A General Overview on Tunnel Boring Machines

SRMEG-NCUS Seminar
31 January 2012

Conventional and TBM Tunnelling

New Singapore MRT are in tunnels
Conventional and TBM Tunnelling

Tunnelling

Excavate a tunnel using machines and/or explosives, and support the tunnel using concrete and steel.

Modern methods are conventional and mechanised methods.
Singapore is the most intensive user of TBM for tunnel construction.
Basic Functions of TBM

1. Excavating the Ground

Basic Functions of TBM

2. Supporting the Ground
### Basic Functions of TBM

#### 3. Mucking the Excavated Materials

![Image of tunneling process](image)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>RISKS</th>
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<tbody>
<tr>
<td>Enhanced health and safety conditions for the workers.</td>
<td>Lack of flexibility: Once the technique has been chosen it is virtually impossible to change it throughout the construction of the tunnel.</td>
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<tr>
<td>Industrialization of the tunnelling process, with ensuing reductions in cost and construction times.</td>
<td>Therefore, a correct analysis of different parameters is needed for the choice of the correct mechanized tunnelling technique.</td>
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<tr>
<td>Possibility of crossing complex geological and hydrogeological conditions safely and economically.</td>
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<tr>
<td>Good quality of finished product (surrounding ground less altered, precast segment lining).</td>
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Tunnel Reaming and Enlarge Machines

- **Non-Shield TBM**
  - Reaming Machine
  - Gripper TBM

- **Rock TBM**
  - Competent rock

- **Soil TBM**
  - Open Face
  - Mechanical Face Support
  - Compressed Air Shield
  - Slurry / Hydro-Shield
  - Earth Pressure Balance Shield
  - Firm soil, soft rock
  - Firm soil, weathered and highly fractured rock
  - Firm soil with groundwater, soil mixed with rock
  - Sand, sandy soil mixed with rock
  - Clay, clayey soil mixed with rock

- **Shield TBM**
  - Mix-Shield
  - Double Shield
  - EPB-Slurry Convertible
  - Soil-rock mixed grounds
  - Rock-soil changing grounds
  - Clay-sand varying grounds

- **Hybrid Shield**

**Tunnel Bore Extender (TBE) used at Uetliberg Tunnel in Switzerland.**

Tunnel is enlarged from a 5 m pilot tunnel to 14.4 m.
Tunnel Reaming and Enlarge Machines

Reaming boring machine bores the final section from an axial pilot tunnel from which it pulls itself forward by means of a gripper unit.

With the production of large diameter TBMs, this machine is no longer needed.

Gripper TBM

- **Non-Shield TBM**
  - **Rock TBM**
    - **Reaming Machine**
    - **Gripper TBM**
  - **Soil TBM**
    - **Open Face**
    - **Mechanical Face Support**
    - **Compressed Air Shield**
    - **Slurry / Hydro-Shield**
    - **Earth Pressure Balance Shield**
  - **Shield TBM**
    - **Mix-Shield**
    - **Double Shield**
    - **EPB-Slurry Convertible**
  - **Hybrid Shield**

- **Competent rock**
- **Firm soil, soft rock**
- **Firm soil, weathered and highly fractured rock**
- **Firm soil with groundwater, soil mixed with rock**
- **Sand, sandy soil mixed with rock**
- **Clay, clayey soil mixed with rock**
- **Soil-rock mixed grounds**
- **Rock-soil changing grounds**
- **Clay-sand varying grounds**
Gripper TBM

Rock excavation machine for competent and hard rocks. Movement of machine uses the grippers.

Gripper TBM

Cutterhead

Gripper

Rock is fragmented by fracturing and chipping between cutters.
**Gripper TBM**

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<tr>
<th>ADVANTAGES</th>
<th>LIMITATIONS</th>
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<tr>
<td>Rapid excavation rate in hard rocks.</td>
<td>No protection or support given to the rock while excavating. Limited to stable ground.</td>
</tr>
<tr>
<td>Capable to excavate hard rocks of UCS up to 300 MPa.</td>
<td>Gripper may have difficult in poor rock masses with low strength.</td>
</tr>
<tr>
<td>For tunnels of diameter up to 14 m (largest 14.4 m, 2008).</td>
<td>Dedusting is needed.</td>
</tr>
<tr>
<td>Flexible rock support measure according to ground conditions.</td>
<td></td>
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</tbody>
</table>
Open Face Shield TBM

- **Reaming Machine**
  - Competent rock

- **Gripper TBM**
  - Competent rock

**Rock TBM**

- **Non-Shield TBM**
  - Firm soil, soft rock

- **Gripper TBM**
  - Competent rock

**Soil TBM**

- **Open Face**
  - Firm soil, weathered and highly fractured rock

- **Mechanical Face Support**
  - Firm soil with groundwater, soil mixed with rock

