysis, which may indicate the nature of the stresses.

The empirical formula commonly applied to obtain a working section is

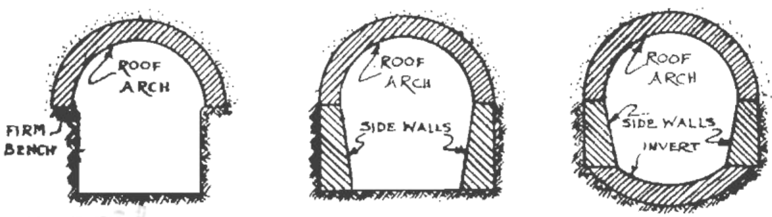
$$T = D$$

where T = Thickness of lining in inches
and D = Diameter of tunnel in feet.

But this thickness is restricted to a minimum of 9″, irrespective of the material used for lining.

Good hard rock is of course self supporting and needs a nominal lining if properly scaled.

Firm soil is usually considered to exert only a downward pressure on the arched roof and though the sides are lined no great consideration is attached to the side or horizontal pressures in designing. As a long tunnel generally passes through varied geological strata, no hard and fast rule could be prescribed. The nature and geological structure of the soil met with should be the primary guide in designing the lining and method of its construction. General practices of providing linings are indicated in (fig. 34).



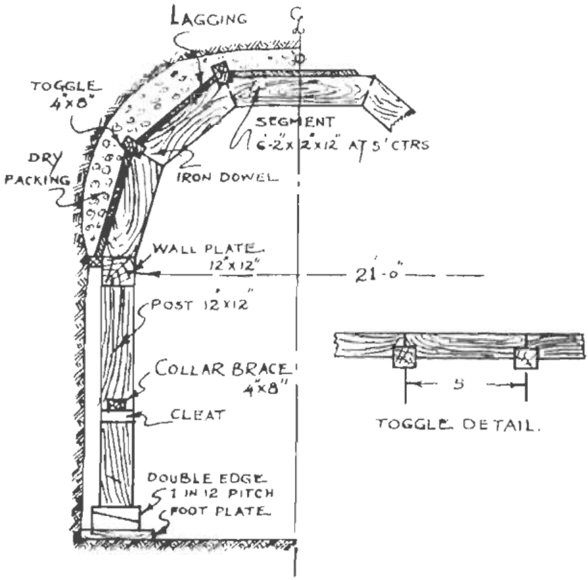
General lining practice.
FIG. 34

(a) In firm soil only a roof arch is provided, resting on benches cut in firm rock at the sides.

(b) If rock is less solid, side walls of masonry are also added.

(c) In soft or treacherous soil an invert is added in addition, to protect the side walls from moving in as also to resist the upward pressure of the soil.

Timber lining: The lining consists of a regular timber arch, formed of straight segments connected together, and approximating to the intended curvature. At the springing the segments are carried on wal plates of heavy timber, and supporting posts. The segments are arranged in three, five or seven piece sets and are spaced about 5 feet centre to centre longitudinally. A timber toggle is used between adjacent sets as a lateral spacer. The whole arrangement is shown in fig. 35.



Typical arch set of five pieces.
FIG. 35

Parts of timber lining:

(i) Segments: They should not be too long, as it is safer to carry the roof load under arch action rather than beam action.

(ii) Wall plate: It supports the arch rib at the springing line and is the weak link in the lining system as it has to be bear compressive load across the grains, the safe load not exceeding about 300 lbs. per sq. inch.

(iii) **Posts:** They are usually set vertical under the wall plates one under each arch rib. Their tops are connected to the wall plate by dowels and at the foot they are supported on double wedges on blocks.

(iv) **Collar braces:** These are introduced at each joint of the arch segment, in the form of toggles to prevent the segment twisting out of line. The posts are also provided with horizontal braces, generally in the centre. The sizes of these braces should not be less than 4″×6″.

(v) **Laggings:** These are of 3″ to 4″ thick planking laid on top of segments. They should be placed close, to retain the fill.

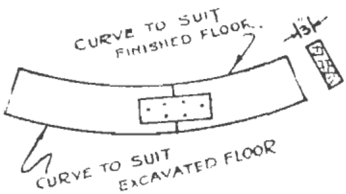
Packing: As soon as the timber arch is erected, it is 'blocked' from the roof by using wooden blocks for the purpose. Then the wedges at the foot of posts are driven tight. Dry packing with muck, or lean cement concrete (1:3:6) shot into the space, fills the gap between lagging and the roof. If concrete is used, it should be of a stiff consistency.

This type of lining, lasts for about 10 to 15 years, especially if the tunnel atmosphere has constant humidity. It is customary to make a thorough inspection of this construction at least once in six months to see if the timber has started to decay in any place. Timber arch is a serious fire hazard and fire fighting measures become an obligatory equipment in such tunnels. A good principle would be to gradually replace the timber lining by concrete, as the timber starts to decay. Miners, mostly prefer timber lining temporarily or permanently, on account of the warning the timber gives by 'groaning' when subjected to unforseen forces, tending to cause collapse.

Concrete lining:

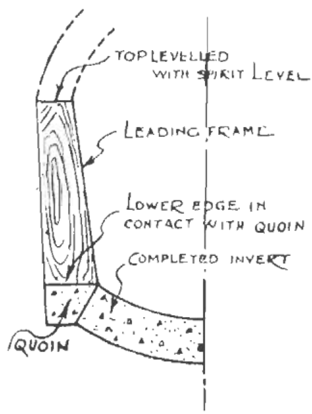
Work: Concrete lining is done using proper form-work. The form should show the true outline of the finished tunnel section. As tunnel lining work is divided into three operations corresponding forms or moulds are used. Thus:

(1) Ground mould is used for floor lining or invert concreting (fig. 36).



Ground mould.
FIG. 36

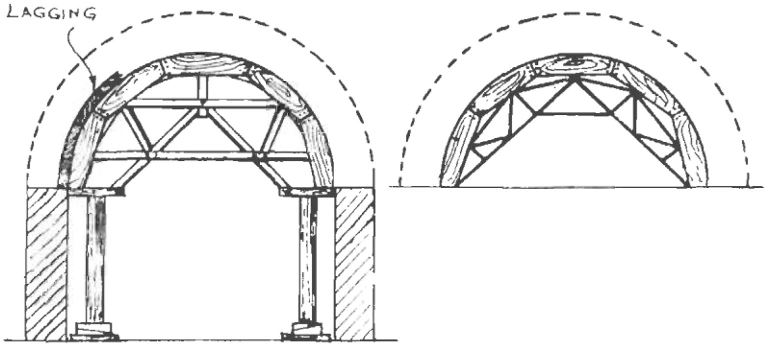
(2) Leading frame is the name applied to the side wall form (fig. 37).



Leading frame.
FIG. 37

(3) Trusses are used as centres for the roof arch (fig. 38).

1. Ground mould: It consists of wooden frame or pattern exactly the form and dimension of the cross-section of the floor lining. The frame is made out of 3″ thick plank to fit the floor curvature correctly. The mould is made in two halves joined together during use by a splice plate. This helps handling the mould in a restricted space like the tunnel interior.



Types of centres.
FIG. 38

Two moulds are used at a convenient distance apart and chords are stretched across from one to the other to give the true profile of floor surface and to which the concrete is laid. The moulds are placed exactly at right angles to the tunnel axis, the level and positions properly checked by a transit. Sometimes only one mould may be enough in the forward position, the finished lining furnishing the back mould.

2. Leading frame: It is made of planks of good thickness one edge cut to the curve of the side excavation and the other edge to conform to the inner face of the finished side wall. The frames are set with the lower end resting on the finished invert or a quoin provided for the purpose. The top of the frames after alignment is correctly checked with a spirit level and adjusted horizontally.

Short heights of the wall section are blocked and concreted over the sides and brought up to the springing.

3. Centres: These are constructed similar to the form work used for arches but are so designed as to leave sufficient head room in the centre for convenience of working (fig. 38). Centres may have to support roof pressures also in addition to the weight of the lining and are therefore constructed very systematically, and properly trussed. Any standard method of easing these centres, could be employed, the more popular one being the use of double wedges. The curing period for the arch should never be less than 7 days to 10 days, and easing should never take place before this period.

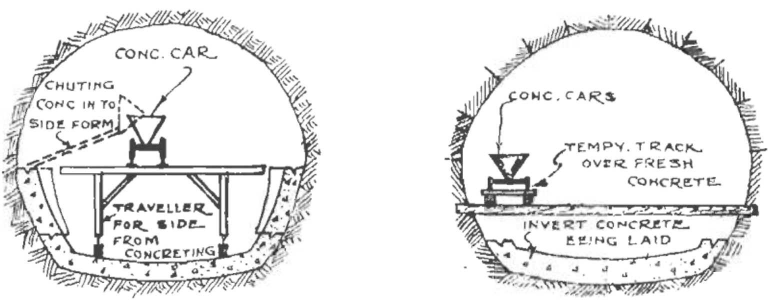
Steel forms and their use:

Two principal types will be explained, viz.,

(i) Separate side wall and arch forms.

(ii) Telescoping forms.

(i) Separate side wall and arch forms: This is a standard arrangement of tunnel forms for large tunnels. In this method the invert is first laid (fig. 39). On this is laid a track for carrying form



Use of separate side wall and archform system.

FIG. 39(*a*)

units for the sides and the arch, one following the other. Side wall concreting is shown in fig. 39(*a*) when from a platform (to which concrete is hoisted by a ramp) concrete is poured down into the side forms. As this form unit is moved forward, it is followed by the arch form unit shown in fig. 39(*b*). The arch forms are filled by concrete placers. The form unit in this method are of the non-telescopic type.

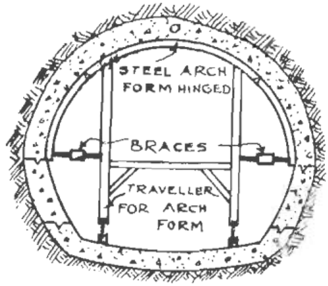
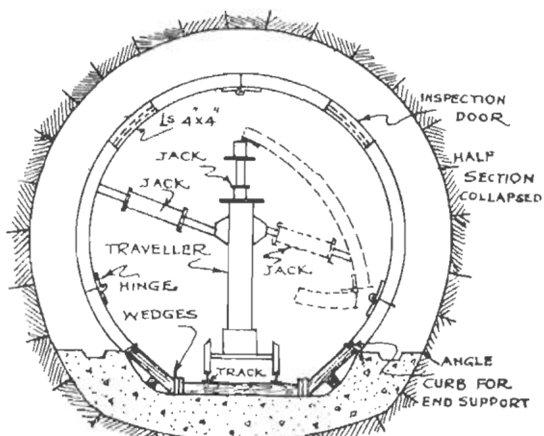


Fig. 39(*b*)

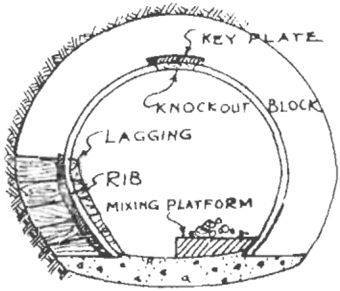
(ii) Telescoping forms: The main ribs are made up of sections hinged together, so that a back unit could be collapsed and moved forward under form units erected and in use, without disturbing, concreting. This type is very suitable for tunnels upto 20 ft. to 25 ft. diameter. As the tunnel size increases



Telescoping steel form. Fig. 40

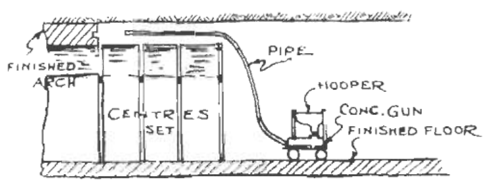
the hinged sections become too heavy for handling, and erecting. The traveller carries jacks for erecting and collapsing the rib sections. Fig. 40 illustrates the use of this type of form.

Placing concrete: For small tunnels 4 ft. to 10 ft. in diameter hand placing is quite satisfactory. The laggings are arranged waist high and the sides are concreted first. Then gradually the concrete is lifted for the regions near the crown. The gap in the crown section is concreted in the longitudinal direction or by pressure method. To assist in this, temporarily a detachable key plate is inserted at the crown, of sufficient size, with a knock out block at the bottom (fig. 41).



Hand placing in small tunnels.
FIG. 41

For bigger jobs the modern practice is to place concrete by the help of pneumatic concrete placers which force concrete through a pipe into the space above the centering. The discharge pipe leads to the far end of the crown, feeding the concrete, over the crown; the concrete slides down the sides



Placing concrete by a gun.
FIG. 42

of the form. The pipe is gradually withdrawn as concreting proceeds. The near end is blocked by a bulk head of steel, through which the pipe is passed. Fig. 42 clearly indicates the process.

Curing concrete: Generally if the humidity inside the tunnel provides enough moisture for this purpose, no further curing may be needed. Otherwise perforated pipes are fixed to the tunnel roof, through which water under pressure is sprayed on to the con crete. If water is not easily procurable in the vicinity owing to arid conditions, the best method is to spray paint the concrete surface with bituminous paints or other ready made asphaltic compounds immediately on stripping.

NOTE ON THE SEQUENCE OF LINING A TUNNEL:

The sequence of placing the lining around depends on various factors. The more popular methods are:

(1) Placing the entire lining in one operation: This method is conveniently adopted in the case of small circular tunnels, in which concreting is done in short lengths.

(2) Placing the invert first, and the rest of the lining next: This method provides a rigid base on which the formwork for the sides and roof could be supported. A good procedure would be to commence concreting the invert from the most interior section towards the portal; this will save the newly laid concrete from being used as a hauling floor before it sets.

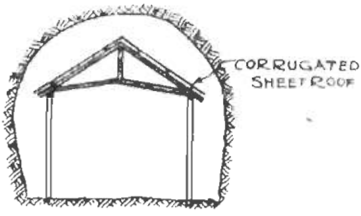
(3) Placing the invert first, the sides next and finally the roof: This is especially suitable for large tunnel sections, where it may be advisable to separately pour the three sections as a matter of constructional convenience. This is the most convenient method and is very popular.

CHAPTER VIII

DRAINAGE OF TUNNELS

In tunnel driving, water comes from two sources; wash water, used for washing drill holes and ground water, from the ground through which the tunnel is driven. Controlling this water consists in preventing excessive quantities from hindering work and removing all the water by suitable means, out of the tunnel. An exploding charge may open up a ground water source, unexpectedly admitting a very large quantity of water into the tunnel.

Pre-drainage: Where seepage is small and comes down from the tunnel roof, it is made to flow over a temporary pitched roof of corrugated sheets on to longitudinal side drains and so led out (see fig. 43).



