Program : **B.Tech**

Subject Name: **Transportation Engineering**

Subject Code: **CE-404**

Semester: **4th**

INTRODUCTION

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

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

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

Selection of Tunneling Route

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

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

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

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

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

Advantages of Tunneling

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

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

compared to the bridge.

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

Tunneling Disadvantages

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

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

Engineering surveys

Surveying Steps in Tunnels:

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

1. Surface Survey:

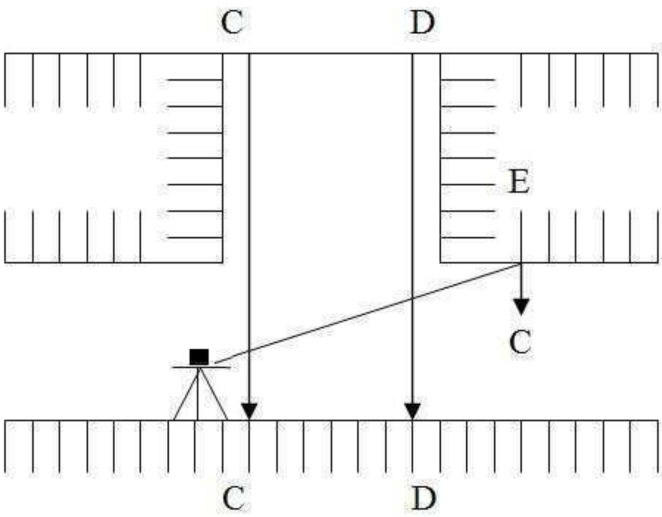
This includes

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

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

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

2. Transferring the alignment underground



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

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

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

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

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

Alignment and Grade in Tunneling Process

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

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

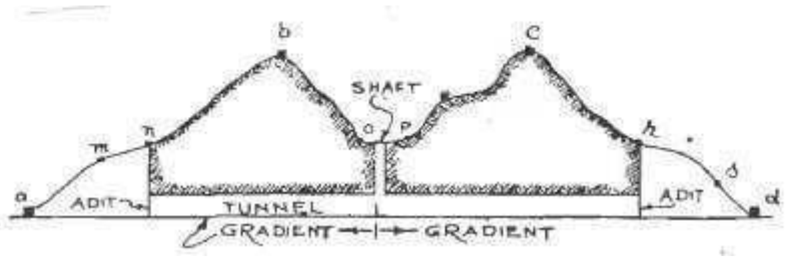


Fig.3: Surface Alignment and the provision of grade for the tunnel

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

Size and Shape of a Tunnel

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

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

Table 30.1 Shape and purpose of tunnels

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

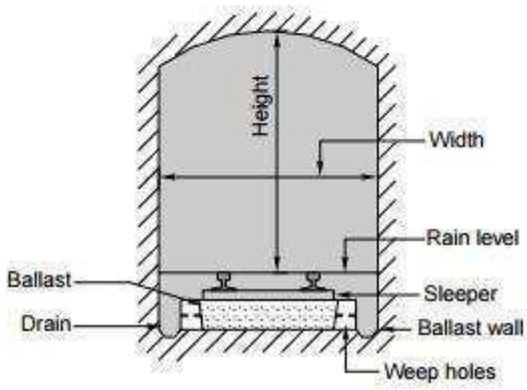
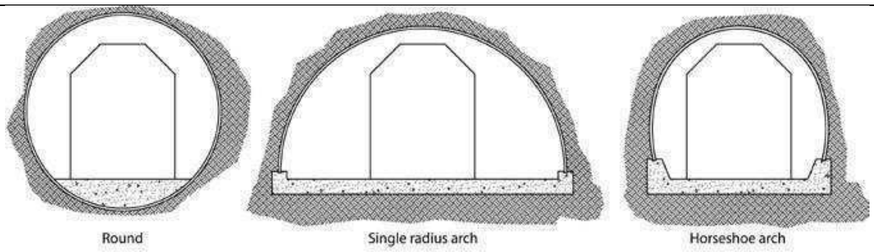
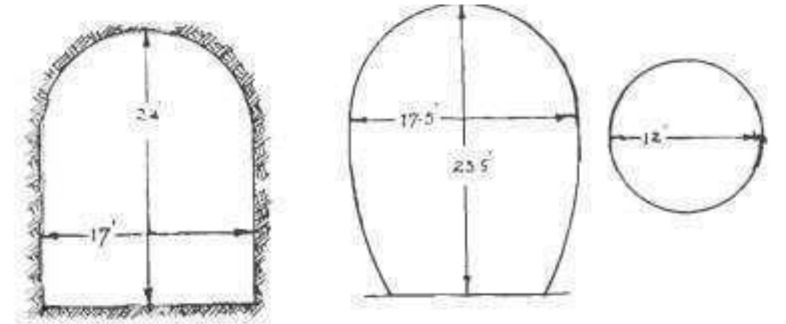


