

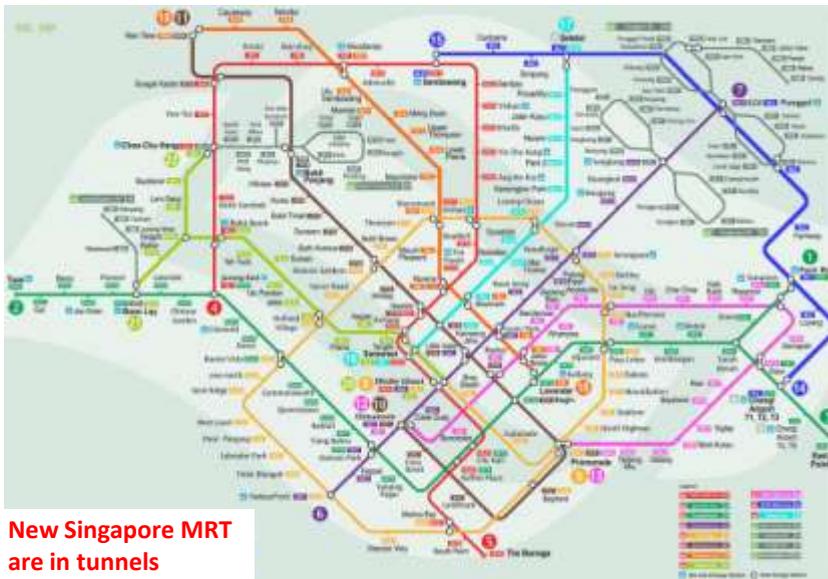
# A General Overview on Tunnel Boring Machines

SRMEG-NCUS Seminar  
31 January 2012

 Ecole Polytechnique Fédérale de Lausanne  
Environnement Naturel Architectural et Construit  
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Rock Mechanics & Tunnelling

## Conventional and TBM Tunnelling



## Conventional and TBM Tunnelling



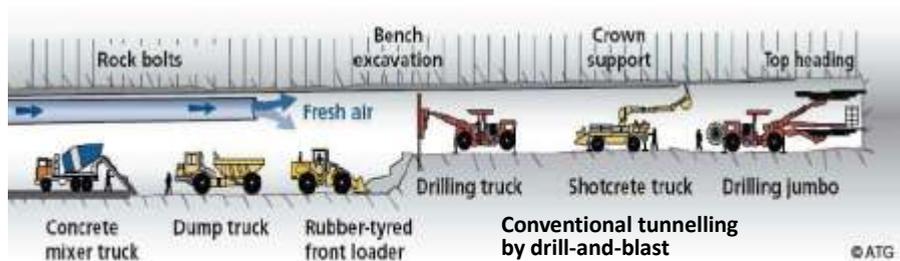
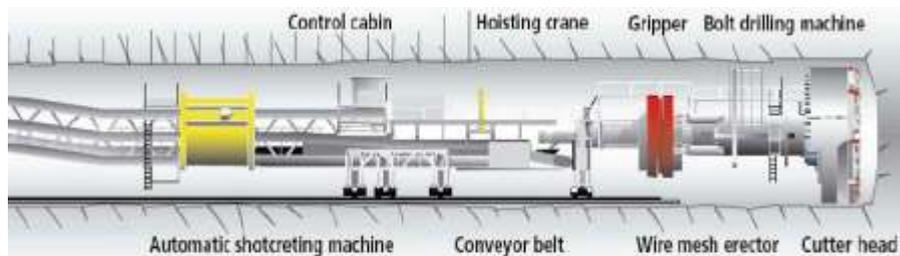
### Tunnelling

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

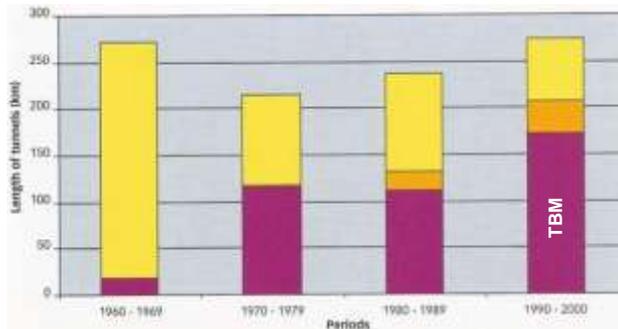
Modern methods are conventional and mechanised methods