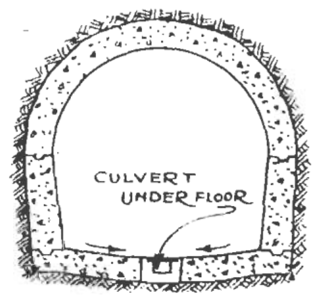
Corrugated sheet to drain roof seepage.
FIG. 43

Ground water is subject to great variation and it would be advisable to drill exploratory holes ahead of and deeper than the face to be removed, to investigate whether the ground is badly broken up and estimate the quantity of the ground water ahead. If this exploration successfully indicates the existence of ground water, it may be possible to grout off heavy discharges and stabilise the formation before tunneling approaches this difficult zone.

Removal of water: The quantity of water that accumulates is collected in sump wells and pumped out of the tunnel. When the tunnel is long it may be necessary to have more than one sump well, so that from the face, the water could be pumped into sumps of increasing capacities by a system of "gathering pumps" and ultimately pumped out of a sump well located near the portal. The sump wells also help in the settlement of solid materials.

Any type of centrifugal pump could be used, and stand by pumps may have to be provided to cope up with unexpectedly large inflows. In designing the pipe line, only frictional force has to be provided for. But in the system of gathering pumps, long delivery lengths are split to suitable or economic lengths to accommodate normal sizes of pipes. Steel pipes of diameter varying from 3″ to 6″ are generally used, without sacrificing, floor working space.

Permanent drainage: The completed tunnel section has to have some kind of permanent drainage arrangement. A very simple method of drainage is to construct drainage ditches (fig. 44) longitudinally,



Central drainage duct.
FIG. 44

sloping towards the portals or shafts, from where they could be pumped out of the tunnel by suitable pumps.

CHAPTER IX

TUNNEL VENTILATION AND DUST PREVENTION

Object: It is necessary to provide proper ventilation during tunnel construction; the main objects are threefold,

(1) To supply fresh air to the working crew.

(2) To remove injurious and obnoxious fumes and gases of explosion.

(3) To safely remove the dust caused by drilling, blasting and mucking.

Natural and Mechanical ventilation: When a drift is driven from portal to portal, it provides fair ventilation during the enlarging operations, particularly when the tunnel is a short one. In long tunnels this natural ventilation is inadequate, and mechanical ventilation becomes necessary.

Volume of air considerations: During working, each worker should be supplied with 200 c. ft. to 500 c. ft. of fresh air constantly. Any compressed air used for the drills is usually contaminated with oil and dust when released from drills and should not be expected to be helpful. After each explosion the air near the face is filled with fumes and dust and is unfit for breathing. This foul air has to be exhausted and replaced with fresh air, before the workmen start removing the debris from the explosion. The time lapse between exploding the charge and commencing mucking will be about 30 minutes within which time, the ventilating system, should clear the tunnel and supply fresh air. Generally the following conditions determine the form and capacity of the ventilating system.

(1) Length and size of tunnel.
(2) Amount of explosive and frequency of blasting.
(3) Temperature and humidity inside the tunnel.

Mechanical ventilation: Mechanical ventilation is provided by one or more electric fans or blowers, which may blow fresh air into a tunnel or exhaust the dust and foul air from the tunnel. There are three systems of ventilation viz:

(1) Blowing.
(2) Exhausting.
(3) Combination of blowing and exhausting.

Blowing:

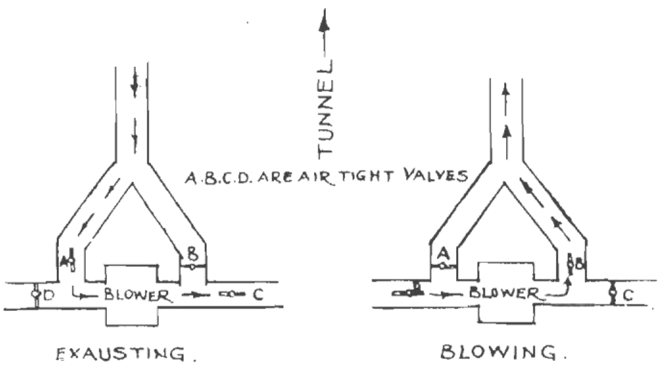
Fresh clean air is blown through pipes near to the working face and as it flows back to the portal through the tunnel, it moves the dust and gases with it. This system has the advantage of supplying fresh air right near the working face, but the disadvantage lies in that the foul air, smoke and dust slowly move out, fogging the atmosphere inside the tunnel, especially in long tunnels.

Exhausting:

In this method the foul air and dust, are drawn into an exhausting duct near the working face, there by creating a flow of fresh air into the tunnel from the enterance or portal. This method has the special advantage of quick removal of dust, and smoke from the working face.

Combination of blowing and exhausting:

Many recent systems have tried to combine both blowing and exhausting, utilising the advantages in either system. Immediately after the blasting operation, the exhausting system is operated for 15 to 30 minuites, to immediately remove the objectionable air, after which, the blowing system operates for the rest of the working period to supply fresh air. The reversal of operations can be carried out by a valve and duct arrangement as shown in fig. 45. The fan rotates only in one direction, but the valves *A*, *B* and *C* could be so manipulated either to exaust from or blow into the tunnel.



Combination of blowing and exausting.
FIG. 45

Dust prevention: The various operations involved in tunnel excavation, such as drilling, blasting and handling muck cause dust accumulation in the tunnel atmosphere. This dust laden air constitutes a serious health risk, unless the dust concentration is limited. In rock tunnels particularly, this hazard is very serious, as extended breathing of the silica dust causes a dangerous lung decease known is "silicosis", which often proves fatal.

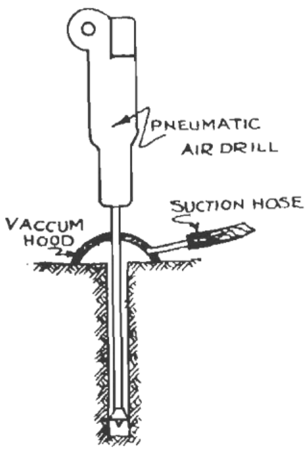
In fact, state laws control tunneling practices and are designed to safeguard workers, by permitting a limited dust concentration inside the tunnel, which could be safe.

Dust control methods: The various methods used to minimise dust accumulation are:

(1) Wet drilling.
(2) Use of vacuum hood.
(3) Use of respirators.

Wet drilling: Modern drilling machines carry arrangements by which water could be used to wet and remove the cuttings, from the drilled holes. This prevents dust flying, to a considerable extent.

Use of vacuum hood: A hood is fitted around the drill steel at the rock face, which is connected to an exaust pipe, through which the drilled rock dust is sucked and removed safely out of the tunel (Fig. 46).



Vacuum hood.
Fig. 46

Use of respirator: Well designed respirators worn by the miners offer the best and most uptodate protection against dust inhalation. It is a method which is becoming increasingly popular in modern tunneling practice.

INTRODUCTION

Definition:

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

Advantages of Railways:

Economical aspects:

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

Cultural & Social aspects:

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

Political aspects:

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

PERMANENT WAY

Definition:

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

Components of a Railway Track:

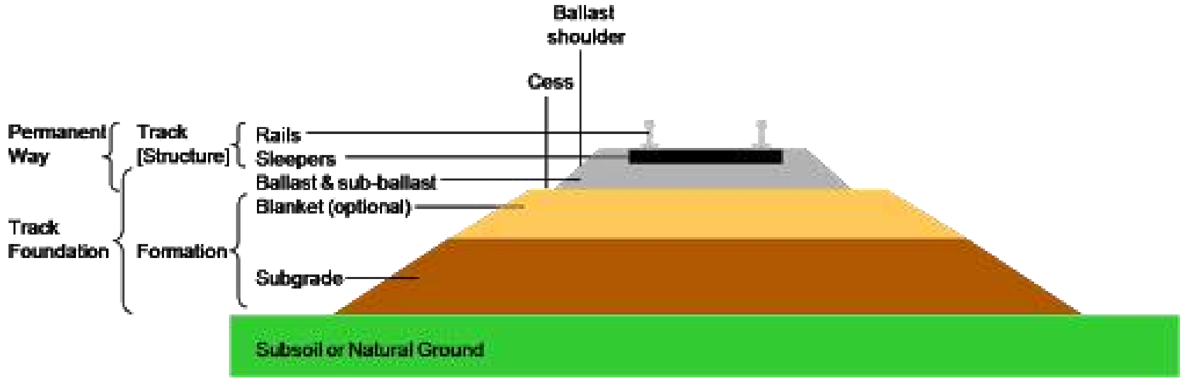
The Typical components are: 1. Rails

2. Sleepers (or ties)

3. Fasteners

4. Ballast (or slab track)

5. Sub grade



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

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

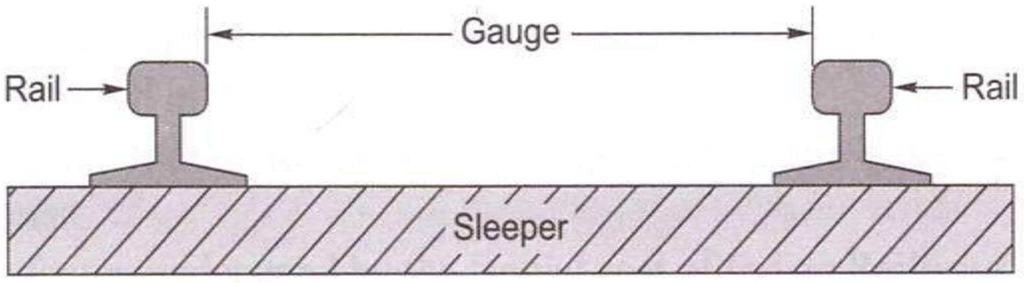
On curved tracks, super elevation is maintained by ballast and the formation is leveled. Minimum ballast cushion is maintained at inner rail, while the outer rail gets kept more ballast cushion. Additional quantity of ballast is provided on the outer cess of each track for which the base width of the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

Requirements of an ideal permanent way:

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

Gauge:

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



Various Gauges in Indian Railways:

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

1. Broad Gauge: -

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

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

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

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

2. Metre Gauge: -

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

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

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

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

3. Narrow Gauge:-

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

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

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

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

Choice of Gauge:

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

Cost considerations:

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

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

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

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

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

Traffic considerations:

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

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

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

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

Physical features of the country:

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

Uniformity of gauge:

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

RAILS

Definition:

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

Functions of Rails:

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

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

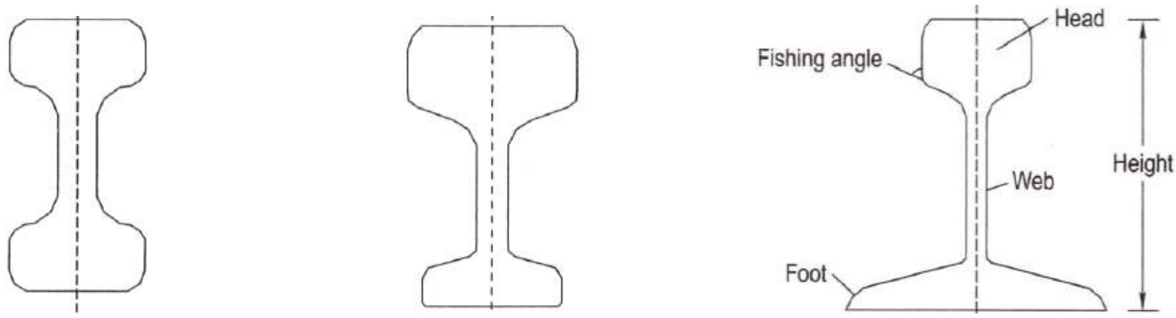
Requirements of an ideal Rail section:

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

Types of Rails:

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

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



D.H. rail B.H. rail F.F. rail

Double headed rails:

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

Bull headed rails:

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

Merits:

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

Demerits:

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

Flat footed Rails:

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

Merits:

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

Demerits:

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

Length of rail:

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

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

RAIL JOINTS

Definition:

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

Ill Effects of Rail joints:

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

Requirements of an ideal rail joint:

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

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

Types of Rail Joints:

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

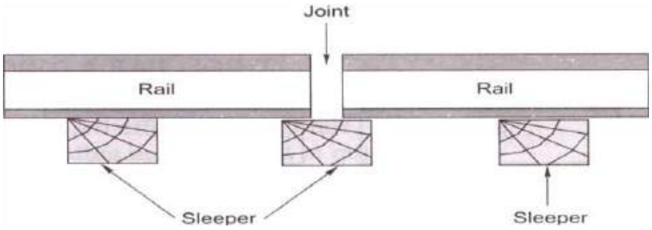
Classification According to Position of Sleepers:

Three types of rail joints come under this category.

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

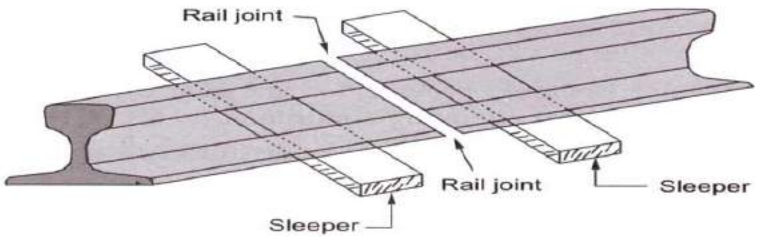
Supported joint:

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



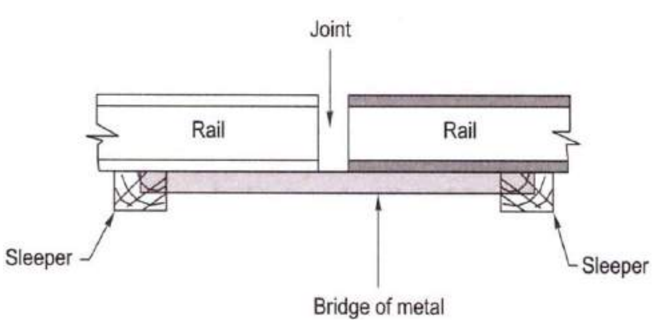
Suspended joint:

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

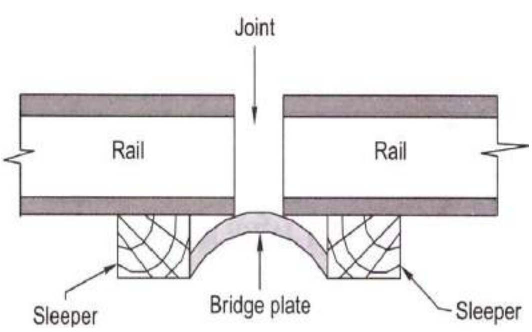


Bridge joints:

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



(Bridge joint with metal flat Joint)



(Bridge joint with bridge plate)

