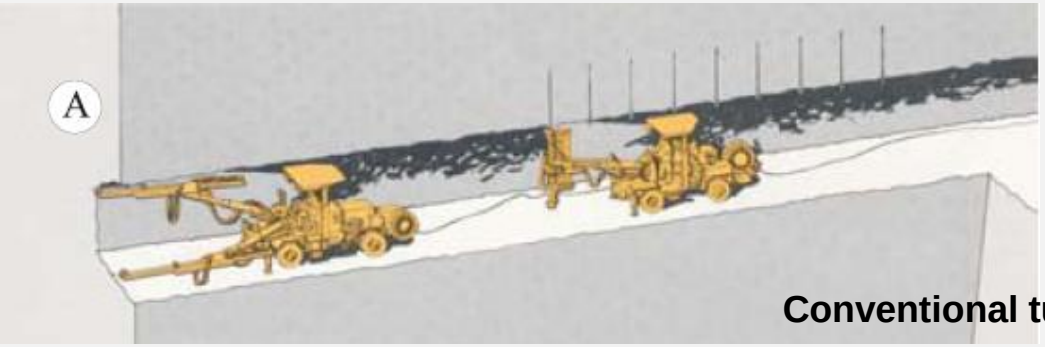
Tunnelling and Underground Construction Technology

Course Lectures

Part 2.1 – Excavation technologies

Dr Ákos TÓTH

Conventional underground tunnelling



Conventional tunnelling

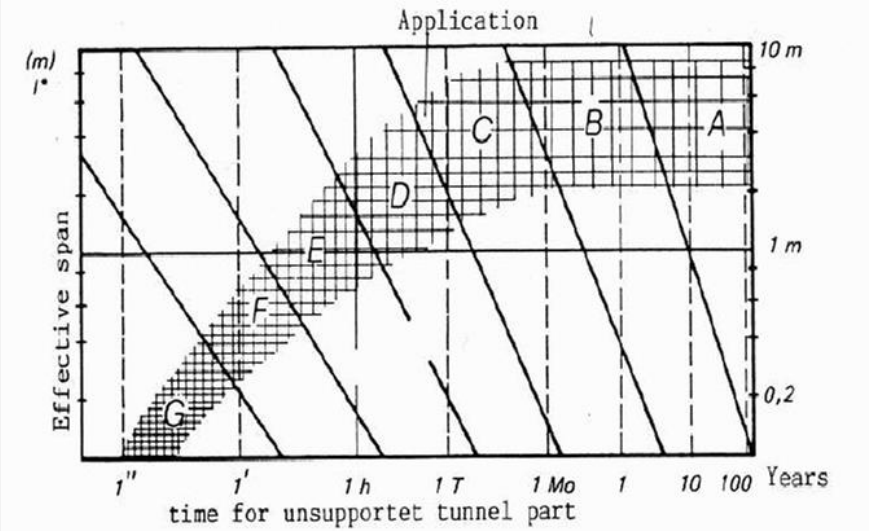
- often called incremental or cyclic tunnelling, is the alternative to continuous tunnelling
- small advance steps (longitudinally and transversally)
- the step length and the surface of excavation face are important design parameters: the freshly excavated space has to remain stable until the support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

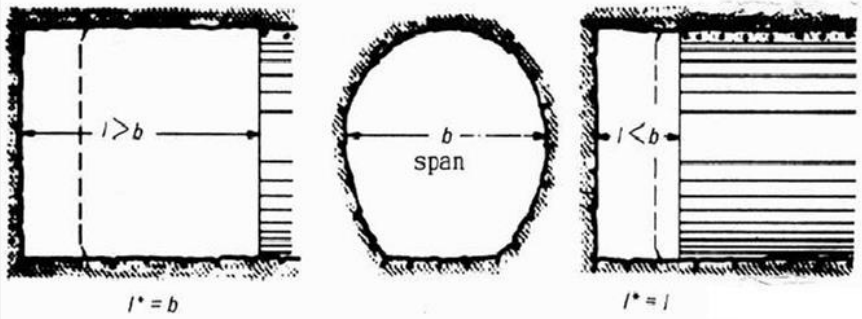
Conventional underground tunnelling

Full face or partial face excavation?

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



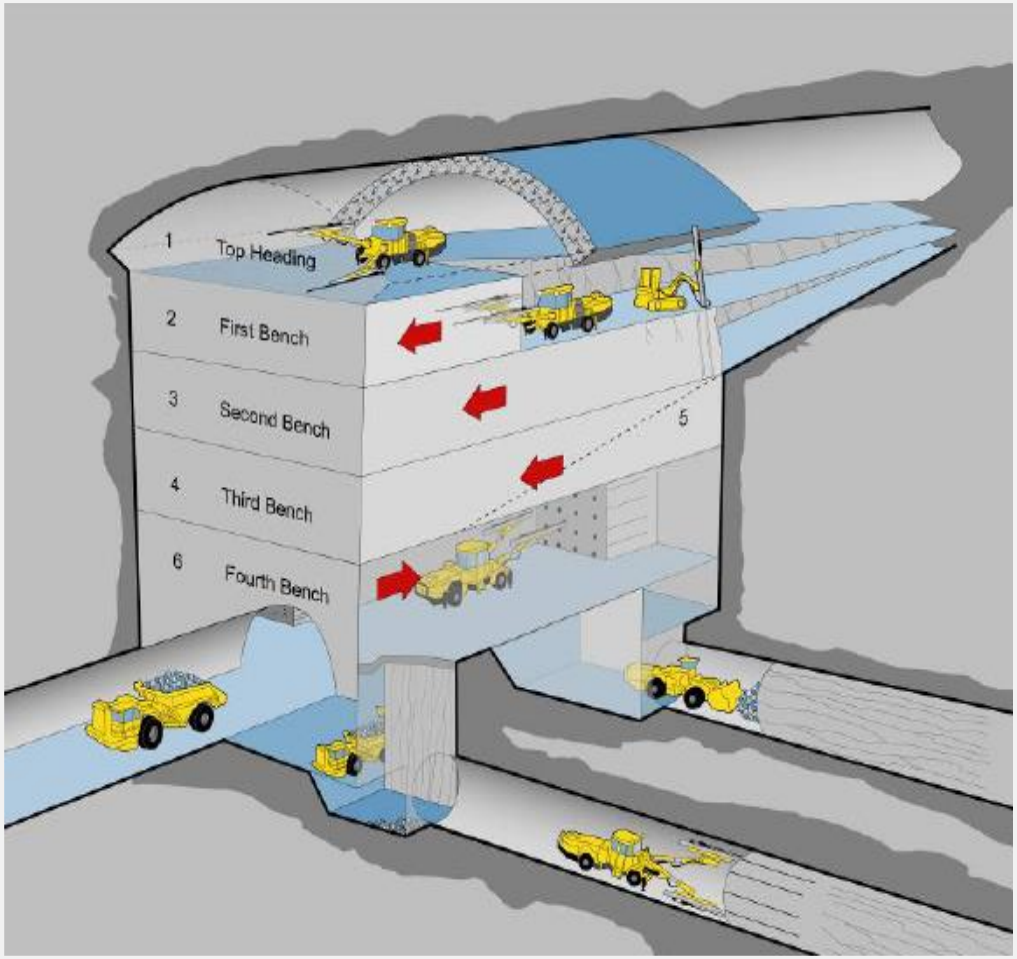


Conventional underground tunnelling

Full face or partial face excavation?

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)

Conventional underground tunnelling

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

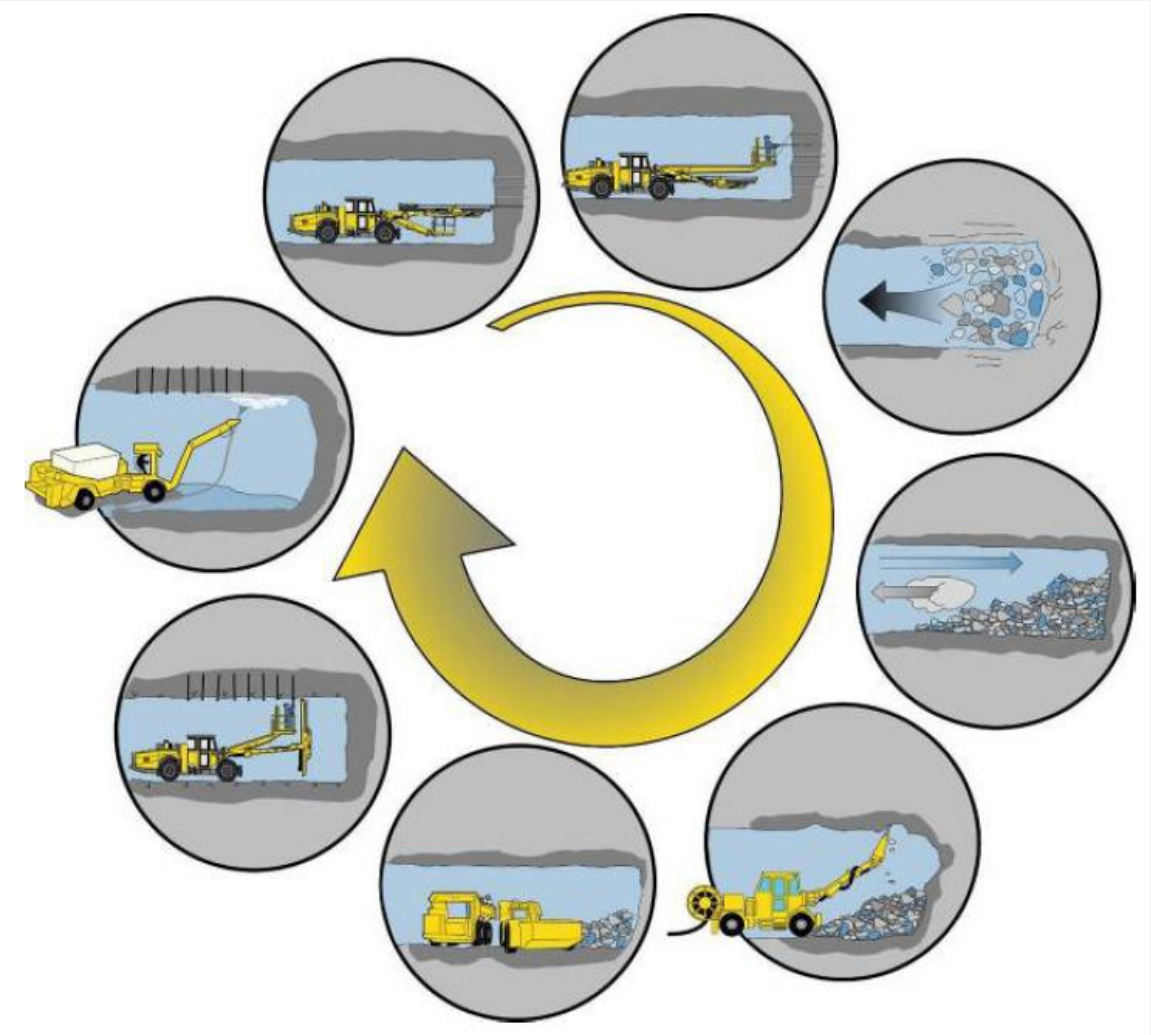
Advantageous for:

- 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

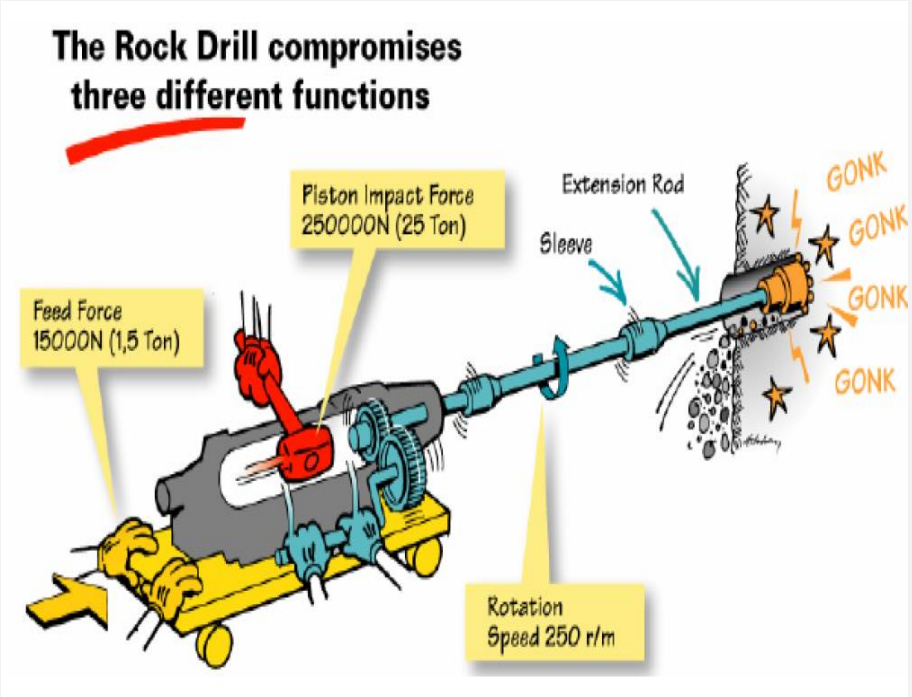
Excavation cycle

- Drilling of blast-holes
- Charging
- Ignition
- Ventilation
- Scaling
- Mucking: Loading
- Mucking: Hauling