- **Compressed Air Shield**
  - Sand, sandy soil mixed with rock

- **Slurry / Hydro-Shield**
  - Clay, clayey soil mixed with rock

- **Earth Pressure Balance Shield**
  - Clay-sand varying grounds

**Shield TBM**

- **Mix-Shield**
  - Soil-rock mixed grounds

- **Double Shield**
  - Rock-soil changing grounds

- **EPB-Slurry Convertible**

**Hybrid Shield**

Open Face Shield TBM has no face support. When needed, compressed air pressure can be used to support the face. It is used limited and only in very consistent firm ground requires no face support.
**TBM with Mechanical Face Support**

<table>
<thead>
<tr>
<th>Type</th>
<th>Face Support</th>
<th>Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Shield TBM</td>
<td>Reaming Machine</td>
<td>Competent rock</td>
</tr>
<tr>
<td></td>
<td>Gripper TBM</td>
<td>Competent rock</td>
</tr>
<tr>
<td>Rock TBM</td>
<td></td>
<td>Firm soil, soft rock</td>
</tr>
<tr>
<td>Soil TBM</td>
<td>Open Face</td>
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<td></td>
<td>Mechanical Face Support</td>
<td>Firm soil with groundwater, soil mixed with rock</td>
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</tr>
<tr>
<td>Shield TBM</td>
<td>Earth Pressure Balance Shield</td>
<td>Clay-sand varying grounds</td>
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<td></td>
<td>Mix-Shield</td>
<td>Soil-rock mixed grounds</td>
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<tr>
<td>Hybrid Shield</td>
<td>Double Shield</td>
<td>Rock-soil changing grounds</td>
</tr>
<tr>
<td></td>
<td>EPB-Slurry Convertible</td>
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</table>

Open face TBM can be for rock and firm soil without the need of face pressure.
It usually does not have a chamber to generate pressure support to the excavation face. Excavated materials can be transported directly from the cutterhead.

It can often to be combined with compressed air pressure when needed.

### Compressed Air Shield

- **Non-Shield TBM**
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  - **Gripper TBM**
- **Rock TBM**
- **Soil TBM**
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    - **Compressed Air Shield**
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- **Shield TBM**
- **Hybrid Shield**
  - **Mix-Shield**
  - **Double Shield**
  - **EPB-Slurry Convertible**

- **Competent rock**
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- **Firm soil, soft rock**
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- **Soil-rock mixed grounds**
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- **Clay-sand varying grounds**
Compressed Air Shield

When open face shield excavating groundwater-bearing soil, water penetration can be prevented by having the shield and a section of the tunnel protected by a lock system using compressed air.

The required pressure is monitored continuously and adjusted automatically where necessary by a compressed air system consisting of two control circuits.

The health consideration under compressed air pressure limits the usage.

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Slurry / Hydro-Shield

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- **Hybrid Shield**
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Slurry / Hydro-Shield

Large diameter slurry shield (φ15.43m, 2006), used for the Shanghai Changjiang River Tunnel Project.

TBM excavation face is supported by pressurizing bentonite in cutterhead chamber. Circulation of the fluid flushes out the muck. Pressure is maintained by controlling discharge rates.

1. Cutting wheel
2. Air bubble
3. Bentonite suspension
4. Drive unit
5. Stone crusher
6. Push cylinder
7. Air lock
8. Steer cylinder/shield tail
9. Segment erecter
10. Segment conveyor
### Slurry / Hydro-Shield

**ADVANTAGES**
- Equal distribution of pressures against mixed-face conditions.
- Good performance in sands and gravels.
- Gives better face stability (formation of mud-cake).
- Allows access to the face with compressed air.

**LIMITATIONS**
- Need of large separation plants for bentonite separation and treatment.
- Not suitable for clayey-silty grounds.

### Earth Pressure Balance Shield

- **Non-Shield TBM**
  - Reaming Machine: Competent rock
  - Gripper TBM: Competent rock

- **Rock TBM**
  - Open Face: Firm soil, soft rock
  - Mechanical Face Support: Firm soil, weathered and highly fractured rock
  - Compressed Air Shield: Firm soil with groundwater, soil mixed with rock
  - Slurry / Hydro-Shield: Sand, sandy soil mixed with rock
  - **Earth Pressure Balance Shield**: Clay, clayey soil mixed with rock

- **Soil TBM**
  - Mix-Shield: Soil-rock mixed grounds

- **Shield TBM**
  - Double Shield: Rock-soil changing grounds

- **Hybrid Shield**
  - EPB-Slurry Convertible: Clay-sand varying grounds
Earth Pressure Balance Shield

Large diameter EPB machine (φ15.2 m, 2006) for Madrid M-30 project.

