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TUNNEL BORING MACHINE(TBM)-AN INTEGRATED MECHANIZED METHOD

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Abstract: Tunnel construction is a complex engineering task due to difficulties and logistics involved in boring and digging over the extended distances underground. However, thanks to advances in equipment technology, complex tunnelling projects are accomplished throughout the world. The tunnel boring machine (TBM), also known as mole, has made the construction of these tunnels possible, in hard or soft rock strata. Two major categories of TBM are used in the modern-day tunnelling process. TBM with full-face excavation and TBM for partial excavation. TBM with full-face excavation includes gripper and shield TBMs, and TBM for partial excavation includes enlarged TBM and unique machines for non-circular sections. To protect the TBM from fault zones, support systems like rock bolts, pipes, grout injection, and freezing are provided over or in front of the cutterhead. Roofing shield support system is useful during advancement in fractured rock. This roofing shield support system safeguards the crew members working behind the cutterhead from rock falls. Shield tunnelling is mainly useful in hard rock with moderate stand-up time and in fractured rock because the shield extends entirely over the complete machine from the cutterhead portion and provides safety to the entire structure.

Key words: TBM, tunnel, roofing shield, supportsystem hard &soft rock, fault zone,rock bolt

I. HISTORY OF TBM

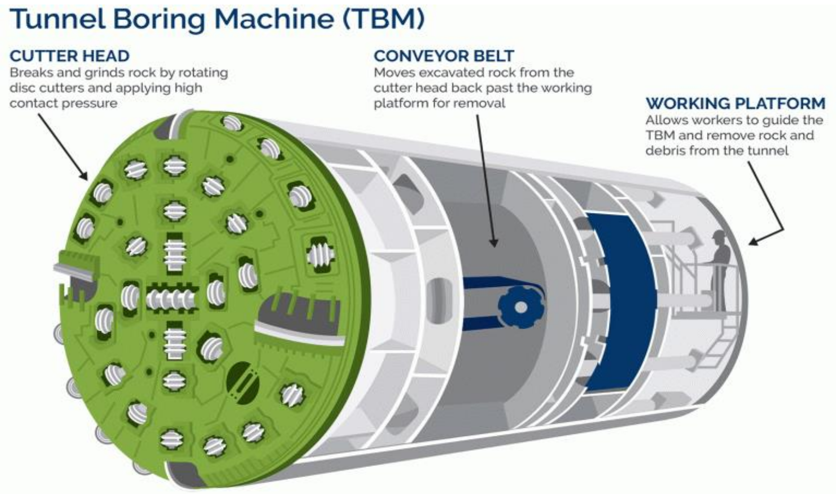
The history of TBM, the first TBM was developed in 1952 by James Robbins for the Oahe Dam Project in South Dakota. This model dragged bits and cutters to excavate week shale rock successfully. However, it was still too weak to excavate rock. Seeing the need for a more advanced machine, Robbins built the rolling disc cutters to bore the first rock tunnel.

Through the years, the TBM was significantly upgraded, ultimately to the development of next -generation hybrid, the crossover in 2015.It was capable to handle multiple geological and geotechnical conditions. Since then, continuous advancement is being done to cut the delivery time, make environment friendly and save huge amount of money.

II. INTRODUCTION

A tunnel boring machine (TBM), also known as mole, is employed for the construction of tunnels in hard or soft rock strata. The cutting process utilizes the rotation of the cutterhead (geared with disc cutters) and the blade pressure for excavation on the face of rock. Mostly, gripper and shield TBMs are ideal for tunneling in difficult rock conditions with medium to high stand-up time. The cost of constructing tunnels using TBM is higher than the traditional methods. However, the additional expense can be compensated by greater advance rates (coverage). But if the wear rate of the tools increases too much on account of the rock strength or other unfavourable criteria, repair and maintenance of regular cutter would lead to a high downtime.