Fig. 30.1 A typical cross section of a tunnel

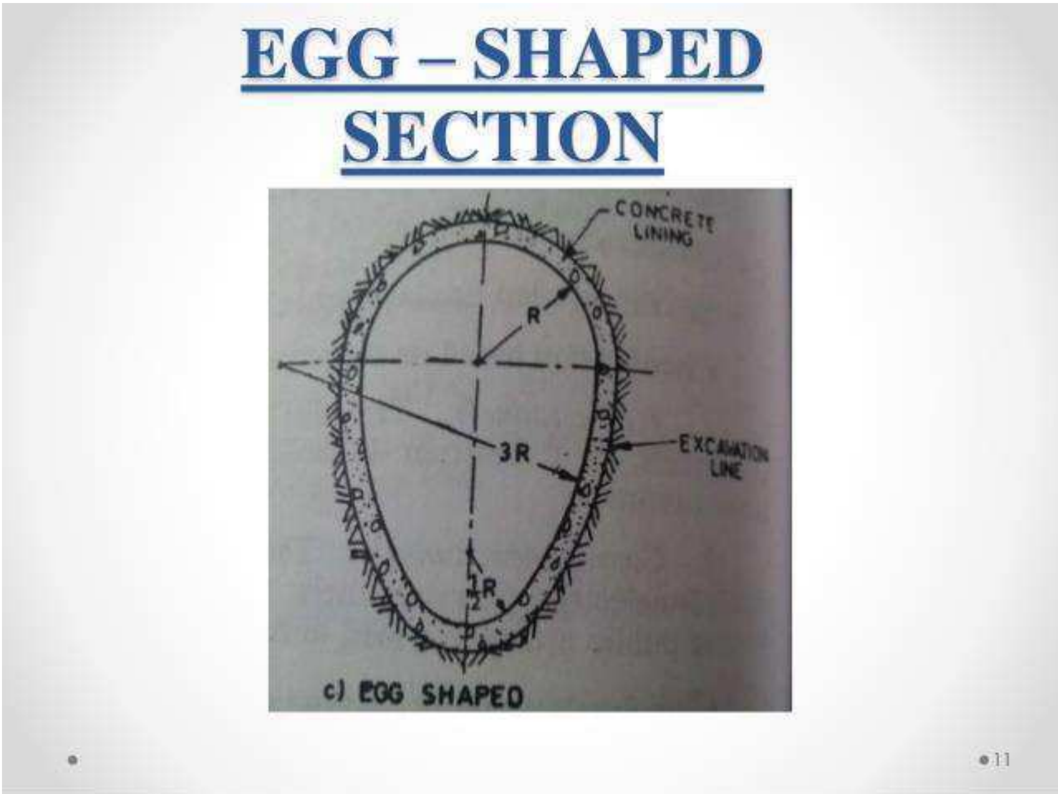
The shapes of tunnel linings are usually determined by their purpose, ground conditions, construction method and/or lining materials.

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





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



Approaches in Tunneling Method

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

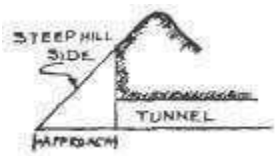


Fig.1: Short Approach in Tunneling

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

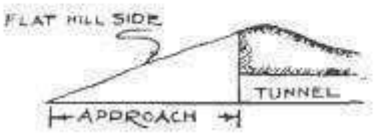


Fig.2: Short Approach in Tunneling

Shaft, Pilot Tunnel:

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

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

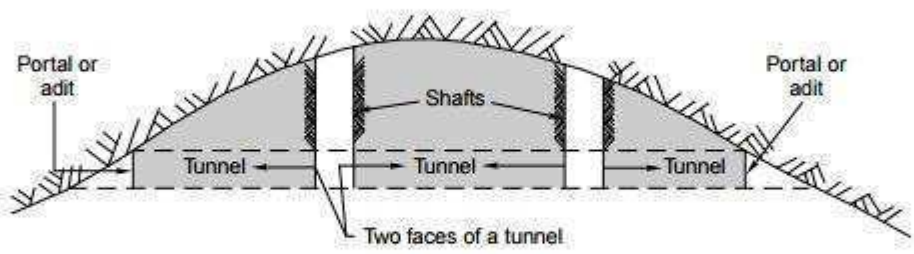


Fig. 30.11 Tunnel shafts

Definition of pilot tunnel

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

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

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

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

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

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

- Needle beam method, sequence of construction operations

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

- Sequence of Working:

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

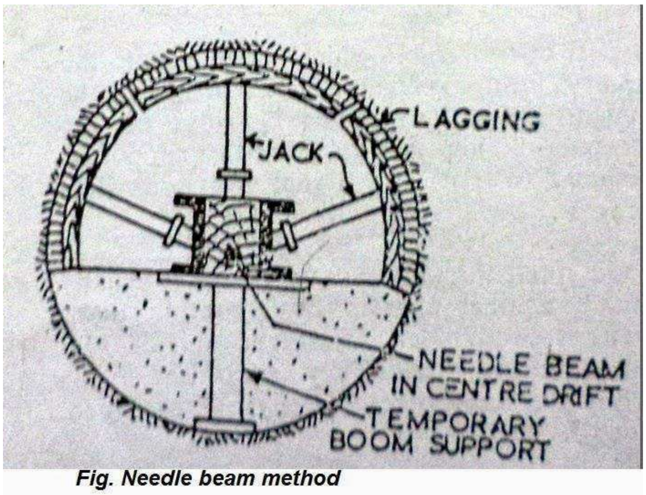


Fig. Needle beam method

Needle beam method- 1

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

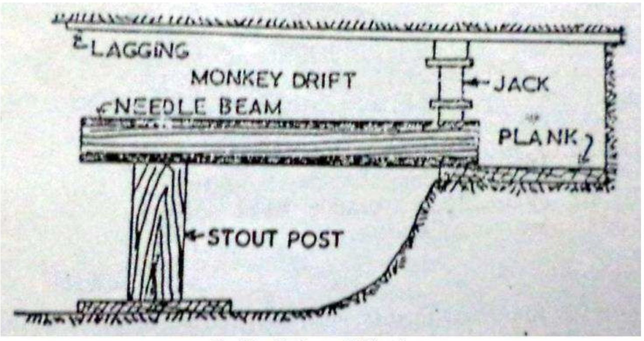


Fig. Needle Beam Method

Needle beam -2

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

- Compressed Air Tunneling Method:

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

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

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

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

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

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

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

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

Here we will discuss the first three methods in details.