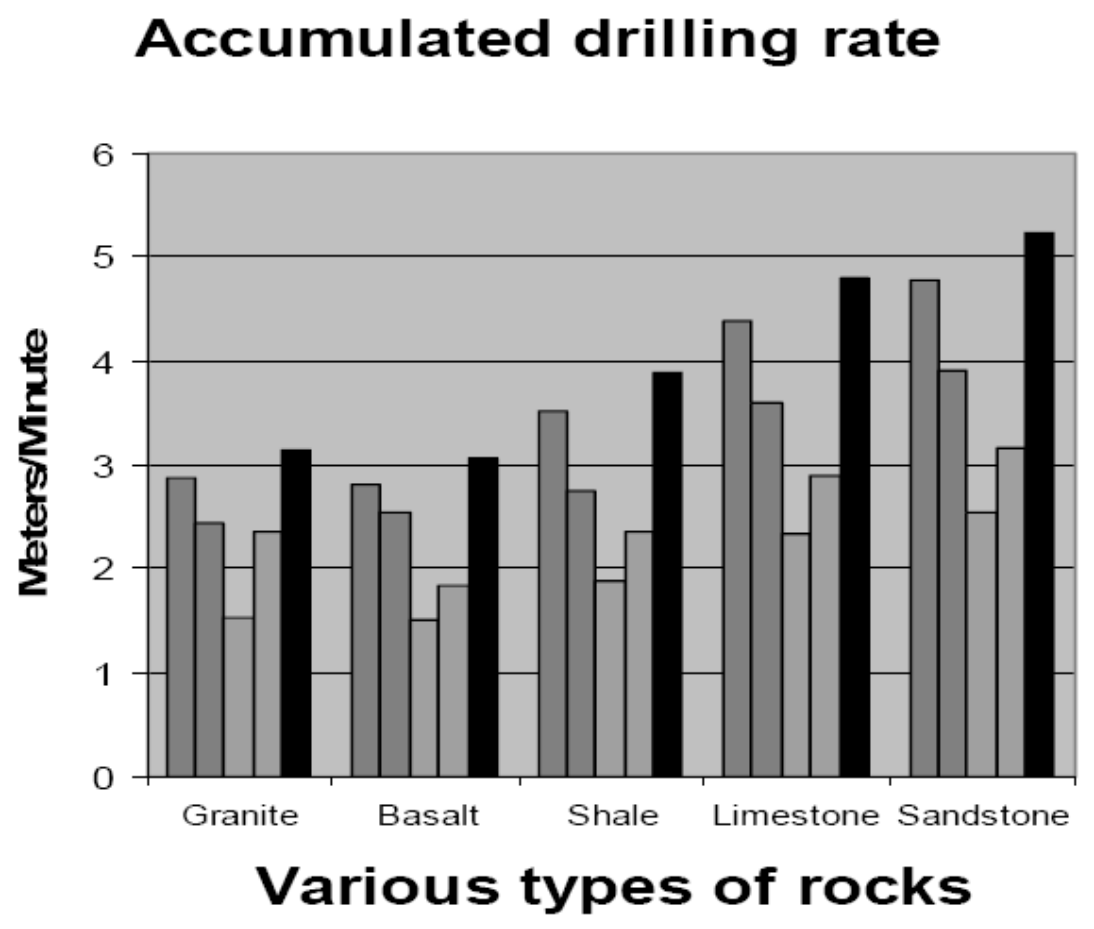
Excavation Methods: Drill and Blast

Drilling of blast-holes - Drilling Technology



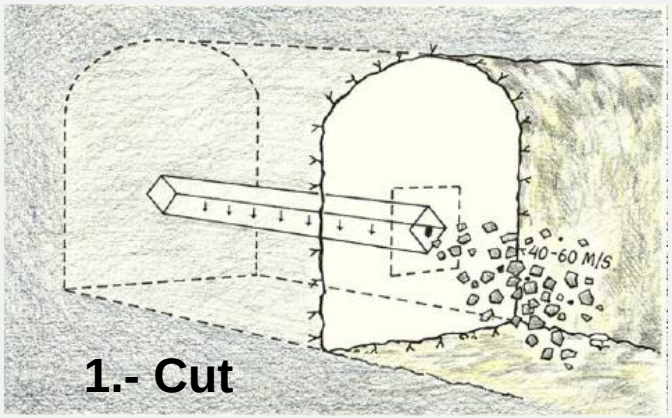
Excavation Methods: Drill and Blast

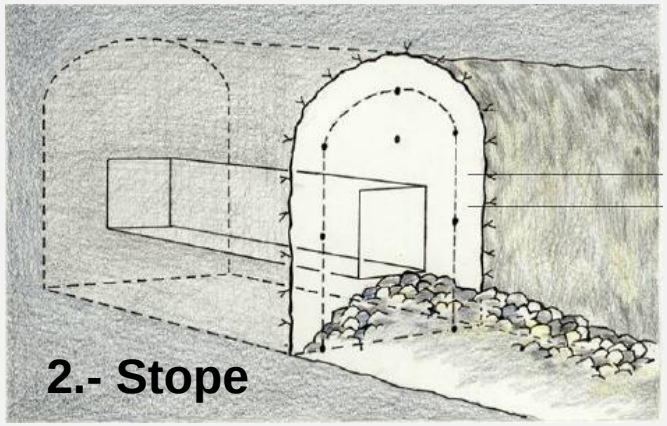
Drilling of blast-holes – Penetration rates

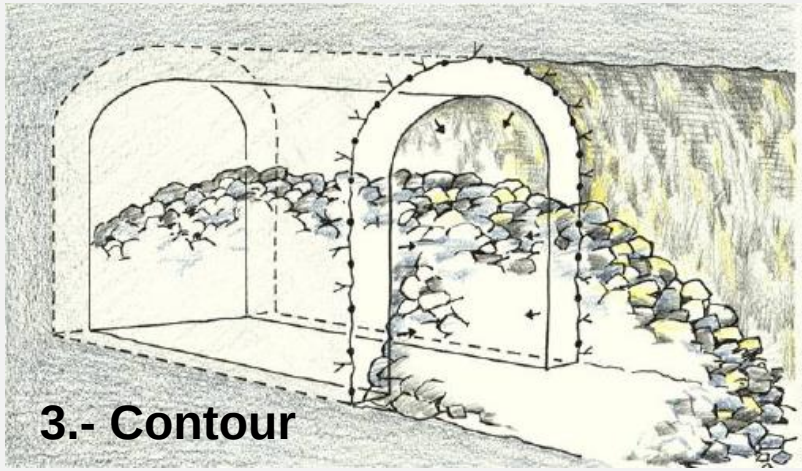


Excavation Methods: Drill and Blast

Drilling of blast-holes – Parallel Cut







Excavation Methods: Drill and Blast

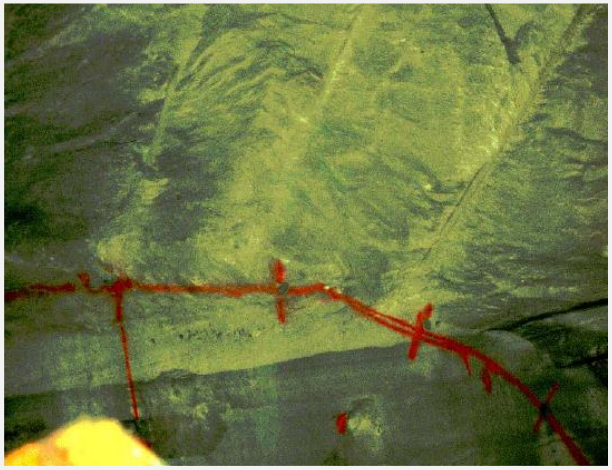
Drilling of blast-holes – Dangers

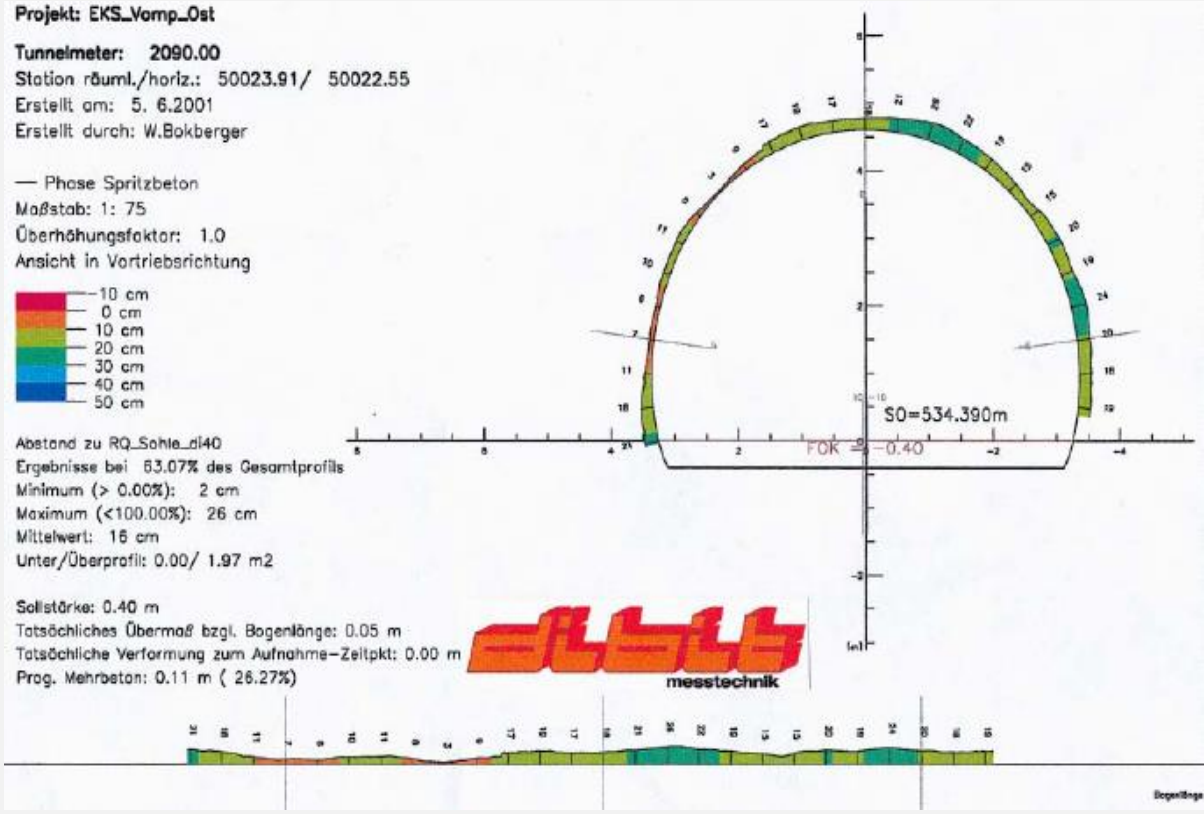
Hole deviation

Excavation Methods: Drill and Blast

Drilling of blast-holes – Dangers

Overbreak





Excavation Methods: Drill and Blast

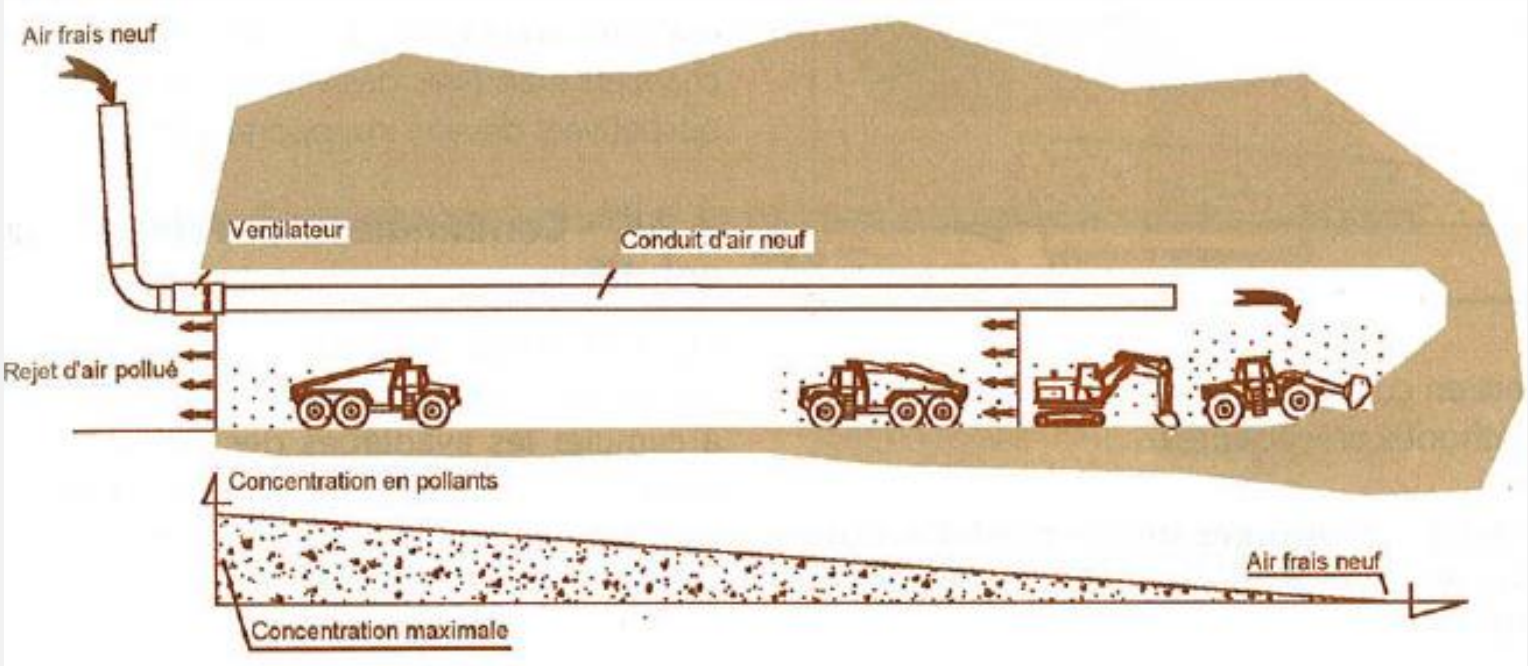
Ventilation

The ventilation is necessary to spread harmful concentrations of:

