A Review Study on Methods of Tunneling in Hard Rocks
Chirag J. Shah\(^1\)  Hiren A. Rathod\(^2\)

\(^1\)M. E. Student (Construction Management) \(^2\)Assistant professor
\(^1,2\)Civil Engineering Department
\(^1,2\)S.N.P.I.T. & R.C, Umrakh, Bardoli, Gujarat, India.

Abstract— This article presents a review on the different methodologies that are used for tunnels excavations in hard rocks in present era. Growing needs for modern transportation and utility networks have increased the demand for a more extensive and elaborate use of underground space or through high mountains / hills. As a result, more projects have to be completed in various ground conditions and one of which is more challenging is to carry out excavation work in hard rocks. Significant technological advances have rendered these projects possible, but have also given rise to new challenges as many of these projects have to be completed in difficult conditions, with very strict environmental constraints, particularly in urban areas where the potential impact of tunneling on existing structures is a major concern. This paper addresses the main aspects of tunneling and underground works performed in hard rocks. A summary is presented of the more recent advances and widely adopted techniques in these regards.

Key words: Hard rock, Excavation, Tunnel Boring Machines (TBM)

I. INTRODUCTION

Tunnel is an underground passage through a mountain, beneath a city or under a waterway or tunnels are enclosed roadways, railways, waterways, etc. with vehicle, trains, ships, etc. access that is restricted to portals regardless of type of structure or method of construction. Tunnels are structures that can require special design considerations that may include lighting, ventilation, fire protection systems, and emergency egress capacity, as documented in design standards or based on the owner’s determination.

Tunnelling can be defined as ‘the continuous excavation of a hole through the earth’s crust’. The portion where the work is carried out while its construction is called the face (heading) and all efforts are made in advancing this face as fast as possible till the end of tunnel is reached. The man at the face are called heading crew. The heading crew is supplied with fresh air, compressed air, water, explosives, drills, mucking and hauling equipment, support and other accessories. Tunnel excavation produces a re-distribution of stresses in the rock and a tendency for closure of the void produces a tendency counteracted by the tunnel support shell.

Modern tunneling work is best regarded as the repetition of a cycle comprising of number of operations and each operation makes a contribution in the controlled advance of a tunnel face. It is essential that tunnel works should be organised on a scientific basis. Factors such as size of the tunnel and the quality of rock will influence details, but the basic order of progressing in all types of tunnels (whether large or small or whether hard or soft), is to:

- Excavate
- Dispose of the muck and
- Line the excavated ground

II. WORLD WIDE SCENARIOS

Some of the examples of carrying out challenging work of tunnel construction through hard rock are highlighted over here. The 1036 m long Eupalinos water supply tunnel was built in 530 BC on the Greek island of Samos. This is the first known tunnel to have been built from two portals and the two drives met with a very small error.

The oldest underground sections of the London underground were built using the cut-and-cover method in the 1860s, and opened in January 1863. What are now the metropolitan, Hammersmith & city and circle lines were the first to prove the success of a metro or subway system.

Thikri tunnel length 800 meters, shape of tunnel d-shape, internal diameter 6.0 meter, longitudinal gradient is 1 in 2500, rock cover 14 metres to 44 metres [>3d as per IS code], existing G.L. (at entrance) is 224.015, existing G.L. (at exit) is 221.695, invert level (at entrance) 203.671, invert level (at exit) 203.349, general geology hard rock strata with RQD value > 75%, method used was drill blast method.

Veligonda tunnel length is about 19.2 km. The TBM method of tunneling was used on the Veligonda project. The bore diameter and segment diameters were 10.0 m and 9.2 m respectively. The whole of the Veligonda tunnel geology has been given an expected RQD value of between 61 and 75 which remains firmly within the Rock class-II category.

Ghatkopar high level Tunnel, Mumbai was constructed for the purpose of Sewage. Geology of soil was Massive & Weathered Basalt. Length of tunnel was 2600 m & its Diameter was 3065 mm. TBM method was used with machine type Single Shield TBM. Support system used was Segmental Lining.