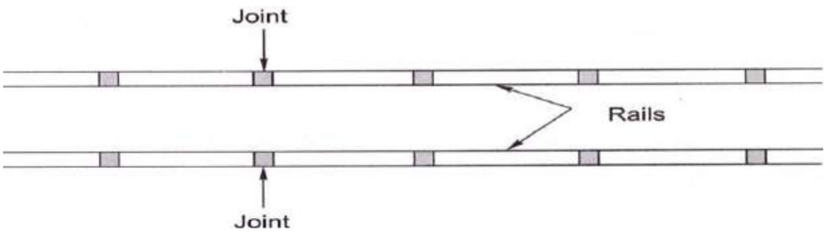
Classification Based on the Position of the Joint:

Two types of rail joints fall in this category.

i. Square Joints
ii. Staggered Joints

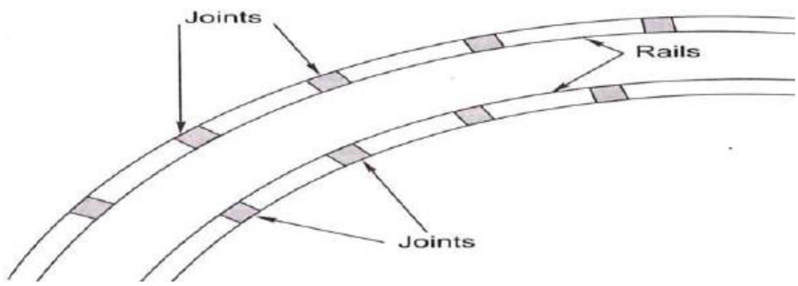
Square joint:

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



Staggered joint:

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



SLEEPERS

Definition:

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

Functions of Sleepers:

Sleepers serve the following functions:

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

Requirements of good sleepers:

The following are the requirements of good sleepers:

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

Types of Sleepers:

Sleepers are of the following types:

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

1. Wooden Sleepers:

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

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

Advantages:

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

Disadvantages:

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

2. Steel Sleepers:

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

Steel sleepers are of two types:
I. Key type steel sleepers
II. Clip and bolt type steel sleepers

Key type steel sleepers:

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

Clip and bolt type steel sleepers:

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

Advantages:

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

Disadvantages:

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

3. Caste Iron Sleepers:

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

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

Pot or bowl sleeper:

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

Plate sleeper:

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

Box Sleeper:

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

CST-9 Sleeper:

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

Duplex Sleepers:

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

Advantages:

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

Disadvantages:

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

4. R.C.C. Sleepers:

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

Through type R.C.C. Sleeper:

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

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

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

Advantages:

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

Disadvantages:

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

5. Pre stressed Concrete Sleepers:

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

BALLAST

Definition:

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

Functions of Ballast:

The ballast serves the following functions in a railway track.

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

Requirements of good ballast:

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

Types of Ballast:

In India, the following materials are used as ballast.

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

1. Broken Stone:

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

Advantages:

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

Disadvantages:

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

2. Gravel:

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

Advantages:

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

Disadvantages:

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

3.Sand:

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

Advantages:

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

Disadvantages:

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

4.Ashes or Cinders:

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

Advantages:

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

Disadvantages:

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

5.Kankar:

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

Advantages:

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

Disadvantages:

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

6.Moorum:

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

Advantages:

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

Disadvantages:

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

7. Blast furnace slag:

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

Advantages:

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

Disadvantages:

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

8. Brick Ballast:

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

Advantages:

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

Disadvantages:

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

9.Selected Earth:

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

FIXTURES AND FASTENINGS

Definition:

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

Functions of Fixtures and Fastenings:

Rail fixtures and fastenings have the following functions:

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

Types of Fixtures and Fastenings:

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

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

Fish Plates:

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

Bearing Plates:

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

Spikes:

Spikes are used to fix rails to wooden sleepers. Spikes are of following types:

(a) Dog spikes
(b) Round spikes
(c) Screw spikes
(d) Elastic spikes

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

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

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

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

Bolts:

Different types of bolts used in Indian Railway are:

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

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

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

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

Keys:

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

1. Wooden keys
2. Metal keys

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

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

Anti-Creepers:

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

3. The pumps may be designed for maximum daily draft plus some additional reserve for break down and repair.
4. The distribution system (to carry water from service reservoir to water taps) should be designed for maximum hourly draft of maximum day or coincident draft with fire, which ever is more.
5. The service reservoir is designed to take care of hourly fluctuations; fire demands and emergency reserves,

VARIOUS SOURCES OF WATER FOR SUPPLY

(A) Surface Water Source
(B) Ground Water Source

- Surface sources are those sources of-water in which the water flow over the surface of earth, and is thus directly available for water supplies.
- Important surface sources of water are:-
  (i) Natural Ponds and Lakes.
  (ii) Streams and Rivers and
  (iii) Impounding Reservoirs.

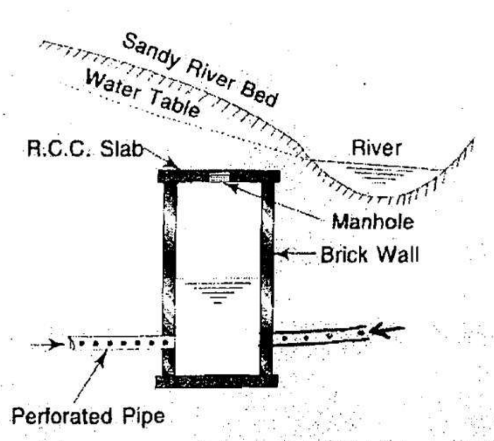
Note : Rivers are the most important sources of water for public water supply schemes because

(a) Most of the cities are settled near the rivers where water is easily available for water supplies.
(b) The quality of river water is generally good (due to self purification) and does not need much purification.

Various ground water sources are:

1. Infiltration gallaries

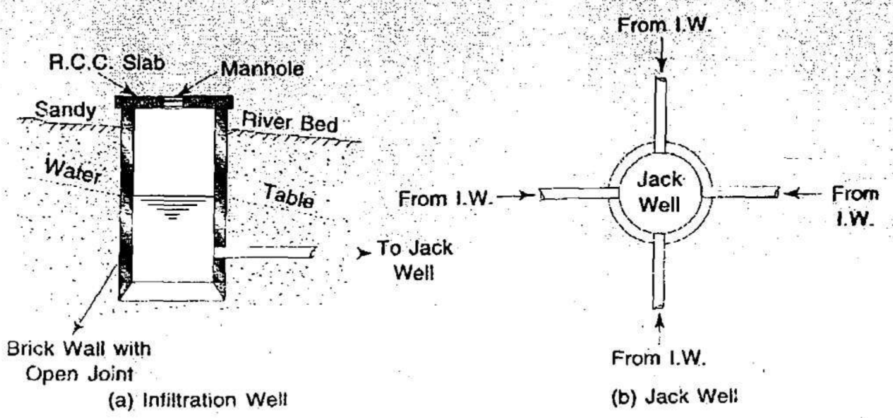
- IG are the horizontal tunnels constructed at shallow depth (3 to 5 meters) along the banks of rivers through the water bearing strata.
- They are sometimes called *horizontal wells.*
- These gallaries are generally constructed of masonry walls with roof slabs, and extract water from the aquifer by various porous lateral drain pipes located at suitable intervals in the gallary.



Infiltration gallery

2. **Infiltration wells**

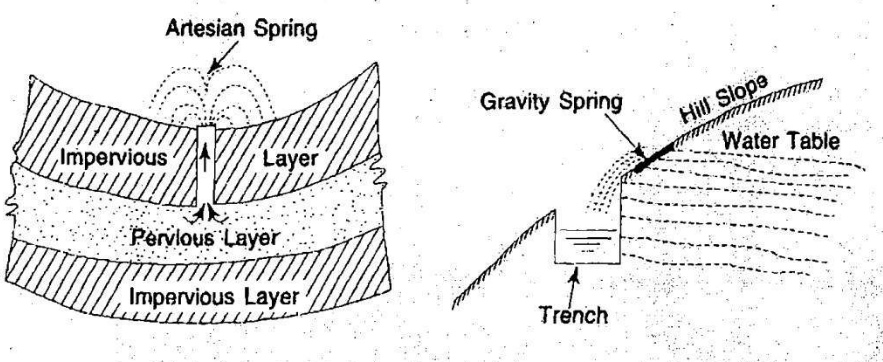
- Infiltration wells are the shallow wells constructed in series along the banks of a river, is order to collect the river water seeping through their bottoms.
- These wells are generally constructed of brick masonry with open joints.
- The water percolates through these joints and gets collected in these wells.
- The various infiltration wells are connected by porous pipes to a sump well called *jack well.*
- The water reaching the jack well from different IW is lifted, treated and distributed to the consumers.



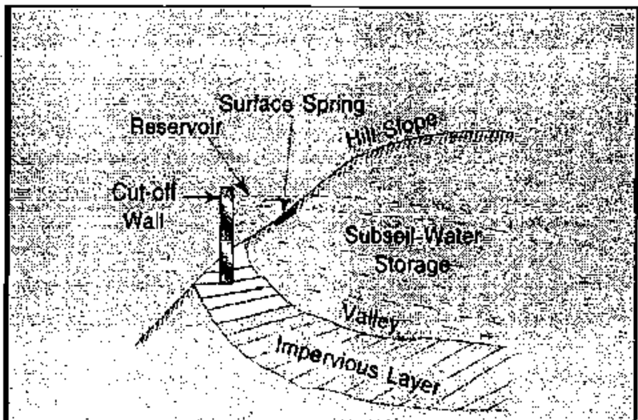
Infiltration well and jack well

3. **Springs**

- The natural outflow of ground water at the earth's surface is said to form a spring.
- A spring indicates the outcropping of the water table.
- The springs are generally capable of supplying very small amount of waters, and are therefore, generally not regarded as sources of water supplies.
- Following are the different forms of spring
  (a) Artesian spring (b) Gravity spring (c) Surface spring



Artesian spring Gravity spring



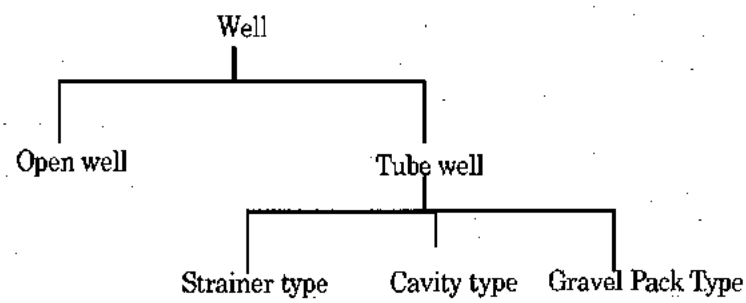
Surface spring

Note : Certains springs sometimes discharge hot water due to the presence of sulphur in them.

4. **Wells**

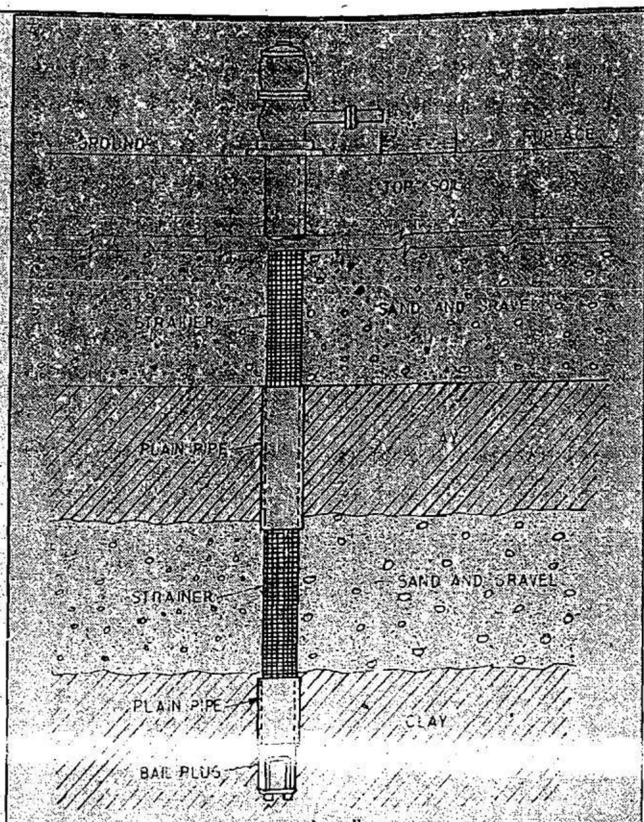
A water well is a hole usually vertical, excavated in the earth for bringing ground water to the surface.

Classification of well



Strainer type well

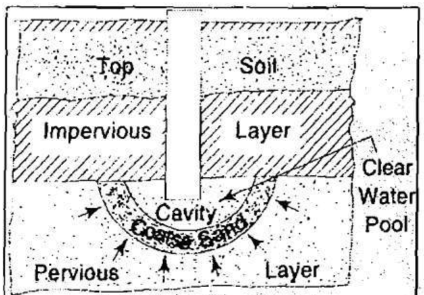
- A strainer tube well uses assembled strainer lengths over perforated pipe which are lowered into the bore hole located opposite to the water bearing formation whereas plain pipe lengths (blind pipes) are located opposite the non water bearing strata.
- Water enters into the well through these strainers and perforations in pipe from the sides, and the flow in the well is thus radial.
- A strainer consists of a perforated pipe with a fine wire mesh wrapped round the pipe which prevents sands particles of size larger than mesh entering into the well.



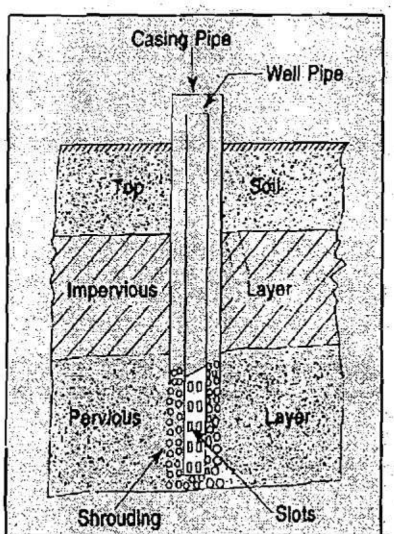
Strainer tubewell

Cavity Type

- No strainer is provided in this well



Cavity type tube well



Gravel Pack Type

- A slotted pipe is lowered into the bore hole and the external gap between the bore hole and slotted pipe is filled up with graded gravel.

INTAKES FOR COLLECTING SURFACE WATER

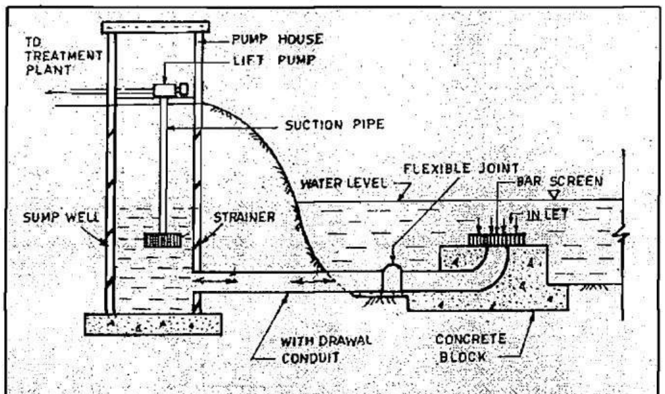
Whenever the water is withdrawn from surface source such as a lake or a river and the entrance of the withdrawl conduit is not an integeral part of a dam or any other related structure, then an intake structure must be constructed at the entrance of the conduit.