- CO
- CO_2
- Nitrogen oxides
- Dust

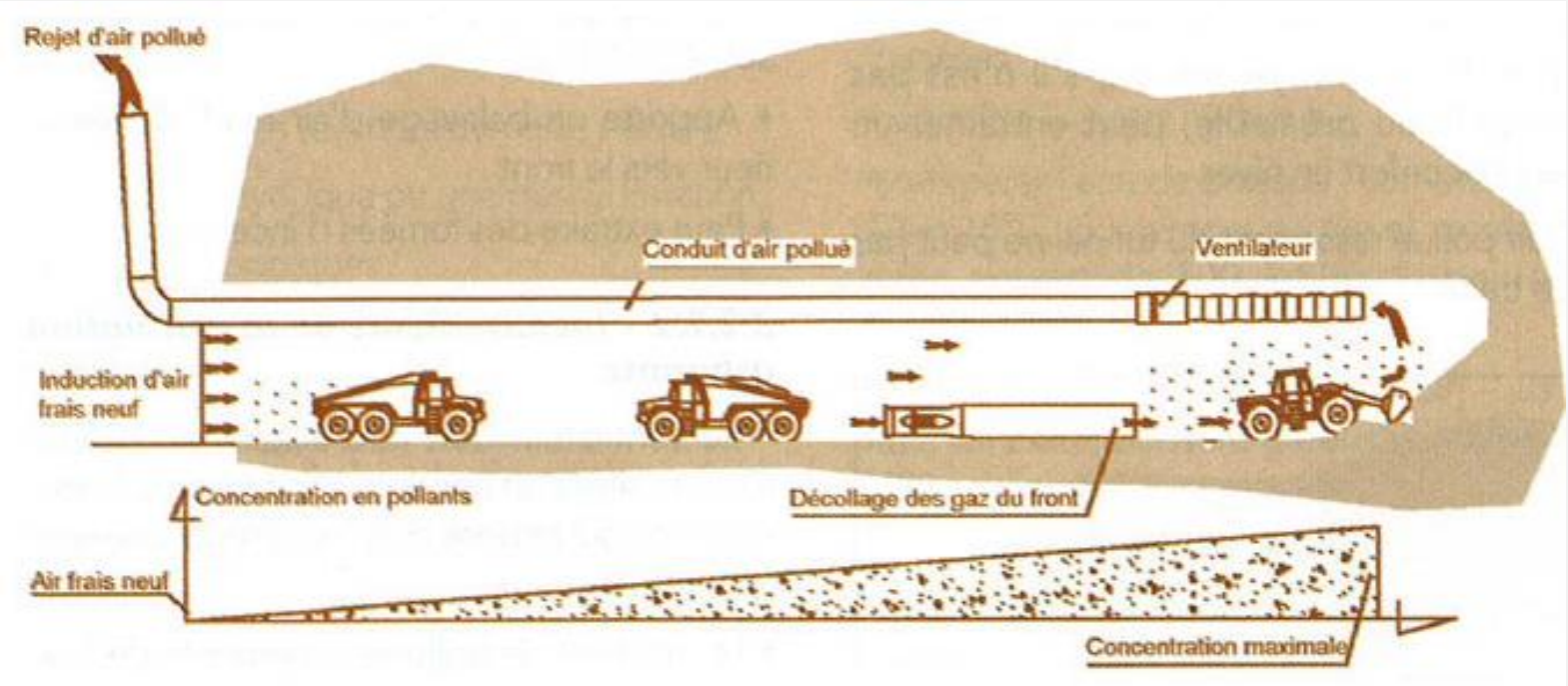
Excavation Methods: Drill and Blast

Ventilation



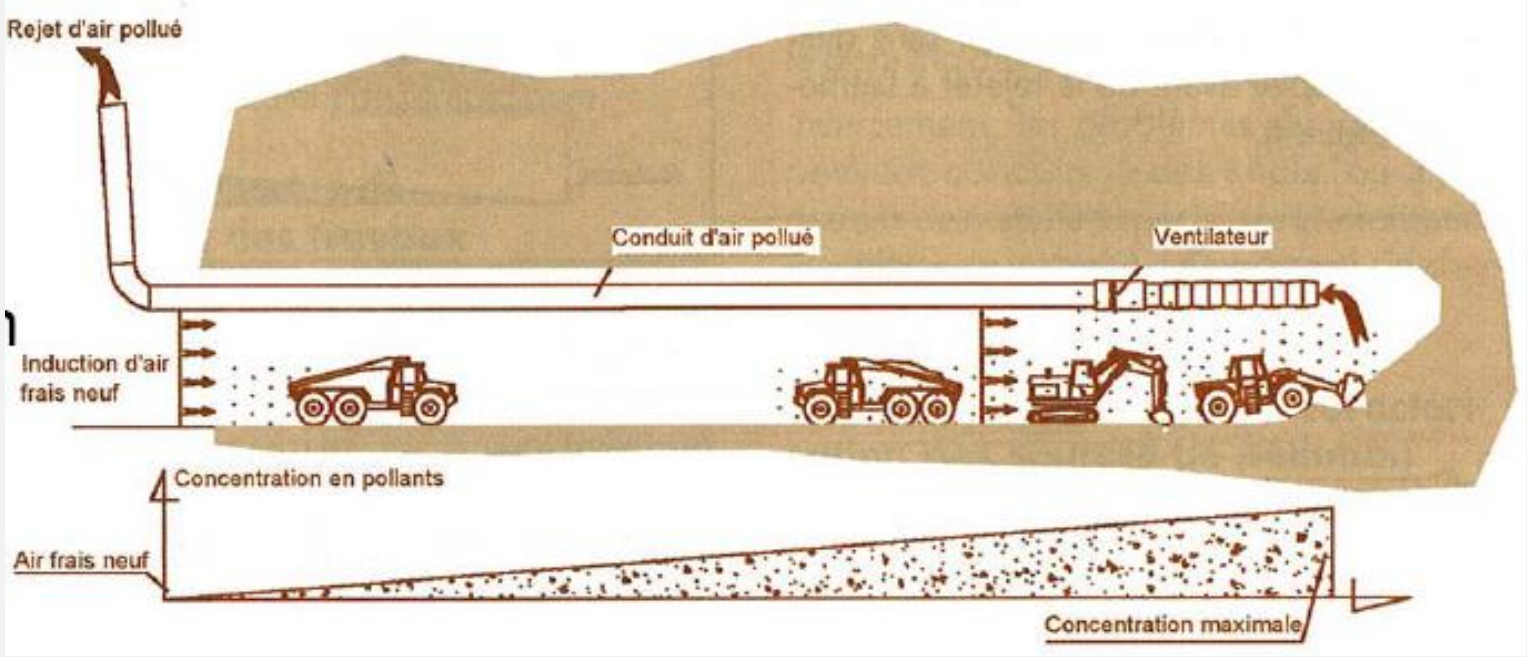
Excavation Methods: Drill and Blast

Ventilation



Excavation Methods: Drill and Blast

Ventilation



Excavation Methods: Drill and Blast

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

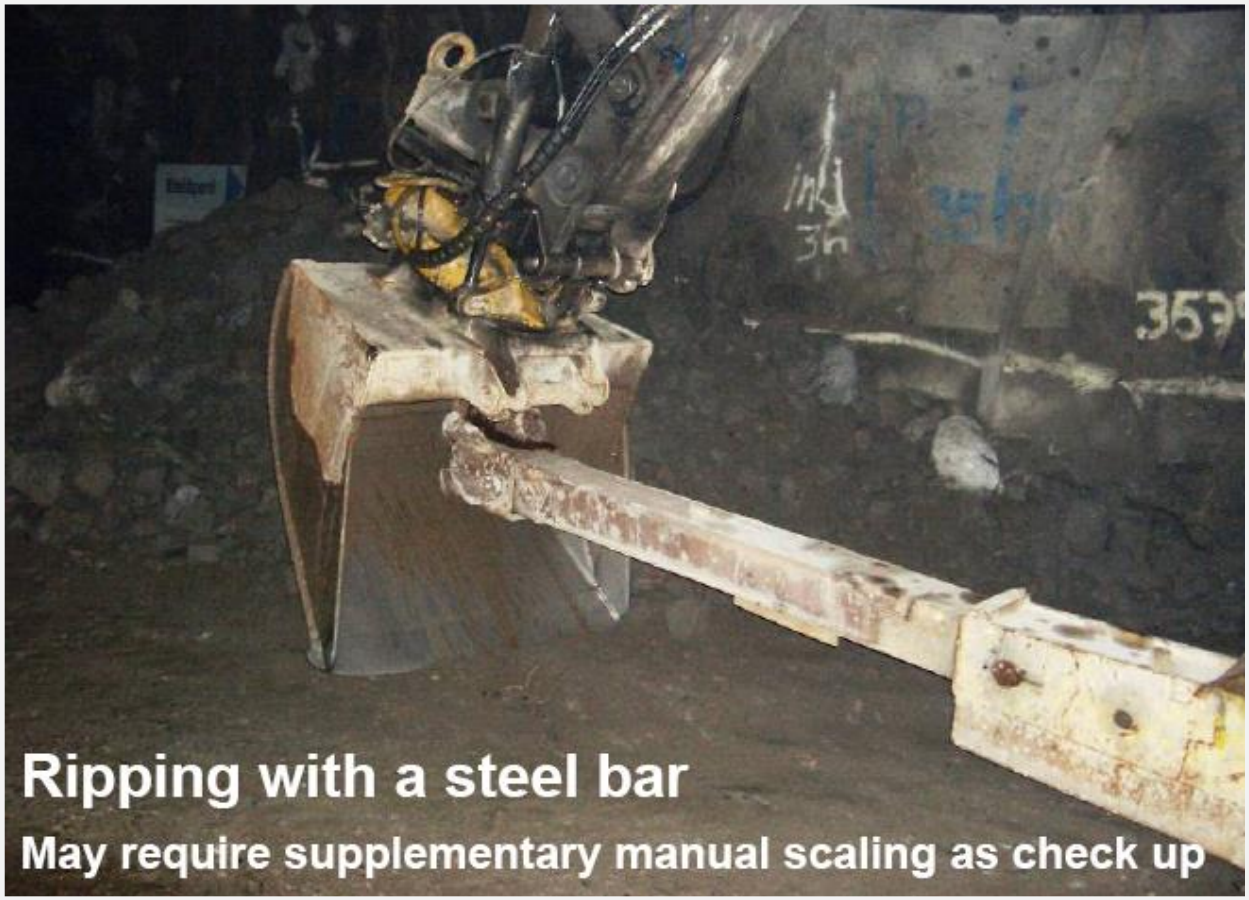
Scaling

Excavation Methods: Drill and Blast

Scaling

Excavation Methods: Drill and Blast

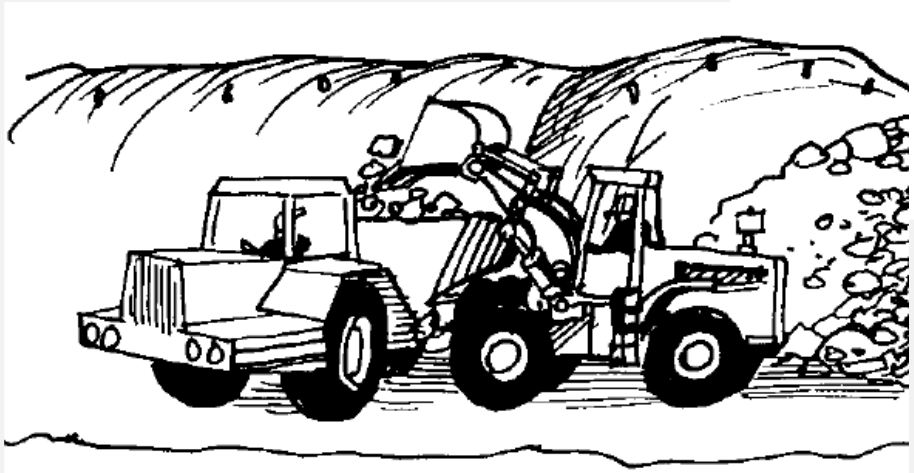
Scaling

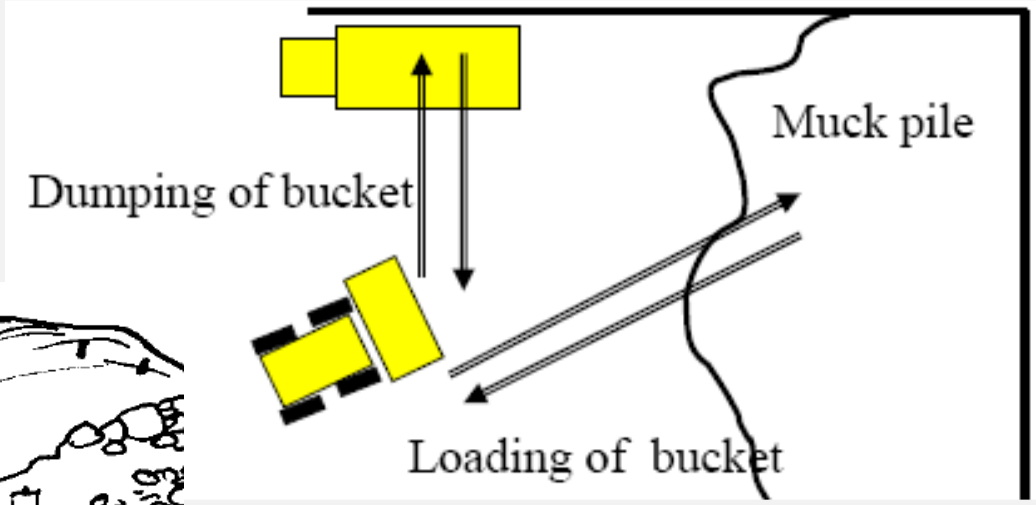


Excavation Methods: Drill and Blast

Mucking: Loading Procedures

Loading at the face

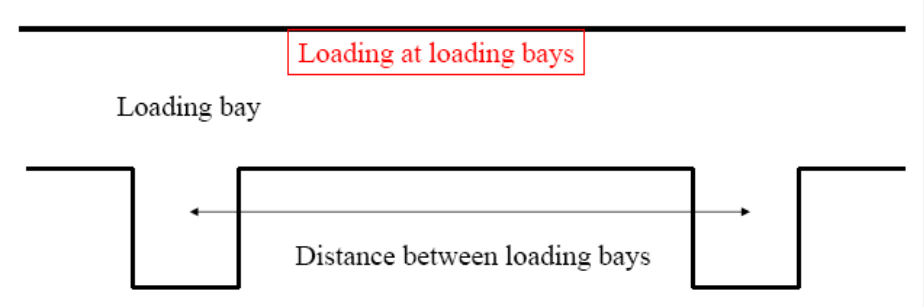


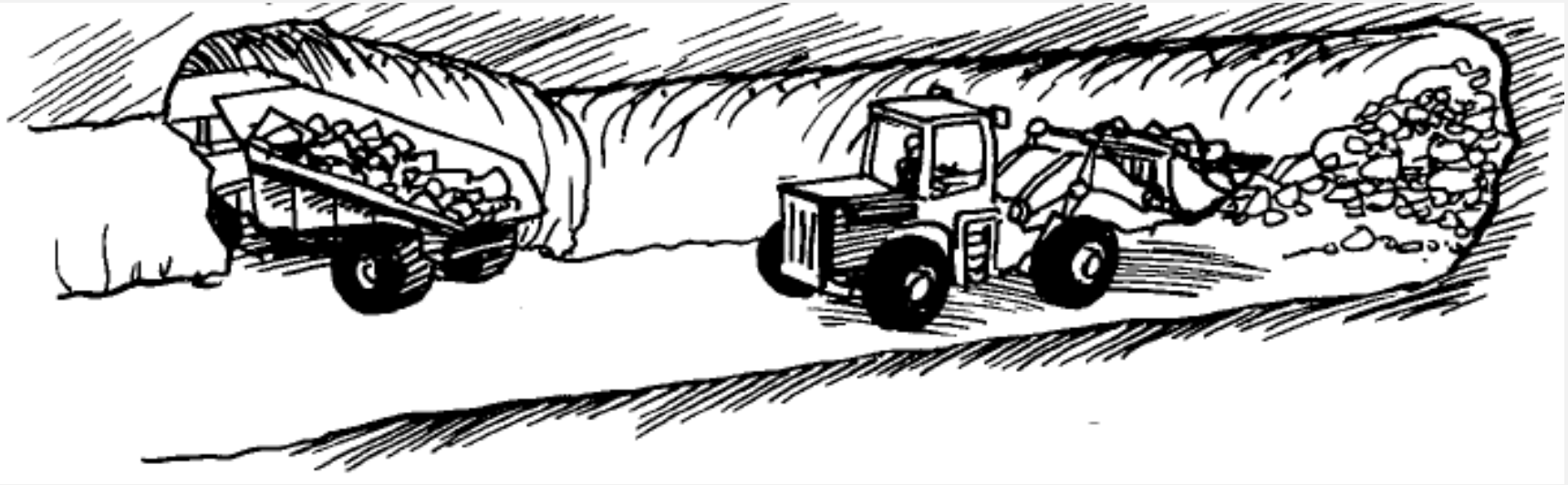


Excavation Methods: Drill and Blast

Mucking: Loading Procedures

Loading with niches