III. PURPOSE & IMPORTANCE

Tunnels are the underground passages which are constructed without distributing the ground surface. They may be constructed through hills, below the ground, streams, etc., for various purposes which may be summarized as follows along with its importance as compared to other means of conveyance:

- To provide passage for roads and railway tracks, access to mines, conduits for water, etc.
- Tunnels protect the railway track, highway, sewer line, oil line, etc., from weathering effects such as rain, snow and other elements.
- Tunnels also protect them during war time from destruction due to bombarding.
- Tunnels have proved cheaper for crossing the mountain or river than open cut or bridges.
- The use of tunnel under a river bed is often economical and convenient than providing a bridge over the river.
- The cost of maintenance of a tunnel is lesser as compared to a bridge or a heavy open cut.

In most congested urban areas, underground railway or highway is the best alternative to provide the means of transportation. Also in soft ground it seems to be cheaper than open cut due to possibility of a large numbers of slips. Tunnels reduce the length of railway line in a circuitous route to reach the other side of the hill. In busy and congested cities due to scarcity of load, tunnels are used for providing underground system, which provide rapid and unobstructed transportation.

IV. METHODS OF TUNNELLING

A. GENERAL

Tunnelling in hard rock is safe, easy and the cost of maintenance of tunnel is also very less. Many of the primary rocks which are categorized under the hard rocks are granite, feldspar, basalt, et. all.

Various methods used for the excavation purpose in such types of rocks are:
- Full face method.
- Heading and bench method.
- Drift method.
- Pilot tunnel method.
- Drill & Blast method.
- Hard TBM method.
- Cut-Cover method.
- Immersed tube method.

Some of the above listed techniques are conventional and not covered under the scope of this paper; only few of the techniques which are predominantly adopted worldwide and have its importance in excavation through hard rocks as compared to other are prescribed here with its brief introduction, procedure, merits and demerits.

B. Drill & Blast Method of Tunnelling

Modern Drill and Blast excavation for civil projects consists the basic approach of:
- To drill a pattern of small holes,
- Load them with explosives,
- Then detonate those explosives

Hence, creating an opening in the rock. The blasted and broken rock (muck) is then removed and the rock surface is supported so that the whole process can be repeated as many times as necessary to advance the desired opening in the rock.

Procedure:

1) Drilling

The drilling should be ensuring minimum overbreak and use of least amount of explosive per unit volume of excavation. Holes are drilled by using pneumatically operated rock drills in conjunction with pneumatic pushers or drifters mounted on column bars or drill carriages as may be found suitable. The size of drill bits used should be such that the diameter of the hole will be about 6 mm greater than the diameter of explosive cartridge to be inserted.

2) Blasting

Blasting explosives are divided into two classes: high explosives and low explosives. Gelignites, Gelatines and Dynamites are the examples of high explosives, whereas, Black powder is low explosive. Most commonly, high explosives are used for tunnelling operations. The strength of these explosive is expressed as a percentage of strength of the blasting gelatine which is the most powerful commercial explosive. The following explosive are used in tunnelling:
- Blasting gelatine used for blasting very hard and tough rocks. This is fully water proof and can also be used in wet locations.
- Special gelatine 9% to 40% is selected to suit the rock requirements.
- Ammonia dynamite is available in strength from 15% to 60% used for soft rock.
- Semi-gelatine is bulkier than other varieties and come in 45% to 60% strength.

b) Detonators:

There are primarily two types of detonators namely, Lead azide aluminium detonator and electric detonators. Lead azide aluminium detonators are used in conjunction with safety fuses and give efficient detonation with all types of blasting explosives. The electric detonators are suitable for singles or simultaneous firing in series or parallel.

c) Detonating Fuse:

It contains a high explosive core with a water proof covering. It is used for shooting a large number of holes in one blast. It is denoted by the use of one or two blasting caps securely attached alongside it.

d) Primer:

It is the cartridge containing the detonator. The primer is supplied with the explosive and is attached with the explosive. It is denoted by Prima cord, which is a high explosive use.

e) Circuit Testers:

To test an electric detonator, it should be placed inside an iron pot or tube to guard against accidental explosion.