Tunnel Boring Machine



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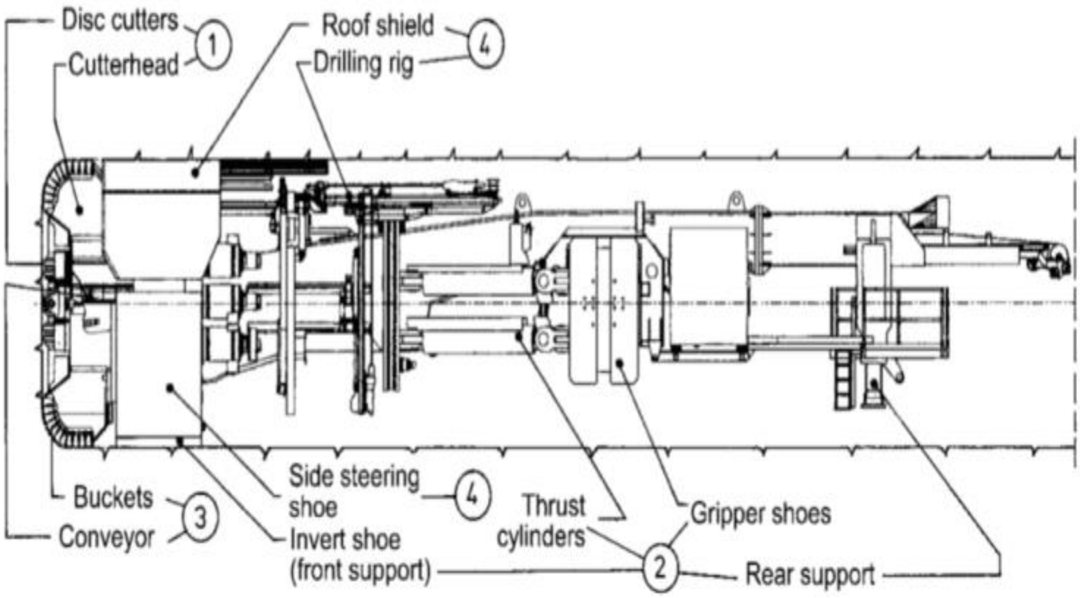
Due to the high downtime, the working time of the device decreases, resulting in reduced efficiency and increased costs. Therefore, the logistical procedures of TBM should be designed very carefully. Also, in the case of traditional methods, it is possible to respond to the tunnel-rock interactions by either subdividing the excavated section or by a rapid adaptation of the support to the geological situation. But this is not possible with TBM.
Above all, the choice to use a TBM needs a much better geological and geotechnical examination than for drilling and blasting methods. Therefore, a comprehensive preparation of the entire driving and supporting procedure becomes very important.

III. BASIC CONSTRUCTION PRINCIPLE

The fundamental elements of a TBM are the cutterhead, the cutterhead provider with the cutterhead drive motors, the machine frame, and the driving and clamping devices. These fundamental elements form four system groups of TBM.

1. **Boring system**
2. **Thrust and clamping system**
3. **Muck-removal system**
4. **Support system**

Types of TBM structure



3.1 Boring System

The boring system is an essential element as it determines the efficiency of a TBM. It consists of a cutterhead with disc cutters mounted over it.When the cutterhead rotates, the setup of the discs should be such that the entire cutting face should come in concentric tracks. The selection of cutterhead and discs depends upon the rock type and the ease of cutting.
The rotating cutterhead presses the discs with a high pressure against the face, producing a slicing movement across the face. The pressure at the cutting edge of the disc cutters exceeds the compressive strength of the rock and grinds it locally.