## Conventional and TBM Tunnelling



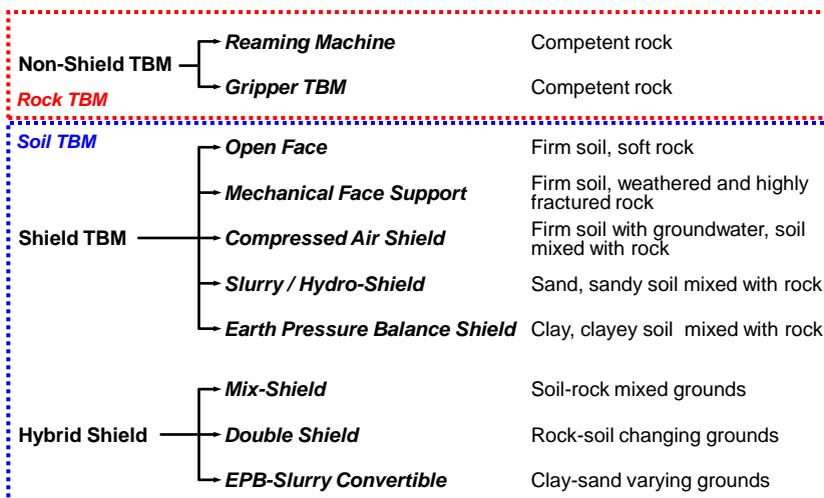
## Conventional and TBM Tunnelling



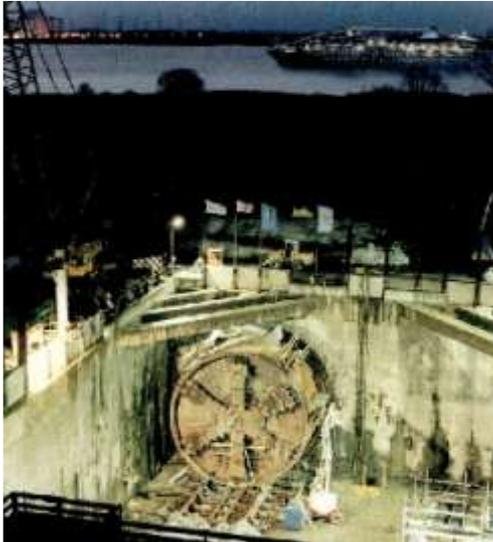
Tunnelling and Use of TBM in Switzerland

Singapore is the most intensive user of TBM for tunnel construction.

## Conventional and TBM Tunnelling



## Basic Functions of TBM

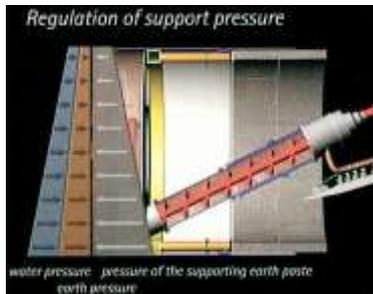


### 1. Excavating the Ground



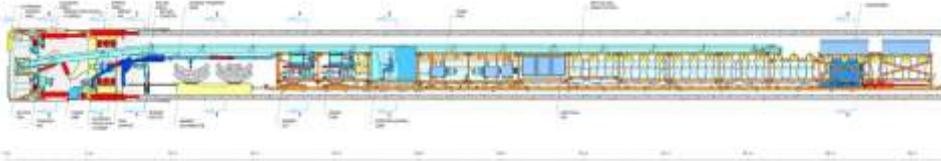
## Basic Functions of TBM

### 2. Supporting the Ground



## Basic Functions of TBM

### 3. Mucking the Excavated Materials



## Basic Functions of TBM

### ADVANTAGES

- Enhanced health and safety conditions for the workers.
- Industrialization of the tunnelling process, with ensuing reductions in cost and construction times.
- Possibility of crossing complex geological and hydrogeological conditions safely and economically.
- Good quality of finished product (surrounding ground less altered, precast segment lining).

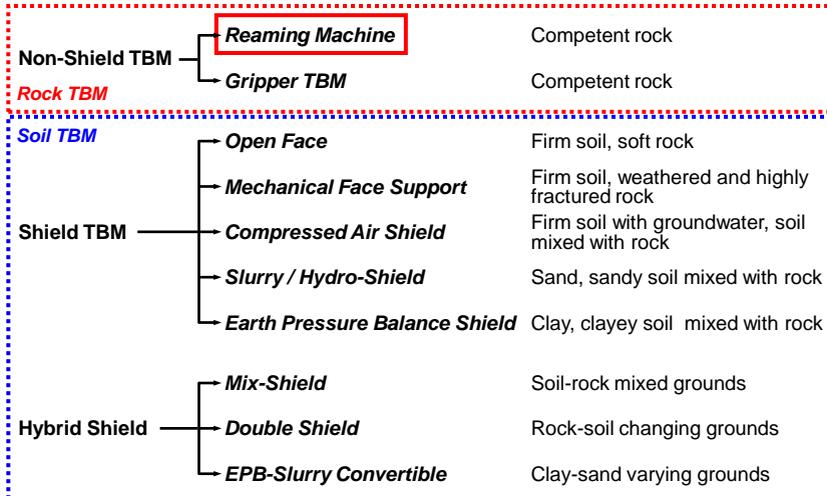
### RISKS

Lack of flexibility: Once the technique has been chosen it is virtually impossible to change it throughout the construction of the tunnel.



