Transportation Engineering – II

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Tunnels

1) Alignment & Surveys.

2) Cross section of highway & railway tunnels.

3) Tunneling methods in hard rock and soft grounds.

4) Tunnel lining, drainage, ventilation and lighting of tunnels.

5) Advances in tunneling techniques.

6) Tunnel boring machines and case studies.
Tunnel

A tunnel is an underground or underwater passageway, dug through the surrounding soil/earth/rock and enclosed except for entrance and exit, commonly at each end.
Tunnel Alignment

1) The alignment should be straight as far as possible since normally such a route would be the shortest and most economical.

2) The minimum possible gradient should be provided for a tunnel and its approaches.

3) Proper ventilation and adequate lighting should be provided inside the tunnel.

4) The side drains in a tunnel should be given a minimum gradient of 1 in 500 for effective drainage.

5) In longer tunnels, the gradient should be provided from the centre towards the ends for effective and efficient drainage.
Alignment of Tunnels
Terminology:

1) **Crown**: The uppermost part of the tunnel.
2) **Drift**: A horizontal excavation.
3) **Heading**: The excavated face of the tunnel.
4) **Invert**: The bottom (floor) of the tunnel.
5) **Wall**: The side of the tunnel.
6) **Portal**: The tunnel entrance.
7) **Springline**: The line at which the tunnel wall breaks from sloping outward to sloping inward toward the crown.
8) **Station**: The distance measured from the portal (chainage)
**Terminology:**

- **Crown:** The uppermost part of the tunnel.
- **Invert:** The bottom (floor) of the tunnel.
- **Heading:** The excavated face of the tunnel.
- **Wall:** The side of the tunnel.
- **Portal:** The tunnel entrance.
- **Top heading:** The upper part of the tunnel cross-section.
- **Bench:** The middle part of the tunnel cross-section.
- **Bottom:** The lower part of the tunnel cross-section.
- **Springline:** The line at which the tunnel wall breaks from sloping outward to sloping inward toward the crown.

**Transportation tunnel cross-sections:**
- Circular
- Horseshoe
- Vertical walls arch roof

**Drift:** A horizontal excavation.
Classification of Tunnels:

Based on purpose

1. Road or highway tunnel
2. Railway tunnel
3. Transportation tunnel
4. Sewer tunnel
5. Water supply tunnel
6. Hydro-electric power tunnel

Based on Rock

1. Tunnel in hard rock
2. Tunnel in mud stone rock
3. Open cut Tunnel

Based on Shape

1. Spiral tunnel
2. Off spur tunnel
Methods of Tunnelling in Hard Rock:-

1. Full Face
2. Heading and Bench System
3. Drift Method
4. Pilot Tunnel
5. Perimeter Method
Steps involved in tunnelling in hard rock:

1. Marking tunnel profile
2. Setting up & drilling
3. Loading explosive and blasting
4. Removing foul gases
5. Checking misfire
6. Scaling
7. Mucking & Guniting
8. Erecting supports.

(sequence of tunnelling)
Full Face Method:

1) The full face method is normally selected for small tunnels whose dimensions do not exceed 3 m.

2) In this method, the full face or the entire façade (front) of the tunnel is tackled at the same time.

3) Vertical columns are erected at the face of the tunnel and a large number of drills mounted or fixed on these columns at a suitable height as shown in Fig.

4) A series of holes measuring 10 mm to 40 mm in diameter with about 1200 mm centre-to-centre distance are then drilled into the rock.
Advantages of Full Face Method:

a. Since an entire section of the tunnel is tackled at one time, the method is completed expeditiously.

b. Mucking tracks, which are tracks used for collecting muck, can be laid on the tunnel floor and extended as the work progresses.

c. With the development of the ‘jumbo’ or drill carriage, this method can be used for larger tunnels too.

Disadvantages:

a. The method requires heavy mechanical equipment.

b. It is not very suitable for unstable rocks.

c. It can normally be adopted for small tunnels only.
Heading and Benching Method:

1) the heading (top or upper half) of the tunnel is bored first and then the bench (bottom or lower half) follows.

2) The heading portion lies about 3.70 m to 4.60 m ahead of the bench portion (Fig).

3) The hard rock permits the roof to stay in place without supports.

4) Adopted for all railway tunnels.

5) In hard rock, the drill holes for the bench are driven at the same time as the removal of the muck.
Drift Method:

1) A drift is a small tunnel measuring 3 m × 3 m, which is driven into the rock and whose section is widened in subsequent processes till it equates that of the tunnel.

2) A number of drill holes are provided all around the drift and these are filled up with explosives and ignited.

3) So that the size of the drift expands to become equal to the required cross section of the tunnel.

4) The position of the drift depends upon local conditions; it may be in the centre, top, bottom, or side as shown in figure.

5) Field experience has shown that the central drift is the best choice, as it offers better ventilation and requires lower quantities of explosives.

6) The side drift, however, has the advantage that it permits the use of timber to support the roof.
Drift Method

Advantages
a) If the quality of the rock is bad or if it contains excessive water, this is detected in advance and corrective measures can then be taken in time.
b) A drift assists in the ventilation of tunnels.
c) The quantity of explosives required is less.
d) A side drift allows the use of timber to support the roof.