Excavation Methods: Drill and Blast

Mucking: Loading Technology

Wheel loader

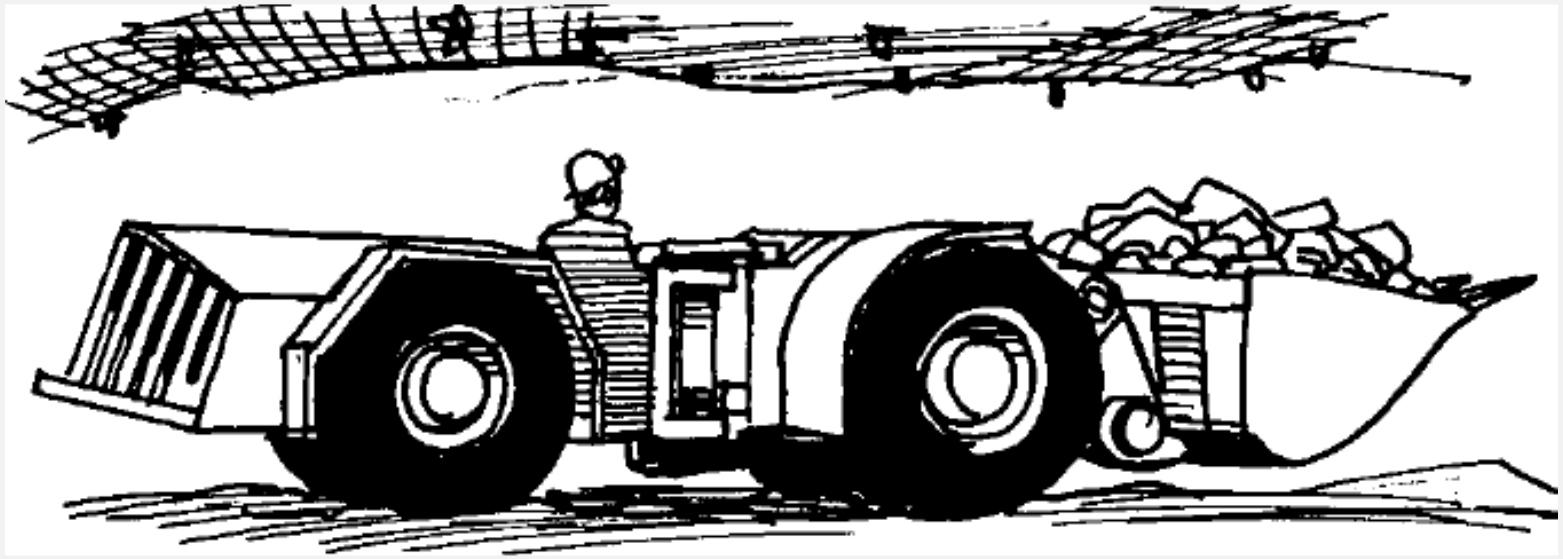
Excavation Methods: Drill and Blast

Mucking: Loading Technology

Wheel loader: Side dumping

Excavation Methods: Drill and Blast

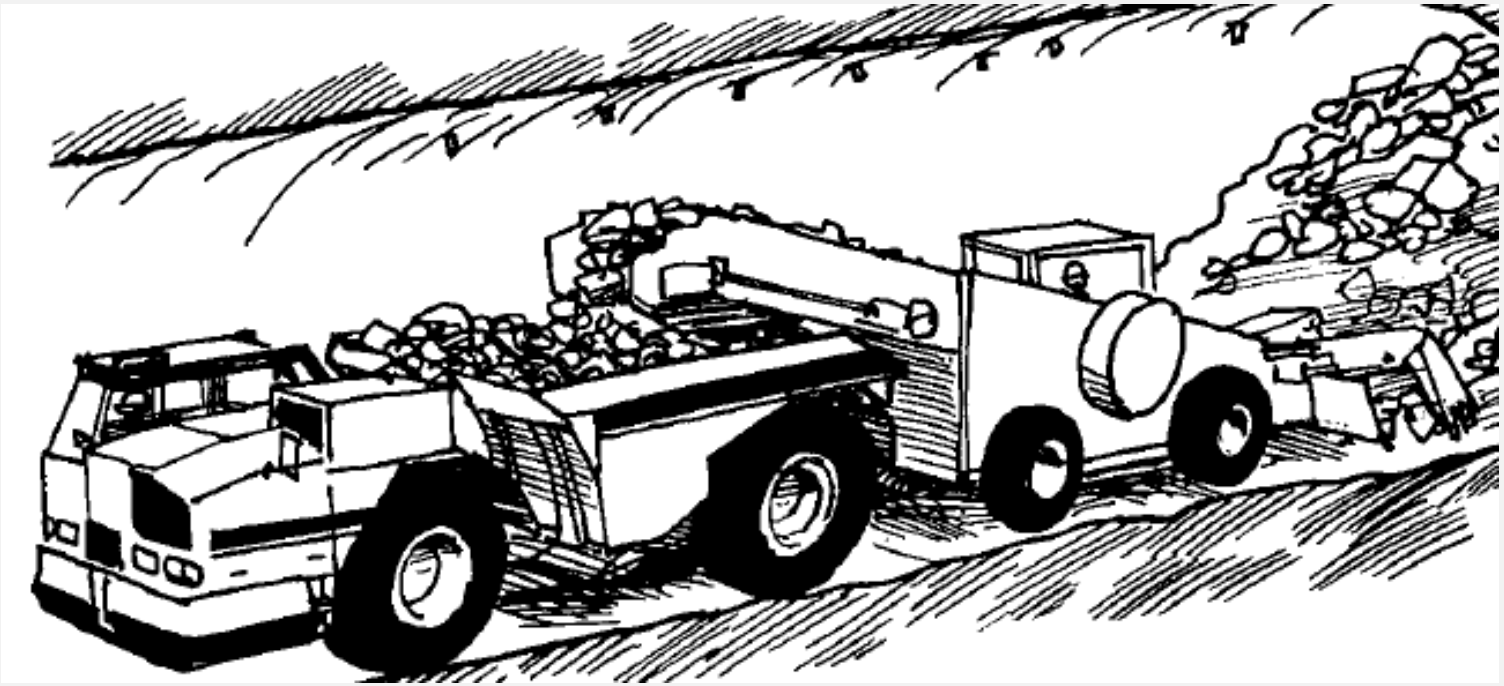
Mucking: Loading Technology



LHD

Excavation Methods: Drill and Blast

Mucking: Loading Technology



Continuous loader

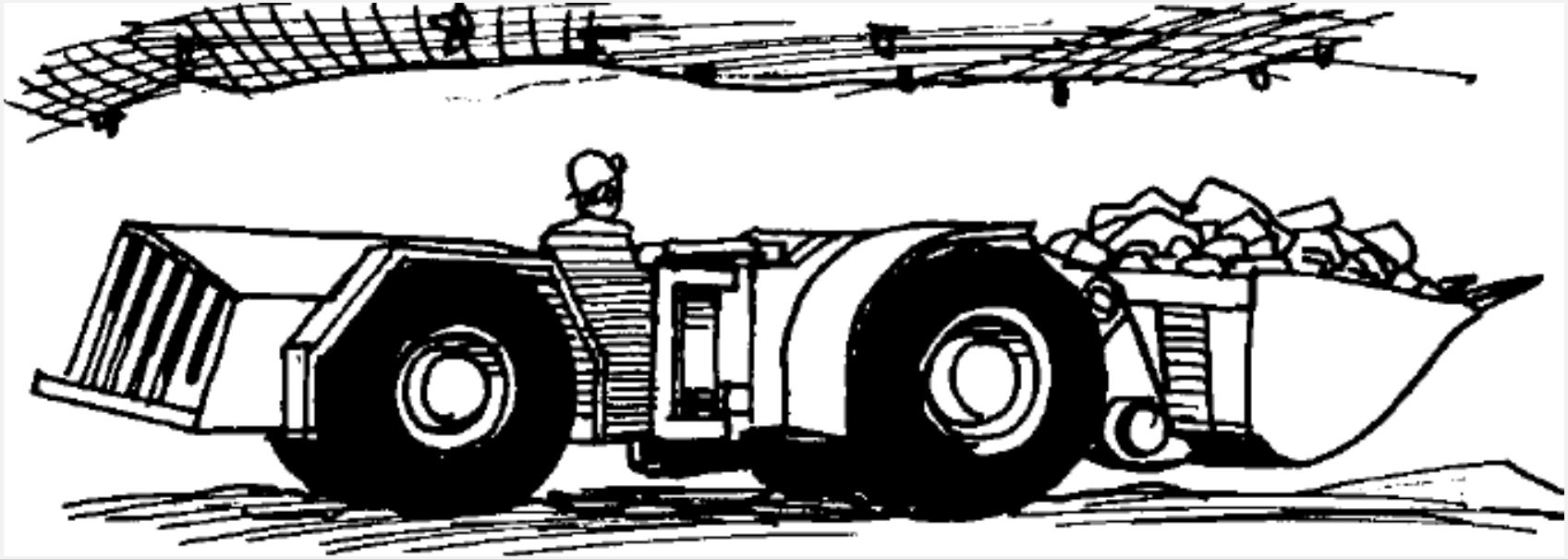
Excavation Methods: Drill and Blast

Mucking: Hauling Technology

Dumper

Excavation Methods: Drill and Blast

Mucking: Hauling Technology



LHD

Excavation Methods: Drill and Blast

Mucking: Hauling Technology

Railbound mucking

Excavation Methods: Drill and Blast

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

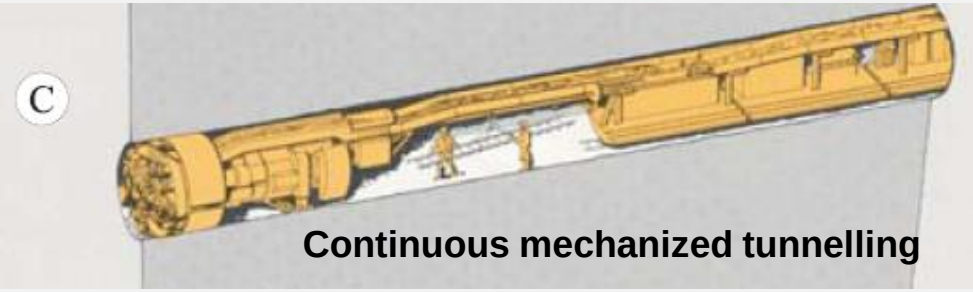
Excavation Methods: Conventional Excavation