Therefore, a correct analysis of different parameters is needed for the choice of the correct mechanized tunnelling technique

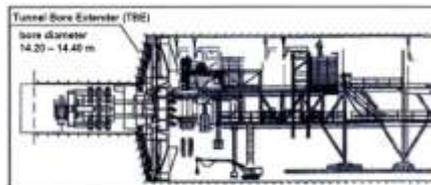
## Tunnel Reaming and Enlarge Machines



## Tunnel Reaming and Enlarge Machines



Tunnel Bore Extender (TBE) used at Uetliberg Tunnel in Switzerland. Tunnel is enlarged from a 5 m pilot tunnel to 14.4 m.

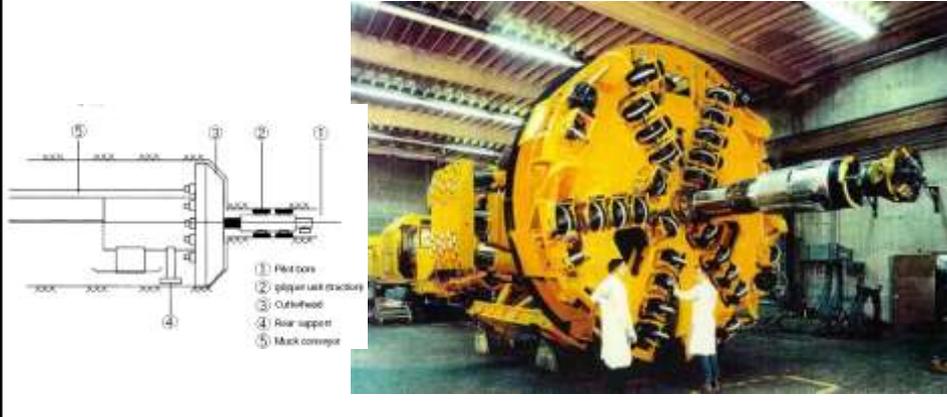


TBE driving using the backcutting technique and installation of supporting anchors and chocks in the back-up system (bore diameter: 14.20 - 14.40 m)

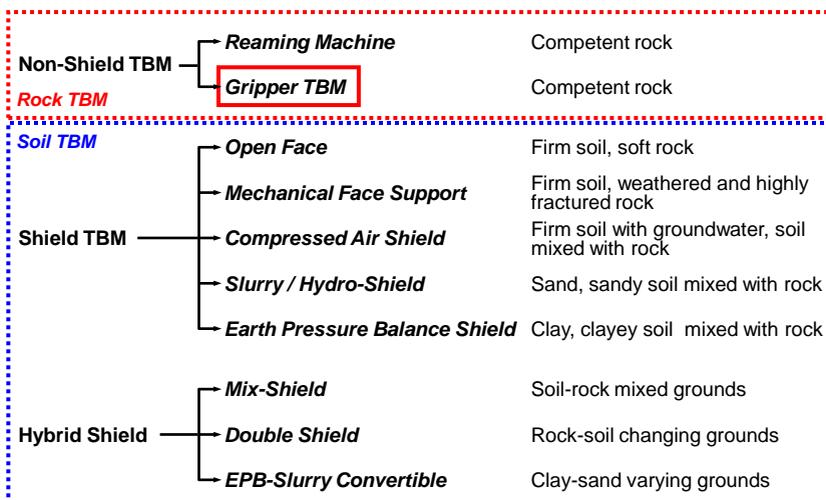
## Tunnel Reaming and Enlarge Machines

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



## Gripper TBM

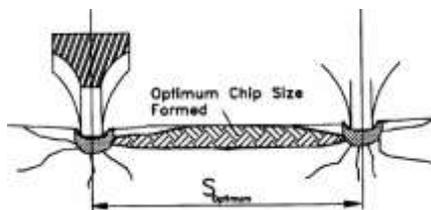
Rock excavation machine for competent and hard rocks.  
Movement of machine uses the grippers.



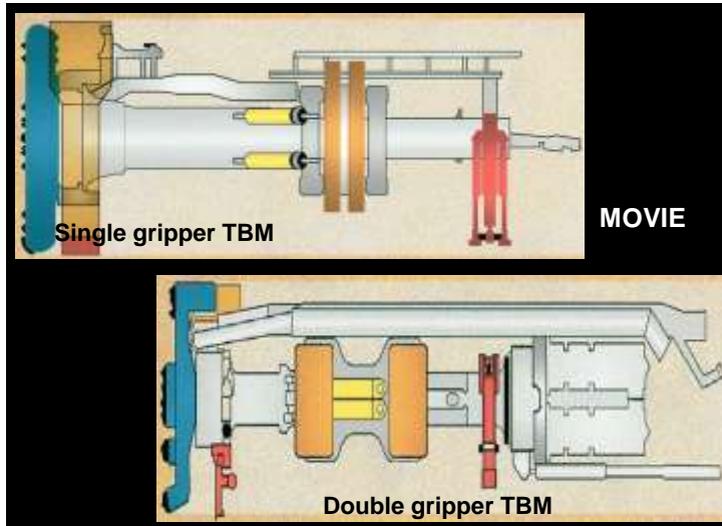
## Gripper TBM



Rock is fragmented by fracturing  
and chipping between cutters.