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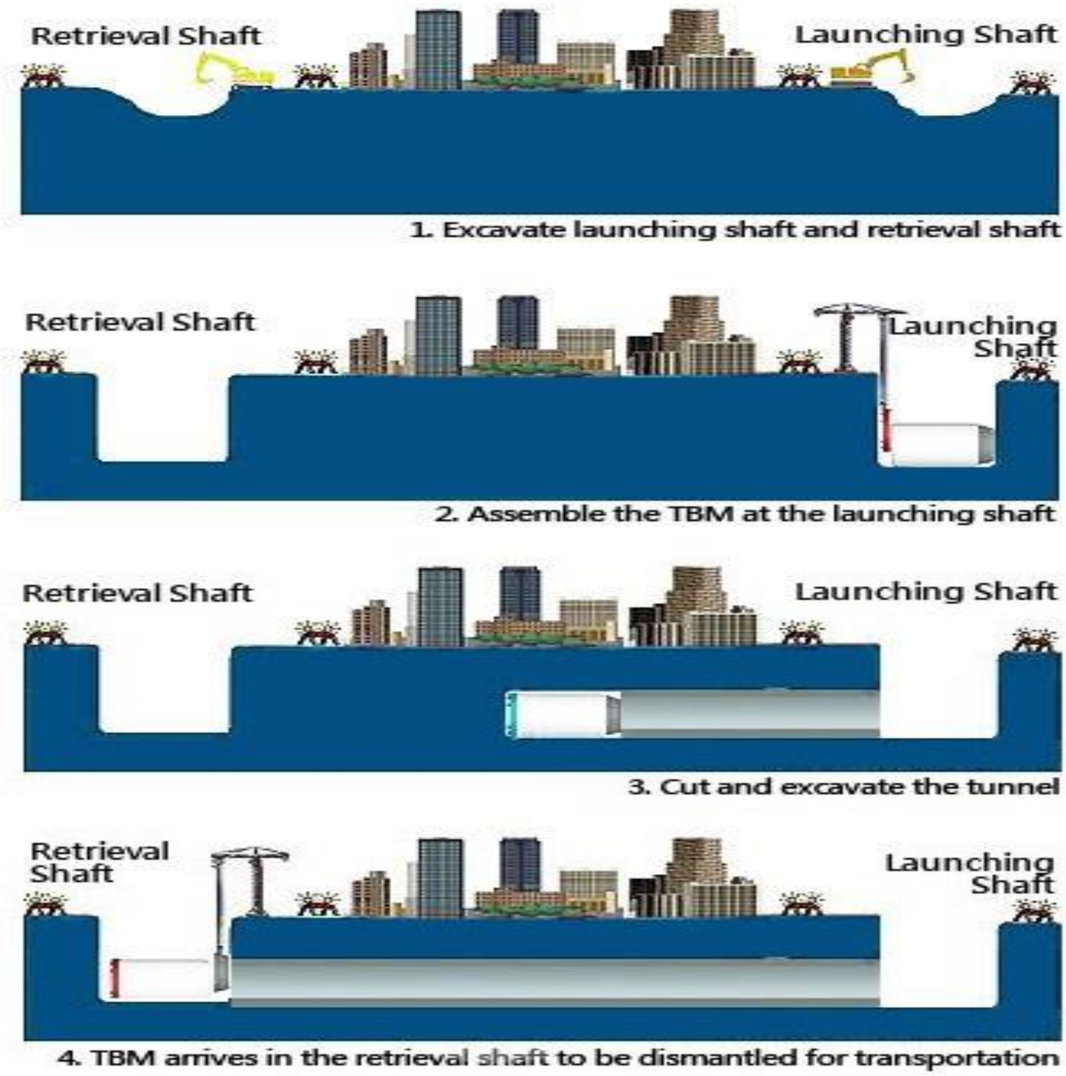
Typical Stages of TBM Construction



3.2 Thrust and Clamping System

The thrust and clamping system impacts the advancement rate of a TBM. A TBM usually attains the advancement rate of up to 2.0 m in a day.This system is responsible for the advance push and the boring process. The thrust system provides the push to the cutterhead through hydraulic cylinders. Thus, this system controls the movement of the cutterhead. The clamping system restricts the possible thrust and withstands the moments developed by the rotation of the cutterhead.

3.3 Muck-Removal System

The slot around the boundary of the cutterhead is known as the cutter bucket. The cutter bucket is connected to the conveyor belts and collects the muck generated near the cutterhead, which ultimately is disposed of outside the tunnel. In order to remove the muck from the tunnel, an effective system should be used, which should not interfere with the supply of the TBM and the essential support systems.

Issues can occur with both the cutterhead bucket and the conveyor belt if the obstruction is triggered by bigger blocks of rock. This would make it difficult for the TBM to operate.

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Conveyor belt installed in tunnel to remove muck

3.4 Support System

It is challenging to use TBM in brittle rock because it would sink in with the increase in tunnel diameter. Therefore, supports are provided to avoid the sinking of TBM.For smaller diameter tunnels, the supports are provided around the rear carriage behind the TBM. While, in the case of bigger diameter tunnels, in addition to supports around the rear carriage, advancement supports such as rock bolts and umbrella reinforcement are provided.