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 mechanized tunnelling

Continuous mechanised tunnelling

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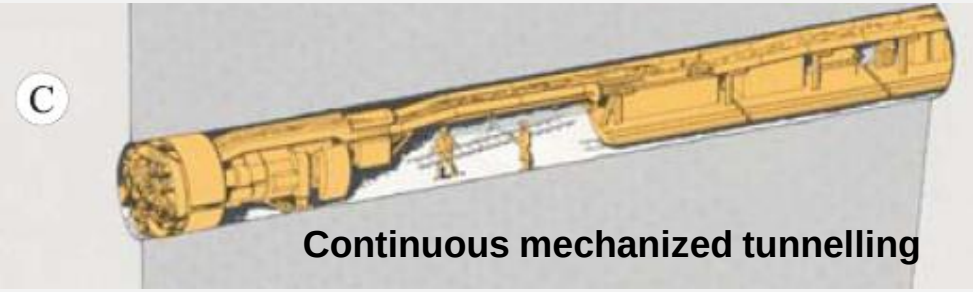


Continuous mechanized tunnelling

Basic Functions of Tunnel Machines

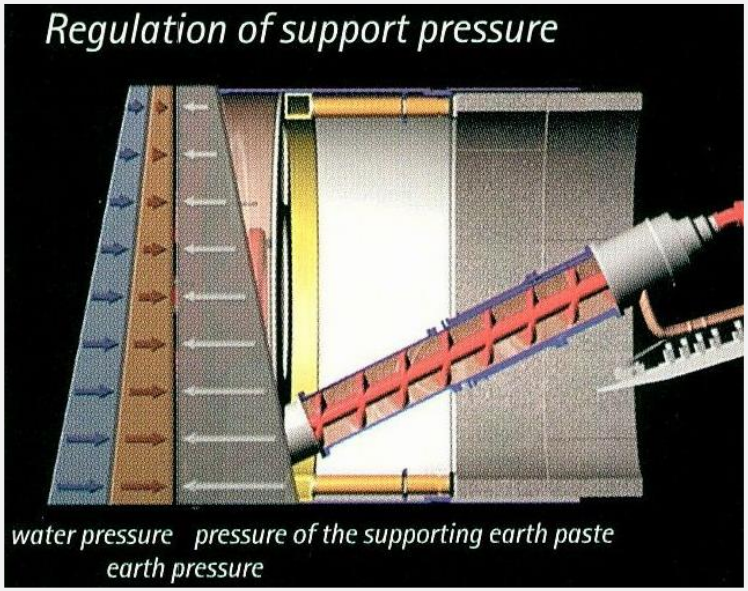
1. Excavation

Partial Face excavation

Full Face excavation

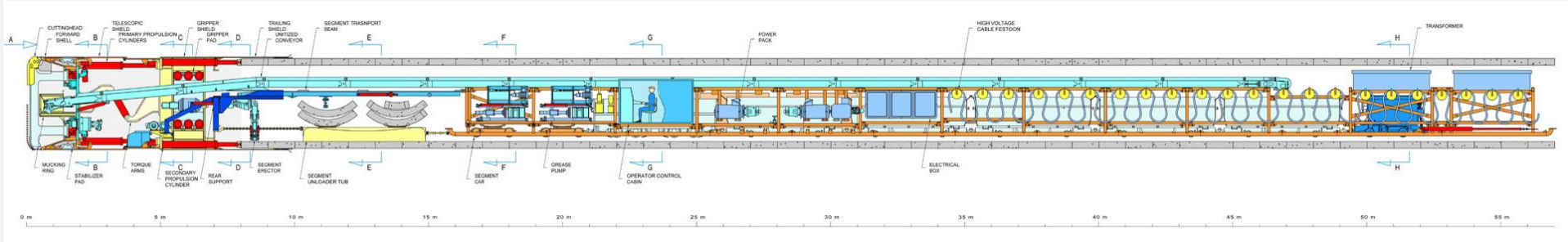
Basic Functions of Tunnel Machines

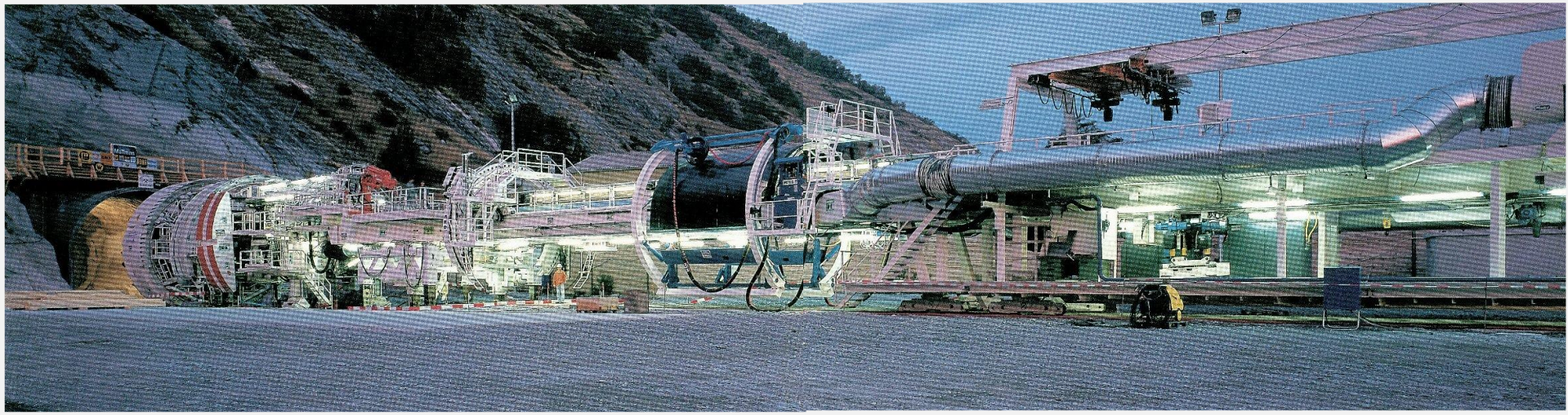
2. Support



Basic Functions of Tunnel Machines

3. Mucking of Excavated Material





Advantages and Risks

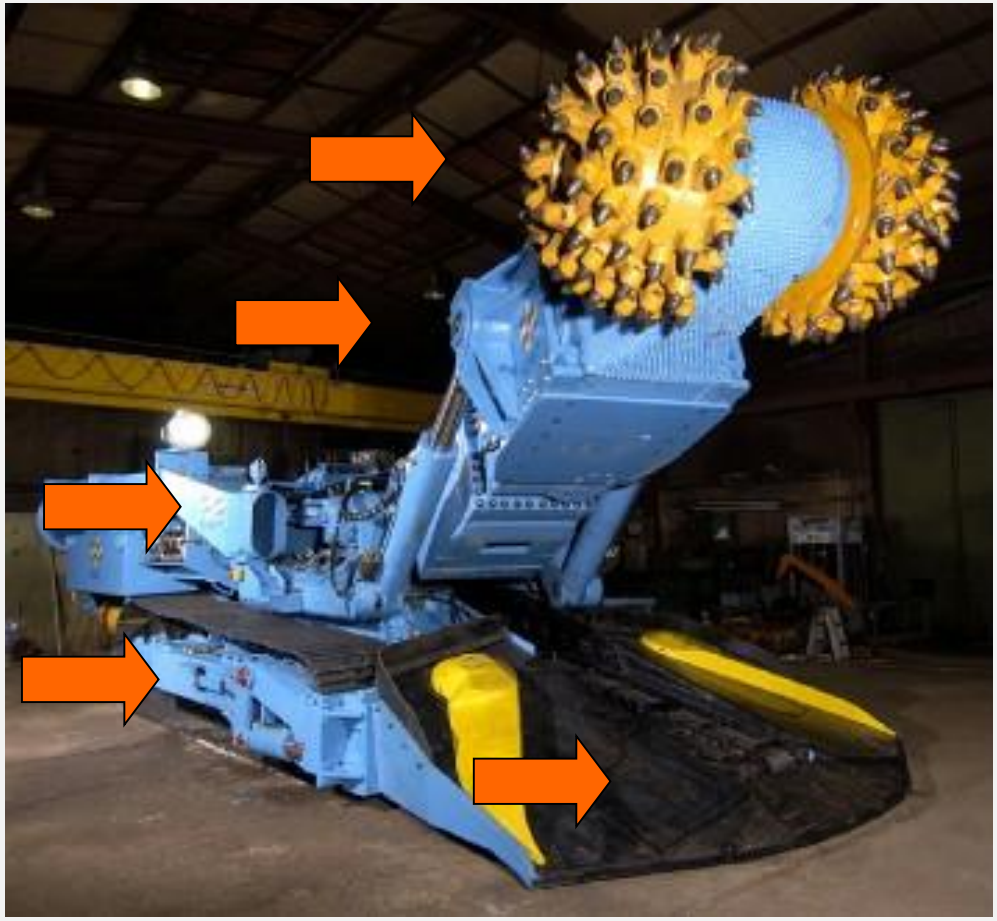
ADVANTAGES	RISKS
• Enhanced health and safety conditions for the workers. • Industrialization of the tunnelling process, with ensuing reductions in cost and construction times. • Possibility of crossing complex geological and hydrogeological conditions safely and economically. • Good quality of finished product (surrounding ground less altered, precast segment lining).	• 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) ↓ Therefore, a correct analysis of different parameters is needed for the choice of the correct mechanized tunnelling technique

Boom Excavator	*Digger*	Impact breaker, ripper, pick, and bucket for weak weathered rock and firm soil	
	Roadheader	Competent rock	
Rock TBM — Non-Shield TBM	*Reaming Machine*	Competent rock	
	Gripper TBM	Competent rock	
Soil TBM — Shield TBM	*Open Face*	Weak, soft rock	Firm soil
	Mechanical Face Support	Weathered, highly fractured rock	Firm soil
	Compressed Air Shield	Rock-soil mixed ground	Firm soil with groundwater
	Slurry / Hydro-Shield	Rock-soil mixed ground	Loose sandy soil
	Earth Pressure Balance Shield	Rock-soil mixed ground	Soft clay
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