## Gripper TBM



## Gripper TBM

### ADVANTAGES

Rapid excavation rate in hard rocks.

Capable to excavate hard rocks of UCS up to 300 MPa.

For tunnels of diameter up to 14 m (largest 14.4 m, 2008).

Flexible rock support measure according to ground conditions.

### LIMITATIONS

No protection or support given to the rock while excavating. Limited to stable ground.

Gripper may have difficult in poor rock masses with low strength.

Dedusting is needed.

## Open Face Shield TBM

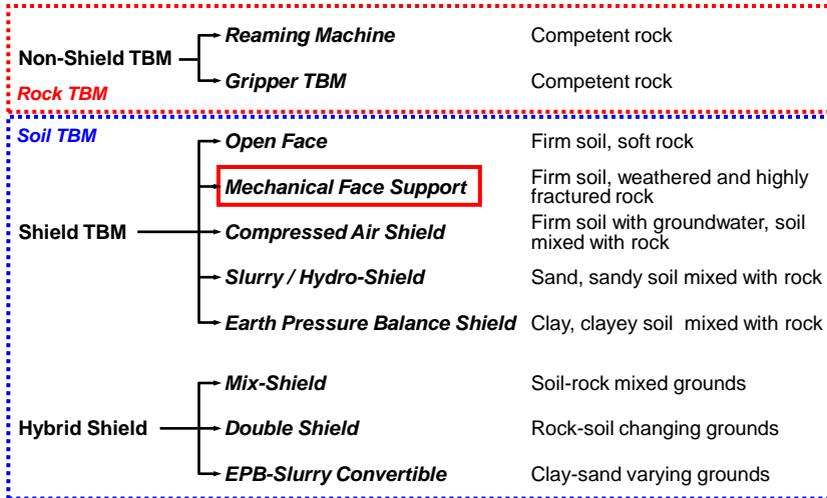
Non-Shield TBM	Reaming Machine	Competent rock
	Gripper TBM	Competent rock
<i>Rock TBM</i>		
Shield TBM	<b>Open Face</b>	Firm soil, soft rock
	Mechanical Face Support	Firm soil, weathered and highly fractured rock
	Compressed Air Shield	Firm soil with groundwater, soil mixed with rock
	Slurry / Hydro-Shield	Sand, sandy soil mixed with rock
	Earth Pressure Balance Shield	Clay, clayey soil mixed with rock
Hybrid Shield	Mix-Shield	Soil-rock mixed grounds
	Double Shield	Rock-soil changing grounds
	EPB-Slurry Convertible	Clay-sand varying grounds

## Open Face Shield TBM

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



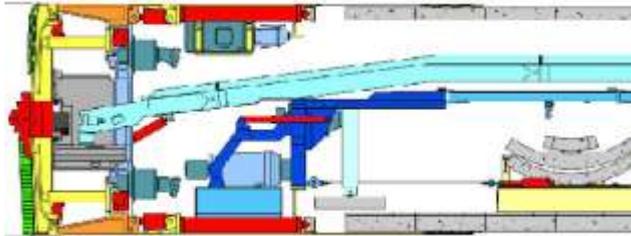
Open face TBM can be for rock and firm soil without the need of face pressure.



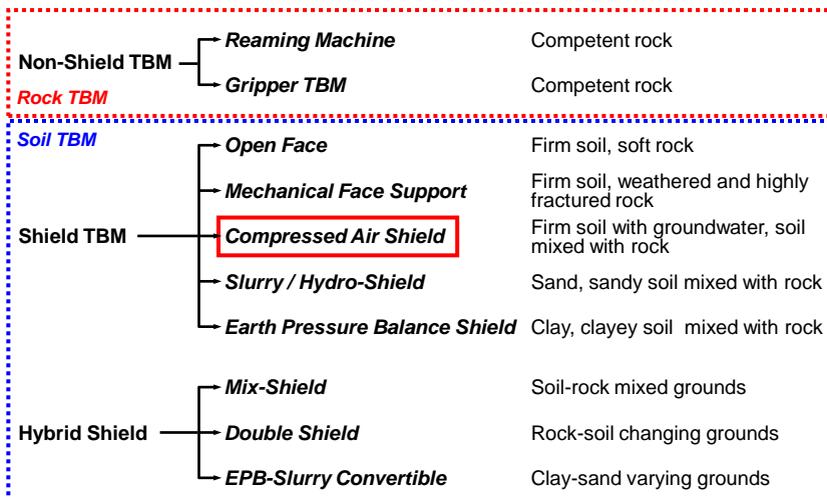


It usually does not have a chamber to generate pressure support to the excavation face. Excavated materials can be transported directly from the cutterhead.