- The intake must be located in the pure zone of source so that the best possible quality of water is withdrawn from the source, thereby reducing the load on the treatment plant.
- The intake should never be located near the navigation channels, as otherwise, there are chances of intake water getting polluted due to the discharge of refuse and waste from ships and boats.
- The intake must be located at a place from where it can draw water even during the driest period of the year. Thus, the intake must be located in deep waters, sufficiently away from the shore line.
- In meandering rivers, the intakes should not be located on curves or at least on sharp curves. If they have to be located on curves, it will be better to locate them on concave banks. Although scouring tendencies will be more on the concave side, yet atleast, the water will remain available on this side, whereas on a convex bank water may not remain available due to silting and consequent blockage.

Types of Intake

(1) *Submerged Intake*

A simple submerged intake consist of a simple concrete block or a rock filled timber crib supporting the intake end (with a bell- mouth) of the withdrawl pipe as shown in figure below:



Submerged Intake

- This type of intake is cheap and there is no obstruction to navigation.

(2) *Tower Type Intakes*

- They are also known as exposed intakes
- They are tower like structures.
- Used for tapping water from reservoirs, lakes and most commonly from rivers.
- In case of reservoirs, sometimes an exposed intake is provided and it is known as "gate house" or valoc tower.
- Depending upon the water tapping source they are classified as river intake or reservoir intakes.

River intakes are Classified into four types

(a) *Intake well*

- They are circular masonry or concrete tower of two to six meter diameter
- The water flows into the intake well through the penstocks located at different level.

(b) *Pipe Intake*

When a small quantity of water is to be drawn the pipe intakes are economical.

(c) *Weir Intakes*

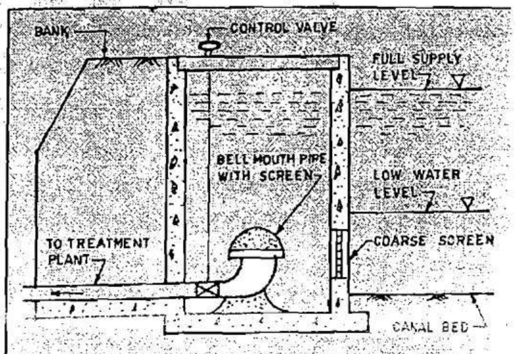
Water is drawn from the weir through a channel into a sump well.

(d) *Floating pantoon Intake*

In case of wide rivers with great fluctuations in flow, weir intake are not economical. In such case floating intakes with a strained bell mouth are provided

(3) *Canal Intakes*

- It consists of a pipe intake placed at the canal bed and enclosed in a concrete well.
- The end of the pipe is provided with a bell mouth with fine screens.
- They are similar to submerged intakes.



A Typical Canal Intake

(4) *Lake Intake*

- Lake intakes are also of tower type intakes.
- Special precaution is to be taken while locating the intakes so that polluted shores water may not enter into the intake conduit.
- To avoid entry of sediments, wet wells may be provided with a blow off valve.

CONDUITS FOR WATER SUPPLY

Depending upon the conditions and characteristics of flow, the conduits may be divided into :-

(A) Gravity Conduits

- Water flows under the mere action of gravity.
- The hydraulic gradient line will coincide with the water surface and will be parallel to the bed of the conduit
- In such a flow, the water is all along at atmospheric pressure.
  Gravity conduits can be in the form of the following

(i) **Canals**

(ii) **Flumes :** Open channels supported above the ground over trestles etc, are called flumes.

- They are used to convey water across valleys and minor depressions.

(iii) **Aqueducts :**Grade aqueducts are closed, rectangular or circular or horse shoe section, built of masonry or R.C.C.

(B) Pressure Conduits

- The water flows under pressure above the atmospheric pressure.
- The pressure pipes can, therefore, follow the natural available ground surface and can freely go up and down hills or can dip beneath valleys or mountains
- Sometimes even rising (ensure –ve pressure) above the hydraulic gradient lines and thus requiring lesser length of conduits.

CHAPTER

2

Quality Parameters of Water

Water impurities are classified as physical, chemical and biological impurities

PHYSICAL WATER QUALITY PARAMETER

- Suspended solids,
- Turbidity,
- Colour,
- Taste and odour .
- Temperature

Suspended Solids

Source: These are called as physical parameters where as dissolved solids are considered as chemical parameters. SS comes from inorganic particles like silt, clay etc., immiscible liquids like oils and greases and organic particles like plant fibre, algae, etc. Inorganic solids are non-degradable solids.

Note: Problem of SS comes only in surface water not in ground water.

Objection: These are objectionable because

(a) Aesthetically displeasing,

(b) It provides adsorption sites for chemical and biological agents

(c) They may also be biologically active and may form disease causing organisms as well as organisms such as toxin producing strains of algae.

Measurement

- Most of the methods are gravimetric i.e. SS are calculated by weighing them.
- Total solids i.e. all solids (suspended or dissolved). are calculated by evaporating the sample and measuring the residue. Heating temperature is 104°C.
- Suspended solid is obtained by filtration and heating the residue on filter at 104°C

  Dissolved solids (DS) = Total solids (TS) – Suspended solids (SS)

Note: Filtration in real terms does not exactly divides the solids into suspended and dissolved fractions because some colloids may pass through the filter and can get measured along with dissolved fraction. Hence, classification is done as filterable and non-filterable solids. Hence suspended solids are coresponding to non-filterable solids and dissolved solids are corresponding to filterable solids.

- The organic content of both total and dissolved solids can be determined by firing the residue at 600°C.

$$\text{Organic fraction} \xrightarrow{600°C} CO_2 + \text{Water} + \text{Other gases}$$

Remaining solids are inorganic solids or fixed solids.

The permissible limits

For suspended solid as per EPA (Environmental Protection Agency) is 30 mg/*l*

Turbidity

Source

Turbidity is the measure of extent to which light is either absorbed or scattered by suspended material in water. It is not a direct quantitative measure of suspended solids.

Objection

- Disinfection of turbid water is difficult because the suspended solids may partially shield the organisms from disinfectant.
- In natural bodies, turbidity interferes with light penetration and hence with the photosynthetic reactions (which gives oxygen to the water).

Measurement

Measurement of turbidity is done using the following:

- Turbidity rod
- Jackson's turbidimeter
- Baylis turbidimeter
- Nephelometer

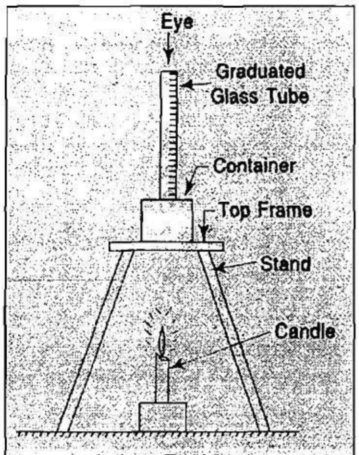
Turbidity Rod

- Rod with platinum needle is inserted inside water and the depth at which platinum needle just becomes invisible gives turbidity in ppm.
- As depth of insertion increases, reading will decrease.
- Turbidity which one milligram of finely divided silica produces in one litre of distilled water is taken as one unit.
- The permissible limit is 5-10 ppm.
- It is a field method.

Note: GOI manual gives turbidity in NTU i.e. Nephelometer turbidity unit. Acceptable limit is 1 and cause for rejetion is 10.

Jackson's Turbidimeter

- The level of water is increased till the image of flame ceases to be seen.
- The turbidity is measured from graduated glass tube.
- It is used when turbidity is greater than 25 ppm.
- It is a laboratory method.
- This method is not used for drinking water.



Jackson Turbidimeter

Note: Turbid raw water of natural source has turbidity greater than 25 ppm.

Baylis Turbidimeter and Nephelometer

- Baylis and Nephelometer turbidimeters are based on colour matching techinques.
- In this case even a small turbidity of one unit or less can be measured.
- Hence these are most widely used for domestic water supplies.
- In Baylis turbiditymeter light intensity is measured in the direction of incident light only where as in nephelometer light intensity is measured at right angles to the incident ray.
- Hence NTU is based on **Scattering principle.**

  If Formazine, a chemical, is used as base in place of SiO_2. The turbidity unit is also sometimes called FTU.

Colour

Source

Colour is caused by suspended and dissolved matter in water.

- After suspended matter causing colur is removed by centrifugation. the colur obtained is called true colour.
- Humic acid gives yellowish brown colour, Iron oxide gives reddish colur. manganese oxide gives brown or blackish water.
- Water containing oxidised iron and magnese impart characteristic reddish or black colour. Heavy growth of algea may also impart colour to the water.

Objection

- Coloured waters is not suitable for dying purpose.
- Organic compounds causing colour may exert chlorine demand and hence reduces the effectiveness of disinfection by chlorine.
- Phenolic compound with chlorine produces taste and odour.
- Some colour causing organic compounds with chlorine becomes carcinogenic.

Measurement

- Measurement of colour is done by colour matching technique (tintometer).
- Result is expresed in TCU or Hazen unit (True colur unit) where 1 TCU is equal to colur produced by 1 mg per litre of platinum in the form of chloroplatinate ion (It is only for yellowish brown colour).
- For colour other than yellowish brown i.e. from industrial effluent, spectro photometric technique is used.
- The colour testing is done within 72 hours of collection as otherwise biological or physical properties may change.

Permissible limit: Acceptable limit is **5 TCU** and cause for rejection is **25 TCU**.

Taste and Odour

- Taste and odour are caused by dissolve gasses like H_2S (Hydrogen sulphide), mercaptans, methan, organic matter derived from certain dead or living micro organism, decomposing organic matter, industrial liquid, waters containing phenols, cresols, ammonia, agricultural chemicals, high residual chlorine and chloro-phenols.

Source

- Sulphur imparts rotten egg like taste and odour.
- Algae secretes oily substances that may result in bad taste ~~and odour~~

Objection: The taste and odour causing compounds may be carcinogenic.

Measurement

- Measurement of taste and odour causing organics can be done using gas or liquid chromatography. However this method is costly and not done in routine.
- Odour is generally measured by an instrument known as **somoscope.**
- Intensity of taste and odour is measured by **Threshold odour number.(TON)**
- It represents the dilution ratio at which odour is hardly detectable.
- TON allowed is between 1 – 3.
- TON testing is done in cold water because increase in temperature may change the taste and odour.
- The formula for TON = $\frac{A + B}{A}$ where A is the volume of odorous water in mL and B is the volume of odour free water required to produce a mixture in which odour is hardly detectable.
- Odours can be removed by mechanical aeration, oxidation by chemicals like chlorine or its compounds or ozone or permanganate and adsorption of odour by agents such as activated carbon. Floc or clays.

Temperature

- Temperature affects the chemical and biological reactions. An increase in 10°C, doubles the bioligical activity. Hence for water supply, the temperature should be between 10-25°C and greater than 25°C is objectional

CHEMICAL PROPERTIES OF WATER

- Total Dissolved Solids (TDS)
- Alkalinity
- pH
- Hardness
- Chloride Content
- Nitrogen content
- Phosphorus
- Fluorides
- Metals

Total Dissolved Solids (TDS)

- The material remaining in the water after filtration is considered to be dissolved.
- A direct measurement of TDS can be made by evaporasing to dryness a sample of water which has been filtered (to remove the suspended solids). The residual is weighed and represents the TDS in the water.
- Approximate analysis of TDS is often made by determining the electrical conductivity of water. (Electrical conductivity in μMho/cm at 25°C) × 0.65 = dissolved solid content in mg/l.
- Electrical conductivity is measured by *di-ionic water tester*. Ions usually account for vast majority of TDS

- Source of Total dissolved solids

Major source	Minor source
Na, Ca, Mg, HCO_3^-, SO_4^{2-} Cl^-	Fe, K, CO_3^{2-}, NO_3^-, Fluoride Boron, Silica

- Major list characterizes the dissolved solid content of water and these are called common ions.
- According to GOI manual, acceptable limit of TDS (mg/*l*) is 500 and cause for rejection is 2000.

Note: The ability of a water to conduct electricity, known as the specific conductance. Unfortunately, specific conductance and concentration of TDS are not related on a one-to-one basis. Only ionized substances contribute to specific conductance. Organics molecules and compounds that dissolve without ionizing are not measured.

Alkalinity

- Alkalinity is defined as quantity of ions in water that will react to neuralize hydrogen ions (H^+). Alkalinity is thus a measure of the ability of water to neutralise acids.
- Most common constituents of alkalinity are CO_3^{2-}, HCO_3^-, OH^-.
- Alkalinity caused by CO_3^{2-} is called *carbonate alkalinity*,, Alkalinity caused by HCO_3^- is called *bicarbonate alkalinity* and alkalinity caused by OH^- is called *caustic alkalinity*.
- The other minor sources of alkalinity are $HSiO_3^-$. $H_2BO_3^-$. HPO_4^{2-}, HS^-. NH_3. $H_2PO^-_4$
- Alkalinity in water comes due to minerals or it may be produced due to atmospheric CO_2 mixed in water or due to microbial decomposition of organic matter. The reaction are as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \quad \text{...(i)}$$

$$H_2CO_3 \rightleftharpoons H^+ + \boxed{HCO_3^-} \quad \text{...(ii)}$$

$$HCO_3^- \rightleftharpoons H^+ + \boxed{CO_3^{2-}} \quad \text{...(iii)}$$

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + \boxed{OH^-} \quad \text{...(iv)}$$

The last reaction (iv) is a weak reaction but utilization of HCO_3^- by algae in water drives the reaction to the right and hence sufficient accumulation of OH^- occurs i.e. If algae is present in water, the water becomes alkaline (pH = 9 to 10). The above reactions are due to microbial decomposition of organic matter. In addition to this alkalinity may be of mineral origin.

- Alkalinity imparts bitter taste to water. The principal objection is that the reaction can occur between alkalinity and certain cations in water. The resultant precipitate can foul pipes and other water system appurtenances.

$$Ca^{2t} + CO_3^{2-} \longrightarrow CaCO_3 \downarrow \text{(ppt)}$$

(ppt cause incraustation of pipes)

Measurements

- Alkalinity measurements are done by titrating the water with an acid and determining the hydrogen equivalent of alkalinity and it is expressed in terms of mg/l as $CaCO_3$.
- If 0.02N H_2SO_4 is used in titration then 1 ml of acid will neutralize 1 mg of alkalinity as $CaCO_3$. 0.02 N H_2SO_4 means 0.02 g eq. of H_2SO_4/litre.

