4.3 TUNNELING SHIELDS:

In its simplest form a tunneling shield is a steel frame with a cutting edge on the forward face shown in Fig.

For circular tunnels this is usually a circular steel shell under the protection of which the ground is excavated and the tunnel support is erected. A shield also includes back-up infrastructure to erect the tunnel support (lining) and to remove the excavated spoil.

Fig. 10.14: Simple Tunnelling Shield

There are two main types of tunneling shield, one with partial and other with full face excavation.

In partially mechanized shields, an excavator or a partial cutter head/ road header works on the face.

Partially mechanized shields (also called boom-in-shield tunneling machines) are used where the cost of full face tunnel boring machines cannot be justified.

Manual excavation, i.e. by "hand", is considered for very special applications only, e.g. very short advances, due to the low advance rate.

This type of tunneling is called the manual shield technique.

Full Face Shields are discussed under Shielded TBMs & Soft Ground TBMs.

Tunneling shields do not have an “engine” to propel themselves forwards, but push themselves forward using hydraulic jacks.

In order to create the necessary force to push the tunnel shield forwards, jacks are placed around the circumference of the shield.

These jacks push against the last erected tunnel segment ring and also push the shield against the tunnel face in the direction of the tunnel construction.

Of course, this principle does not work at the start of the tunnel construction and therefore in the starting a reaction frame is necessary to take the jacking forces.

The jacks can be operated individually or in groups, allowing the shield to be steered in order to make adjustments in line and level and to be driven in a curve if required.

When the shield has advanced by the width of a tunnel segment ring, the jacks are retracted leaving enough room in the tail of the shield to erect the next tunnel segment ring

The support usually adopted with shield tunneling these days is circular segments. These segments form, when connected together, a closed support ring.

As the tunnel segments are connected together inside the shield tail, the diameter of the completed tunnel segment ring is smaller than that of the shield.

This creates a gap between the ground and the tunnel lining. When the shield is jacked further into the ground the size of this gap is approximately 50 and 250mm.

Tunnel Boring Machine (TBM) also known as a “mole“, is a machine used to excavate tunnels with a circular cross section through a variety of soil and rock strata. They can bore through hard rock, sand and almost anything in between.

Tunnel diameters can range from a meter (done with micro TBMs) to almost 17 18m to date. Tunnels of less than a meter or so in diameter are typically done using trenchless construction methods or horizontal directional drilling rather than TBMs.

TBMs have the advantages

Limiting the disturbance to the surrounding ground and producing a smooth tunnel wall.

This significantly reduces the cost of lining the tunnel and makes them suitable to use in heavily urbanized areas.

The major disadvantage

Is the upfront cost and difficulty in transportation.

TBM tunnels have very high start-up (pre-excavation) costs and accompanying long lead time, though the high rate of advance reduces the per m excavation cost.

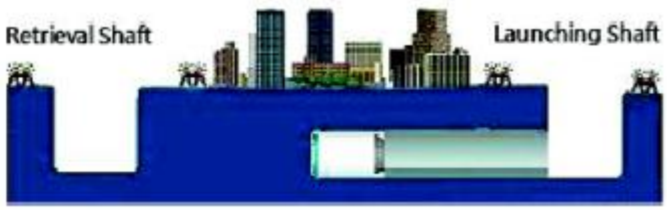
The decision on undertaking excavation by TBM requires careful consideration of techno-economic factors.

Stages of TBM Construction:

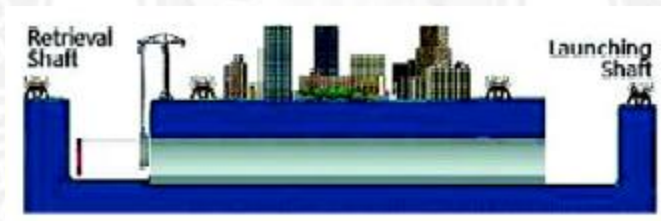
Following stages are involved, before and after the main activity of tunneling by TBM:
(i) Excavation for launching Shaft and Retrieval Shaft

(ii) Assembly of TBM at the launching Shaft

(iii) Tunnel excavation by TBM



(iv) Arrival of TBM in retrieval Shaft, to be dismantled and taken out



<u>Types of TBM</u>:

TBMs are often grouped under categories of "**Hard Rock TBMs**" & "**Soft Ground TBMs**".