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



## Compressed Air Shield



## Compressed Air Shield

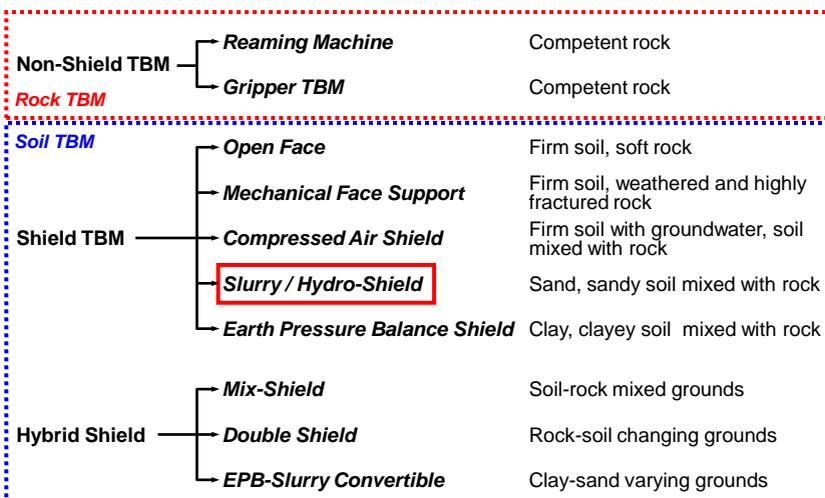
When open face shield excavating groundwater-bearing soil, water penetration can be prevented by having the shield and a section of the tunnel protected by a lock system using compressed air.



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.

## Slurry / Hydro-Shield



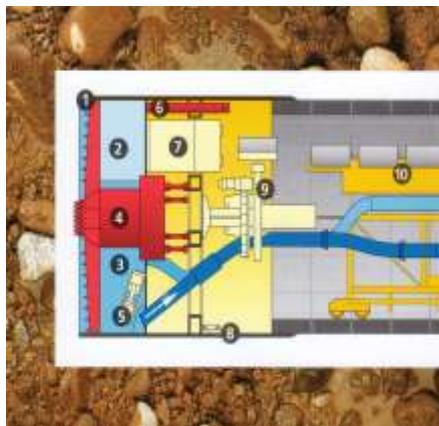
## Slurry / Hydro-Shield

Large diameter slurry shield ( $\phi 15.43\text{m}$ , 2006), used for the Shanghai Changjiang River Tunnel Project.



## Slurry / Hydro-Shield

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 erector
10. Segment conveyor

MOVIE

## Slurry / Hydro-Shield

ADVANTAGES	LIMITATIONS
<p>Equal distribution of pressures against mixed-face conditions.</p> <p>Good performance in sands and gravels.</p> <p>Gives better face stability (formation of mud-cake).</p> <p>Allows access to the face with compressed air.</p>	<p>Need of large separation plants for bentonite separation and treatment.</p> <p>Not suitable for clayey-silty grounds.</p>

## Earth Pressure Balance Shield

<p>Non-Shield TBM</p> <p style="color: red;"><i>Rock TBM</i></p>	<ul style="list-style-type: none"> <li>→ <i>Reaming Machine</i></li> <li>→ <i>Gripper TBM</i></li> </ul>	<p>Competent rock</p> <p>Competent rock</p>
<p style="color: blue;"><i>Soil TBM</i></p> <p>Shield TBM</p>	<ul style="list-style-type: none"> <li>→ <i>Open Face</i></li> <li>→ <i>Mechanical Face Support</i></li> <li>→ <i>Compressed Air Shield</i></li> <li>→ <i>Slurry / Hydro-Shield</i></li> <li>→ <span style="border: 1px solid red; padding: 2px;"><i>Earth Pressure Balance Shield</i></span></li> </ul>	<p>Firm soil, soft rock</p> <p>Firm soil, weathered and highly fractured rock</p> <p>Firm soil with groundwater, soil mixed with rock</p> <p>Sand, sandy soil mixed with rock</p> <p>Clay, clayey soil mixed with rock</p>
<p>Hybrid Shield</p>	<ul style="list-style-type: none"> <li>→ <i>Mix-Shield</i></li> <li>→ <i>Double Shield</i></li> <li>→ <i>EPB-Slurry Convertible</i></li> </ul>	<p>Soil-rock mixed grounds</p> <p>Rock-soil changing grounds</p> <p>Clay-sand varying grounds</p>

