Tunnelling and Underground Construction Technology

Course Lectures

Part 2.1 – Excavation technologies

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Conventional underground tunnelling

- often called incremental or cyclic tunnelling, is the alternative to continuous tunnelling
- small advance steps (longitudinally and transversally)
- the step length and the surface of excavation face are important design parameters: the freshly excavated space has to remain stable until the support has been installed
- can be executed in full face or partial face
1. Stability issues

- The stand-up time depends on the span of the tunnel and the geomechanical characteristics of the rock mass.

- Partial face excavation might be used as piloting to gather information on geology and reduce uncertainty.

Conventional underground tunnelling

Full face or partial face excavation?
Conventional underground tunnelling

Full face or partial face excavation?

2. Production issues

- The face is too large to be covered by regular tunnelling equipment
- Opportunity to create another face
- Optimization of the advance rate
- The support measures can be installed in due time
Conventional underground tunnelling

Full face excavation

• The whole section of the tunnel is excavated at once

• It might need stabilisation of the face (i.e. fibre glass bolts)
Partial face excavation

Top heading and bench

- The crown is excavated before the bench
- The temporary support of the crown can be conceived as a sort of arch bridge
- Special measures might need to be taken to prevent the abutments to fail: micro-piles strengthening, « elephant feet » or temporary invert
Excavation Methods: Drill and Blast

Advantageous for:

– Very hard rock
– Rocks with varying properties (high flexibility)
– Short tunnels where TBM does not pay
– Non-circular cross sections
– Tunnels with different cross sections
– Big underground spaces: Caverns, stations, etc
Excavation Methods: Drill and Blast

Excavation cycle

- Drilling of blast-holes
- Charging
- Ignition
- Ventilation
- Scaling
- Mucking: Loading
- Mucking: Hauling
Excavation Methods: Drill and Blast

Drilling of blast-holes - Drilling Technology
Excavation Methods: Drill and Blast

Drilling of blast-holes – Penetration rates

Accumulated drilling rate

![Graph showing accumulated drilling rates for different types of rocks.](image)

Various types of rocks:
- Granite
- Basalt
- Shale
- Limestone
- Sandstone

Meters/Minute
Excavation Methods: Drill and Blast

Drilling of blast-holes – Parallel Cut

1.- Cut

2.- Stope

3.- Contour
Excavation Methods: Drill and Blast

Drilling of blast-holes – Dangers

Hole deviation
Excavation Methods: Drill and Blast

Drilling of blast-holes – Dangers

Overbreak
Excavation Methods: Drill and Blast

Ventilation

The ventilation is necessary to spread harmful concentrations of:

- CO
- \( \text{CO}_2 \)
- Nitrogen oxides
- Dust
Excavation Methods: Drill and Blast

Ventilation
Excavation Methods: Drill and Blast

Ventilation
Scaling

- Scaling is necessary in order to bring down potentially unstable blocks of rock around the contour.
- It is also important for cleaning and preparing the rock surface for shotcrete and/or rock-bolts
- Due to its danger, workers safety must be very well taken into account
- Different procedures exist, from manual to completely mechanised
Excavation Methods: Drill and Blast

Scaling

Mechanical scaling with hydraulic breaker
Tunnelling application
Excavation Methods: Drill and Blast

Scaling

High water pressure flushing
Scaling

Ripping with a steel bar
May require supplementary manual scaling as check up
Excavation Methods: Drill and Blast

Mucking: Loading Procedures

Loading at the face

Dumping of bucket

Loading of bucket

Muck pile
Mucking: Loading Procedures

Loading with niches
Excavation Methods: Drill and Blast

Mucking: Loading Technology

Wheel loader
Excavation Methods: Drill and Blast

Mucking: Loading Technology

Wheel loader: Side dumping
Mucking: Loading Technology

LHD
Excavation Methods: Drill and Blast

Mucking: Loading Technology

Continuous loader
Excavation Methods: Drill and Blast

Mucking: Hauling Technology

Dumper
Excavation Methods: Drill and Blast

Mucking: Hauling Technology

LHD
Excavation Methods: Drill and Blast

Mucking: Hauling Technology

Railbound mucking
Mucking: Hauling Technology

Conveyor mucking
Excavation Methods: Conventional Excavation

Hydraulic and Pneumatic Hammers

- OK on weak rocks
- Performances ~ drill and blast
- Vibrations and fumes are avoided
- Flexible and no explosives required
- Dust is treated by water spraying
Excavation Methods: Conventional Excavation

Conventional Excavators

- OK on weak rocks
- Rippers are applied when hard rock inclusions are encountered
- The tools must be sufficiently free to rotate
- Vibrations and fumes are avoided
Continuous mechanised tunnelling

