International Congress on
"*Mechanized Tunnelling: Challenging Case Histories*"

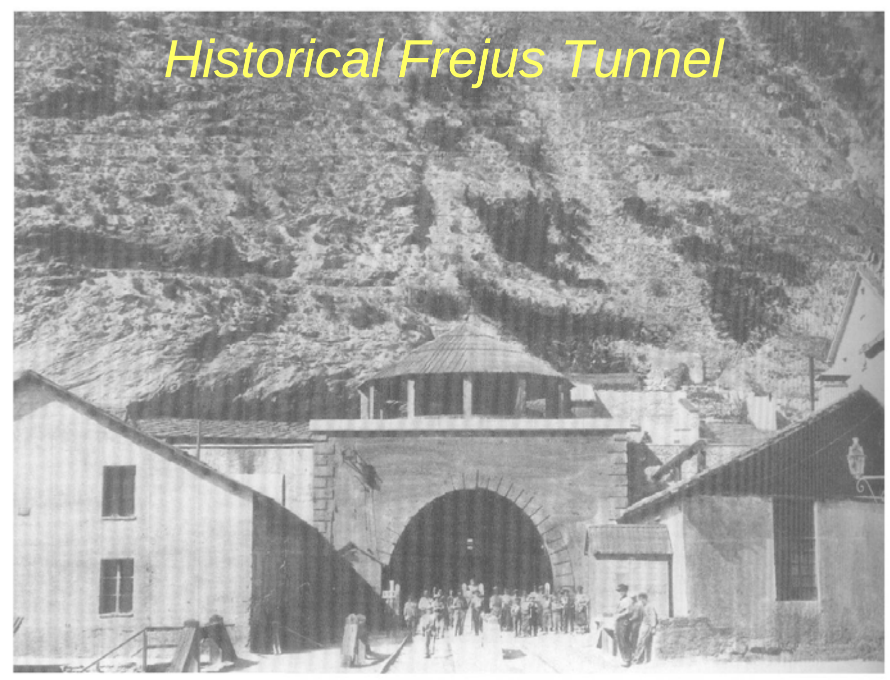
# TUNNELS IN ROCK

*Piergiorgio Grasso*

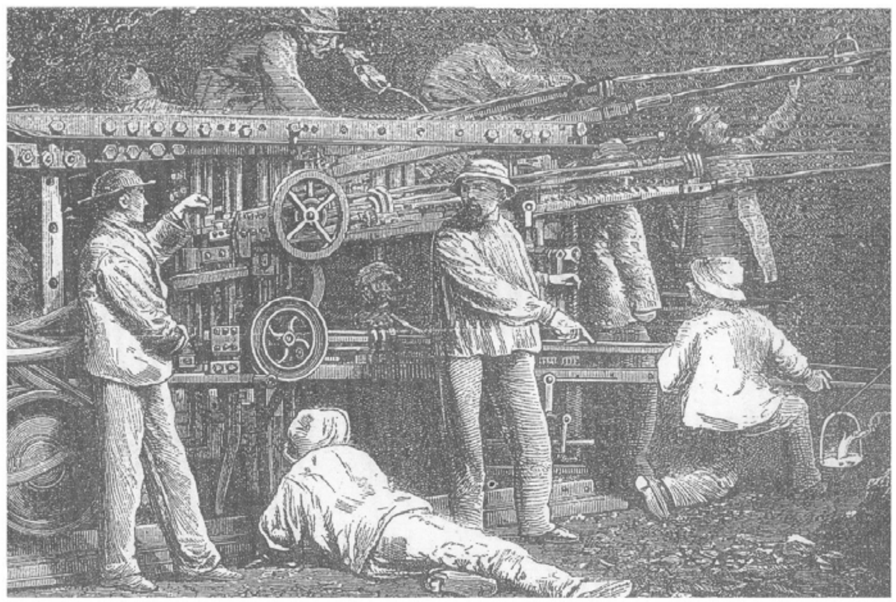
Torino, 17 Novembre 2004

# The complexity of the new challenges

**Tunnelling in rock is often related with the construction of long and deep tunnels, which have always represented one of the most complex and ambitious engineering undertakings.**