Disadvantages
a) It is a time-consuming process, as the excavation of the main tunnel gets delayed till the drift is completed.
b) The cost of drilling and removing the muck from the drift is high, as the work has to be done using manually operated power-driven equipment.
Pilot Tunnel Method:

1) Involves the digging of two tunnels, namely, a pilot tunnel and a main tunnel.

2) The cross section of the pilot tunnel usually measures about $2.4 \text{ m} \times 2.4 \text{ m}$ & driven parallel to main tunnel at a distance of 22m.

3) The pilot tunnel is driven parallel to the main tunnel and connected to the centre line of the main tunnel with cross cuts at many points.

4) The main tunnel is then excavated from a number of points.

5) Many long railway tunnels are constructed by this method.
Perimeter Method:

1) Excavation is done along the perimeter in order of stages no. 1, 2, 3, 4 & 5.

2) This method is also known as German method.
Tunnelling Through Soft Ground:

1) Compressed Method
2) Forepoling Method
3) Needle Beam Method
4) Five Piece Set Method
5) Liner Plates Methods
6) Other Methods
   1) American Method
   2) English Method
   3) German Method
   4) Austrian Method
   5) Italian Method
   6) Belgian Method
   7) Army Method
   8) Shield Method
Compressed Method of Tunnelling Through Soft Ground:

1) Most modern method of tunneling in soft ground having water bearing stratum.

2) Compressed air is forced into the enclosed space to prevent the collapse of the roof and sides of the tunnel.

3) Compressed air is used with air tight locks and in conjunction with the shield.

4) The air pressure forces back the percolating water or water mixed soil and keep the tunnel dry.

5) As the compressed air escape through the pores of the soil, it continuously decreases. Hence the air pressure should be varied from time to time to the actual required pressure inside the tunnel.

6) Air pressure is approximately 1 kg/cm².
1) Calcutta Metro:

India’s first, Asia’s Fifth, 1984-95, distance 16.45 km from dum dum to Tollygunge, 15 stations are underground.

1) Tube Railway:

London, 10 underground lines of total length 408km, 248 stations, 8 lakh passengers.
Mucking:- Removal of excavated material

1) The process of loading & removing of the excavated or blasted material from the tunnel proper is called mucking.

2) Hand mucking has only limited use these days.

3) Most of mucking are mechanized to achieve better efficiency.

4) Machine are operated by electric power or compressed air.

5) Shovel, conway digger, mine car loaders, gathering arm loader, vibrating type loader, duck bill loader, slushers, scrappers, excavators, etc.
Lining of Tunnels:

1) The Tunnels in soft soil & in loose rocks are liable to disintegrate.

2) Provided with inside lining of masonry or concrete or reinforced concrete.

3) Grouting to seal off water in rock tunnels is done before concrete lining is placed.

4) After the tunnel is concreted, it may be necessary to grout it again.

5) The object of second grouting is to fill any space left between concrete and the rock.

6) Grout is placed by pneumatic placer or mechanical machines.

7) Grout mix use 1:1 or 1:2 cement : sand ratio mixed with sufficient water.

8) Timber lining, brick lining, stone lining, iron lining, cast steel lining, pressed steel plates lining, plain & RCC lining.
Ventilation :-

1) The use of drilling machine, detonators, large explosive charges, loading machine, dust etc. require the provision of an efficient system for ventilation in view of the large number of men working at the tunnel face.

2) The most efficient ventilation system relies upon a combination of blower & exhaust fan.

3) Immediately after blasting, exhaust system is used for 15 to 30 min. to draw smoke & dust.

4) For rest of the working time, fans are reversed for blowing in fresh air.
Drainage :-

1) In tunnel driving, control of water consists of the following two operations:
   1) Prevention of excess quantities of water, entering the tunnel.
   2) Removal of water that enters the tunnel.

2) Water coming through the roof of the tunnel, is made to flow over temporary roofs of corrugated sheets leading it to longitudinal side drains.

3) The ground water can be removed by either:
   1) Open ditch drainage system
   2) By pumping system

4) Piston type reciprocating or centrifugal pumps are used for removing the water.
Shafts :-

1) The vertical wells or passages constructed along the alignment of tunnel is known as shafts.

2) When the length of the tunnel to be excavated is very long and the work is to be completed in a short time, shafts are constructed at suitable places along the centre line of the tunnel.

3) Since each shafts provide two additional faces to work, the excavation work of the tunnel can be started at several points at the same time and completed in a short time.

4) Vertical shafts, inclined shafts, Permanente shafts & temporary shafts.
Safety Precautions to be adopted in Tunnel Construction :-

1) The shape of the tunnel should be decided according to its purpose.

2) Cross sectional dimensions of the tunnel should be decided to achieve economy in its construction.

3) Economic calculations for extent of equipment and labor should be made before starting the tunnel construction.

4) The sequence of operations must be decided so that proper use of labor and equipment is made.

5) Labor should be well organized to maintain continuous progress of the tunnel operations.

6) The use of outdated or unsuitable tools should be avoided.

7) Care should be exercised to see that every operations is completed at scheduled time.

8) Loading and hauling of muck should be carried out efficiently.
Explosives commonly used in Tunnel Construction :-

1) Power Explosives.

2) Disruptive Explosive.