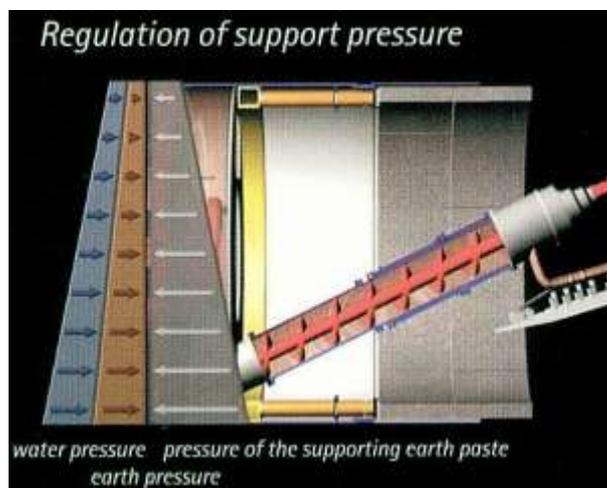
## Earth Pressure Balance Shield

Large diameter EPB machine ( $\phi 15.2$  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.



## Earth Pressure Balance Shield



Foams and chemical additives are used to conditioning soil for better control of pressure and muck discharge, in sandy grounds.

MOVIE

## 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-gravelly 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.

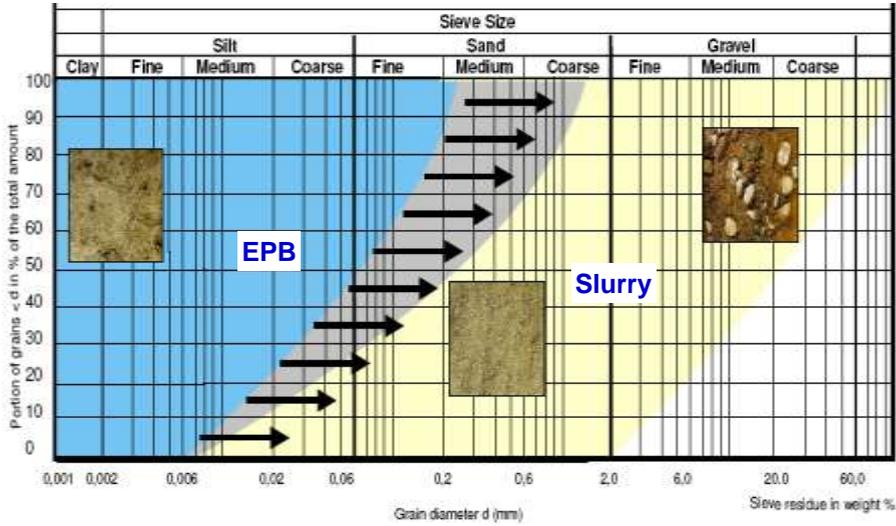


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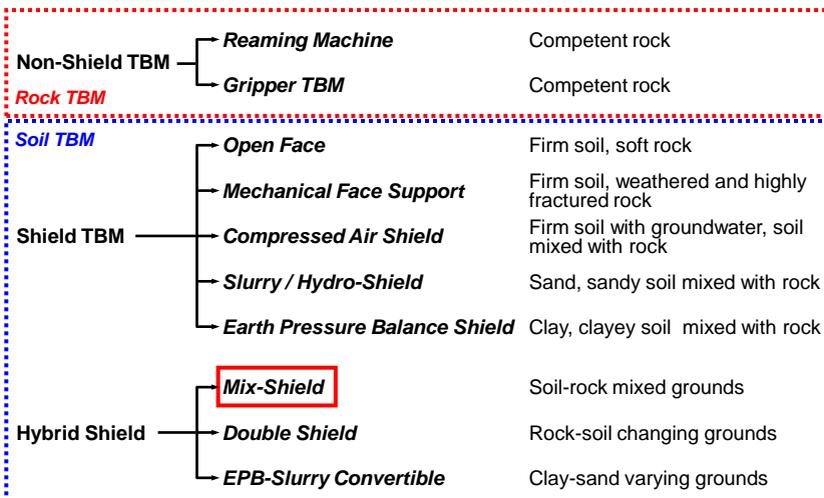
Tunnelling

# Earth Pressure Balance Shield

## Selection of Shield Boring Machine Based on Soil Grain Size Distribution



# Mix-Shield



## 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 Slurry



Mix-Shield EPB

## Mix-Shield

### ADVANTAGES

Flexible in excavation of rock, soil, and mixed ground.

Face pressure features are maintained by either EPB or slurry.

Other advantages of EPB or slurry shields.

### LIMITATIONS

Maintaining face pressure may be difficult, particularly for EPB based machine.

Cutter wear and damage is generally high.