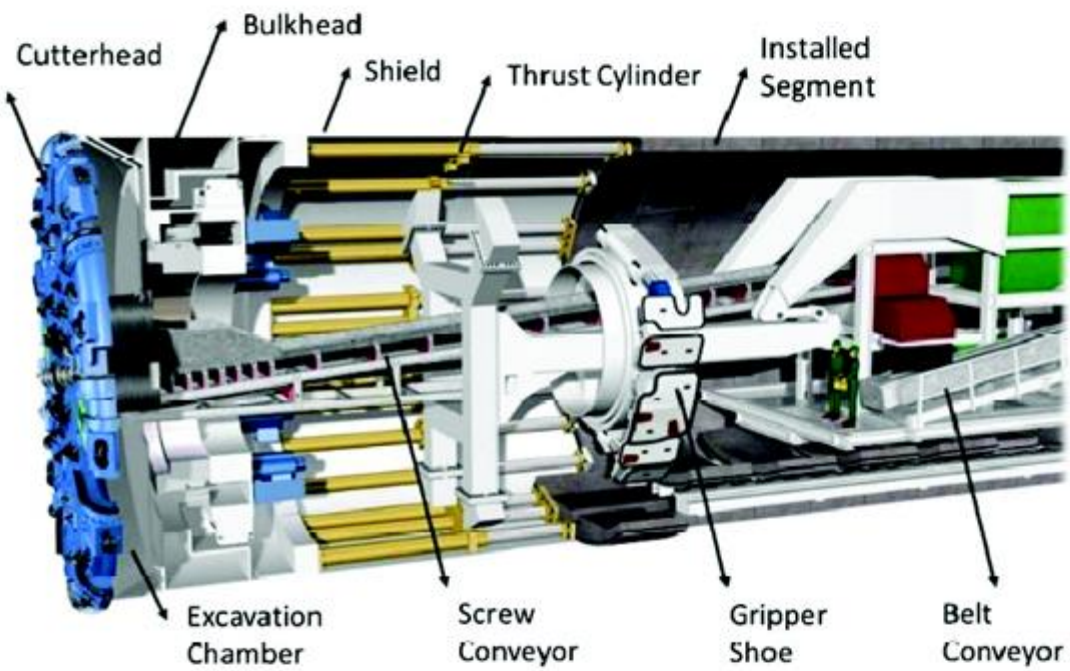
Hard Rock TBMs:

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.



Hard rock TBMs comprise of following four key sections :

(i) Boring section, consisting of the cutter head,

(ii) Thrust and clamping section, which is responsible for advancing the machine,

(iii) Muck removal section, which takes care of collecting and removing the excavated material, and

(iv) Support section, where the tunnel support is erected.

Open-type TBMs have no shield, leaving the area behind the cutter head open for rock support. To advance, the machine uses a gripper system that pushes against the side walls of the tunnel.

The machine can be continuously steered while gripper shoes push on the side-walls to react the machine's forward thrust.

At the end of a stroke, the rear legs of the machine are lowered, the grippers and propel cylinders are retracted.

The retraction of the propel cylinders repositions the gripper assembly for the next boring cycle. The grippers are extended, the rear legs lifted and boring begins again.

The open-type TBM does not install concrete segments behind it as other machines do. Instead, the rock is supported using ground support methods such as ring beams, rock bolts, shotcrete, steel straps and wire mesh (Stack, 1995).

Hard Rock TBMs primarily fall under following categories:

Gripper TBM: Open hard rock TBM - suited for boring in stable rock.

Shielded TBM: Shielded hard rock TBM suited for tunneling in varying rock formations that alternate between stable and unstable formations.

Working principles of these TBMs are briefly described below:

Gripper TBM:

The Gripper TBM is braced radially with grippers against the tunnel wall, with hydraulic cylinders pressing the cutter head against the tunnel face to enable a further section of tunnel to be excavated.

The maximum boring stroke is governed by the length of the pistons in the thrust cylinder. The cutter head is fitted with cutter rings (disks).

The rotating cutter head forces the disks against the tunnel face under high pressure. In this process, the disks roll over the tunnel face, thereby loosening the native rock.

The excavated rock, or "chips" as it is commonly known, is collected in muck bucket lips (openings in the cutter head) and discharged via hoppers onto a conveyor belt. The excavated material is brought outside the tunnel by conveyers.

Typical advance of cutter head is approximately 0.7 to 1.2m. After completion of a boring stroke, the drilling process is interrupted and the machine moved forwards, with the Gripper TBM being stabilized by an additional support system.

Shielded TBM:

In contrast to Gripper TBMs, the body of the shield TBM has an extended shield over the front section of the machine.

This shield has the function of supporting the ground and protecting the personnel, thus allowing safe erection of the tunnel lining.

There are two basic types of shield TBMs for hard rock available; **the single-shield and double-shield.**

The single-shield TBM in hard rock is mainly used in unstable conditions where there is a risk of ground collapse.

The double-shield TBM in hard rock is mainly used in stable conditions.

Soft Ground TBMs:

The application of a TBM technique in less stable soft ground commonly requires the face to be supported. This is in contrast to the open face TBMs (often used in hard rocks) where the ground is able to support itself during excavation by virtue of its significant strength and stand-up time.

In soft ground, with little or no standup time, the ground would simply collapse into the machine and attempts to control the excavation of this material and to prevent large displacements occurring within extensive amounts of the ground around the tunnel heading would be very difficult.

In addition, for tunnels constructed below the groundwater table in permeable materials, water flow into the tunnel must be controlled in order to prevent the machine and tunnel from flooding. Soft ground TBMs are designed to simultaneously provide immediate peripheral and frontal support and as such they belong to the closed-faced group of TBMs

Soft ground TBMs are classified into following types depending upon frontal support technique they employ:

Mechanical support TBM:

A mechanical-support TBM has a full-face cutter head which provides face support by constantly pushing the excavated material ahead of the cutter head against the surrounding ground.