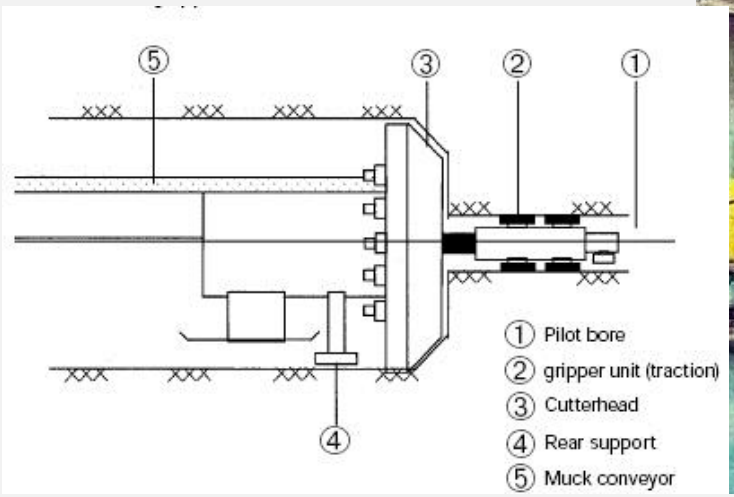
Roadheaders and Mobile Excavators

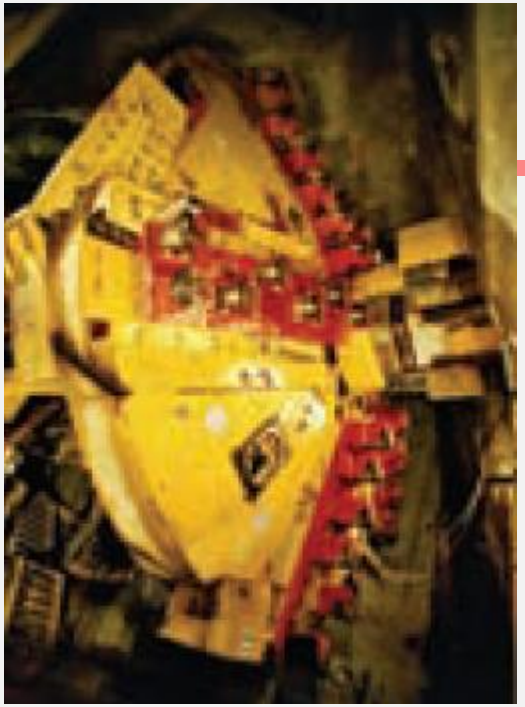
Continuous Mining Machine

Mobile Miner

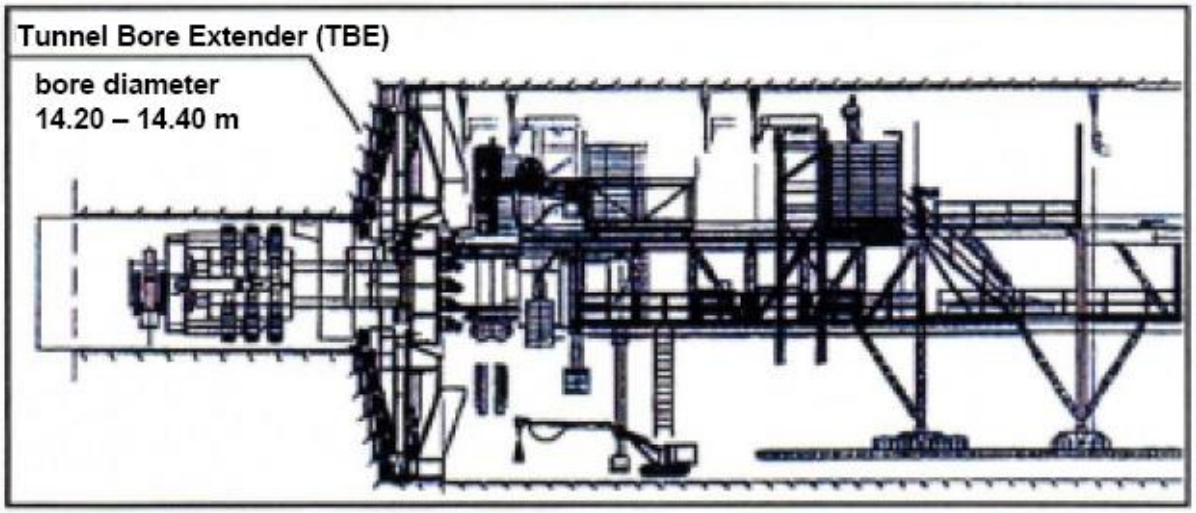
Tunnel Reaming and Enlarge Machines

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





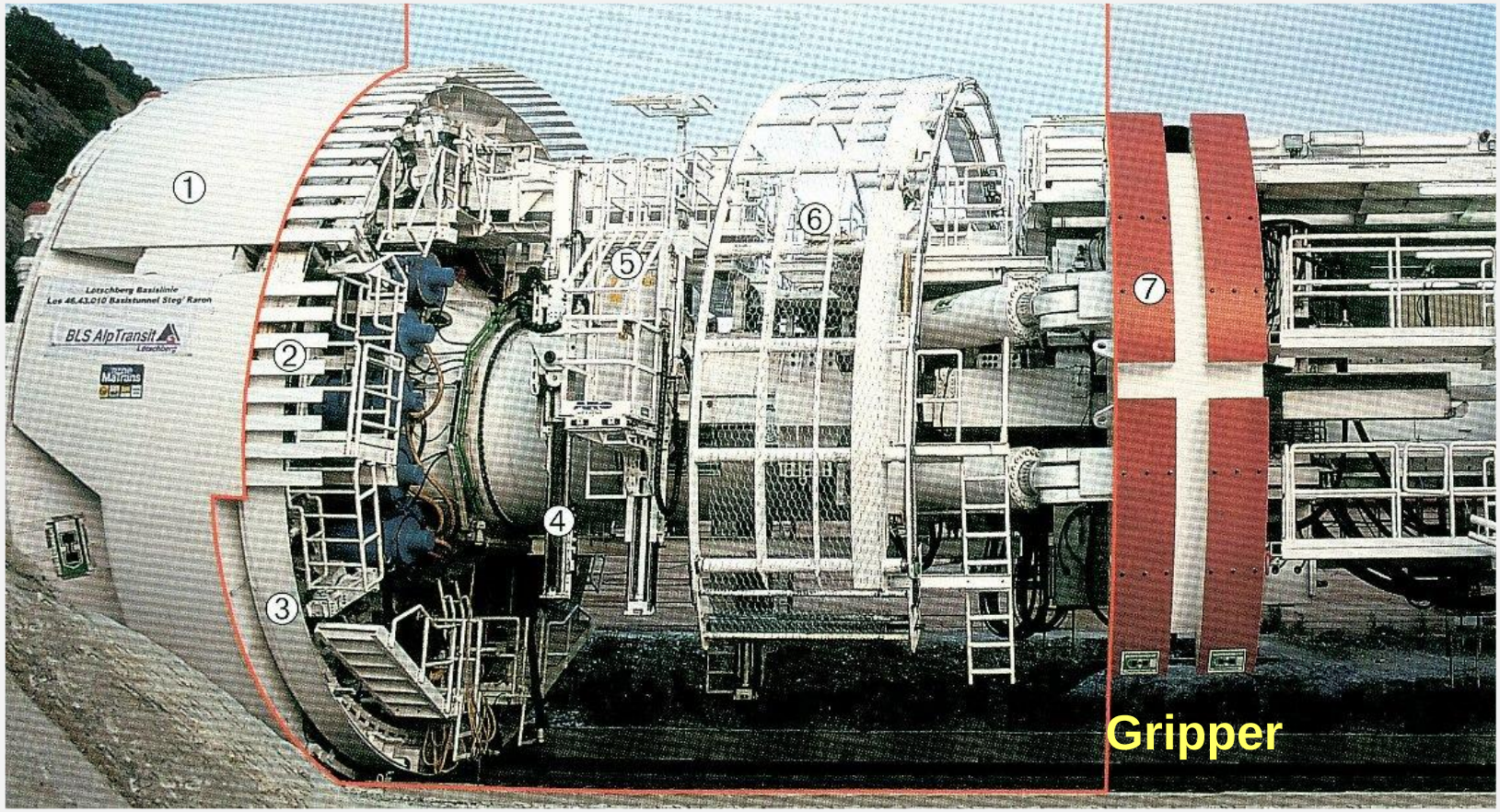
Tunnel Bore Extender (TBE) used at Uetliberg Tunnel in Switzerland. Tunnel is enlarged from a 5 m pilot tunnel to 14.4 m.



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

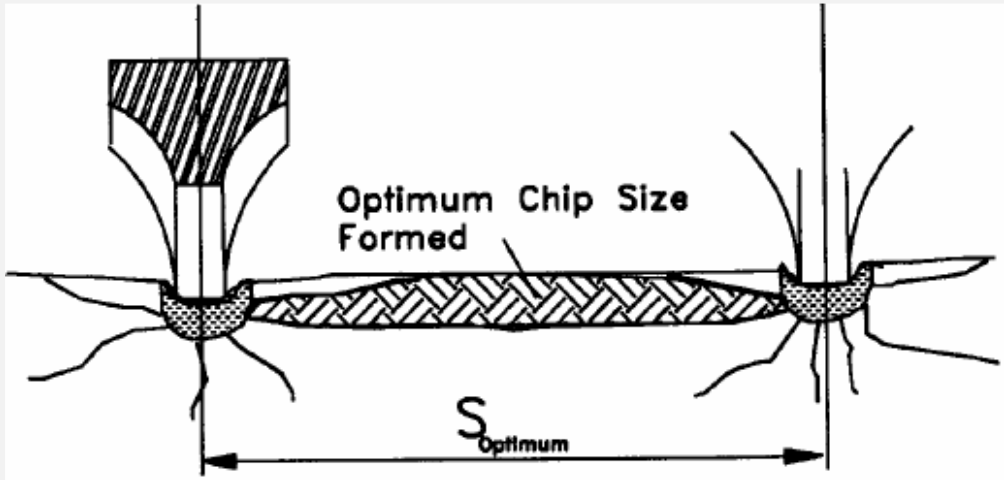
Gripper TBM

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

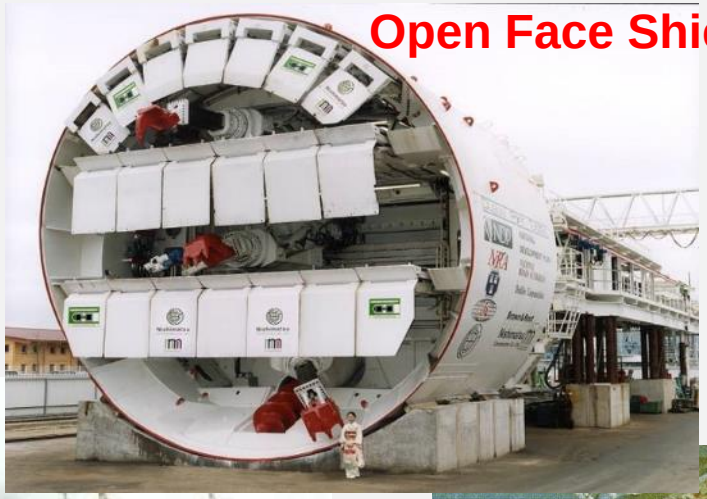


Gripper TBM

Rock is fragmented by chipping between cutters.



Open Face Shield and TBM



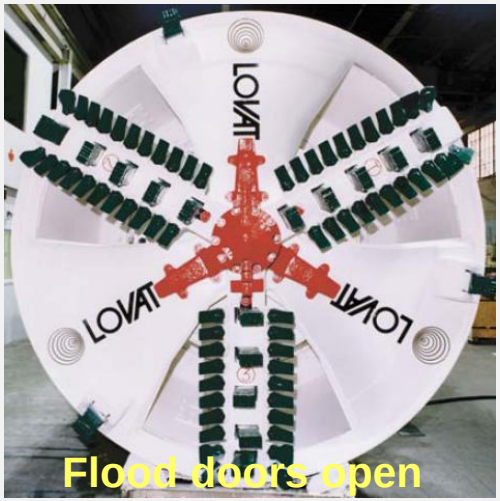
TBM with Mechanical Face Support

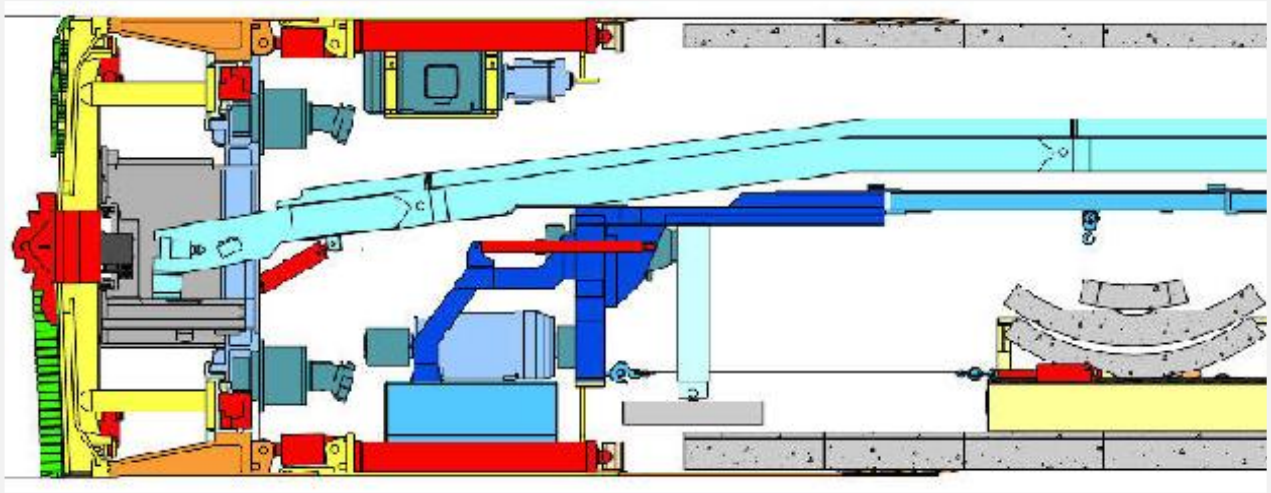
These TBM's can be used for rock and firm soil without the need of face pressure.

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

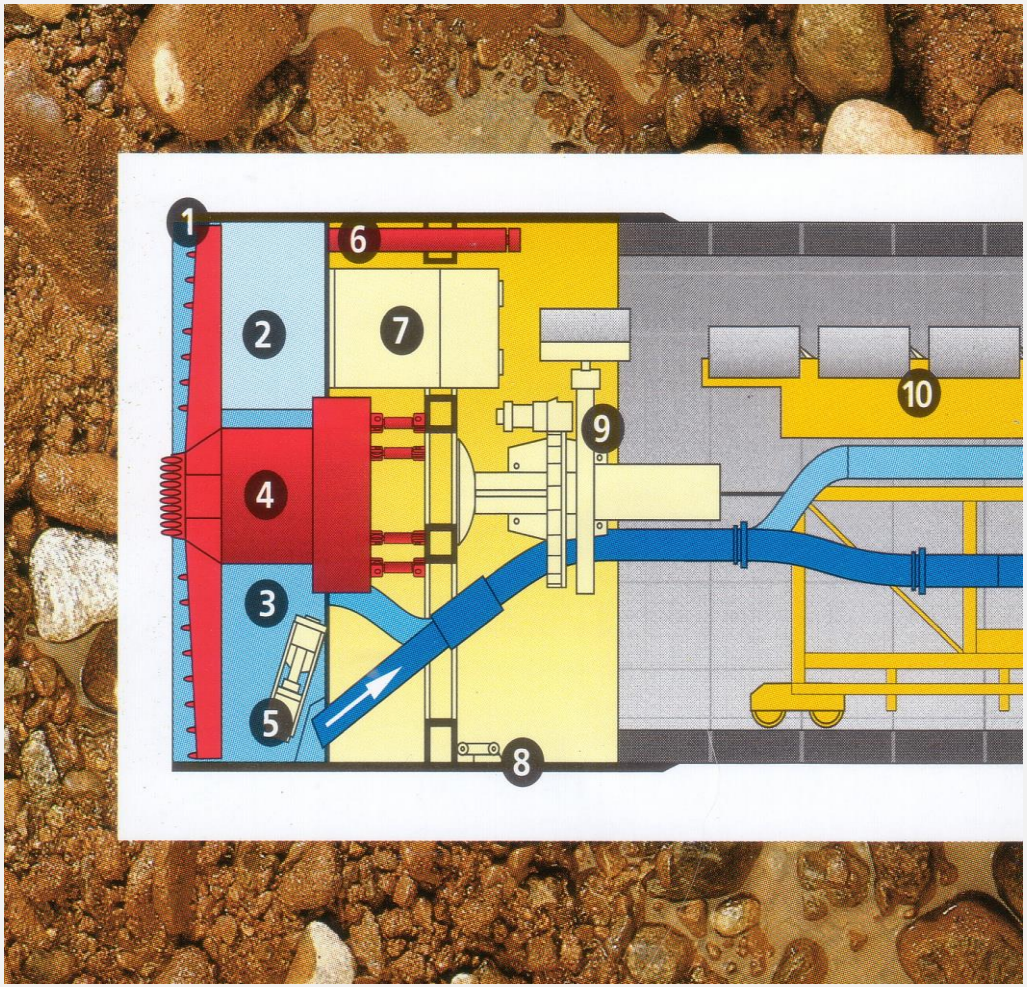
When open face shields excavate through groundwater-bearing soil, water penetration can be prevented by having the shield and a section of the tunnel protected by a lock system using compressed air.