To protect the fault zones, supports like bolts, pipes, grout injection, and ground freezing should be used over or in front of the cutterhead. However, the roofing shield support system is more useful during advancement in fault zones. This roofing shield support system safeguards the crew members working behind the cutterhead from rockfalls.

Nowadays, mainly two types of TBMs are used. In the first type, the tunnel driving through a gripper TBM forms a single invert sector. This invert sector provides temporary as well as permanent support and is also useful in mounting the rails of rear carriage and rail conveyor.

The second type is the tunnel driving through shield TBM, in which the shield guarantees temporary support to the rock around the periphery of the tunnel. Reinforced concrete segments are mostly used for support. The segments are installed singly by the erector and provide immediate support. Compressed air and earth pressure support is beneficial for the shield TBM during the ingress of water.

IV. TYPES OF TBMs

Different kinds of TBMs were used in the past for mechanized tunnelling in hard or soft rock. However, two major categories of TBMs are used in the modern-day tunnelling process. TBM with full-face excavation and TBM for partial excavation.

4.1 TBM with Full-Face Excavation

The following are the different types of TBMs with full-face excavation:

1. Gripper TBM
2. Shield TBM

4.1.1 Gripper TBM

Gripper TBM is the oldest form of TBM. It is mainly useful in hard rock with medium to high stand-up time. In such rocks, the requirement of continuous support such as rock anchors, steel arches, and shotcrete is significantly less. Thus, the higher advancement rates are possible by producing more thrust. In order to produce the thrust behind the cutterhead, the gripper TBM should be braced radially to the tunnel wall by clamping shoes. Such clamping shoes are called as grippers.

Gripper TBMs are further categorized into open TBMs, TBMs with roofing system, with roofing and side steering shoes, and with cutterhead shield.

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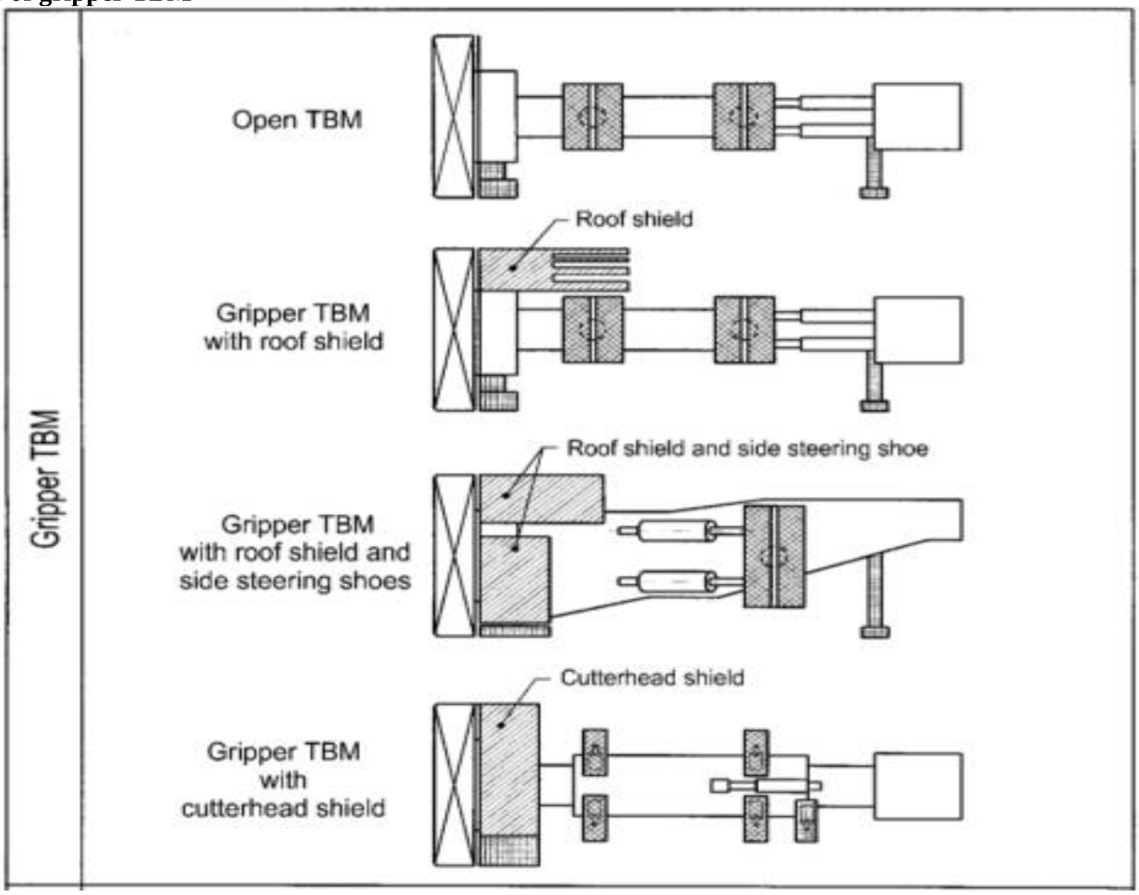
Types of gripper TBM