1 ml of acid will have $\frac{0.02}{1000}$ g eq. of H_2SO_4.

(1 gram equivalent of anything reacts with 1 gram equivalent of other thing).

0.02N H_2SO_4 contains 0.02 gram euivalents per litre of H_2SO_4.

$$\frac{0.02}{1000} \text{ g eq of } H_2SO_4 \equiv \frac{0.02}{1000} \text{ g. eq. } CaCO_3$$

$$\text{Equivalent weight} = \frac{\text{Molecular weight}}{\text{Valency}}$$

$$\text{Gram equivalent} = \frac{\text{Weight in gram}}{\text{Equivalent weight}}$$

$$\text{Equivalent wt of } CaCO_3 = \frac{\text{molecular wt}}{\text{valency}} = \frac{100}{2} = 50.$$

$$\frac{0.02}{1000} \text{ g eq. of } CaCO_3 = \left(\frac{0.02}{1000} \times \text{equivalent wt of } CaCO_3\right) \text{g of } CaCO_3$$

$$= \frac{0.02 \times 50}{1000} \text{g of } CaCO_3 = 1 \text{ mg of } CaCO_3$$

Thus, $\quad$ 1 ml of 0.02N H_2SO_4 $\equiv$ 1 mg of alkalinity expressed as $CaCO_3$.

Example 1

Water contains 210 gm of CO_3^{2-}, 122 gm of HCO_3^- and 68 gm of OH^- what is the total alkalinity of water expressed as $CaCO_3^-$.

Sol.

$$210 \text{ gm } CO_3^{2-} \text{ will have} = \frac{210}{60/2} = \frac{210}{30} = 7 \text{ gm equivalent.}$$

$$\therefore \quad 7 \text{ gm equivalent of } CO_3^{2-} = 7 \text{ gm equivalent of } CaCO_3$$

$$122 \text{ gm of } HCO_3^- \text{ will have} = \frac{122}{61/1} = 2 \text{ gm equivalent of } HCO_3^-$$

$$\therefore \quad 2 \text{ g equivalent of } HCO_3^- = 2 \text{ gm equivalent of } CaCO_3$$

$$68 \text{ gm of } OH^- \text{ will have} = \frac{68}{17/1} = 4 \text{ gm equivalent of } OH^-$$

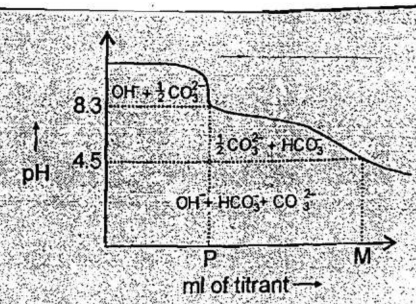
$$\therefore \quad 4 \text{ gm equivalent of } OH^- = 4 \text{ gm equivalent of } CaCO_3$$

$$\therefore \quad \text{Total alkalinity of water} = 7 + 2 + 4 = 13 \text{ gm equivalent of } CaCO_3$$

$$\therefore \quad \text{Weight in gm of } CaCO_3 = \frac{100}{2} \times 13 = 650 \text{ gm of } CaCO_3$$

$$\therefore \quad \text{Total alkalinity of water} = 650 \text{ gm expressed as } CaCO_3$$

Relative Quanity of Alkalinity Species are pH Dependent



(Titration curve)

Reaction of alkalinity with hydrogen ion is shown below.

$$H^+ + OH^- = H_2O$$
$$CO_3^{2-} + H^+ = HCO_3^-$$
$$HCO_3^- + H^+ = H_2CO_3$$

During titration measurement of pH is done at every stage and a titration curve is plotted.

- Conversion of CO_3^{2-} to HCO_3^- is essentially complete at pH = 8.3, but resultant HCO_3^- also requires acid. Hence half of CO_3^{2-} is thought of to have been neutralised upto pH = 8.3
- Neutralization OH^- is complete upto PH = 8.3. Hence $(OH^- + \frac{1}{2}CO_3^{2-})$ alkalinity is completely neutralized upto pH = 8.3.
- At pH = 4.5 all the bicarbonates will have been converted to carbonic acid H_2CO_3 (neutralised). Hence, the amount of acid required to titrate a sample of water to pH = 4.5 is equivalent to total alkalinity of water.
- If P = M all alkalinity is caustic alkalinity.
- If $P = \frac{M}{2}$, all alkalinity is carbonate alkalinity
- If $P < \frac{M}{2}$, predominant species are carbonate and bicorbonate
- If $P > \frac{M}{2}$, predominant species are carbonate and Hydroxide
- If P = 0 total alkalinity is bicarbonate alkalinity.

Example 2

A 200 ml of sample of water has initial pH of 10. 30 ml of 0.02 N H_2SO_4 is required to titrate the sample to pH = 4.5. What is the total alkalinity of water in mg/l as $CaCO_3$?

Sol.

30 ml of 0.02 N H_2SO_4 is required to reduce the pH upto 4.5.

∴ Total alkalinity of 200 ml of water sample = 30 mg as $CaCO_3$

∴ Total alkalinity of water in mg/l $= 30 \times \frac{1000}{200} = 150$ mg/l as $CaCO_3$

Example 3

In the previous question determine the concentration of species OH^-, HCO_3^- and CO_3^{2-}. If pH = 8.3 is reached at 11 ml of acid.

Sol.

$$\text{Initial pH} = 10$$

$$\text{pH} + \text{pOH} = 14$$

$$\Rightarrow \quad \text{pOH} = 14 - 10 = 4$$

$$\Rightarrow \quad -\log_{10}[OH^-] = 4$$

$$\Rightarrow \quad [OH^-] = 10^{-4} \text{ mol/litre}$$

$$10^{-4}\frac{\text{mole}}{\text{litre}} = 10^{-4} \times 17 \text{ gm/litre} = 10^{-4} \times \frac{17}{17} \text{ gm equivalent/litre}$$

$$= 10^{-4} \text{ (gm-equivalent/litre) of } OH^-$$

$$= 10^{-4} \text{ (gm-equivalent/litre) of } CaCO_3$$

$$= 10^{-4} \times 50 \text{ gm/litre of } CaCO_3$$

$$= 5 \text{ mg/litre as } CaCO_3$$

$$\text{upto pH} = 8.3 \text{ acid consumed} = 11 \text{ ml of } 0.02 \text{ N } H_2SO_4 = 11 \text{ mg of } CaCO_3$$

$$\text{200 ml of sample will contain} = 5 \times \frac{200}{1000} \text{ mg of } OH^- \text{ as } CaCO_3$$

$$= 1 \text{ mg of alkalinity as } CaCO_3$$

$$\frac{1}{2}CO_3^{2-} \text{ alkalinity in the sample} = 11 - 1 = 10 \text{ mg as } CaCO_3$$

$$\Rightarrow \quad CO_3^{2-} \text{ alkalinity in the sample} = 10 \times 2 = 20 \text{ mg as } CaCO_3$$

$$\Rightarrow \quad \left[CO_3^{2-}\right] \text{ in mg/litre as } CaCO_3 = 20 \times \frac{1000}{200} = 100 \text{ mg/litre}$$

$$\text{Total alkalinity (upto pH} = 4.5) = 30 \text{ ml of } 0.02 \text{ } H_2SO_4$$

$$= 30 \text{ mg of } CaCO_3 \text{ in 200 ml of sample}$$

$$= 150 \text{ mg/l as } CaCO_3$$

$$[HCO_3^-] = 150 - (100 + 5) = 45 \text{ mg/litre as } CaCO_3$$

pH

- $pH = -\log_{10}[H^+]$ where $[H^+]$ is in moles/litre
- pH is measured by potentiometer in which potential exerted by H^+ is measured .
  Permissible value of pH in water

  7 – 8.5 is acceptable limit **< 6.5 and > 9.2 is cause for rejection.**

  It can also be measured by colour indicators. Colour formed is compared with standard colour.
- Indicators used are methyl orange. Its original colour is red and colour produced is yellow. pH range is 2.8 – 4.4. Methyl orange is an acidic indicator.
- Phenolphthalein red has pH range of 8.6 – 10.3. Original colour is yellow and final colour is red. Phenolphthalein is a basic indicator.
- Acidic water causes corrosion and alkaline water causes incrustation of pipe.
- Alkaline water causes difficulty in chlorination. (Chlorine is a disinfectant.)

Degree of hardness of water

Limit (mg/l)	Degree of hardness
0-55	Soft
56-100	Slightly hard
101-200	Moderately hard
201-500	Very hard

Note : Sodium cation imparts pseudo-hardness to water.

Chloride Content

- Chlorides in water are derived mostly from natural mineral deposit, agricultural or irrigation discharges.
- Presence of chloride in high quantity indicates pollution of water due to sewage or industrial water.
- Chlorides are estimated by Mohr's method in which raw water is titrated with standard $AgNO_3$ solution using K_2CrO_4 (Potassium chromate) as indicator.
- Argentormetric method is also used to detect choloride content.
- Acceptable limit is 200 mg/l and cause for rejetion is 1000 mg/l.

Nitrogen Content

- Presence of nitrogen in water indicates presence of organic matter.
- It occurs in the form of –
  - (a) Free ammonia → indicates recent pollution
  - (b) Organic ammonia (Albuminoid) → indicates quantity of nitrgen before decomposition has started.
  - (c) Nitrite → indicates partly decomposed condition
  - (d) Nitrate → indicates old pollution (fully oxidised)
- Free ammonia should not be more than 0.15 mg/l and it can be measured by simply boiling the water and measuring the liberated ammonia by distilltion process.
- Organic ammonia should not be more than 0.3 mg/l and it is measured by boiling a sample of already boiled water plus strong alkaline solution like $KMnO_4$ and measuring the ammonia so liberated.
- Free ammonia + organic ammonia = **Kjedahl Nitrogen Ammonia**.
- Nitrite is highly dangerous, hence its permissible limit is zero. It is measured by colour matching techinque. The colour for nitrite is developed by sulphonic acid + Napthamine
- Nitrate is not harmful as it is fully oxidised. But too much of nitrat affects infants. because it causes **blue baby disease** or **Mathemoglobineming** Nitrate concentration should not be more than **45 mg/l**. Its concentration is measured by colour matching technique. Colour is formed by phenol-di-sulphonic acid + Potassium Hydroxide.

Phosphorus

- It is not toxic and do not represent direct health threat. But is indirect threat to water quality because:
  - (a) It facilitates rapid growth of aquatic plants.
  - (b) It interferes with water treatment like chemical coagulation.
- Even a low concentration of 0.2 mg/l interferes with the water treatment process.

Hardness

- It is defined as concentration of multivalent metallic cations in solution. Multivalent metallic ions most abundant in natural water are Calcium & Magnisium. Other ions which leads to hardness are Fe^{2+}, Mn^{2+}, Strontium (Sr^{2+}) and Aluminium (Al^{3+}). But Fe^{2+}, Mn^{2+}, Sr^{2+} & Al^{3+} are found in much smaller quantities and hence for all practical purposes hardness may be represented by the sum of Ca^{2+} and Mg^{2+}, ions.
- Hardnes can be divided in two parts i.e. carbonate hardness and non-carbonate hardness.
- It is measured by using spectrophotometric techniques.
- HCO_3^- and CO_3^{2-} of calcium and magnesium cause carbonate hardness. It is also called temporary hardness becausse this hardness can be removed by simple boiling of water in which calcium carbonate precipitates.

Note: Magnesium carbonate is soluble in water, hence it does not precipitate.

- Sulphate, chloride and nitrate of calcium and magnesium gives permanent hardnes. It is also called non-carbonate hardness. This hardness cannot be removed by simple boiling. It requires softening techniques.
- Hard water leads to lesser foam formation, hence consumption of soap would be more. It leads to scaling of boilers. It causes corrossion and incrustation of pipes. It makes food tasteless.
- Magnesium hardness with sulphate ion have laxative effect.
- Calcium hardness however does not cause any health problem.
- Hardness is expressed as $CaCO_3$ equivalent of Ca^{2+} and Mg^{2+} present in water in mg/litre.
- Amount of Ca^{2+} and Mg^{2+} in water is determined by titration with **versanate solution** (EDTA method). In EDTA method water is titrate with ethylene diamine tetra-acetic acid using **Eriochrome Black T** (EBT) as an indicator. EBT forms **red** colour and titration changes the colour to **blue**.
- If 0.01 M EDTA is used, 1 ml of the titrant is equivalent to 1 mg of hardness as $CaCO_3$.
- If $[Ca^{2+}]$ and $[Mg^{2+}]$ is known in mg/litre, total handness would be equal to

$$\text{Total Hardness} = \frac{\left[Mg^{2+}\right]mg/l}{\text{eq. wt of Mg}} \times \text{eq. wt of } CaCO_3 + \frac{\left[Ca^{2+}\right]mg/l}{\text{eq. wt of Ca}} \times \text{eq. wt. } CaCO_3$$

$$\therefore \text{ Total Hardness} = \left[Ca^{2+}\right] \times \frac{50}{20} + \left[Mg^{2+}\right] \times \frac{50}{12}$$

Alkalinity and Hardness

- Bicarbonate and carbonate ions in water are usually given by calcium, magnesium and sodium.
- If $NaHCO_3$ and Na_2CO_3 are absent (i.e. sodium alkalinity is absent), then **carbonate hardness** will be equal to **alkalinity.**
- But sodium alkalinity will be absent only when SO_2^{2-} and Cl^- of calcium and magnesium are present i.e. Non-carbonate hardness is present (because sodium alkalinity will be converted to calcium and magnesium alkalinity). This implies that if non-carbonate hardness is present, carbonate hardness = alkalinity
- If non-carbonate hardness is absent,

$$\text{Alkalinity} > \text{Carbonate hardness}$$

$$\therefore \quad \text{Total Hardness} = \text{Carbonate hardness}$$

Hence carbonate hardness is equal to total hardness or alkalinity whichever is less.

- Non-carbonate hardness is equal to total hardness in excesss of alkalinity.
- Acceptable limit of total hardness = 200 mg/l and cause for rejection = 600 mg/l

Fluorides

- Upto 1 mg/l, it helps to prevent dental cavities. During formation of permanent teeth it combines chemically with tooth enamel, resulting in harder, stronger teeth that are more resistant to decay.
- Excess value (greater than 1.5 to 2 ppm) results in decolouration of teeth called mottling of teeth. (Infants are affected not adults).
- Greater than 5 mg/l causes deformation of bones called bone fluorosis.
- Excessive dosages of fluoride can also result in bone fluorosis and other skeleton abnormalities.
- Acceptable limit is upto 1 mg/l and greater than 1.5 mg/l is cause for rejection.

Metals

- Metals are of two types i.e. toxic and non-toxic.
- Ca, K, Na, Fe, Mn, Zn are non-toxic metals.
- Arsenic, Barium, Cadmium, Chromium, Cynide, Lead & Mercury are toxic metals.