Its specific field of application is, therefore, in soft rock and consolidated soft ground with little or no water pressure.

Compressed air TBM:

A compressed-air TBM can have either a full face cutter head or excavating arms like those of the different boom-type units. Confinement is achieved by pressurizing the air in the cutting chamber.

Compressed-air TBMs are particularly suitable for ground of low permeability with no major discontinuities (i.e. no risk of sudden loss of air pressure).

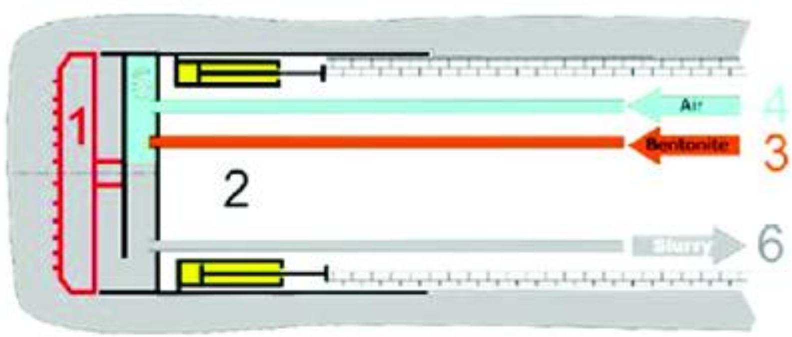
The ground tunneled must necessarily have an impermeable layer in the overburden. Compressed-air TBMs tend to be used to excavate small-diameter tunnels.

Their use is not recommended in circumstances where the ground at the face is heterogeneous. They should not be used in organic soil where there is a risk of fire.

Slurry Shield TBM:

In soft ground with very high water pressure and large amounts of ground water, Slurry Shield TBMs are needed. These machines offer a completely enclosed working environment (Fig.).

Soils are mixed with bentonite slurry, which must be removed from the tunnel through a system of slurry tubes that exit the tunnel. Large slurry separation plants are needed on the surface for this process, which separate the dirt from the slurry so it can be recycled back into the tunnel.



1. Cutter Head 2. Shield 3. Bentonite Injection 4. Air regulation 5. Air Bubble 6. Extraction of slurry with Soil

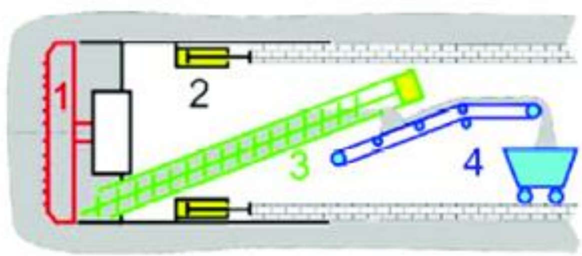
<u>Earth Pressure Balance TBM</u>:

Earth Pressure Balance Machines are used in soft ground with less than 7 bar of pressure.

An earth pressure balance machine has a full face cutter head. The cutter head does not use disc cutters only, but instead a combination of tungsten carbide cutting bits, carbide disc cutters and/or hard rock disc cutters.

The EPB gets its name because it is capable of holding up soft ground by maintaining a balance between earth and pressure (Fig.).

The TBM operator and automated systems keep the rate of soil removal equal to the rate of machine advance. Thus, a stable environment is maintained.



1. Cutter head 2. Shield 3. Screw conveyor 4. Belt Conveyor

<u>Special purpose TBMs</u>:

In addition to above, there are Special Purpose TBMs also.

Some of these are:

(I) **Reaming Boring Machines -** allows a tunnel made using a TBM (pilot tunnel) to be widened (reaming).

(II) **Raise Borer** - used for shaft excavation which enables the top-to-bottom reaming of a small diameter pilot tunnel created using a drilling rig.

(III) **Mixed Face TBMs** – allows tunneling under mixed face conditions.

(IV) **Multi-Mode TBMs** – can operate in different modes with appropriate modifications to configuration & support techniques.

<u>Selection of TBM</u>:

Careful and comprehensive analysis should be made to select proper machine for tunneling taking into considerations its reliability, safety, cost efficiency and the working conditions. In particular, the following factors should be analyzed:

- Suitability to the anticipated geological conditions.
- Applicability of supplementary supporting methods, if necessary tunnel alignment and length.

- Availability of space necessary for auxiliary facilities behind the machine and around the access tunnels.
- Safety of tunneling and other related works.

Advantages TBM

Minimize works on the ground besides both shafts for launch and arrival of shield TBM.

Minimize noise, vibration, dust, pollution, etc. from construction.

Minimize disturbance

Minimize diversion of existing underground facilities along tunnel alignment.

The process is repetitive, so that most of the works can be automated and easily managed.

Compared to cut & cover method, the depth of tunnel has influence on the construction cost.

Tunneling under river, sea, buildings, etc. is made easy compared to other methods of tunneling.

It is possible to construct more curved and steep tunnel than other methods.

Since many researches are still ongoing in the advancement of shield TBM, it is expected to be applied under any ground conditions hereafter.