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.

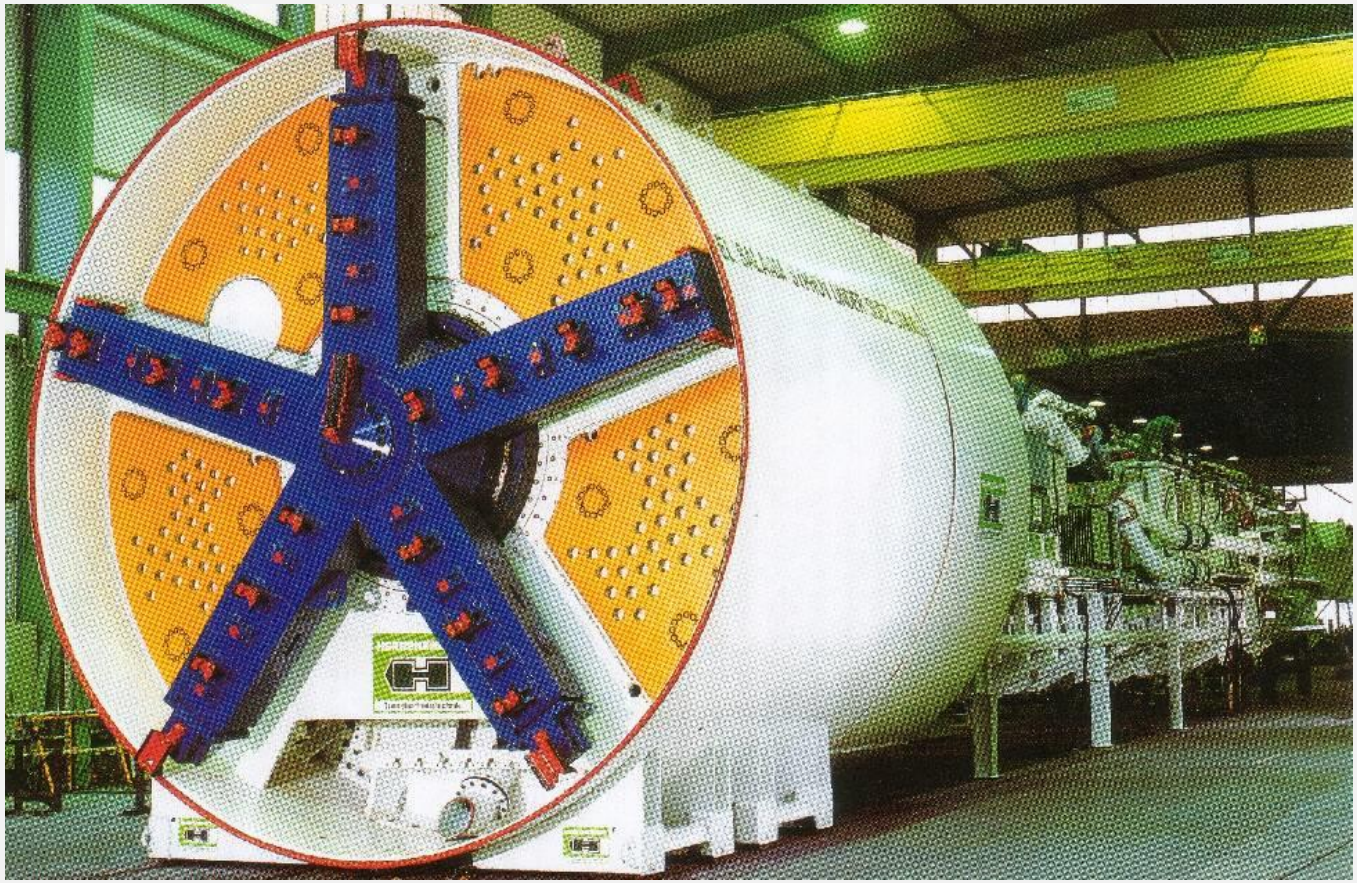
Slurry / Hydro-Shield – MixShield



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

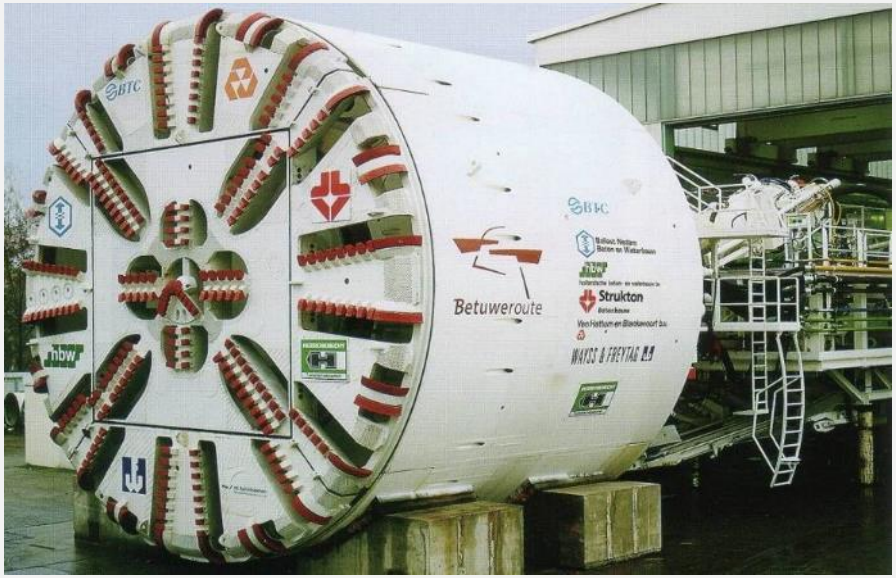
Slurry / Hydro-Shield – MixShield

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.

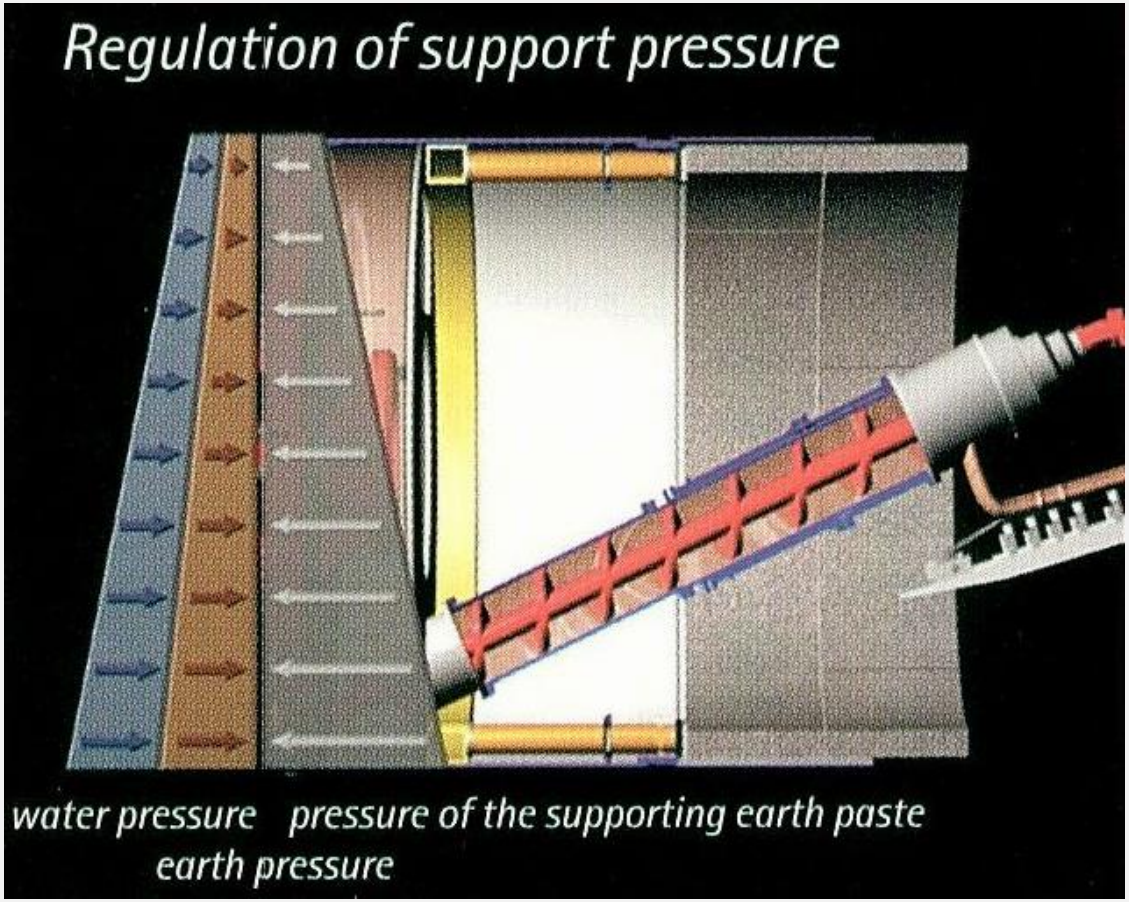


Machine is suited for drilling tunnels through ground with limited or no self-supporting capacity. Mainly used for excavating in silts or clays with sand.

Earth Pressure Balance Shield

The largest EPB machine ϕ15.2 m (2006) for Madrid M-30 project.