- Full Face Method

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

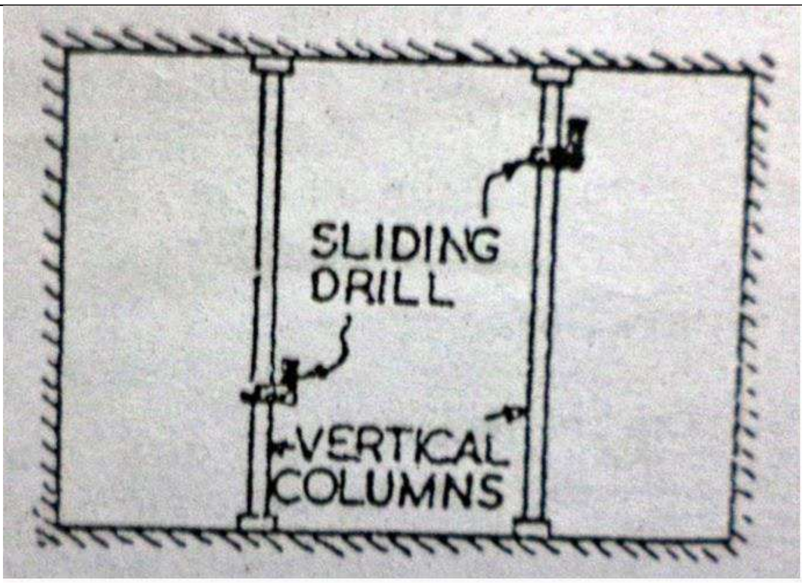


Fig. Full Face Method of Tunneling

- **Heading and Benching Method**

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

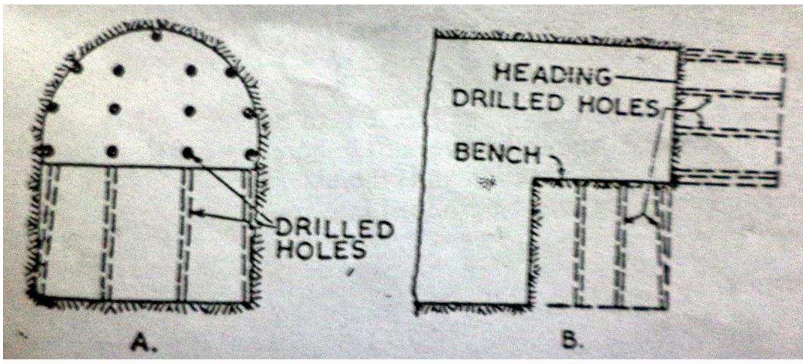


Fig. Heading and Benching (Tunneling)

Heading and Benching Method (Tunneling)

- **Drift Method:**

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

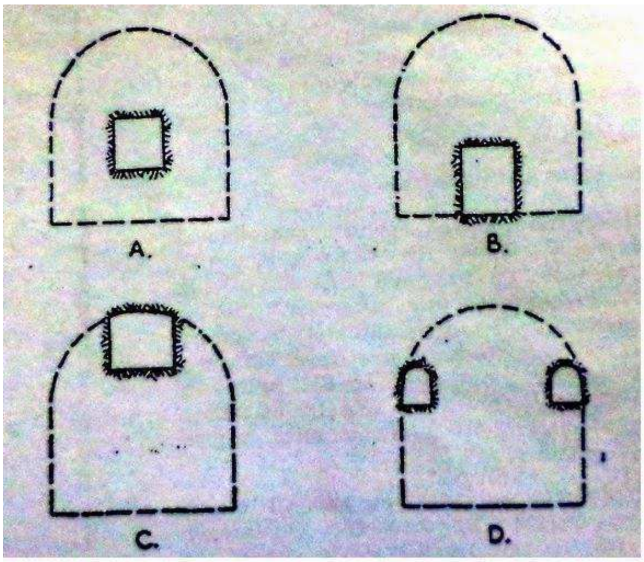


Fig. Drift Method of Tunneling

Drift Method (tunneling)

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

Different types of lining-

Lining of Tunnels

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

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

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

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

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

(e) Reducing the maintenance cost of the tunnel.

1 Sequence of Lining

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

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

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

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

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

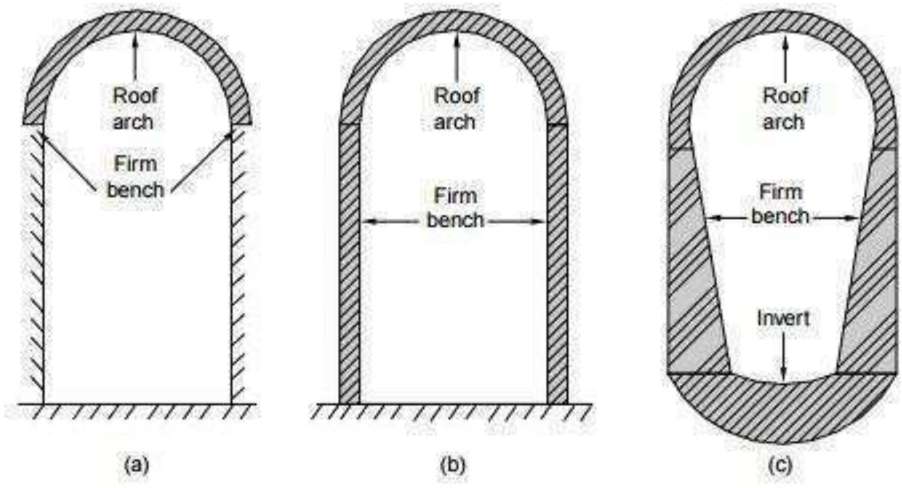


Fig. 30.12 Linings of tunnels

2 Types and Thickness of Lining

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

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

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

Drainage of Tunnels

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

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

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

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

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

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

Methods of ventilation –

1. Natural Ventilation

2. Artificial or Mechanical Ventilation.

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

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

Examples of existing important tunnels in India and abroad-

S.no.	Tunnel	Length in	Location	Purpose	Year

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

Tunnels in other countries-

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

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