3) Liquid Air.
Commonly used shaped of the tunnel:-

1) Circular
2) Horse shoe
3) Rectangular
4) Elliptical
5) Egg shaped
6) Segmental roof section
Safety Measures in Tunnel Construction :-

1) The design of the planks & vertical supports should checked carefully to prevent rock falls.

2) Safety rules, regulations and preventive measure should be taught to every worker working on the site ands should be followed strictly without any violations.

3) All electric light and power line should be properly installed as per prevailing codes of practice and rules.

4) Drilling of holes, loading of holes with explosives and the firing should be done with great care.

5) All the tools and equipment should be kept in best working conditions.

6) Water should not be allowed to remain inside the tunnel.

7) Loading of the much and their hauling should be done with great care.

8) All shafts provided with safety ladder for use during emergency for exit and access.

9) All workers should have metals hats and medically fit for working inside the tunnel.

10) After blasting, inside poisonous gases should be removed.
Drilling Pattern & Types of Drills :-
General:

The subject of tunnelling itself is very much complicated and it is not possible to accommodate all the aspects of the subject in this small book. However its main features are briefly summarized in this chapter.

The art of tunnelling is quite old. But due to considerable advancement in this field, it has become easier, simple and safe at present. Some of the recent notable examples of tunnelling all over the world are as follows:

(1) 14.70 km long Mount Mac-Donald tunnel in British Colombia;
(2) 53 km long Seikan tunnel connecting Honshu and Hokkaido islands in Japan; and
(3) 150 km long Euro tunnel providing a fixed transportation link between the road and rail systems of Great Britain and the European continent.

Our country during the past four decades has also witnessed the construction of many long tunnels which are mainly for the hydro-electric and water supply projects. The notable amongst these may be mentioned as follows:

(1) 3.75 km long head-race tunnel for Koyna hydro-electric project;
(2) 1.54 km and 4.25 km long water supply tunnels in Bombay;
(3) 4.77 km total length of five diversion tunnels for the Beas dam project;
(4) 6.62 km long head-race tunnel for Loktak project;
(5) 3.80 km long Malbar Hill project;
(6) 12.79 km long lower Periyar tunnel; etc.

A railway tunnel is required when an obstacle in the form of a hill or a rising ground is met with. The longest railway tunnel in the world with length of 22.3 km has been constructed in 1979 in Japan. It is known as the Daishimizu tunnel and it connects the towns of Gumma and Nigata.

It has thus beaten the record held by the Simplon No. II tunnel on the Swiss Federal State Railway having length of 19.82 km and connecting Switzerland and Italy. The Simplon tunnel was opened
for traffic on October 16, 1922 and it has thus preserved the record of the longest tunnel in the world for quite a long period of 1922 to 1979.

Parsik tunnel near Thana on the Central Railway is the longest railway tunnel in India. This tunnel was constructed in 1913-16 and its length is 1317 metres. The second longest tunnel 1267 m on the Indian railways was completed in 1980 with the South-East Ghat line project of the Central Railway at a cost of about Rs. 2 crores. The tunnel is situated in a very difficult mountainous terrain. It is partly on straight track and partly in curvature and thus it required all the technical expertise from the railway engineers in setting out and execution of the work. The tunnel is on a very steep gradient of 1 in 40 and the railway engineers showed the high quality of precision in its survey work.

It may be noted that if all the railway tracks in tunnels on the Indian railways were to be laid in one stretch, the total length would only be 150 km. It thus hardly forms 0.10 per cent of total route kilometre of the Indian railways.

Definition of a tunnel:

A tunnel is defined as an underground passage for the transport of passengers, water, sewage minerals, gas, etc.

Tunnelling through rock:

Following methods are adopted for carrying out the tunnelling operations through rock:

1. Full face method
2. Heading and bench system
3. Cantilever car dump method
4. Drift system
5. Pilot tunnel method.

Each of the above method of tunnelling will now be briefly described.

(1) Full face method (fig. 21-1): The full face method is adopted only for small tunnels whose dimensions do not exceed about 3 m. The vertical columns are fixed at the face of the tunnel to which drills can be fixed at any suitable height. A series of drillholes about 10 mm to 40 mm diameter are drilled at about 1200 mm centres and preferably in two lines. These holes are then charged with explosives. The charge is ignited and it is essential to remove the material of the explosion before the next set of drillholes is bored.

As the full section of the tunnel has to be tackled, extra units of tunnelling equipment will become necessary. But the method has
(4) Drift system (fig. 21-4):
In this system, a drift is first driven of appropriate size, usually of 3000 mm x 3000 mm. The drillholes are provided all round the drift in the entire cross-section of the tunnel. When these holes are filled up with explosives and are ignited, the drift is expanded to the full cross-section.

The drift may be arranged either centrally or on the sides. The central drift system is economical as regards explosion and it also provides good ventilation. But it has the disadvantage that the full drift is to be driven before the widening of the cross-section can be taken up. The side drift system is employed in large tunnels where the strata do not consist of one mass of rock. It has the advantage that the sides can be suitably supported by timbering in case of bad ground.

(5) Pilot tunnel method (fig. 21-5): Many long railway tunnels are constructed by this method. Following two tunnels are required to be driven in this method:
(i) Main tunnel
(ii) Pilot tunnel.