4.1.1.1 Open TBM

Open TBM is useful only in smaller diameter tunnel section as there is no protection provided behind the cutterhead.

4.1.1.2 TBM with Roof Shield

The construction process of the tunnel using TBM with a roofing shield is the same as the open TBM. However, the roof shield provides protection against rockfalls throughout excavation. Such roofing shields are set up behind the cutterhead.

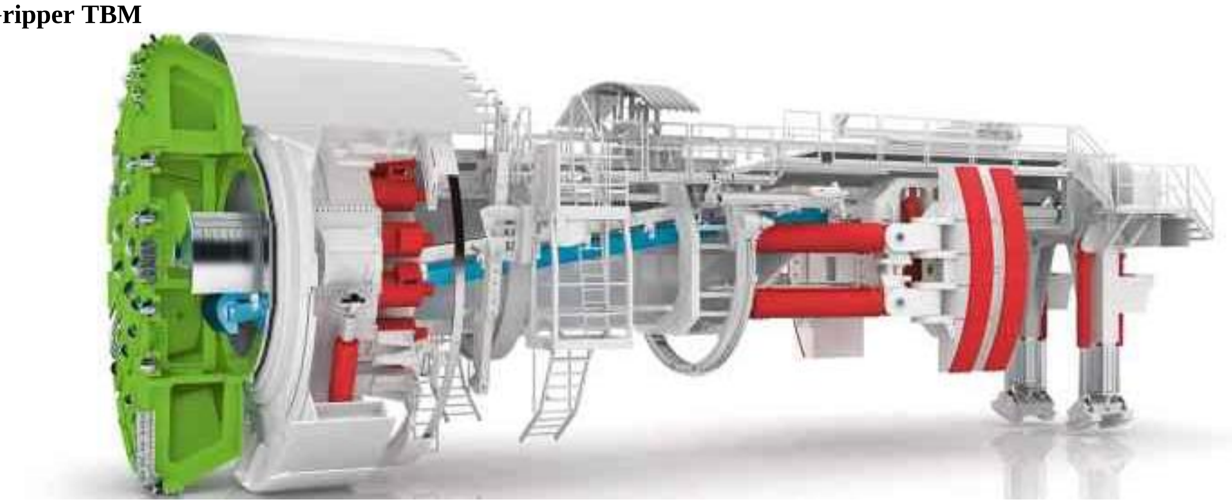
4.1.1.3 TBM with Roofing Shield and Side Steering Shoes

The side steering shoes provide additional support at the front of the machine when moving the machine and steering throughout boring.

4.1.1.4 TBM with Cutterhead Shield

The cutterhead shield provides protection to the workers working under the location of the cutterhead. When moving the machine, the cutterhead shield liner also contributes to the forward support.