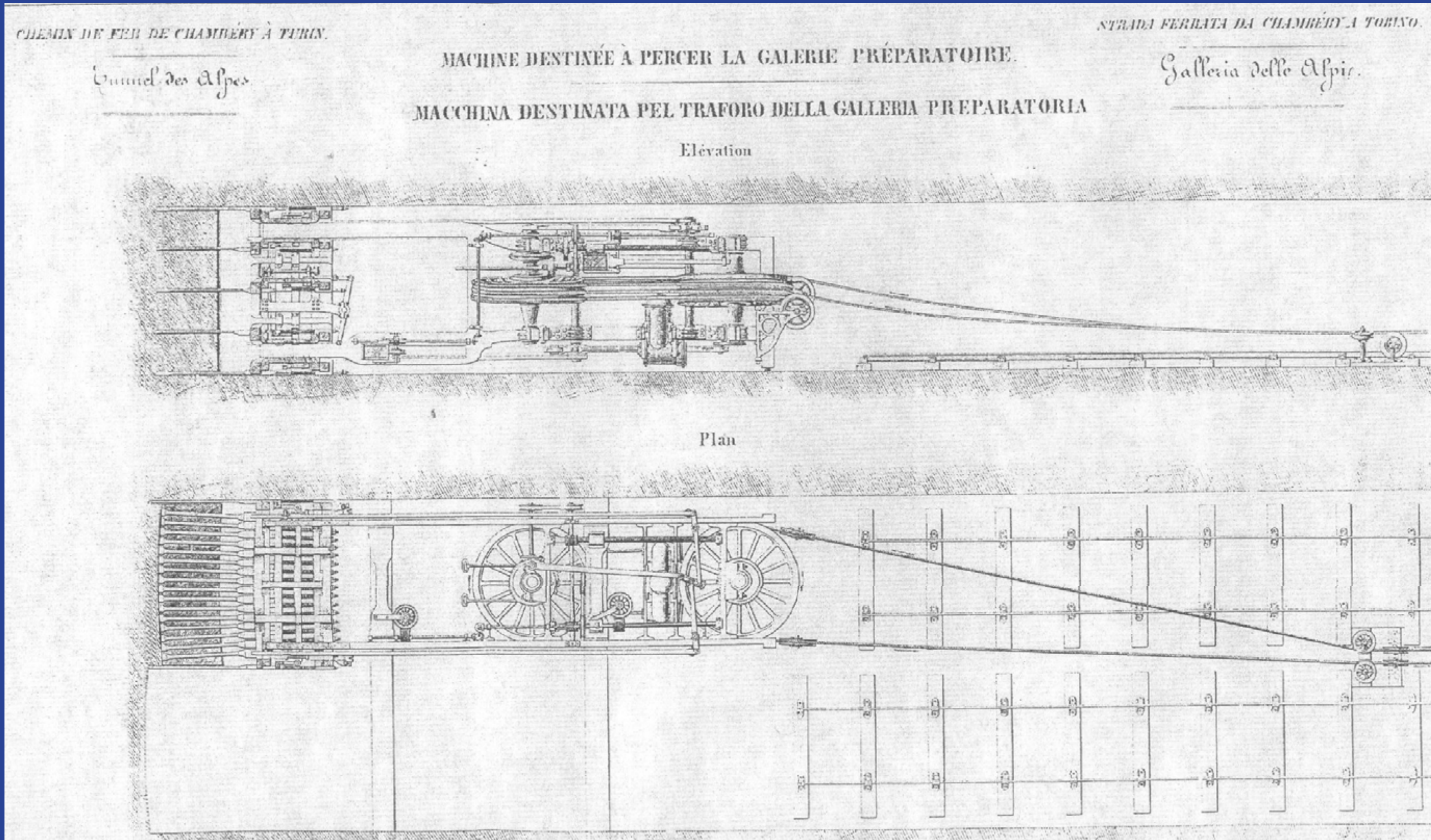



**The increasing number of new challenging projects together with the pressing market requirements – in terms of quality, safety and costs – continuously lead to new difficulties to be overcome.**