This method is adopted for speeding up the driving of the main tunnel. The pilot tunnel which is first driven to the full size is connected to the centre-line of the main tunnel at as many points as required and the main tunnel can therefore be started from a number of holes. The pilot tunnel also helps in the removal of muck and the lighting and ventilation of the main tunnel. The pilot tunnel is of minimum cross-section, usually about 2400 mm x 2400 mm and it is driven parallel to the main tunnel at a distance of about 22 m.

Tunnelling through soft ground:
Following methods are used to carry out the tunnelling operations in soft ground:

(1) Forepuling method
(2) Needle beam method
(3) Five-piece set method
(4) Liner plates method
(5) Other methods.

Each of the above method of tunnelling will now be briefly described.

(1) Forepuling method: In this method, a frame in the shape of A is prepared and placed near the face of the tunnel covered with suitable planks. The poles are then inserted at top and continued to a depth upto which they can be easily taken up. The excavation can then be started below these poles which are supported by the vertical poles. The excavation is carried on the sides also and they are suitably supported by the timbering and thus the full section of the tunnel is excavated. The process is then repeated.

The forepuling is an old method and it can be used successfully for carrying out tunnelling operations through running ground. The term running ground is used to indicate the ground which has to be instantly supported. The forepuling is a slow and a tedious process and it requires skilled supervision. There are no short cuts in this method as such and every step has to be carried out in proper sequence and order.

(2) Needle beam method: This method is useful when the soil is hard enough to stand for few minutes. A small drift is prepared for inserting a needle beam consisting of two I-girders and bolted together with a wooden block in the centre. The rear end of the needle beam is supported by a vertical post resting on the floor of the tunnel while the front end of the needle beam is resting on the drift itself. The jacks are then fixed on this needle beam and with the help of suitable timbering work, the tunnel section is excavated.

(3) Five-piece set method: In this method, the widening of the tunnel is carried out by using a set of timbering consisting of five pieces.

(4) Liner plates method: In this method, the timbering is replaced by pressed steel plates of standard sizes. The advantages claimed for using liner plates are:
(a) They are light and can be handled easily.
(b) They are larger in size than timber pieces and hence require less number of joints.
(c) They are fire-proof and hence they can be safely used while working under compressed air.
(d) They save a great deal of excavation and concrete.
(e) They can be erected by unskilled labour.

(5) **Other methods:** In addition to the above methods, several other methods such as casing method, square sets and lagging method, horse cups method, etc. have been successfully used to carry out the tunnelling work through soft ground.

In casing method, a cap with mortise at each end is provided at the top and a sill without mortise is provided at the bottom. The side posts have corresponding tenons on the top ends to fit the mortise on the cap. This method is useful for driving small tunnels through soft but running ground.

In square sets and lagging method, the sets of timbers of sections 100 mm × 150 mm are made and they rest on a sill of section 50 mm × 200 mm. This method is useful for tunnels of small size.

In horse cups method, the horse cups are made up of two 200 mm × 200 mm timbers and the lower ends of these timbers are resting on a sill set provided in the side wall. This method is useful in fairly good ground and it proves to be satisfactory when brick lining is to be provided to the tunnel.

**Methods of tunnelling through sub-aqueous strata:**

It becomes very difficult to drive tunnel through water bearing strata. Following two methods are generally used:

1. Shield tunnelling
2. Plenum process or compressed air tunnelling.

**1. Shield tunnelling:** A shield is a movable frame and it is used to support the face of tunnel. The excavation and lining of tunnel can be carried out under the protection of shield. It essentially consists of four parts:

(a) Skin plate: A number of curved plates are riveted to one another to form a shell like structure.

(b) Cutting edge: This consists of a number of cast steel segments which are bolted together.

(c) Hood: This is the extension at the top of the shield and extends to about 150 degrees of the circumference at the top.

(d) Inner structure: This consists of a face jack to which a sliding platform is fitted and a number of ring girders which help to stiffen the steel plates are provided. The propelling jacks are arranged all round the circumference. The face of the shield is covered with bulkhead and it is divided into pockets by horizontal and vertical frames. The ports are provided which can be closed by port doors. The rear section projecting a little distance over the completed lining is known as the **tail**.

The methods of shield tunnelling through different types of soil are briefly discussed below.

(a) **Silt:** In case of silt, it is enough to open only one or two port doors. The material is excavated and deposited at the bottom of the tunnel. The shield tunnelling is also suitable for moist silt.

(b) **Clay:** In case of clay, it is necessary to remove the soil soon after its excavation. One or two port doors are opened and the material flows continuously in the tunnel. The experience has shown that it is necessary to take only 90% of the flowing material, the rest being deposited at the bottom to act as tunnel flooring.

(c) **Sand:** In tunnelling through sand, the open type of shield is employed. The sand lies on the floor of the shield and it should be continuously removed. The care should be taken to see that the material does not choke up the propelling jacks and other equipment.

(d) **Running sand:** The bulkhead shield is used in case of running sand. Other details are same as above.

The tunnels driven by the shields are usually of circular cross-section because of the following reasons:

1. It affords easy rotation of shield.
2. It grants protection to the primary lining which is being erected within the tail.
3. It is ideally suited to resist the semi-fluid pressures of soft ground.
4. It provides the greatest cross-sectional area with minimum perimeter.