Gripper TBM



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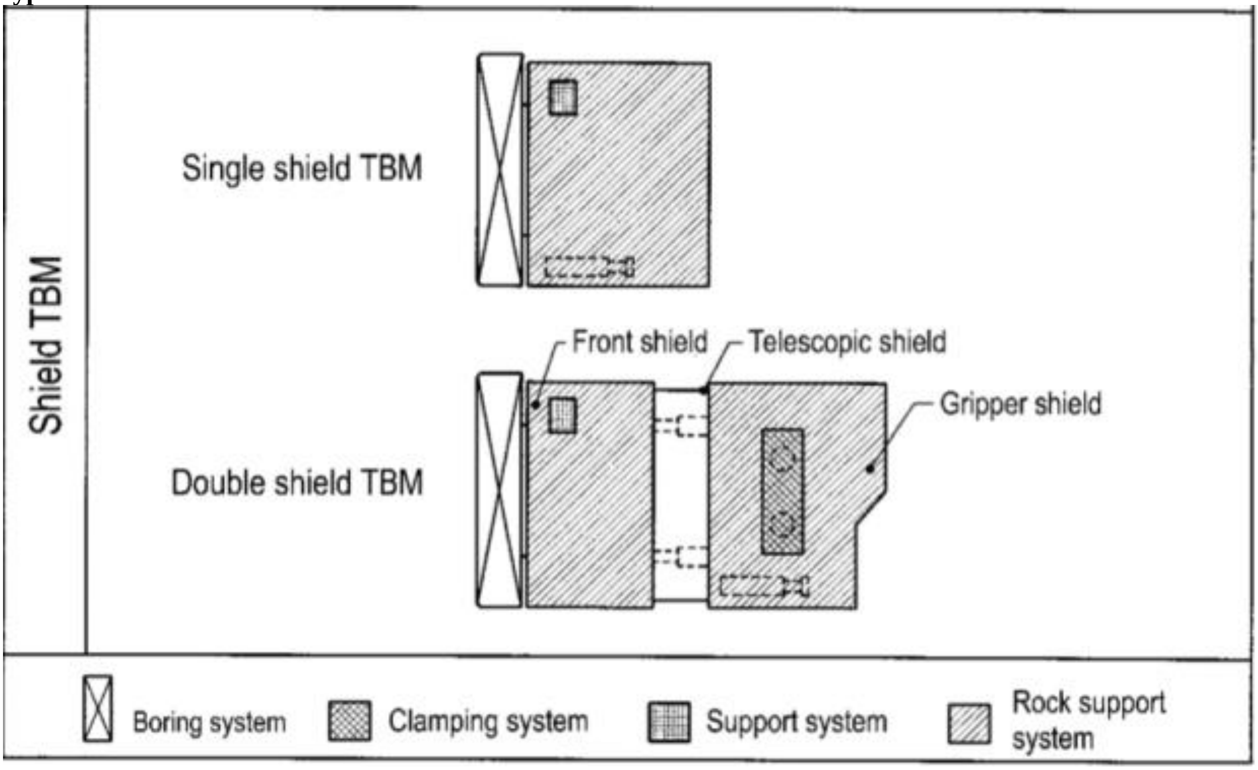
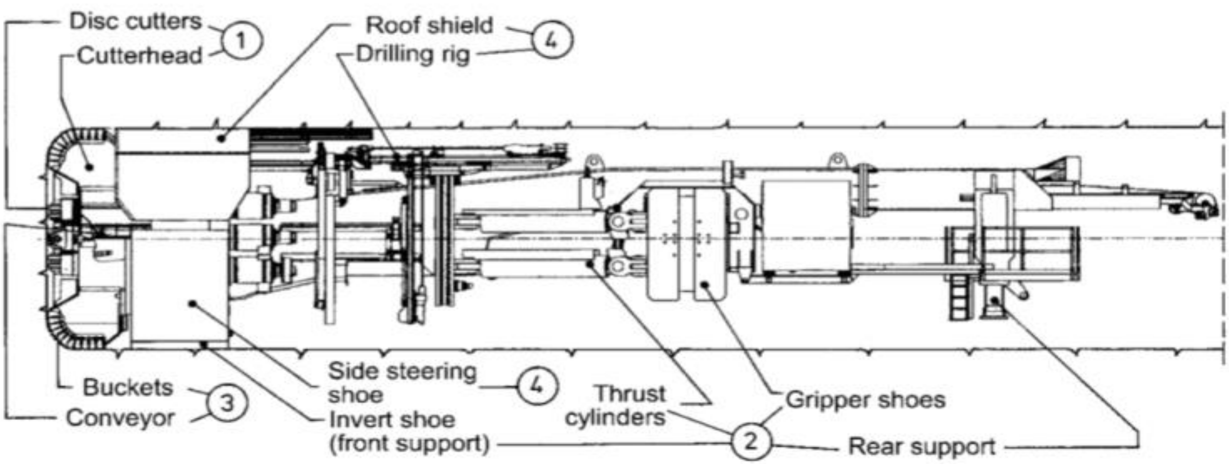
4.1.2 Shield TBM
Shield TBM is a recent invention. It is useful in both hard and fractured rock with medium to high stand-up time. Shield TBMs are categorized into single shield TBM, double shield, or telescopic shield TBM.