Operating the drilling machine at the tunnel face

# The past offers many examples of how challenges were faced …

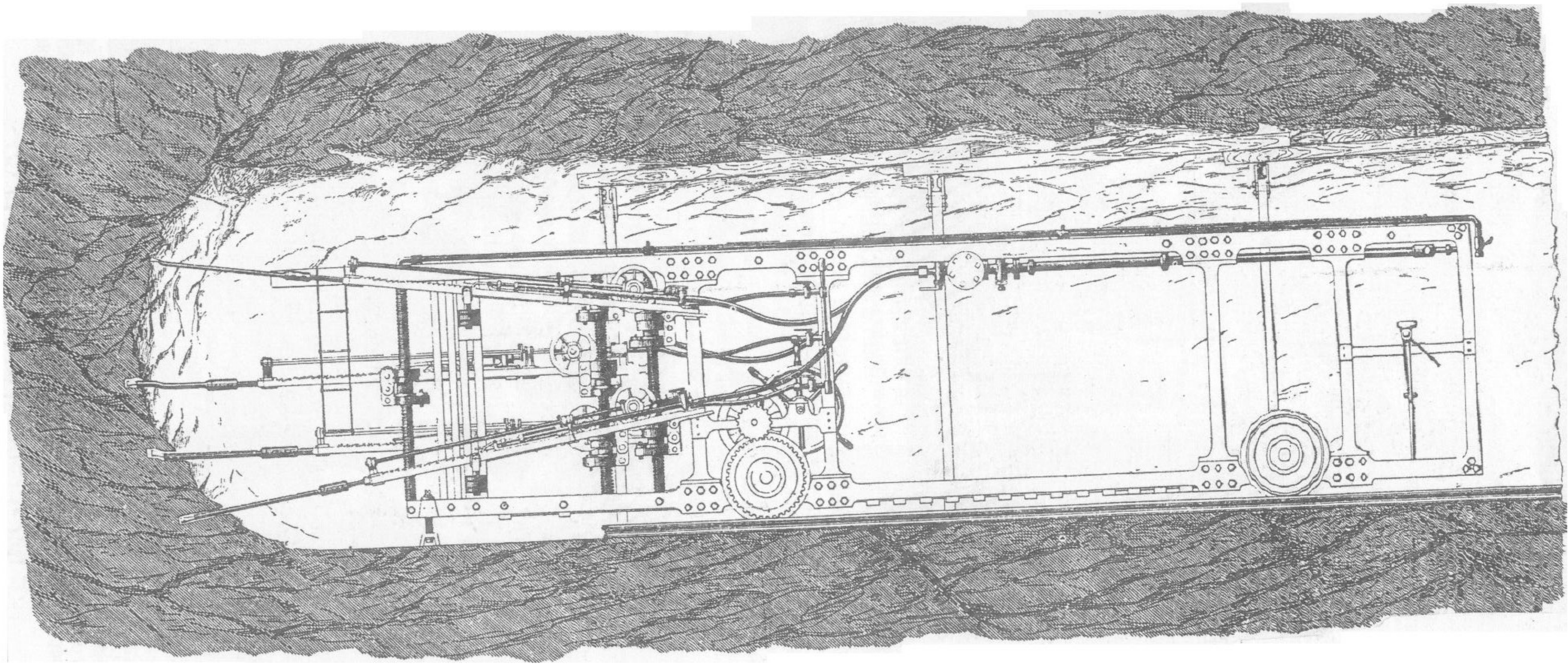



Historical FREJUS Tunnel – The tunnel boring machine designed by Eng. Henry Maus (1848)