**2. Plenum process or compressed air tunnelling:** In this process, the use is made of compressed air to prevent the collapse of the sides and the top of the tunnel. Theoretically 0.003 N/mm² air pressure is equivalent to 305 mm of head of water. But practically 0.0035 N/mm² pressure will be required for 305 mm head of water.

The application of air pressure to tunnel driving is not so simple as in case of pneumatic caissons for the following reasons:

(a) There will be varying earth pressure from top of the tunnel to the bottom of the tunnel.

(b) The pressure on the floor of the tunnel depends upon the strata and cannot be theoretically determined.
(c) The value of pressure varies with the moisture content in the different strata and this is a factor which cannot be estimated correctly.

(d) There will be escape of compressed air through the pores of the soil and hence the pressure will be continuously diminishing.

Hence the application of air pressure will have to be varied from time to time to get a balanced value and the determination of this value depends more on experience than on theoretical considerations.

The equipment consists of bulkhead which is an air-tight diaphragm in which the air lock is fixed. The air lock is a long air-tight cylindrical steel chamber having a door at each end and both the doors are opening inwards. The door openings are provided with the gaskets to prevent the leakage of compressed air.

Depending upon the magnitude of work, the locks similar to air locks may be provided for the movements of men and materials. The compressed air is supplied to the air lock through a system of pipes by air compressors which are installed outside the tunnel.

The compressed air method in various materials is briefly discussed below.

(a) Clay: The plenum process is ideally applied in case of clay which is a soil which does not contain many pores. Hence the variation of pressure from top to bottom is not considerable. It is observed that in most of the cases, the timbering can be completely eliminated and about half the theoretical requirements will be sufficient in the clay soil.

(b) Silt: There is not much difference between clay and silt regarding application of air pressure. The only difference is that silt being porous will require varying air pressure. Also the silt begins to flow at the bottom unlike clay. If the silt is having moisture content, it is better to adopt the shield process than the plenum process.

(c) Sand: In case of sand and especially, if it contains moisture, the air that is used penetrates a certain distance into the sand and a line of equilibrium is established. Some type of support will be required in order to prevent the collapse of the dried portion of the sand and this is provided in the form of steel liner plates.

(d) Gravel: The plenum process is rarely used in carrying out tunnelling operations through gravel because of many pores in this material. Thus the gravel is porous and permits escape of air and makes it difficult to sustain sufficient working pressure inside the tunnel. The good clay is used for plugging the leaks and liner plates are used for the face and roof.

Precautions to be taken to maintain the air pressure at desired value: The success of plenum process depends on the proper maintenance of air pressure at the desired level. The precautions to be taken to achieve this purpose are as follows:

1. The concrete lining should be as near as possible to the heading.
2. A wash of cement mortar should be given to the concrete lining near the heading.
3. The building paper should be used to cover the surface which is not lined.
4. A continuous supply of fresh air should be maintained to counter-balance the fall in air pressure.

Drainage of tunnels:

Suitable arrangements have to be provided to take out the water that is met with during driving operations. Otherwise it would interfere with the setting out, driving and lining operations of the tunnel. The drainage system is arranged in one of the following ways:

1. Sumps and pumps: The sumps connected by a pipe line are provided at a distance of about 300 metres and water is pumped from one sump to the other until it is thrown out of tunnel opening. The dimension of the sump and the capacities of the pumps will have to be varied as we proceed away from the working face of the tunnel.

2. Grouting: The above method cannot be adopted, if water is percolating from the sides or from the top of the tunnel. In such cases, the grouting is adopted to make the seams water-tight. Alternatively a corrugated iron sheet roofing may be fixed to divert the water from the roof to the sides and to the floor.

3. Pilot tunnel: In cases where large quantities of water are met with, the pumps cannot cope up with the drainage. A method often adopted under such circumstances is to construct a parallel pilot tunnel at a lower level than the main tunnel and the water to be drained is diverted to the pilot tunnel.

It will also be necessary to have some kind of permanent drainage arrangement for the completed tunnel section. A very simple method of drainage is to construct drainage ditches longitudinally, sloping towards the portals or shafts, from where they could be pumped out of the tunnel by suitable pumps.

Ventilation of tunnels:

A tunnel should be properly ventilated during construction as well as after the construction. The main reasons for proper ventilation of tunnel during construction are as follows:
(1) The workers employed for the work will require fresh air.
(2) A lot of dust, dynamite fumes and other objectionable gases are formed during the blasting and other operations adopted in tunnel driving. These are to be removed.

The ventilation during construction of the tunnel is achieved by means of fans which may be of blow-in or exhaust type. Sometimes a combination is adopted.

In the blow-in method, the fresh air is forced by a fan through a pipe and it is supplied near the working face. This method has the advantage that a positive supply of fresh air is guaranteed where it is most essentially required. The disadvantage is that the foul air and smoke have to travel a long distance before exit and it is likely that the fresh air will absorb the dust and smoke particles.

In the exhaust method, the foul air is pulled out through a pipe and is exhausted by a fan. This sets up a current of fresh air to enter the tunnel. This method has the advantage that the foul air is kept out from the working face. But the disadvantage is that the fresh air has to travel a long distance before it reaches the working face, during which time, it is likely to absorb heat and moisture.