(i) Sodium

- Excess Na (sodium) concentration causes bad taste and harmful for cardiac and kidney patients. It is also corrosive to metal surface and in large concentration, it is toxic for plants.
- **Measurements:** Atomic absorption spectrophotometry.

(ii) Iron and Manganese

- Fe and Mn Pose colour problem, if concentrations are greater than 0.3 mg/l and 0.05 mg/l respectively.
- Some bacteria use iron and manganese compounds for an energy sourceand resulting slime growth may produce taste and odour.
- $Fe(HCO_3)_2 \xrightarrow{O_2} Fe(OH)_3 \downarrow$ (Similarly manganese also precipitates.)

  $FeCl_3 \xrightarrow{O_2} Fe(OH)_3 \downarrow$

  $FeSO_4 \xrightarrow{O_2} Fe(OH)_3 \downarrow$
- Iron and Manganese poses problems in ground water and bottom layers of lakes but not in surface water. Because surface water has sufficient O_2 and hence ppt of $Fe(OH)_3$ and MnO_2 will occur.
- Acceptable limit for Iron is 0.1 – 1.0 mg/l and for Mn 0.05 – 0.5 mg/l.

(iii) Copper

- Its large quantity affects lungs and respiratory organs.
- Its limit is 0.05 – 1.5 mg/*l*
- $CuSO_4$ greater than 250 mg/*l* has laxative effect.

(iv) Calc]ium (as Ca)

- Acceptable limit is 75 and cause for rejection is 200 mg/*l*.
- Essential for bones and teeth formation.

(v) Sulphate (as SO_4)

- Acceptable limit is 200 and cause for rejection is 400 mg/*l*

(vi) Zinc (as Zn)

- Essential nutrient for life.
- Acceptable limit 5 and cause for rejection 15 mg/*l*.

(vii) Arsenic

- Acute or chronic toxicity to humans
- Acceptable limit 0.01 and cause for rejection is 0.05 mg/*l*.

(viii) Cadmium

- Cumulative, highly toxic in humans and livestock.
- Affects all life.
- Its concentration must not be greater than 0.01 mg/*l*.

(ix) Chromium (as hexavalent Cr)

- Toxic to human and plants
- It should not be greater than 0.05 mg/*l*.

(x) Cynide (CN)

- Cynides renders tissues incapable of oxygen exchange
- It should not be greater than 0.05 mg/*l*.

(xi) Lead (Pb)

- Is is toxic to many organs and tissues including the heart, bones, kidney intestines and reproductive and nervous systems.
- It should not be greater than 0.05 mg/*l*.

(xii) Mercury

- Toxic to all form of life.
- Mercury Poisoning causes depression. numbness sensations. leaky gut syndrome, immune dysfunction etc.
- It should not be greater than 0.001 mg/*l*.

Dissolved Gas

(i) CH_4 which is studies for its explosive tendency.

(ii) H_2S imparts bad taste and odour

(iii) CO_2 indicates biological activity, imparts bad taste and water becomes corrosive

(iv) Oxygen level less than saturation level indicates oxygen deficiency.

- To determine oxygen deficiency of water 10% solution of $KMnO_4$ is exposed to 27°C for 4 hours and the amount of oxygen absorbed is calculated.

Organics

- These are classified as biodegradable and non-biodegradable organics.

Biodegradable

- Biodegradable organics are utilised for food by naturally occuring microorganisms examples of biodegradable organics are starch, fats, proteins, alcohols, acids, alldehydes and esters. Microbial utilization of discolved organice is occompanied by:

  (a) oxidation (b) reduction

- Reaction in the presence of oxygen is called **aerobic reaction** and reaction in the absence of oxygen is called **anaerobic reaction**.

- Aerobic reaction gives stable end products whereas end product of anaerobic reaction is unstable.
- Amount of oxygen consumed during microbial utilization of organics is called BOD (biochemical oxygen demand).
- BOD after 5 days at 20°C is taken as standard BOD.
- BOD_5 = [Initial Dissolved oxygen – Find dissolved oxygen] × Dilution factor

where, $$\text{Dilution factor} = \frac{\textit{Final volume}}{\textit{Sample volume}}$$

Note: Sample + pure water is diluted upto 300 ml and initial DO is noted in the diluted sample. The diluted sample is incubated at 20°C for 5 days and final DO is noted. Thus BOD_5 is calculated.

Note: In BOD test all sources of light are removed otherwise if algae is present, algal growth will take place and in that process oxygen will be released in water.

- BOD of treated water should be zero.

Non-biodegradable

- Examples of non-biodegradable organics are tannic acid, lignic acid, cellulose and phenols.
- They are constituents of woody plants.
- These organics decompose so lowly that they are called non-biodegradable. Besides these molecules with strong bonds are non-biodegradable like benzene, detergent compounds organic pesticides, industrial chemicals. Hydrocarbon combined with chlorine are toxic to organisms hence considered non-biodegradable.
- Measurement of non-biodegradable organics is done by COD i.e. chemical oxygen demand and also TOC i.e. total organic carbon.
- Both COD and TOC also measures biodegradable organics. COD is determined by mixing the sample with very strong oxidising agent like $K_2Cr_2O_7$ which oxidises all organic matter.
- Non-biodegradable organics = COD – BOD_u

BOD_u = ultimate BOD

BIOLOGICAL WATER QUALITY PARAMETERS

- The most important organisms are called pathogens. These are capable of transmitting diseases.
- Examples are bacteria, virus, protozoa and helminthes.

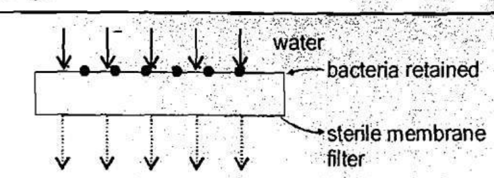
Note : Bacteria are grouped under four categories based on their shapes are as given below:

(i) Spherical – Coccus (Pl : Cocci)
(ii) Rod shaped – Bacillus (Pl : Bacilli)
(iii) Comma Shaped – Vibrium (Pl : Vibrio)
(iv) Spiral – Spirillum (Pl : Spirrilla)

- Pathogenic bacteria can be tested and counted in laboratory but only with great difficulty. Hence these tests are not performed generally in routine.
- The usual routine tests are generally conducted to detect and count the presence of **coliforms**, which in themselves are harmless aerobic loctose fermenters organisms but their presence or absence indicates the presence and absence of pathogenic bacteria.

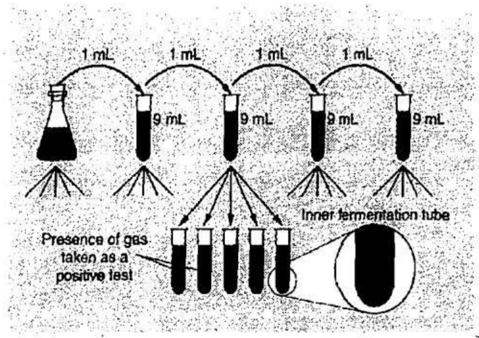
- The rod shaped Bacillus Coliform bacteria gives gram negative test to check the pathogenicity of bacteria.
- Coliform called bacteria coli (B-Coli, E-Coli) are important harmless acerobic microogranisms which are found residing in the intestine of all warm blooded animals and excreted with their faces. These bacteria live longer in water than pathogenic bacteria. Hence if coliform is absent pathogens would be absent.
- The tests for coliforms are :
  (a) Membrane filter technique
  (b) MPN test (Most Probable Number)
  (c) Coliform index.

(a) Membrane Filter Technique



- Water sample is poured on the sterile membrane filter.
- Membrane is then put in contact with nutrients (M-endo medium) that permits the growth of only **coliform colony.** After incubation for 20 hrs number of visible colonies are counted. No visible colonies should be detectable in any 100 ml sample.

(b) Most Probable Number (by Multiple Tube Fermentation Test)



- Mix different dilutions of a sample of water with lactose broth and incubate them in test tubes at 37°C for 48 hours (other substances which inhibit the growth of non-coliform organism is also added).
- The presence of **acid** or **carbon dioxide** in the test tube will indicate presence of coliform bacteria.
- Coliform actually is believed to ferment lactose and the end products are acid and CO_2.
- Then referring to standard table MPN of B-Coli per 100 ml of water is found out.
- MPN represents bacterial density which is most likely to be present.
- Say 10 ml, 1 ml and 0.1 ml dilution samples are taken and 5 number of test tubes with each dilution are tested. If positive test is seen in 4 no. of 10 ml samples, 2 No. of 1 ml sample, and 2 No. of 0.1 ml sample then from standard table MPN per 100 ml is obtained from series 4-2-2.
- If sample size is taken as 1 ml, 0.1 ml and 0.01 ml then MPN/100 obtained from table of (10 ml, 1 ml, 0.1 ml) is multiplied by 10 to get actual value. If more than three dilution samples are available then the dilutions chosen for MPN calculation should be three consecutive dilutions which shows dilution of organism to extinction [i.e., max +ve results to min results in three consecutive dilutions]
- When MPN tables are not available, then Thomas equation can be used to estimate the MPN.

$$\text{MPN/100 } ml = \frac{\text{Number of positive tube} \times 100}{\sqrt{(ml \text{ of sample in negative tube}) \times (ml \text{ of sample in all tube})}}$$

In applying the Thomas equation, the count of positive tubes should begin with the highest dilution in which at least one negative result has occured.

Example 4

Size of Sample (ml)	Number of +ve	number of –ve
1	4	1
0.1	3	2
0.01	2	3
0.001	0	5

Determine the MPN using the Thomas equation

Sol.

$$\text{Number of the tube} = 4 + 3 + 2 = 9$$

$$ml \text{ of sample in –ve tube} = 1 \times 1 + 2\times 0.1 + 3 \times 0.01 + 5 \times 0.001 = 1.235$$

$$ml \text{ of sample in all tube} = 5 \times 1 + 5 \times 0.1 + 0.01 \times 5 + 0.001 \times 5 = 5.555$$

$$\text{MPN/100 } ml = \frac{9\times 100}{\sqrt{1.235\times 5.555}} = 344$$

Example 5

Determine the most probable number of coliforms. A standard multiple fermentation test is run on a sample of water from a surface stream. The results of the analysis for the confirmed test are shown below.

Size of sample *Ml*	No. of positive	No. of negative
10	4	1
1	2	3
0.1	1	4
0.01	0	5

Determine the MPN of coliform organisms.

Table: MPN index and 95% confidence limits for various combination of positive results when 5 tubes are used per dilution (10mL, 1 mL, 0.1 ml)

Combination of positive	MPN index /100ml	95% confidence limit	
		Lower	Upper
2-1-0	7	1	17
4-2-1	26	9	78

Sol. In this problem we have more than three dilution. Hence we will choose three consecutive dilutions sample which start from max +ve results to closer to extinction values. Thus 4–2–1 will be better representation. Corresponding MPN per 100 ml = 26 as shown in the table for 10 ml, 1 ml, 0.1 ml dilution.

Note: If however it is asked to find out MPN per 100 ml in the dilution 1ml, 0.1 ml and 0.01 ml than it will correspond to 2-1-0 value. The corresponding MPN from the table is 7× 10 = 70 because sample is $\frac{1}{10}$ th of the 10, 1, and 0.1 ml sample sizes used in table. The 95% confidence limit will be 10-170 is this case

(C) Coliform Index

- It is defined as the reciprocal of smallest quantity of a sample which will give positive B-coli test. MPN and B-Coli index are now obsolete.

Water Borne Diseases

Bacteria	– Typhoid fever (salmonella bacteria typhi which is responsible for enteric fever)
	– Cholera (vibrio cholerae boactrum)
	– Bacillary Dysentry (Sonne bacilus)
Virus	– Jaundice (Hapatitis virus)
	– Poliomyelitis
Protozoa	– Amoebic dysentry

Nuisance Bacteria

(i) *Iron Bacteria:* It causes pitting and tuberculation in pipes and renders water unsuitable for industrial purposes.

(ii) *Sulphur Bacteria:* Acid produced during their metabolism is destructive to concrete and other structures.

CHAPTER

1

Introduction

Hydrology is the science that deals with the occurrence, circulation and distribution of water of the earth and its atmosphere.

HYDROLOGICAL CYCLE

- The hydrological cycle is a global sun-driven process whereby water is transported from the oceans to the atmosphere, from atmosphere to the land and then back to the sea.
- The processes constituting this cycle extend from an average depth of about 1 km in the lithosphere (the crust of the earth), to a height of about 15 km in the atmosphere. The hydrological cycle has no beginning or end.
- A convenient starting point to describe the cycle is in the oceans.
- Water in the oceans evaporate due to the heat energy provided by solar radiation. The water vapour moves upwards and forms clouds. While much of the clouds condense and fall back to the oceans as rain, part of the clouds is driven to the land areas by winds. There they condense and *precipitate* onto the land mass as rain, snow, hail, sleet, etc.
- A part of the precipitation may evaporate back to the atmosphere even while falling.
- Another part may be intercepted by vegetation, structures and other such surface modifications from which it may be either evaporated back to atmosphere or move down to the ground surface.
- A portion of the water that reaches the ground, enters the earth's surface through infiltration, enhances the moisture content of the soil and reaches the groundwater body.
- Vegetation sends a portion of the water from under the ground surface back to the atmosphere through the process of transpiration.
- Some infiltrated water may emerge to surface-water bodies as interflow, while other portions may become groundwater flow.
- Groundwater may ultimately be discharged into streams or may emerge as springs.
- After an initial filling of depression storages and interception, overland flow (surface runoff) begins provided that the rate of precipitation exceeds that of infiltration.
- The hydrology cycle is usually described in terms of six major components: Precipitation (P), Infiltration

(I), Evaporation (E), Transpiration (T). Surface Runoff (R), and Ground water flow (G). For computational purposes, evaporation and transpiration are sometimes lumped together as evapotranspiration (ET). Figure 1.1 define these components and illustrates the paths they define in the hydrological cycle.