Earth Pressure Balance Shield

TBM excavation face is supported by pressurizing soil (earth) inside the cutterhead chamber. Earth pressure in the chamber is regulated by the rate of earth discharge through the screw conveyer.
Foams and chemical additives are used to conditioning soil for better control of pressure and muck discharge, in sandy grounds.

Earth Pressure Balance Shield

ADVANTAGES

- Very well adapted for excavating silty and clayey grounds.
- No need of separation plant.
- The use of additives (foams) enables EPB’s to be used with sandy-gravely soils.

LIMITATIONS

- Irregular distribution of pressure against mixed face conditions.
- Problems when boulders are encountered: no possibility of fitting a rock crusher.
- Wearing of the screw can lead to bad pressure distribution.
Selection of Shield Boring Machine
Based on Soil Grain Size Distribution

Earth Pressure Balance Shield

- EPB
- Slurry

Mix-Shield

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  - Grippe TBM: Competent rock
- Rock TBM
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- Shield TBM
  - Slurry / Hydro-Shield: Sand, sandy soil mixed with rock
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- Hybrid Shield
  - Double Shield: Soil-rock mixed grounds
  - EPB-Slurry Convertible: Clay-sand varying grounds

<table>
<thead>
<tr>
<th>Soil Grain Size Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
</tr>
<tr>
<td>Sand</td>
</tr>
<tr>
<td>Gravel</td>
</tr>
</tbody>
</table>
Mix-Shield

The cutterhead has combined features for hard rock and soil excavation. It enables the shield TBM to excavate through both rocks and soils, and rock-soil mixed face. Mix-shield can be EPB or slurry based. The largest shield is a mix-shield of 19.25 m.

Mix-Shield

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<tbody>
<tr>
<td>Flexible in excavation of rock, soil, and mixed ground.</td>
<td>Maintaining face pressure may be difficult, particularly for EPB based machine.</td>
</tr>
<tr>
<td>Face pressure features are maintained by either EPB or slurry.</td>
<td>Cutter wear and damage is generally high.</td>
</tr>
<tr>
<td>Other advantages of EPB or slurry shields.</td>
<td>Muck discharge may be difficult due to mixing of rock and soil.</td>
</tr>
<tr>
<td>Other limitations of EPB or slurry shields.</td>
<td></td>
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Laboratoire de Mécanique des Roches – LMR  
Tunnelling
Double Shield

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- **Shield TBM**
  - **Mix-Shield**
  - **Double Shield**
  - **EPB-Slurry Convertible**

**Double Shield**

It combines the features of gripper and shield in one TBM, and enables fast excavation even in varying rock formations.
Double Shield

In poor ground condition, it works as a single shield machine. When in rocks, grippers are used for forward movement, so segment can be simultaneously installed while excavating.

**ADVANTAGES**

- Good flexibility for varying grounds.
- High advancement rates.
  The increase depends on operation.
- Possibility to have different support measures, e.g., segmental lining, and bolts-shotcrete.
- Possibility of ground treatment and/or probing through the gap between shields.

**LIMITATIONS**

- Maintenance problems of articulation between the shields.
- Long shield length: possible drawback for squeezing grounds.
- More expensive than conventional shields.
EPB-Slurry Convertible Shield

It is a machine has both EPB and slurry system installed. It can convert between EPB mode and slurry mode, to cope with grounds suitable for both type of machines.
It allow the machine to change the mode to suit the ground condition.

Support of TBM Tunnels

For non-shield TBMs, typical rock support are applied, using bolts, shotcrete, wire mesh or steel sets, as determined by the ground condition.
Support of TBM Tunnels

For shield TBMs, precasted concrete segments are erected inside the shield to form a ring to support the ground.

The segments are jointed by bolts. Gap between ground and ring is filled. Rubber gaskets are used to stop water inflow.
New TBM Technologies

Difference cross section shape to optimize space: double-circle, square, rectangular etc.

New TBM Technologies

Optimizing advancement by continuing face excavation during segment installation.
New TBM Technologies

Optimizing machine with variable and complex ground condition, aiming towards Universal TBM.

New TBM Technologies

e-Tunnelling and Smart TBM

- Focus on the use of information technology in tunnelling;
- Instrumentation and real-time monitoring of ground condition, ground movement, TBM reaction;
- Data and information management to guide the best operation of TBM;
- Future toward self-learning and smart TBM.
TBM Machines at a Glance

Non-Shield TBM
- Reaming Machine: Competent rock
- Gripper TBM: Competent rock

Shield TBM
- Soil TBM
  - Open Face: Firm soil, soft rock
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