**Lighting:**

The various activities and operations in tunnelling work cannot be effectively and satisfactorily carried out if there is poor light in the tunnel. The situations which demand adequate light can be mentioned as obstructions in tunnel, drilling and mucking zones, bottoms of shafts, storage points, pumping stations, underground repair shops, etc.

The spacing of lights will depend on various factors such as tunnel dimensions, size of light source, nature of rock surface, etc. On the whole, sufficient lights should be installed in the tunnel so as to reduce the intensity of darkening effect on the drivers entering the tunnel.

The common types of lights used in tunnelling work are acetylene gas lighting, coal gas lighting, electric lighting and lanterns. The electric lighting has become very popular source of tunnel lighting at present as it affords various advantages such as absence of smoke, easy removal and extension of wires, non-consumption of oxygen, brilliant light of required density, etc.

**Shafts:**

The shafts are used for ventilation after the construction of the tunnel. They are also useful to accommodate the pipes of fans during construction work. The shafts are of two types:

(1) Working shafts, and
(2) Ventilation shafts.

The working shafts are generally vertical and of minimum size 3700 mm x 3700 mm or 4300 mm diameter. The ventilation shafts are generally inclined and of smaller size say about 1200 mm diameter.

The shafts in rock may be formed by any one of the following three methods:

(1) Drilling
(2) Raising
(3) Gloryholing.

**Drilling:** The drilling is done from the top. The drillholes are suitably arranged and filled with explosives. The broken material is then transported to the top by means of the mechanical hoists. The timbering will be required, not to resist the earth pressure, but to define the cross-section of the shaft.

**Raising:** In order to avoid the lifting up of the excavated material to the surface, the shafts can be conveniently raised from the bottom. This method avoids the necessity of pumping out the water also. But this method can be adopted only for small shafts such as ventilation shafts.

**Gloryholing:** The large shafts can be shanked economically by gloryholing. In this method, two side holes are drilled at a shallow depth and holes reach upto the tunnel section. The excavated material is dumped into these holes. The care should be taken to see that the cross-section of these holes is not locked up.

The shafts in soft ground are not generally deep. Elaborate timbering arrangements are required to sink the shafts in soft ground. Moreover the backfilling will also be required after the timber framework has been inserted.

**Mucking:**

In case of tunnelling through rocks, the blasted rock or earth has to be removed from the tunnel. This process is known as the mucking and it can be performed in the following four ways:

(1) Manual labour
(2) Power shovels
(3) Mucking machines
(4) Tractor loaders.

**Manual labour:** For small tunnels with small quantity of debris to be removed, the manual labour may be employed for the mucking.
(2) **Power shovels:** For tunnels having no problem of ventilation, the diesel or gas operated special type of shovels may be used for the process of mucking.

(3) **Mucking machines:** The various types of mechanical muckers are available for speedy and efficient operation of mucking. For this purpose, the railway track of suitable gauge may be installed on the tunnel floor. The mucking machine discharges the contents either to the belt conveyor or muck cars.

(4) **Tractor loaders:** Several types of tractor-mounted loaders are available for the process of mucking. The tractor during its forward motion dumps the debris into bucket which is placed in its front. The bucket is then lifted over the tractor to discharge the load into a track. It is safe to adopt diesel-powered equipment in place of gasoline-powered equipment because of the fact that the former does not produce carbon monoxide.

**Hauling:**

In the early days of tunnel excavation, the horses and mules were employed for the hauling work. Then the wheeled barrows began to be used for this purpose. Later on, the steam engine came to be used in the tunnel excavation. But as it produced smoke, it was found unsuitable and hence the use of compressed air locos became popular for the hauling work. At present, the hauling process is carried out by the electrically driven cars.

The haulage is an important item of tunnelling work and it should be well organized to avoid undue delay in various other operations of the tunnelling job. Following points should be observed for having a good haulage organization:

- **(1)** The cars with adequate motive power should be selected for the hauling of muck.
- **(2)** The tracks should be laid out by experts so as to have an efficient hauling system.
- **(3)** The movements of the trains should be properly controlled and efficiently managed.

**Lining of tunnels:**

The lining will be required in practically all the tunnels to give a finishing touch to the tunnel cross-section. Most common materials used as lining are stones, bricks, cement concrete and pre-cast pipes.

In case of rocky ground, the lining can be carried out in any one of the following three ways:

(1) Invert first and then sides and top.
(2) Side walls first and then arch section and then invert.
(3) Full section in one operation.

In the first method, where the invert is first lined, there will be a firm base on which the formwork for the sides and the top can be placed. But it has the disadvantages that the muck track will have to be dismantled and also that the invert has to be cleaned after the tunnel lining is complete.

In the second method, both the disadvantages are eliminated. But it cannot be adopted where there is likely to be excessive side thrust from the arch.

The third method is adopted only in case of circular cross-sections and in case of small tunnels. The main problem in this case will be to support the formwork. The support is usually provided in the form of a central beam supported beyond the section to be lined.

In case of soft ground, the lining will have to be placed immediately behind the excavation. The maximum gap allowed is about 4600 mm to 7600 mm. The main problem in this case will be to transport concrete on freshly laid lining and also to suitably support the formwork. The telescopic forms are used for this purpose.