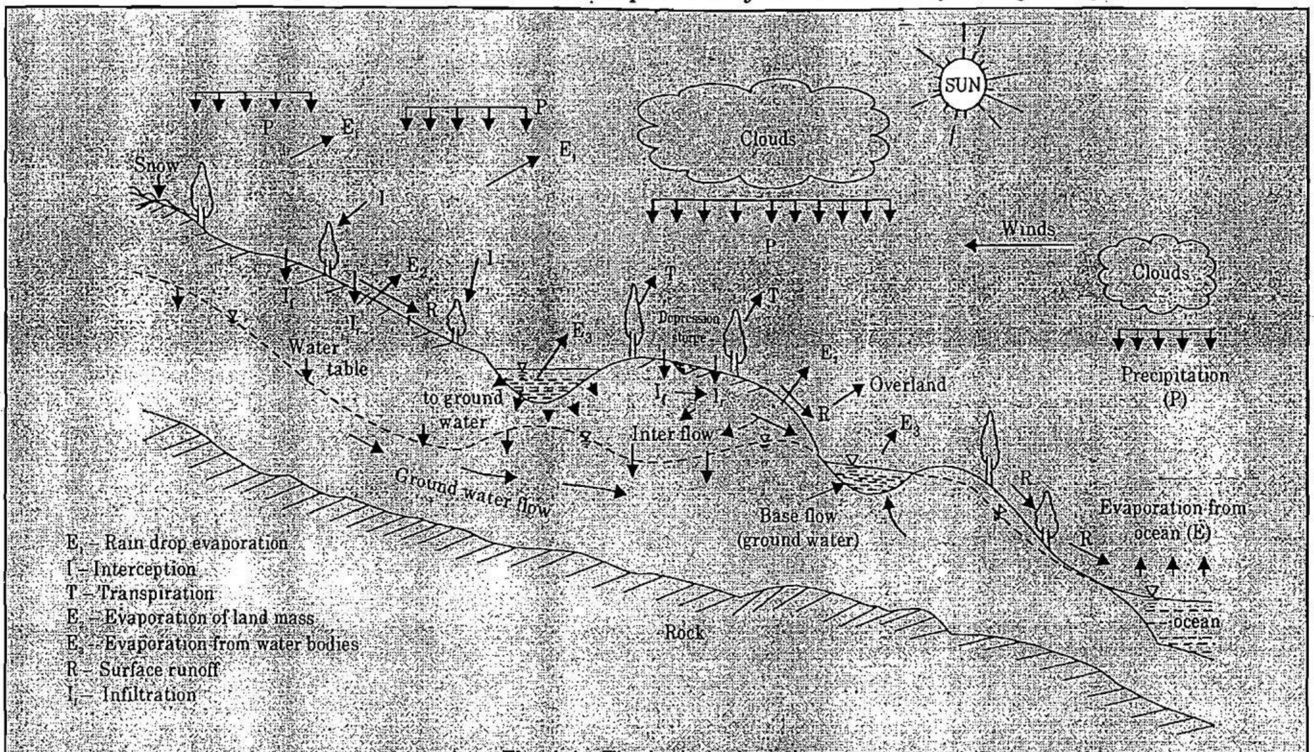


Fig. 1.1 : The hydrologic cycle

The magnitude and duration of a precipitation event determine the relative importance of each component of the hydrological cycle during that event. During storm events, evaporation and transpiration may be of minor considerations, but during rain-free periods, Evapotranspiration becomes a dominant feature of the hydrological cycle.

Note :

- **Evaporation** is the transfer of water from a liquid state to a gaseous state, i.e., it is the conversion of liquid to the vapour phase.
- **Precipitation** is the deposition of water on the earth's surface in the form of rain, snow, hail, frost and so on.
- **Interception** is the short-term retention of rainfall by the foliage of vegetation.
- **Infiltration** is the movement of water into the soil of the earth's surface.
- **Percolation** is the movement of water from one soil zone to a lower soil zone.
- **Transpiration** is the soil moisture taken up through the roots of a plant and discharged into the atmosphere through the foliage by evaporation.
- **Storage** is the volume of water which gets stored in natural depressions of a basin.
- **Runoff** is the volume of water drained by a river at the outlet of a catchment.

HYDROLOGICAL BUDGET

- For a given catchment in a time interval Δt,

Inflow – Outflow = Storage [continuity equation]

This continuity equation expressed in terms of various phase of hydrological cycle is called water budget

Rainwater Harvesting

Rainwater Harvesting: Water is why life exists on planet Earth; without it, life is unimaginable. How will you plan your survival if one day there is no water on earth? It is hard to even conceive that there is no water on earth. Freshwater sources are becoming scarce over time. Unless the current water situation changes and preventive measures are taken, the world will run out of freshwater by 2050. Here comes Rainwater Harvesting, a sustainable process that helps conserve rainwater for different purposes. Rainwater Harvesting is best defined as the technique by which rainwater is accumulated and stored for later use when there is a scarcity or a drought.

Definition:

Rainwater harvesting may be defined as the simple technique of collection and storage of rainwater at the surface or in the subsurface aquifer before it is lost as surface runoff from rooftops, parks, roads, open grounds, etc., for later use.

Types of Rainwater Harvesting

There are two ways of Rainwater harvesting:
1. Rooftop Rainwater Harvesting
2. Surface Runoff Rainwater Harvesting

Rooftop Rainwater Harvesting

a. Rooftop rainwater harvesting or domestic rainwater harvesting is the technique through which rainwater is captured from roof components and stored in tanks/reservoirs/groundwater aquifers.
b. It consists of the conservation of rooftop rainwater in urban areas and utilizing it to augment groundwater storage by artificial recharge.
c. This technique is particularly useful in dryland, hilly, urban and coastal areas. If the system is properly installed and maintained, clean water fit for drinking can be collected and stored.

Components of Rooftop Rainwater Harvesting System

The various components of rooftop rainwater harvesting system are:
1. Roof/catchment area
2. Gutters and downpipes
3. Filter unit or leaf screen
4. Storage tank
5. Delivery system
6. Water treatment unit

Surface Runoff Rainwater Harvesting

Harvesting of surface runoff water and storage of the same into reservoirs makes it available for use when required. In this method of collecting rainwater for irrigation, water flowing along the ground during the rains will be collected to a tank below the surface of the ground.

Methods/Process of Rainwater Harvesting

There are three methods of harvesting Rainwater as given below :

(a) Storing rainwater for direct use: Collecting rainwater for direct use is a simple process in places where rains occur throughout the year. Rainwater can be stored in tanks. However, at places where it rains for 22 to 33 months, a huge volume of storage tanks would have to be provided.

In such places, it will be more appropriate to use rainwater to recharge groundwater aquifers rather than to go for storage. If the strata are impermeable, then storing rainwater in storage tanks for direct use is a better method. Similarly, if the groundwater is saline/unfit for human consumption or the groundwater table is very deep, this method of rainwater harvesting is preferable.

(b) Recharging groundwater aquifers from rooftop runoff: Rainwater that is collected on the rooftop of the building may be diverted by drain pipes to a filtration tank from which it flows into the recharge well. The recharge well should preferably be shallower than the water table. This method of rainwater harvesting is preferable in the areas where the rainfall occurs only for a short period in a year, and the water table is at a shallow depth.

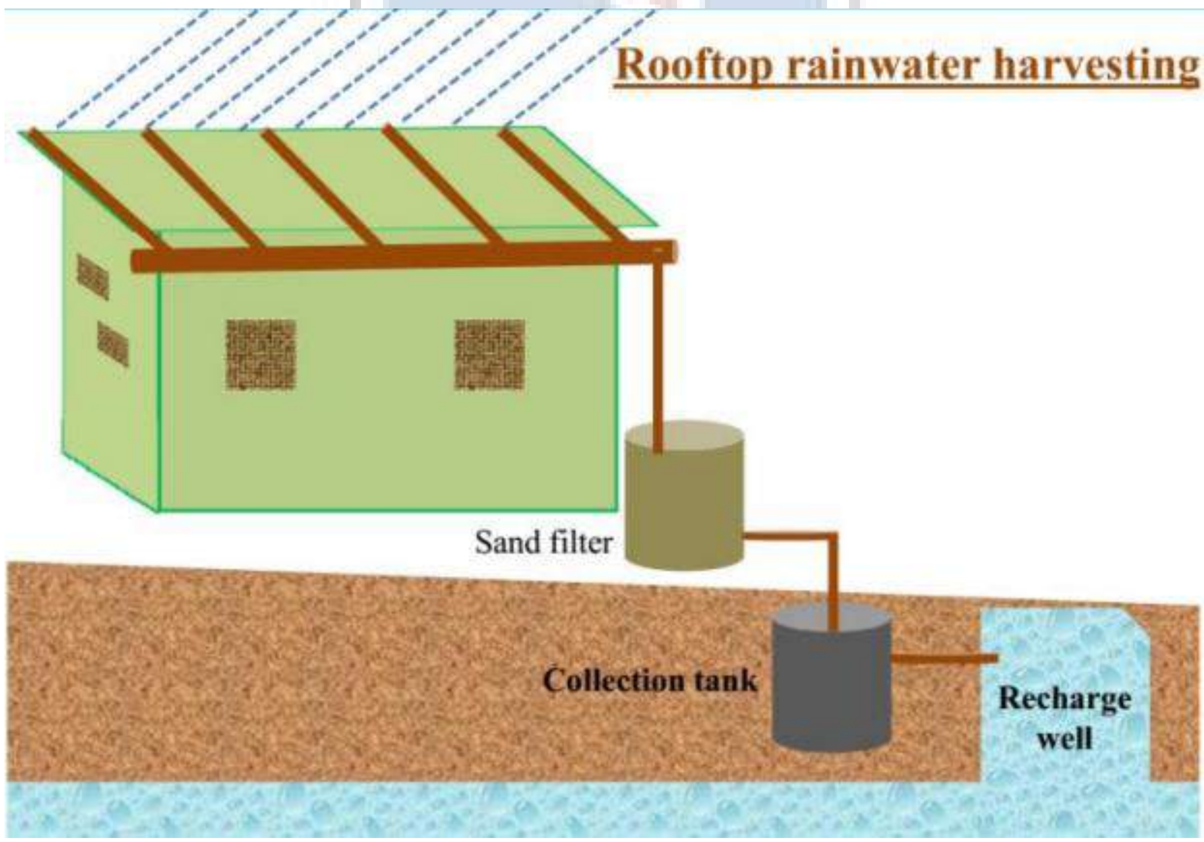


Fig: Recharging Groundwater Aquifers from Rooftop Runoff

(c) Recharging groundwater aquifers with runoff from the ground area: The rainwater collected from the open areas may be diverted by drain pipes to a recharge dug well through filter tanks. The abandoned borewell can be used cost-effectively for this purpose.

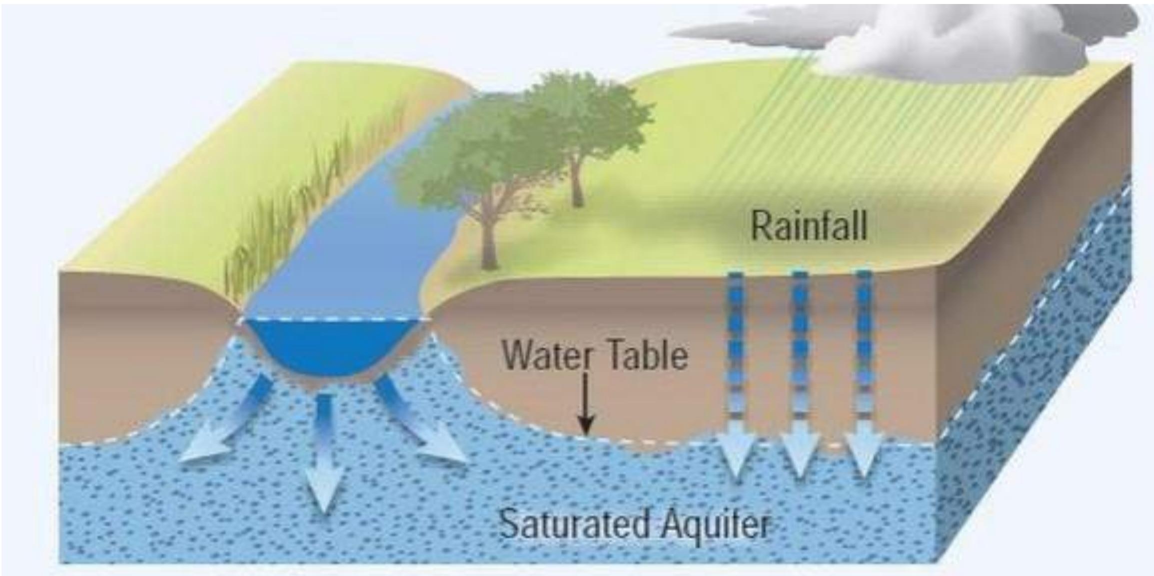


Fig: Recharging Groundwater Aquifers with Runoff from the Ground Area

Advantages of Rainwater Harvesting

1. Promotes adequacy of underground water.
2. Mitigates the effect of drought.
3. Reduces soil erosion as surface runoff is reduced.
4. Decreases load on stormwater disposal systems and reduce flood hazards.
5. Improves groundwater quality/decreases salinity (by dilution).
6. Prevents ingress of seawater in subsurface aquifers in coastal areas.
7. Improves groundwater table, thus saving energy (to lift water).
8. The cost of recharging subsurface aquifers is lower than surface reservoirs.
9. The subsurface aquifer also serves as a storage and distribution system.
10. No land is wasted for storage purposes, and no population displacement is involved.
11. Storing water underground is environmentally friendly.

Disadvantages of Rainwater Harvesting

1. The cleaning and regular maintenance of tanks are required.
2. No rainfall or limited rainfall affects the storage system.
3. Stagnant water in tanks leads to the breeding of mosquitoes and other waterborne diseases.
4. The setup of a system should be accurate.

17

Dams in General and a few Dams in Particular

17.1. Definition and Uses of Dams

A dam may be defined as an obstruction or a barrier built across a stream or a river. At the back of this barrier, water gets collected, forming a pool of water. The side on which water gets collected is called the upstream side, and the other side of the barrier is called the downstream side. The lake of water which is formed upstream is often called a *reservoir*, or a *dam reservoir*, or a *river reservoir*, or a *storage reservoir*.

The water collected in this reservoir can be supplied for irrigating farm lands through a system of canal network, or may be supplied for drinking purposes. The lake so formed can be used for recreation uses. The energy of this collected water can be used to turn a mill to grind wheat or to turn the blades of a tubrine to generate electrical power. And in times of floods, the dams can serve as protections for the towns and cities farther down the river.

Apart from these numerous advantages and uses (such as navigation, irrigation, electricity, flood control, etc.) of a dam, it sometimes helps us in planning war strategy and helps us in controlling the advancement of enemies and their forces. Dams have been frequently opened in times of war. The Dutch breached their dikes during Second World War to bedevil the invading Germans. Chinese used to destroy their dikes to flood out the enemy. Russian army retreating from the Nazi marauders, partly destroyed the famous Dneprostroi Dam in the Ukraine to keep its power plant from falling into the hands of Hitler's men.

17.2. History of Dam Construction.

It is very difficult to say as where and when the first man-made dam was built. Archaeological evidences help in estimating that the very first man made dam is at least 3000—5000 years old. Whenever it was built, that first dam was almost certainly an irrigation dam. Its designer might have observed beavers at work or he might have thought of it the some other way. Beavers are mammel creatures belonging to the family of rats, mice, squirrels. They live under water and are generally 1.2 m long including more than 0.3 m of tail, and weigh upto 25 to 30 kg. These rodents produce fur. These creatures create dam type barriers to create a place where their family can live. They provide themselves with comfortable ponds to live in, by building dam type barriers across the stream with the help of trees which they themselves cut.