- All phases at the same time
- No interruption
- Continuous cycle:
  1. Excavation
  2. Support
  3. Mucking
Continuous mechanised tunnelling

- All phases at the same time
- No interruption
- Continuous cycle:
  1. Excavation
  2. Support
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Basic Functions of Tunnel Machines

1. Excavation

Partial Face excavation

Full Face excavation
Basic Functions of Tunnel Machines

2. Support

Regulation of support pressure

- water pressure
- pressure of the supporting earth paste
- earth pressure
Basic Functions of Tunnel Machines

3. Mucking of Excavated Material
### Advantages and Risks

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<th>ADVANTAGES</th>
<th>RISKS</th>
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<td>• Enhanced health and safety conditions for the workers.</td>
<td>• Lack of flexibility: Once the technique has been chosen it is difficult to change it throughout the construction of the tunnel... (specially in the case of TBM machines)</td>
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<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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<td>• Possibility of crossing complex geological and hydrogeological conditions safely and economically.</td>
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<td>• Good quality of finished product (surrounding ground less altered, precast segment lining).</td>
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**Rock TBM**
- **Reaming Machine**
  - Competent rock

**Non-Shield TBM**
- **Gripper TBM**
  - Competent rock

**Open Face**
- **Mechanical Face Support**
  - Weathered, highly fractured rock
- **Compressed Air Shield**
  - Rock-soil mixed ground
- **Slurry / Hydro-Shield**
  - Rock-soil mixed ground
- **Earth Pressure Balance Shield**
  - Rock-soil mixed ground

**Shield TBM**
- **Digger**
  - Impact breaker, ripper, pick, and bucket for weak weathered rock and firm soil
- **Roadheader**
  - Competent rock

**Soil TBM**
- **Non-Shield TBM**
  - Firm soil with groundwater

**Hybrid Shield**
- **Double Shield**
  - Ground conditions from competent rock to loose/soft soil
- **EPB-Slurry Convertible Shield**
  - Varying ground conditions suitable for EPB and slurry machines
Roadheaders and Mobile Excavators

Rock excavation machine for moderate rock strength (up to 120 MPa), consisting of:

- Cutterhead
- Extension arm or boom
- Muck conveyor
- Crawler chassis
- Loading apron
Roadheaders and Mobile Excavators

Continuous Mining Machine

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

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

Rock is fragmented by chipping between cutters.
Open Face Shield and TBM

Open Face Shield

Open Face Tunnelling Shield

Open Face Platform Shield
TBM with Mechanical Face Support

These TBM’s can be used for rock and firm soil without the need of face pressure.
TBM with Mechanical Face Support

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

However, it can often be combined with pressurised TBM but operate without pressure (open mode).
Compressed Air Shield

When open face shields excavate through 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.
Slurry / Hydro-Shield

- TBM fitted with a full face cutterhead which provides face support by pressurizing boring fluid inside the cutterhead chamber
- The circulation of the fluid in the chamber flushes out the muck, with a regular pressure being maintained by directly or indirectly controlling discharge rates.
- TBM suited for tunnels through unstable material subjected to high groundwater pressure or water inflow that must be stopped by supporting the face with a boring fluid subjected to pressure.
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
Slurry / Hydro-Shield – MixShield

The largest slurry shield φ15.43m (2006), used for Shanghai Changjiang Under River Tunnel Project.
Earth Pressure Balance Shield

- TBM fitted with a full face cutterhead which provides face support by the excavated earth which is kept under pressure inside the excavation chamber.

- Excavation debris is removed from the excavation chamber by a screw conveyor which allows the gradual reduction of pressure.

Machine is suited for drilling tunnels through ground with limited or no self-supporting capacity. Mainly used for excavating in silts or clays with sand.
The largest EPB machine φ15.2 m (2006) for Madrid M-30 project.
Earth Pressure Balance Shield

Regulation of support pressure

water pressure  pressure of the supporting earth paste
earth pressure
Double Shield

It combines the features of gripper and shield in a TBM, and enables fast excavation even in varying rock formations.
EPB-Slurry Convertible Shield

It is able to convert between EPB mode and slurry mode, to cope with grounds suitable for both type of machines.
EPB-Slurry Convertible Shield

Open Mode ➔ EPB ➔ Slurry ➔ EPB

Tunnelling and Underground Construction Technology
New TBM Technologies

Optimizing underground space

Diagram of tunneling equipment.
New TBM Technologies

Optimizing advancement
New TBM Technologies

Optimizing machine with variable ground condition
New TBM Technologies

Advanced ground probing