Earth Pressure Balance Shield

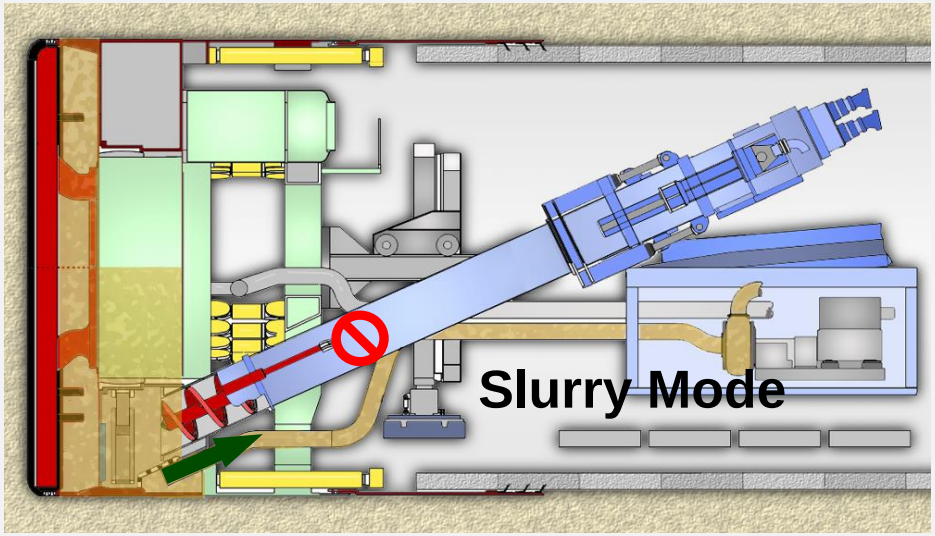


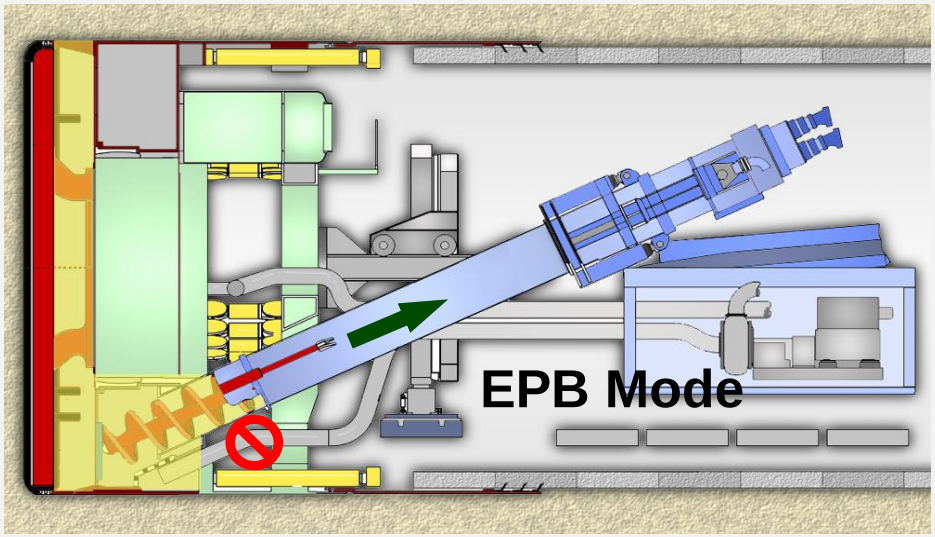
Double Shield

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

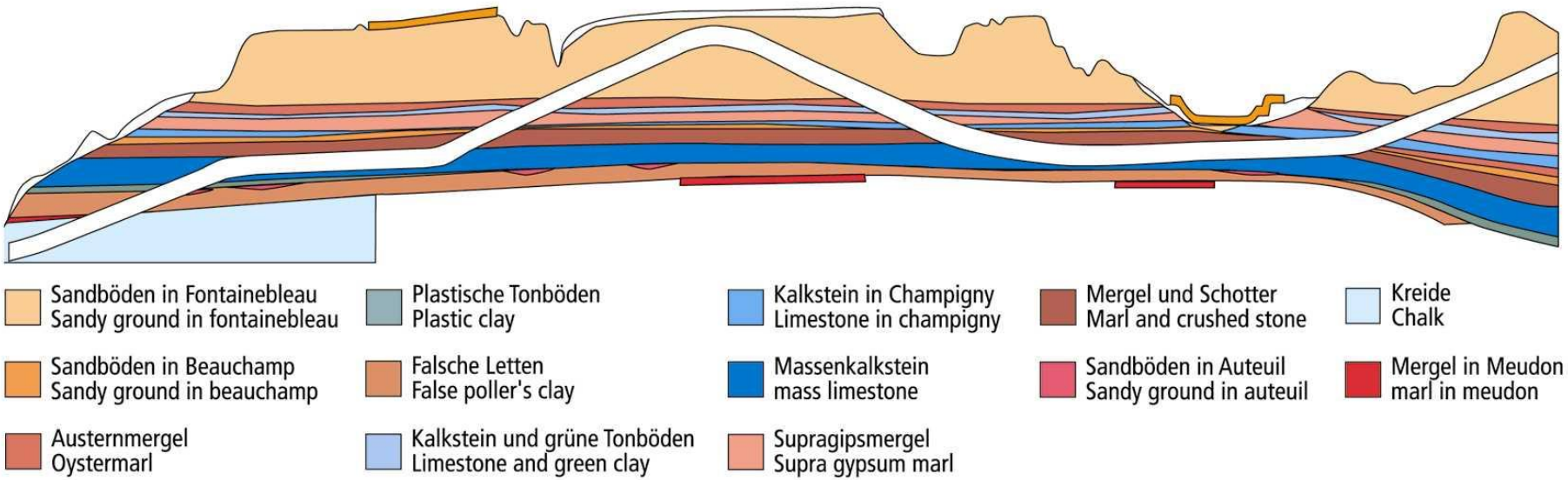
EPB-Slurry Convertible Shield

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



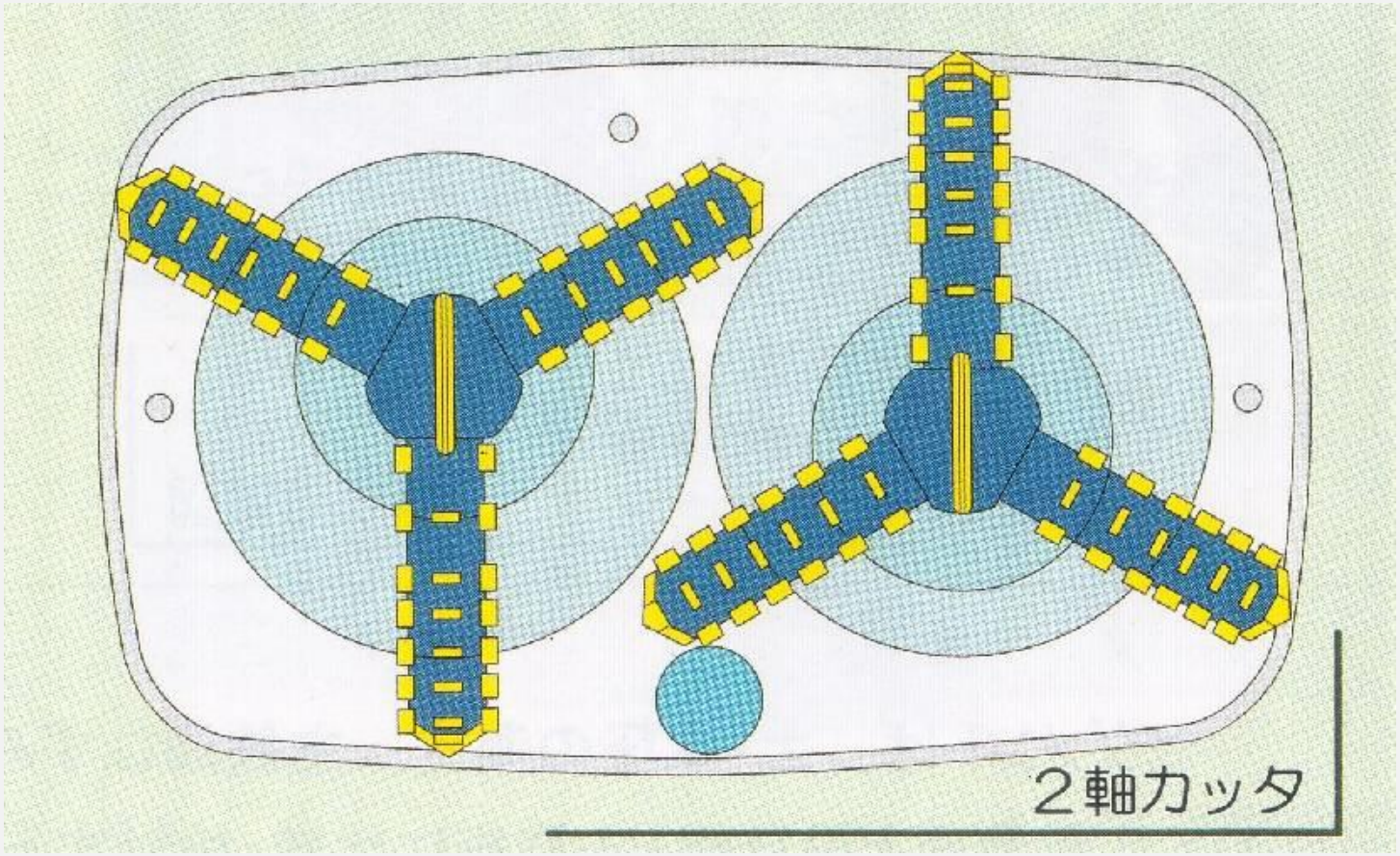


EPB-Slurry Convertible Shield



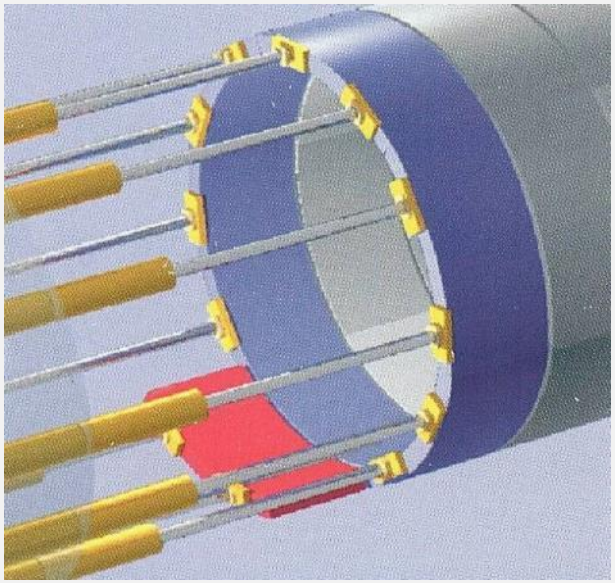
New TBM Technologies

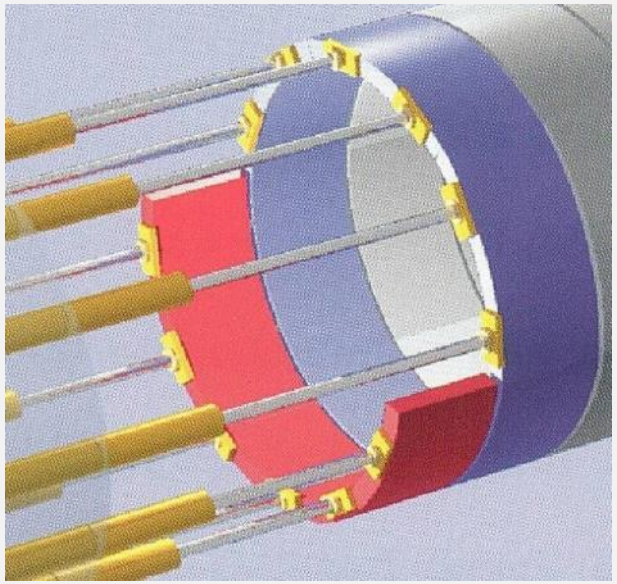
Optimizing underground space

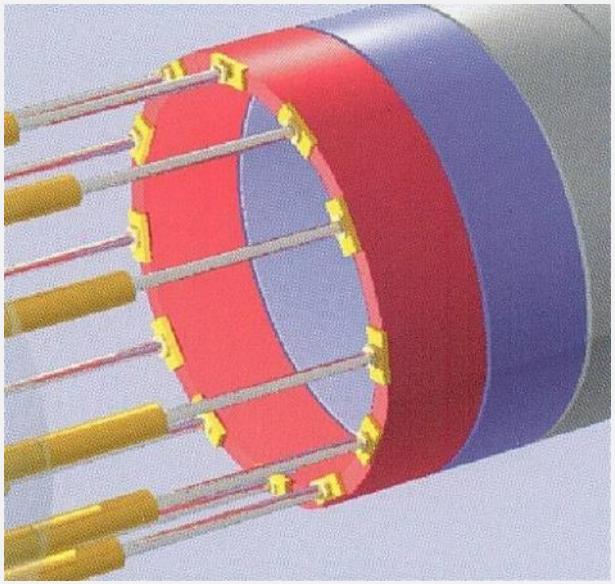


New TBM Technologies

Optimizing advancement

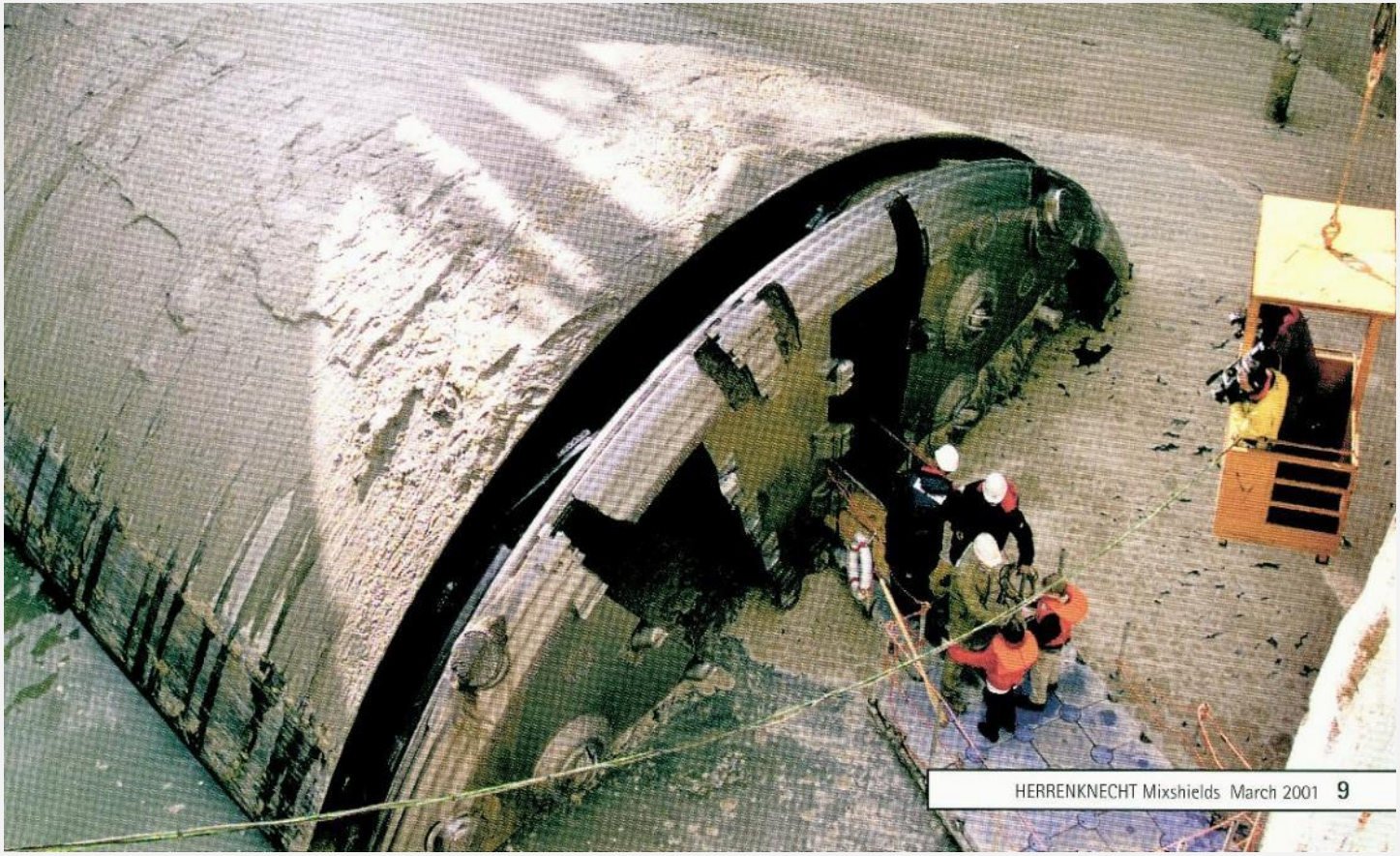






New TBM Technologies

Optimizing machine with variable ground condition



New TBM Technologies

Advanced ground probing