**Size and shape of tunnels:**

The size of the tunnel is determined by its utility. For irrigation purpose, the tunnel is generally designed to run full and if lining is of concrete, the velocity may be taken as 366 cm/sec. In case of road tunnels, the size will be determined by the number of traffic lanes and in case of railway tunnels, it will depend on the number of lines and type of gauge.

The shape of the tunnel is determined by the material of which the cross-section is built and the material through which the tunnel is bored. For tunnels in soft ground, the pressure from the sides as well as from the top is to be resisted and in some cases, there will be pressure even from the bottom. Therefore the circular section is the best theoretically as it gives the greatest cross-sectional area for the least diameter. But this section can be adopted only for irrigation tunnels. For the road and railway tunnels, a compromise is made between the circular section and the vertical sides and the horse-shoe shape is adopted.

A typical cross-section of a single line track is shown in fig. 21-6. The ballast walls are provided to protect drain ditches. The values
of $H$ and $H$ will depend on the type of gauge and also on the number of gauge. For a single track for B.G. and M.G., the usual values are 4880 mm to 5490 mm and 4270 mm to 4880 mm for $B$ and 6700 mm to 7320 mm and 6100 mm to 6700 mm for $H$. In case of double track, the values of $H$ are practically the same while $B$ is increased up to about 8530 mm to 9140 mm depending on the centre to centre distance of the tracks.

**Underground railways:**

The idea of constructing railways underground has been developed due to the fact that the congestion of traffic is increasing day by day. An elevated system was also tried. But it was soon observed that it is much more convenient to go underground rather than to move above the street with a terrific noise.

The railways constructed just a little distance below the ground level are known as the **underground railways.** Such railways are constructed at places where it is not possible to construct a tunnel at deep level due to the nature of the soil.

A method commonly adopted in the construction of underground railways is known as the **cut and cover method** i.e. a portion of the roadways is cut out and it is covered by means of a suitable roofing material such as concrete. The buildings and roofs may be constructed above this roof.

Following are the advantages of underground railways:

1. It assists in shifting population away from the central area of city and thus enables to some extent in the improvement of city by demolishing slums, widening of roads, etc.

2. It enables the middle class people and the workers to live in better surroundings outside the city in suburbs and to come to work in the city daily by paying cheap fares.

3. It facilitates the movements of workers from their homes to their places of work.

4. It proves to be the most suitable for commuters or season ticket holders for travelling relatively longer distances.

It may be noted that at present 40 large cities of the world possess the underground railways. The progress of underground railways with respect to time and number of cities is as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before world war I</td>
<td>13 cities</td>
</tr>
<tr>
<td>Between wars</td>
<td>13 cities</td>
</tr>
<tr>
<td>After world war II</td>
<td>14 cities</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>40 cities</td>
</tr>
</tbody>
</table>

The credit of constructing first underground railway goes to London (1863) and that of recent one to Montreal Metro (1966). The lengths of first three leading underground railways are: London 393 km, New York 381 km and Paris 205 km.

**Calcutta Metro:** India's first underground railway was thought of for the city of Calcutta because it has the surface area for roads as only 6% as compared to 25% for Delhi and even 30% for other cities. It was launched in 1972 for connecting Dum Dum and Tollygunge, a distance of 16.45 km, through 17 stations averaging a distance of less than 1 km. Out of 17 stations, 15 stations are underground and the two end stations Dum Dum and Tollygunge are at the ground level.

The trains have maximum speed of 80 km p.h. with average speed as 30 km p.h. The trains have frequency of less than 2 minutes during peak hours and it is estimated that about 17 lakh passengers are carried daily for 16.45 km stretch in only 33 minutes, a feat which would be difficult to achieve by any surface based system. The entire Metro system requires 53 megawatts of electrical power and the traction power is collected from a third rail laid parallel to the tracks.

Calcutta Metro, India's first and Asia's fifth, became a reality on 24-10-1984 with the commissioning of partial commercial service covering a distance of 4 km with five stations between Esplanade and Bhowanipore. This was quickly followed by another 2 km stretch in the North between Dum Dum and Belgachia on 12-11-1984. The commuter service was extended up to Tollygunge on 28-4-1986 covering a distance of about 8 km. The Metro railway line was fully commissioned for public use on 26-9-1995.
The delay and cost escalation in construction of Calcutta Metro have taken place mainly from the combined effects of the following three problems:

1. Complex subsoil conditions,
2. Inadequate flow of funds, and
3. Land acquisition problems.

The problem became more serious also due to the facts that it was the first project of its kind taken up in India without any experience and that the import technology was kept to a minimum. The dispute between the labour union and Hindustan Construction Company (HCC), the main civil engineering contractor for the project, also played a great role in upsetting the time schedule of the project.

The Rapid Transit System (RTS) of this underground railway is unique in the sense that such a highly technical and complicated project is managed by the country’s own railway engineers and experts, and largely with indigenous resources. Following are some of the important features of Calcutta Metro:

1. All trains have automatic over-speed protection with cab signalling system.
2. All trains have a uniform class of accommodation.
3. The automatic fire warning and fire fighting arrangements are provided for any incident of fire inside the train or on station premises.
4. The provision is made for communication within the train and the world outside.
5. The journey is mostly through an underground R.C.C. box tunnel.
6. There are no chances of the air pollution hazard.
7. There is no interference with the surface transport.
8. The trains run on the ballast-less track laid on concrete.
9. The tunnels are fully ventilated with the provision of cooled air.
10. The chances of power failure in the tunnel are brought down to nil.
11. The doors of the coaches are pneumatically opened and closed by the motorman.
12. The stations have been built well above the highest recorded flood level and adequate number of pumps have been installed inside the tunnel to pump out the water that may accumulate due to seepage.