Muck discharge may be difficult due to mixing of rock and soil.

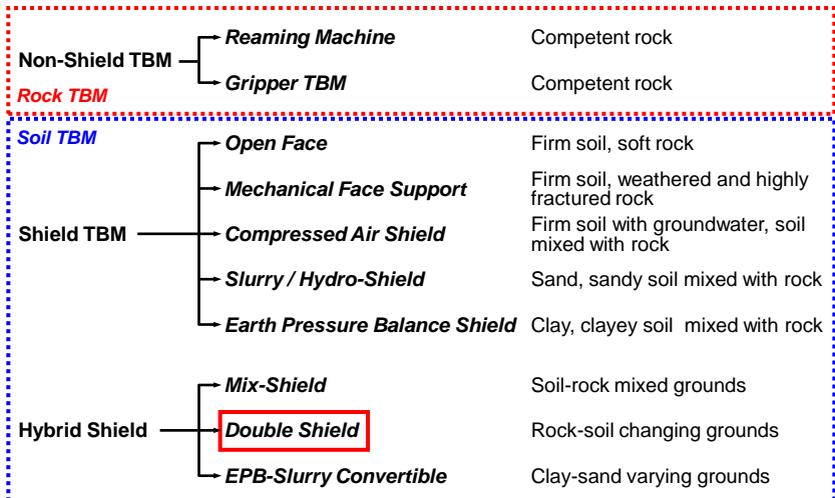
Other limitations of EPB or slurry shields.



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## Double Shield



## 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.



## Double Shield

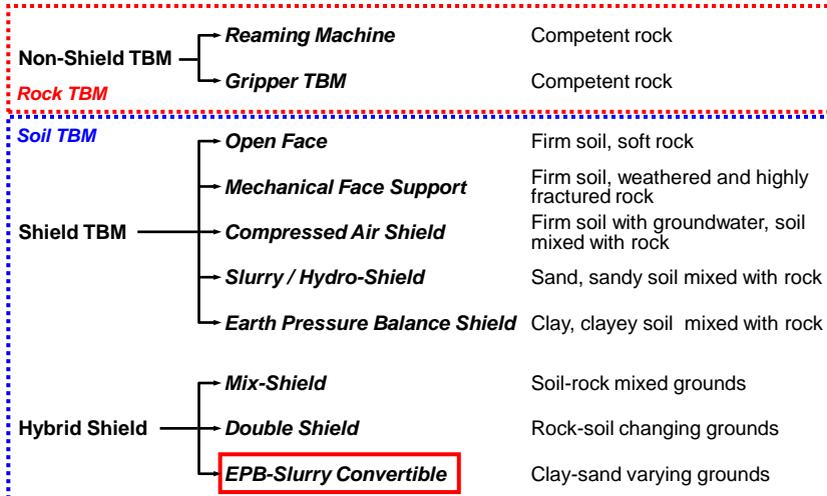
### ADVANTAGES

- 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

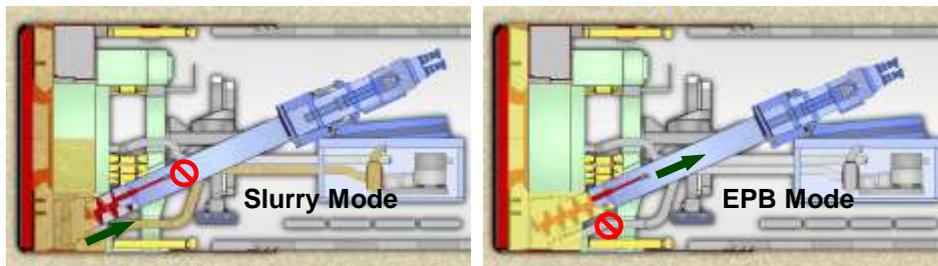
- Maintenance problems of articulation between the shields.
- Long shield length: possible drawback for squeezing grounds.
- More expensive than conventional shields.

## EPB-Slurry Convertible Shield

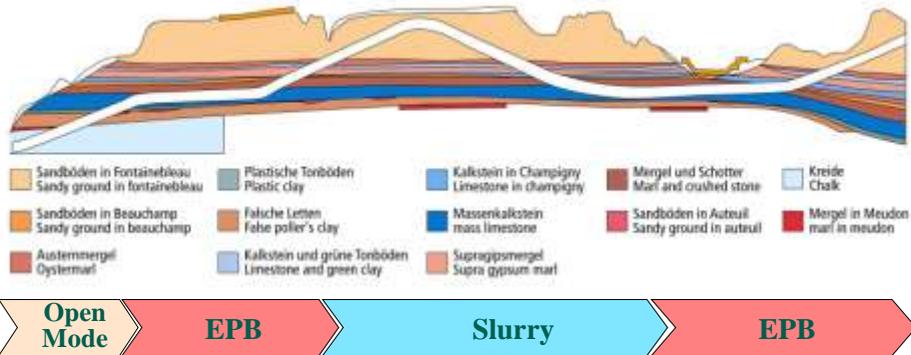


## EPB-Slurry Convertible Shield

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.