Types of shield TBM



4.1.2.1 Single Shield TBM
Single shield TBMs are mainly used in hard rock with moderate stand-up time. The cutterhead system and muck-removal system are the same as in gripper TBM. However, this type of TBM is useful in supporting the tunnel for a short duration. The shield extends entirely over the complete machine from the cutterhead portion. In contrast to the gripper TBM, the machine moves forward with thrust jacks directly against the existing tunnel support.

Single shield TBM



4.1.2.2 Double Shield or Telescopic Shield TBM
The double shield or telescopic shield TBM is similar to the single shield TBM for driving the machine in fractured rock with moderate stand-up time. However, it has the following distinctions from the single shield TBM:

1. The double shield TBM consists of two primary shields, the front shield and the gripper shield.

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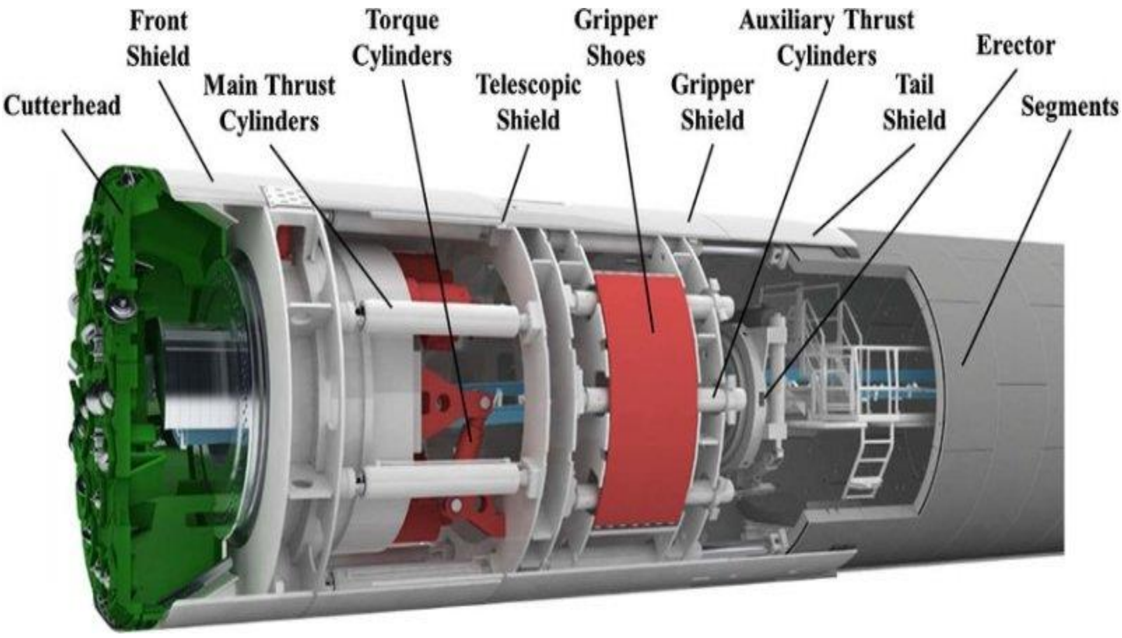
2. The machine can adequately clamp itself radially in the tunnel using the clamping units. Also, where the geology is bad, it can push off the existing lining in the direction of the drive.
3. The front shield can provide the thrust without affecting the gripper shield.
4. The basic operation is also possible without the setup of lining.

The double shield TBM also has downsides in comparison to the single shield TBM. When double shield TBM is utilized in fractured rock with high strength, the rear shield can obstruct the material getting into the muck-removal unit.

Double shield or telescopic shield TBM



4.2 TBM for Partial Excavation

For a full-face excavation, the TBMs can excavate a tunnel with a limited diameter. Also, the excavated profile is limited to a circular section. Thus, for constructing bigger diameter and non-circular section tunnels, the TBMs for partial excavation are used. TBMs for partial excavation are categorized into enlarged TBM and unique machines for non-circular section.