3) Loading & Stemming

Loading means charging the drill holes. Before loading, each hole is blown out with a high pressure air jet to remove loose cuttings and water. Then, primer cartridge is gently placed into drill hole next to the bottom. A full cartridge is inserted first, tamped well into bottom, then the primer is inserted with the end containing detonator pointing towards

Fig.1: Drill & Blast Method
the bottom of drill hole. Both the primer and next placed cartridge are tamped lightly with a wooden rod. When the tamping material is being inserted, the leading wires or safety fuse should be held to one side, to facilitate the action of the tamping rod and prevent damage to fuse.

The remaining portion of the drill hole is filled with an inert material and tightly tamped by wooden rod. Soft rolled plugs of clay, damp mixture of sand and clay or a rubber plug with a wooden core may be used as inert material.

4) Firing
   a) Firing by Safety Fuse:
      After charging or loading the holes, personnel and everything liable to injury must be placed to a safe distance. When necessary, the blast may be covered with rope blasting mats or a heavily weighted blanket of scrub. Special fuse-lighter should be used for ignition.
   b) Firing by Electricity:
      Before attempting to connect up an electric circuit, it should be ensured that the main cables are intact and that the exploder is working correctly and capable of supplying sufficient current to fire the number of charges in the circuit. No naked wire should be left touching the ground. Also, the exploder is not connected to the firing circuit until all men have left the danger area and signal to fire has been given.

5) Inspection & Handling Misfire
   After completion of firing, the site is examined by the foreman before he gives the all-clear signal. If a misfire has occurred, no person shall approach the site for one hour if safety fuse was used or 15 minute, if electrically fired. Misfires may occur due to improper primers, use of non-water resistance explosive in wet condition or improper loading.

   Immediately after the smoke is cleared away from a blast, inspection is carried out by a competent and experienced tunnel foreman. All loose rock is removed carefully by barring to ensure that the access to the face is safe.

   Merits:
   - Potential environmental impacts in terms of noise, dust and visual on sensitive receives are significantly reduced and are restricted to those located near the tunnel portal;
   - Compared with the cut-and-cover approach, quantity of C&D materials generated would be much reduced;
   - Compared with the cut-and-cover approach, disturbance to local traffic and associated environmental impacts would be much reduced;
   - Blasting would significantly reduce the duration of vibration, though the vibration level would be higher compared with bored tunnelling;

   Demerits:
   - Potential hazard associated with establishment of a temporary magazine site for overnight storage of explosives shall be addressed through avoiding populated areas in the site selection process.
   - There is a high risk of over breaking the tunnel profile and damaging the surrounding rock
   - High levels of noise and vibration make this unsuitable for an urban area.

C. Cut Cover Method of Tunnelling
Cut and cover tunneling is a common and well-proven technique for constructing shallow tunnels. The method can accommodate changes in tunnel width and non-uniform shapes. Cut and cover is a simple method of construction for shallow tunnels where a trench is excavated and roofed over with an overhead support system strong enough to carry the load of what is to be built above the tunnel.

Fig. 2: Cut Cover Method

Procedure:
1) Excavation and support
   The initial “cut” is undertaken to facilitate the tunnel construction. This uses similar technology to road cuttings. Prior to excavation, buried utilities and services crossing the route have to be protected, temporarily raised or permanently diverted to avoid the tunnel alignment where possible. For gravity sewers this may involve pump installation. The cut is constructed in a number of ways, depending on the support requirements of the ground. In hard rock this may be vertical walls supported by rock bolts and sprayed concrete; in soft rocks and soils stable slopes may be created by constructing benches. If surface space is restricted, or the disturbance caused by construction needs to be minimized, then retaining walls can be used to stabilise the excavation. These may be permanent, incorporated into the final structure or temporary and removed or abandoned after the tunnel structure has been completed.
2) Tunnel fabrication
   Once a stable open cut has been constructed, the tunnel structure is fabricated in the trench. This structure is generally constructed from reinforced concrete using large tunnel forms. As considerable materials and excavated fill storage is required this operation requires a significant work site.
3) Reinstatement
   After construction, fill is used to reinstate the ground surface. Where possible this fill may be reserved material from the trench excavation. Additional fill may be required to assist with compaction and drainage, or if the trench material is unsuitable. Reinstatement may be to the original topography and land use. In some cases this offers the opportunity to improve surface conditions, such as utility and drainage improvements or local road upgrades.