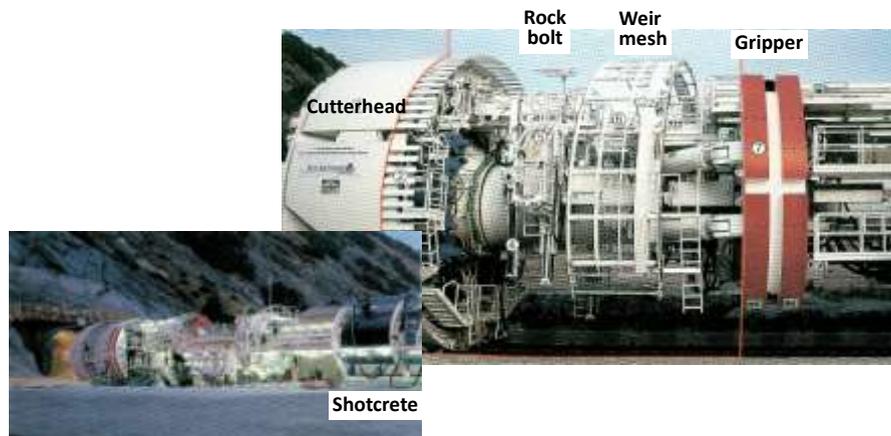
## EPB-Slurry Convertible Shield



It allow the machine to change the mode to suit the ground condition.

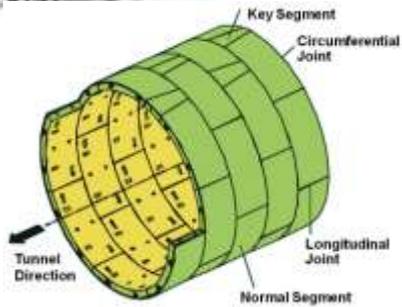
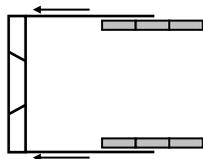
## Support of TBM Tunnels

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, precast concrete segments are erected inside the shield to form a ring to support the ground.

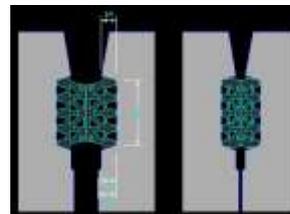


## Support of TBM Tunnels

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

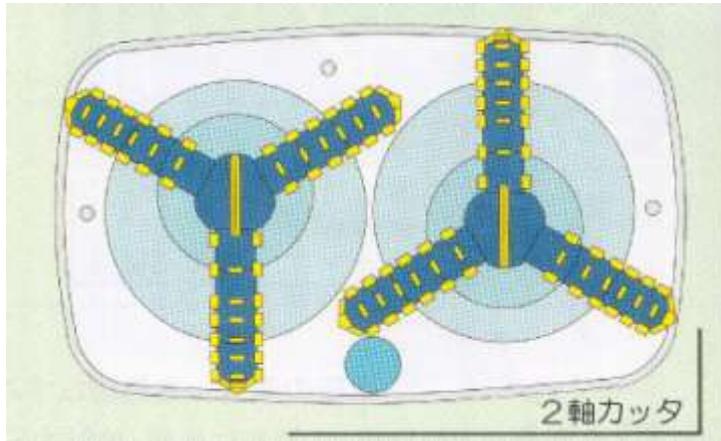


Gasket



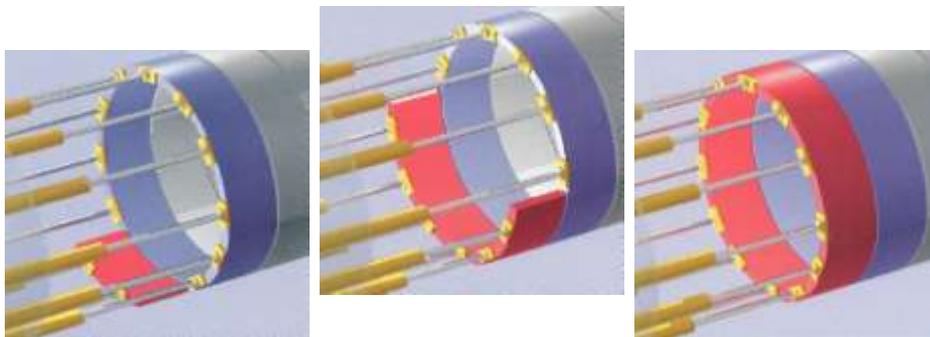
## New TBM Technologies

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**

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



## **New TBM Technologies**

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### **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