These elegant structures, built out of logs, buttressed with twigs and branches and sealed with mud and stone help us many a times in controlling silt entry into the stream. A beaver dam accumulates silt brought down by its stream. When a beaver dam is breached, the silted water pours through, and the fertile silt is deposited over the wide area. This creates what farmers call a *beaver's meadow*, where crops grow particularly well.

Beavers are sometimes encouraged to build dams in areas where man can not reach easily to construct man-made dams.

17.3. Construction of Modern Dams

The first modern dam of the world was perhaps constructed on the Nile river, in Egypt at *Aswan*. It was completed in 1902 and was a major engineering project.

This famous **Aswan Dam** was designed primarily to control the flooding of the Nile river, to promote irrigation in the Nile Valley, and to further navigation along the river.

Aswan is 1200 km from the mouth of the Nile. The site was chosen because the river at Aswan is shallow and has a granite bed, on which a firm foundation could be erected.

The first step in damming any major river is to divert the flow of water so as to permit dam construction. This was accomplished at Aswan, by constructing a circular earthen barrier around the area chosen from the dam foundations. At low river, this enclosure was pumped out. All the work had to be completed before the river flooded again. The foundation was laid round the clock with a huge labour force. So much so that 3,600 tons of masonry were put in places in a single day.

This 120′ high dam, running for about $1\frac{1}{2}$ miles from shore to shore, 100 feet thick at its base and 24′ wide at top, costed about 1.5 crore dollars, when completed in 1902. A roadway ran along the upper rim. About 1 billion tons of water was its storage capacity, and 180 sluices were constructed into this barrier. Water could be collected during the rainy season and released through the sluice gates during the summer and drought.

Roosevelt Dam. The next famous dam of the world was completed in 1911 on the Salt River of Arizona (U.S.A.) and was called Roosevelt dam.

The Aswan dam was constructed with stone, while the Roosevelt dam was constructed with solid blocks of concrete : which was of the type known as 'Solid Masonry Gravity Dam' : which simply means that it was built with solid blocks of concrete, which hold back the flow of water by sheer weight. This type of dam is one of the most ancient.

The construction was started in 1905. Despite the numerous troubles in its construction, the dam was completed in 1911 with a reservoir capacity of $\frac{1}{2}$ billion gallons of water. The completed dam, 280 feet high, was *158 feet thick* and spanning for a length of 1,125 feet. Had the dam been built without the benefit of 19th century engineering advances in design and stress control, it would have had to be 700 to *1000 feet thick* at base ; a far more expensive and cumbersome thing to build.

The Roosvelt dam was a fascinating advancement, but was soon overshadowed by other vastly greater dams, such as *Hoover Dam*, (726′ high), *Bhakra Dam* (740′ high), etc. All of them are 'solid concrete gravity type' dams.

17.4. Various Types of Dams

Before we describe some of the famous dams of the world, it is worth while to classify the various types of dams.

Most engineers recognise seven general types of dams. Three of them are ancient in origin, and four have come into general use only in the last about 100 years or so.

The three older types of dams are :

(1) *Earth Dams*

(2) *Rook-fill dams*

(3) *Solid masonry gravity dams.*

These three types of dams are discussed below :

(1) **Earth Dams**. Earth dams are made of soil that is pounded down solidly. They are built in areas where the foundation is not strong enough to bear the weight of a concrete dam, and where earth is more easily available as a building material compared to concrete or stone or rock.

Some important earth dams of the world are :

(*i*) Green mountain dam on Colorado river in U.S.A.

(*ii*) Swift dam in Washington in U.S.A.

(*iii*) Side flanks of Nagarjun Sagar dam in India.

(*iv*) Trinity Dam in California in U.S.A.

(*v*) Maithan Dam in India (which is partly Earthen and partly Rockfill).

(2) **Rockfill Dams.** Rockfill are formed of loose rocks and boulders piled in the river bed. A slab of reinforced concrete is often laid across the upstream face of a rockfill dam to make it water-tight.

Some important rock-fill dams of the world are ;

(*i*) The Salt Springs Dam in California (345′ high) in U.S.A.

(*ii*) The San Gabriel No. 1 Dam (321′ high) in U.S.A.

(*iii*) Cougar Dam on Mc-Knezie River in Oregon (445′ high) in U.S.A.

(3) **Solid-masonry Gravity dams.** These are familiar to us by now, after we have talked about Aswan, Roosevelt, Hoover, and above all Bhakra dam.

These big dams are expensive to be built but are more durable and solid than earth and rock dams. They can be constructed on any dam site, where there is a natural foundation strong enough to bear the great weight of the dam.

These three types of dams were all found in ancient days. In recent times, *four other types of dams have come into practice.* They are :

(4) *Hollow masonry gravity dams* ;

(5) *Timber dams* ;

(6) *Steel dams* ; and

(7) *Arch dams.*

(4) **The hollow masonry gravity dams**. These are essentially designed on the same lines on which the solid masonry gravity dams are designed. But they contain less concrete or masonry ; about 35 to 40% or so. Generally, the weight of water is carried by a deck of R.C.C. or by arches that share the weight burden. They are difficult to build and are adopted only if very skilled labour is easily available, otherwise the labour cost is too high to build its complex structure.

(5) **Steel dams.** These are not used for major works. Today, steel dams are used as temporary coffer dams needed for the construction of permanent dams. Steel coffer dams are usually reinforced with timber or earthfill.

(6) **Timber dams.** These are short lived, since in a few years time, rotting sets in. Their life is not more than 30 to 40 years and must have regular maintenance during that time. However they are valuable in agricultural areas, where a cattle

raiser may need a pool for his live stock to drink from, and for meeting other such low-level needs.

(7) **Arch dams.** Arch dams are very complex and complicated. They make use of the horizontal arch action in place of weight to hold back the water. They are best suited at sites where the *dam must be extremely high and narrow.* Some examples are :

(*i* *Sautet dam* on the Drac River in France, 414′ high, but only 230′ long at top and 85′ long at bottom of the gorge, 56′ thick at bottom and 8′ thick at top.

(*ii*) *The Tignes dam* in France (592′ high).

(*iii*) *Mauvoisin dam* on the Drause River in Switzerland, (780′ high).

(*iv*) *Idduki* dam in Kerala State, across the Periyar river, which is the only arch dam in India. It is 366 m (1200′) long double curvature arch dam, made in concrete, and has a height of about 170 m (560′).

17.5 Problems in Dam Construction

18

Reservoirs and Planning for Dam Reservoirs

18.1. Definition and Types

When a barrier is constructed across some river in the form of a dam, water gets stored on the upstream side of the barrier, forming a pool of water, generally called a *dam reservoir* or an *impounding reservoir* or *a river reservoir,* or a *storage reservoir.*

The quality of water stored in such a reservoir is not much different from that of a natural lake. The water so stored in a given reservoir during rainy season can be easily used almost throughout the year, till the time of arrival of the next rainy season, to refill the emptying reservoir again.

Depending upon the purpose served by a given reservoir, the reservoirs may be broadly divided into the following three types.

(1) *Storage or Conservation reservoirs* ;

(2) *Flood Control reservoirs* ; and

(3) *Multipurpose reservoirs.*

The fourth type of a reservoir is a simple storage tank constructed within a city water supply system, and is called a *Distribution reservoir* ; and such a reservoir is evidently not a river reservoir, but is a simple storage tank.

18.1.1. Storage or Conservation Reservoirs. A city water supply, irrigation water supply, or a hydroelectric project drawing water directly from a river or a stream may fail to satisfy the consumers demands during extremely low flows; while during high flows, it may become difficult to carry out their operations due to devastating floods. *A storage or a conservation reservoir can retain such excess supplies during periods of peak flows, and can release them gradually during low flows as and when the need arises.*

Incidentally, in addition to conserving water for later use, the storage of flood waters may also reduce flood damage below the reservoir. Hence, a reservoir can be used for controlling floods either solely or in addition to other purposes. In the former case, it is known as a 'Flood Control Reservoir' or a 'Single Purpose Flood Control Reservoir'; and in the latter case, it is called a 'Multipurpose Reservoir'.

18.1.2. Flood Control Reservoirs. A flood control reservoir, generally called a flood-mitigation reservoir, stores a portion of the flood flows in such a way as to minimise the flood peaks at the areas to be protected downstream. To accomplish this, the entire inflow entering the reservoir is discharged till the outflow reaches the safe capacity of the channel downstream. The inflow in excess of this rate is stored in the reservoir, which is then gradually released, so as to recover the storage capacity for the next flood.

The flood peaks at the downstream of the reservoir are thus reduced by an amount AB, as shown in Fig. 18.1. A flood control reservoir differs from a conservation reservoir only in its need for a large sluiceway capacity to permit rapid drawdown before or after a flood.

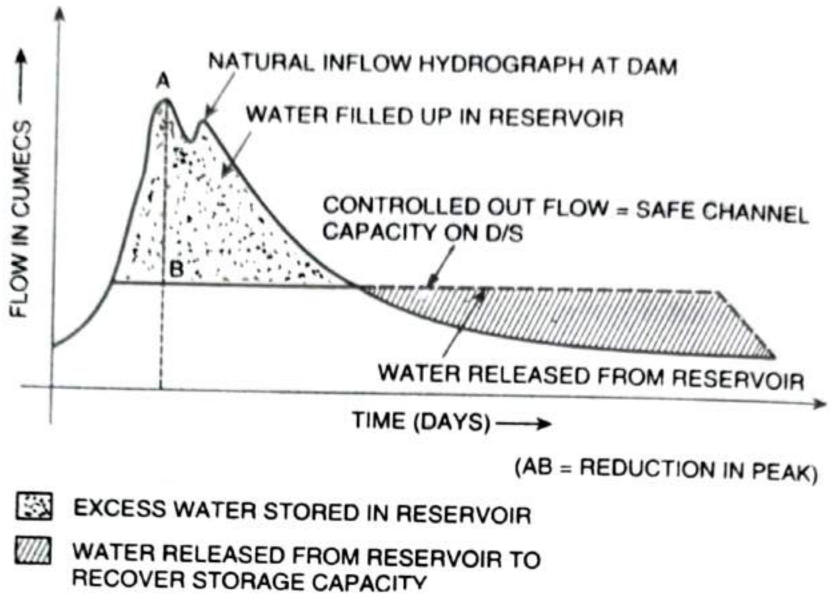


Fig. 18.1.

Types of flood control reservoirs. There are two basic types of flood-mitigation reservoirs; *i.e.*

(*i*) *Storage reservoirs or Detention basins* ; and

(*ii*) *Retarding basins or Retarding reservoirs.*

A reservoir having gates and valves installation at its spillway and at its sluice outlets is known as a storage reservoir; while on the other hand, a reservoir with uncontrolled and ungated outlets is known as a **retarding basin.**

Functioning and Advantages of a Retarding Basin

A retarding basin is usually provided with an uncontrolled spillway and an uncontrolled orifice type sluiceways. The automatic regulation of outflow, depending upon the availability of water, takes place from such a reservoir. The maximum discharging capacity of such a reservoir should be equal to the maximum safe carrying capacity of the channel downstream. As floods occur, the reservoir gets filled, and discharges through sluiceways. As the reservoir elevation increases, the outflow discharge increases. The water level goes on rising until the flood has subsided, and the inflow becomes equal to or less than the outflow. After this, the water gets automatically withdrawn from the reservoir until the stored water is completely discharged. The advantages of a retarding basin over a gate controlled detention basin are:

(*i*) Cost of the gate installation is saved.

(*ii*) There are no gates and hence, the possibility of human error and negligence in their operation is eliminated.

(*iii*) Since such a reservoir is not always filled, much of the land below the maximum reservoir level will be submerged only temporarily and occasionally, and can be successfully used for agriculture, although no permanent habitation can be allowed on this land.

Functioning and Advantages of a Storage Reservoir

A storage reservoir with gated spillway and gated sluiceways, provides more flexibility of operation, and thus gives us better control and increased usefulness of the reservoir. Storage reservoirs are, therefore, preferred on large rivers, which require better control; while retarding basins are preferred on small rivers. In storage reservoirs, the flood crest downstream, can be better controlled and regulated properly, so as not to cause their coincidence. This is the biggest advantage of such a reservoir and outweighs its disadvantages of being costly and involving risk of human error in installation and operation of gates.

18.1.3. Multipurpose Reservoirs. A reservoir planned and constructed to serve not only one purpose but various purposes together is called a multipurpose reservoir. Reservoir, designed for one purpose, incidentally serving other purposes, shall not be called a multipurpose reservoir, but will be called so, only if designed to serve those purposes also in addition to its main purpose. Hence, a reservoir designed to protect the downstream areas from floods and also to conserve water for water supply, irrigation, industrial needs, hydroelectric purposes, etc. shall be called a multipurpose reservoir. Bhakra dam and Nagarjun Sagar dam are the important multipupose projects of India.

18.1.4. Distribution Reservoirs. A distribution reservoir is a small storage reservoir constructed within a city water supply system. Such a reservoir can be filled by pumping water at a certain rate and can be used to supply water even at rates higher than the inflow rate during periods of maximum demands (called critical periods of demand). Such reservoirs are, therefore, helpful in permitting the pumps or the water treatment plants to work at a uniform rate, and they store water during the hours of no demand or less demand, and supply water from their 'storage' during the critical periods of maximum demand.

In this chapter, we shall however, confine ourselves to the river reservoirs only.

18.2. Capacity-Elevation and Area-Elevation Curves of a Reservoir Site

Whatever be the size or use of a reservoir, the main function of a reservoir is to store water and thus to stabilize the flow of water. Therefore, the most important physical characteristic of a reservoir is nothing but its *storage capacity*. The capacity of reservoirs on dam sites, is determined from the contour maps of the area. A topographic survey of the dam site is carried out, and a contour map such as shown in Fig. 18.2 is drawn. The area enclosed within each contour can be measured with a planimeter.

In fact, the general practice adopted for capacity computations is to actually surve, the site contours only at vertical distances of 5 m or so. The areas of the intervening contours at smaller intervals of say 0.5 m or so, are then interpolated by taking the square root of the surveyed contours, and to assume that the square root of the interpolated ones, vary in exact proportion to their vertical distance apart. For example, suppose the area of the reservoir at 200 m contour is A_1 hectares, and that at 205 m contour is A_2 hectares; then

The area at 200.5 m contour is

$$= \left[\sqrt{A_1} + \frac{200.5 - 200}{205 - 200}\left(\sqrt{A_2} - \sqrt{A_1}\right)\right]^2$$

$$= \left[\sqrt{A_1} + \frac{0.5}{5.0}\left(\sqrt{A_2} - \sqrt{A_1}\right)\right]^2 \qquad \text{...[18.1 (a)]}$$