   Demerits:
   - More dust and noise impact may arise, though these can be mitigated through implementation of sufficient control measures;
Temporary decks are often installed before bulk excavation to minimise the associated environment impacts;
- Larger quantity of C&D materials would be generated from the excavation works, requiring proper handling and disposal.

D. Hard TBM Method of Tunnelling

In hard rock, either shielded or open-type TBMs can be used. All types of hard rock TBMs excavate rock using disc cutters mounted in the cutter head. The disc cutters create compressive stress fractures in the rock, causing it to chip away from the rock in front of the machine, called the tunnel face. The excavated rock, known as muck, is transferred through openings in the cutter head to a belt conveyor, where it runs through the machine to a system of conveyors or muck cars for removal from the tunnel.

Procedure:
1) Excavation Advance:
   - The cutting head is rotated against the ground to commence cutting
   - Thrust is applied by the rams or side gripper pads in the drive section to assist cutting and maintain face pressure
   - Cutting and advance continues until enough space is created in the tail shield to construct the next lining ring
   - The gap between the ground and the previous lining ring is grouted as it leaves the tail shield.

   ![Fig. 3: Excavation Advance](image)

2) Lining erection:
   - The thrust rams are withdrawn into the drive section leaving clear space for the erection of the lining
   - Each segment forming the lining is maneuvered into position and bolted together to form a completed lining ring
   - The thrust rams are then reengaged to commence the next excavation cycle

   ![Fig. 4: Lining erection](image)

Merits:
- Potential environmental impacts in terms of noise, dust and visual on sensitive receives are significantly reduced and are restricted to those located near the launching and retrieval shafts;
- Compared with the cut-and-cover approach, disturbance to local traffic and associated environmental impacts would be much reduced;
- Compared with the cut-and-cover approach, quantity of C&D materials generated would be much reduced

Demerits:
- The major disadvantage is the upfront capital cost. TBMs are expensive to construct, difficult to transport, require significant backup systems and power.
- Their applicability is limited to long tunnels where the high rates of advance and tunnel quality can offset their high capital cost.

V. CONCLUSION

Referring to the various literatures mentioned below and the contents mentioned above in the paper the importance of tunneling can be clearly understood as compared to other means of conveyance such as bridges, open cuts, etc. i.e. through tunnels we can get many benefits such as low maintenance cost, no need for acquiring the land & it can be used in any type of area such as in congested cities. Also referring to many recent methodologies in tunnels we found that most suitable method was the method using TBM. Though it is very costlier than all other methods, but it also has many advantages compared to others like it is easier in operation, very fast, can be used in any ground conditions depending on cutterhead with little modifications, perfection of work, safety etc.

ACKNOWLEDGMENT

The authors are thankfully acknowledge to Mr. J. N. Patel, Chairman Vidyabharti Trust, Mr. K. N. Patel, Hon. Secretary, Vidyabharti Trust, Dr. H. R. Patel, Director, Dr. J. A. Shah, Principal, S.N.P.I.T. & R.C., Umrak, Bardoli, Gujarat, India for their motivational & infrastructural supports to carry out this research, Dr. Neeraj D. Sharma, HOD Civil Department, SNPIT & RC, Umrak.

REFERENCES

[8] “Construction safety in hard rock tunnelling” By: Dr. Zhou Yingxin Programme Manager (Underground
Technology & Rock Engineering), Defence Science & Technology Agency.