The cost for the entire Metro system is around Rs. 1,550 crores with original estimate at Rs. 140 crores in 1972. It has the distinction of being one of the costliest Metro in the world. It is evident that the system will not be self-sufficient economically as the fare structure will have to be kept on par with road transport. Hence the subsidies to some extent will have to be provided. But the social benefits which Calcutta Metro grants far outweigh the subsidies.

In 1989, The Public Broadcasting System, an US television network conducted a survey of metro railways around the world with standards of performance like punctuality, cleanliness, attitude of the people, etc. It is significant to note that the Metro Railway, Calcutta scored all the 10 points out of 10 and was declared the best.

![Route of metro railway line with station locations](Fig. 21-7)

The metro tunnel project also received the second prize in the competition for the most outstanding concrete structures in India—1994.

Fig. 21-7 shows the sketch of metro railway line with the locations of stations and the lengths for which the following two methods of the tunnelling were adopted:
(1) Cut and cover method
(2) Shield tunnelling.

Fig. 21-8 shows the cross-section for the cut and cover method. The retaining walls were initially constructed both sides of the tunnel primarily with reinforced concrete diaphragm walls. The temporary decking was provided using precast units.

The excavation was then done manually to detect the underground services such as water lines, sewerage lines, telephone lines, etc. which were diverted. The excavation was thereafter carried out with the help of special excavators imported from Japan. The work was carried out for few working hours in the night.

![Cross-section for cut and cover method](Fig. 21-8)

The foundations of buildings were located quite close to the retaining walls, sometime as close as 2 m to 3 m. Hence adequate strutting to the retaining walls became absolutely necessary.

After the excavation was completed up to the designed level, the construction of the R.C.C. box was started. The ground water table was much higher than the bottom level of the R.C.C. box. Hence an effective system of dewatering using the well-point system was adopted.

The entire work of cut and cover method was carried out under very careful planning regarding the choice of equipments and the method of working. The back-filling was done on the top of the box and the original road was resorted.

Fig. 21-9 shows the cross-section for shield tunnelling method which was adopted for a small length only. The ground water table was much higher in the tunnel area. Hence the compressed air was used to keep the water out from the working space. The excavation in front of the shield was done manually when the shield gave protection from the collapsing soil.

The liners were assembled at the tail end of the shield and they were pushed towards the already-laid liners using jacks. The grouting was done in the space around the liners and also at the joints.

**Tube railways:**

The tube railways are deeper than the underground railways, the usual depth being about 27.45 m. The main aim of tube railways is to avoid interference due to pipe lines of gas, sewage, water, etc. Many excellent tube railways are existing in U.K. The section of a tube railway is completely circular and stations are of cylindrical form. Some of the features of a tube railway are as follows:

1. Formerly the lifts were provided to get an entrance to the tube railway station. But at present, the escalators or ever-moving flights of stairs have taken place of lifts. These escalators are kept in motion by a revolving drum. A few steps at top and bottom are kept level though moving individually. The only thing a passenger has to do is to occupy a step of the escalator for his upward or downward motion.
(2) The safety devices are provided in the tube railways. The mechanism is such that the train cannot start until all the doors are closed and further, the signalling is also automatic. The train is automatically brought to a standstill when the signal ahead is in danger position.

All these devices are due to electric traction. Moreover, due to electrically operated railways, the problem of disposing smoke of the engine was also solved. At present, all the tube railways are electrically operated.

(3) The tube railways carrying mail only are also constructed. They are of a smaller diameter and are fully automatic. The trains travel from one station to the other without any driver, guard or passengers. This is the world's only underground train service of such type and it carries nearly 35000 mail sacks daily on a rail system of 10 km from Paddington in the west of London to Whitechapel in the east. The journey takes 38 minutes at speeds of upto 56 km p.h.

These automatic trains were constructed in 1930 or so. There are 18 trains in the system at any one time and during peak hours, a train often runs at every four minutes or so.

(4) In order to give more facilities to the passengers and to speed up the traffic, number of automatic machines issuing both the tickets and the change are installed on the platform of tube railway station.

(5) The tube railway connecting four main London rail termini having a total length of about 22.50 km is made fully automatic. The driver and guard are replaced by a train operator.

After the operator presses the button, the movement of train till next station is controlled automatically by an electronic brain. It is so arranged that the train will stop automatically, if the section ahead is not clear and it will start automatically as soon as the section becomes clear.

Also the train will correctly halt at the station platform irrespective of passenger loads. In case of an emergency, the operator can manually operate the train.

(6) At present, the London underground covers the largest geographic area of any of the world’s metros. There are two lines having their terminal stations about 40 km from the central London. There are ten underground lines with a combined length of about 408 km and most of these lines are double track. They carry nearly 8 lakh passengers everyday on a network of 248 stations.