4.2.1 Enlarged TBM

It is used to construct tunnels with a diameter of over 8 meters. Firstly, the section of the tunnel is enlarged with a continuous pilot heading, which is completely driven into the centre of the tunnel. After that, the tunnel enlargement is done using enlarged TBM machines.

Enlarged TBM

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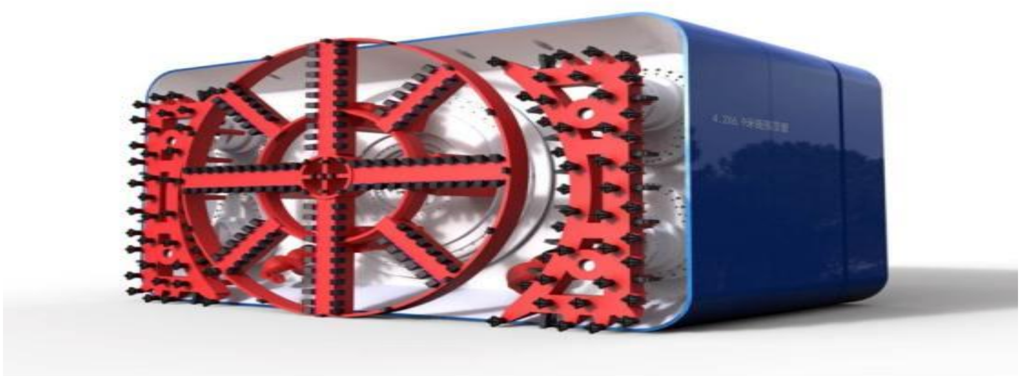
4.2.2 Unique Machines for Non-Circular Section

All types of machines, which excavate the face in a partial process and thus enable sections varying from circular, are categorized as unique machines for Non-Circular TBM.



V. ADVANTAGES & DISADVANTAGES OF TBM OVER CONVENTIONAL TUNNELLING METHODS

The various advantages and disadvantages of a TBM drive in contrast to traditional tunnelling methods are as follows:

5.1 Advantages

1. A specific excavation profile can be achieved.
2. Higher advance rates are achievable.
3. The work is completely automated and continuous.
4. Low labour expense.
5. Better operating conditions.
6. Complete mechanization and automation of the drive is possible.

5.2 Disadvantages

1. High financial investment, hence viable for longer tunnel.
2. Specific and detailed geological information is a must for TBM.
3. Longer preparation time is required for the design of the machine.
4. TBM has limitations on curve radii, especially, on tight radius curves; it is difficult to rotate the whole setup of TBM.
5. Adjustment to different rock types and high-water inflow is limited to a certain level.
6. The transportation cost of the TBM to the tunnel site is very high.

VI. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The invention of the tunnelling machine has revolutionised tunnelling history indeed it had revolutionised the creation of spaces under our cities allowing metro systems, transportation system, water and sewage systems, and underground cable networks, all to be built in a safe and sustainable manner.

History has taught us that each development of a new machine, which will eventually result in progress of the tunnelling industry, may present short term challenges to the underwriter. TBMs are very varied and their suitability for different soil conditions means that the correct choice of machine and the level of experience of the operators is critical in their successful use.

Closer cooperation between the tunnelling machine suppliers, contractors and insurers should allow insurers to develop in the future methods of clearly differentiating the levels of risks involved in insuring these machines. More exchange of information about losses will allow insurers to more closely match the industry's perceptions of the level of risk. By the very nature of the conditions in which a TBM works, it will always be a relatively high-risk piece of equipment of the tunnelling industry.

6.2 Recommendation

a) Higher advance rates: One of the significant advantages of TBM includes high advance rates or the excavation rate which is calculated on the basis of shift time and the total distance mined.

b) Continuous operations: TBM is a giant that can work continuously without any significant delay thereby, increasing the advance rate.

c) Less rock damage: TBM causes less rock damage as compared to the other drilling machines that decrease the over break value.

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d) Fewer support requirements: TBM doesn't need huge support to operate. It can operate on minimal system requirements.
e) Uniform muck characteristics: could be reused for various suitable purposes
f) Greater worker safety: TBMs are safer than other machines and cause less damage to the site as well as to the people working on site.
Potential for remote, automated operation

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