**Since the very first experiences of tunnelling in the Alps two requirements have been raised:**

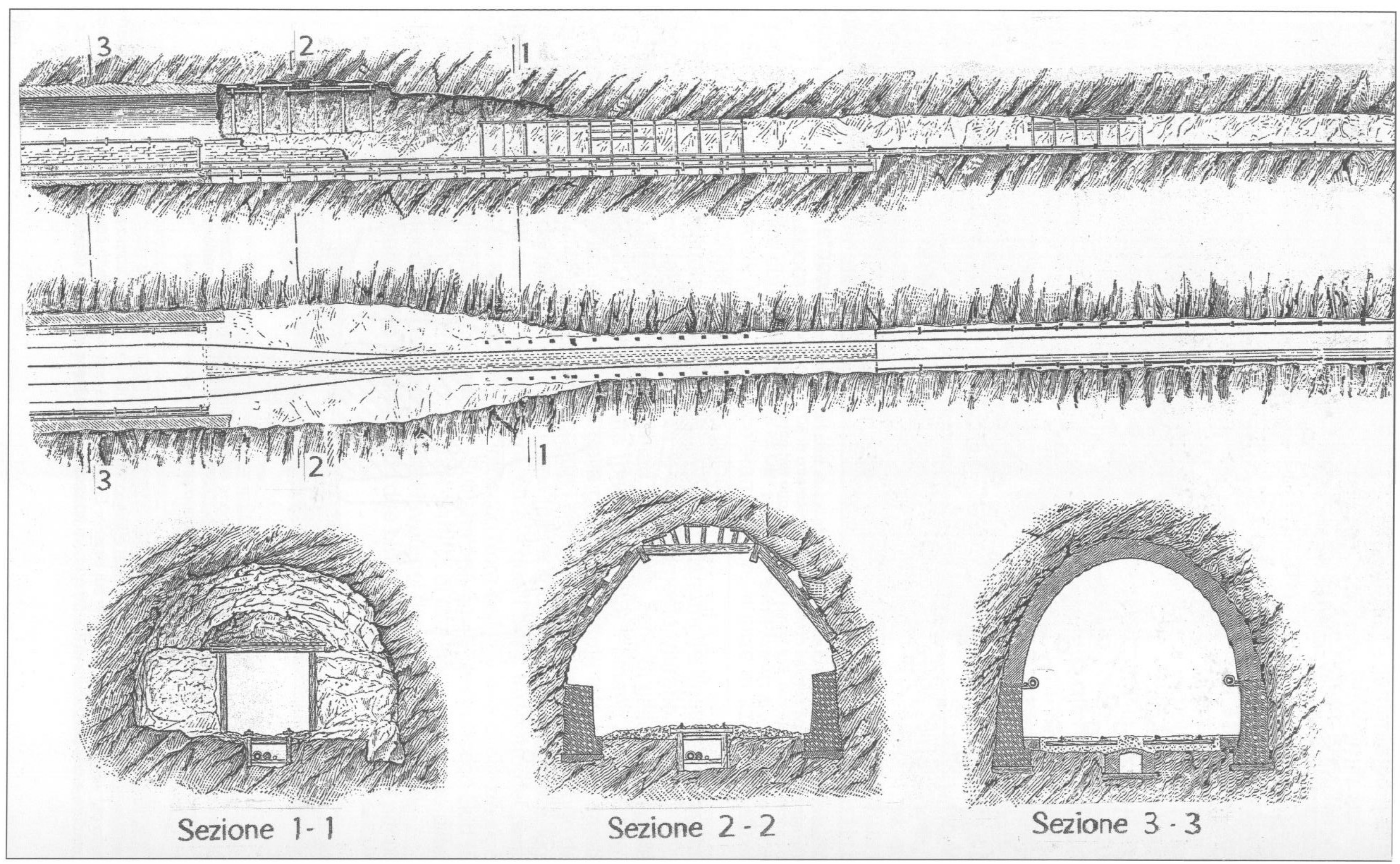
- ***excavating as fast as possible***
- ***limiting the costs as much as possible***

## … and how they were successfully overcome

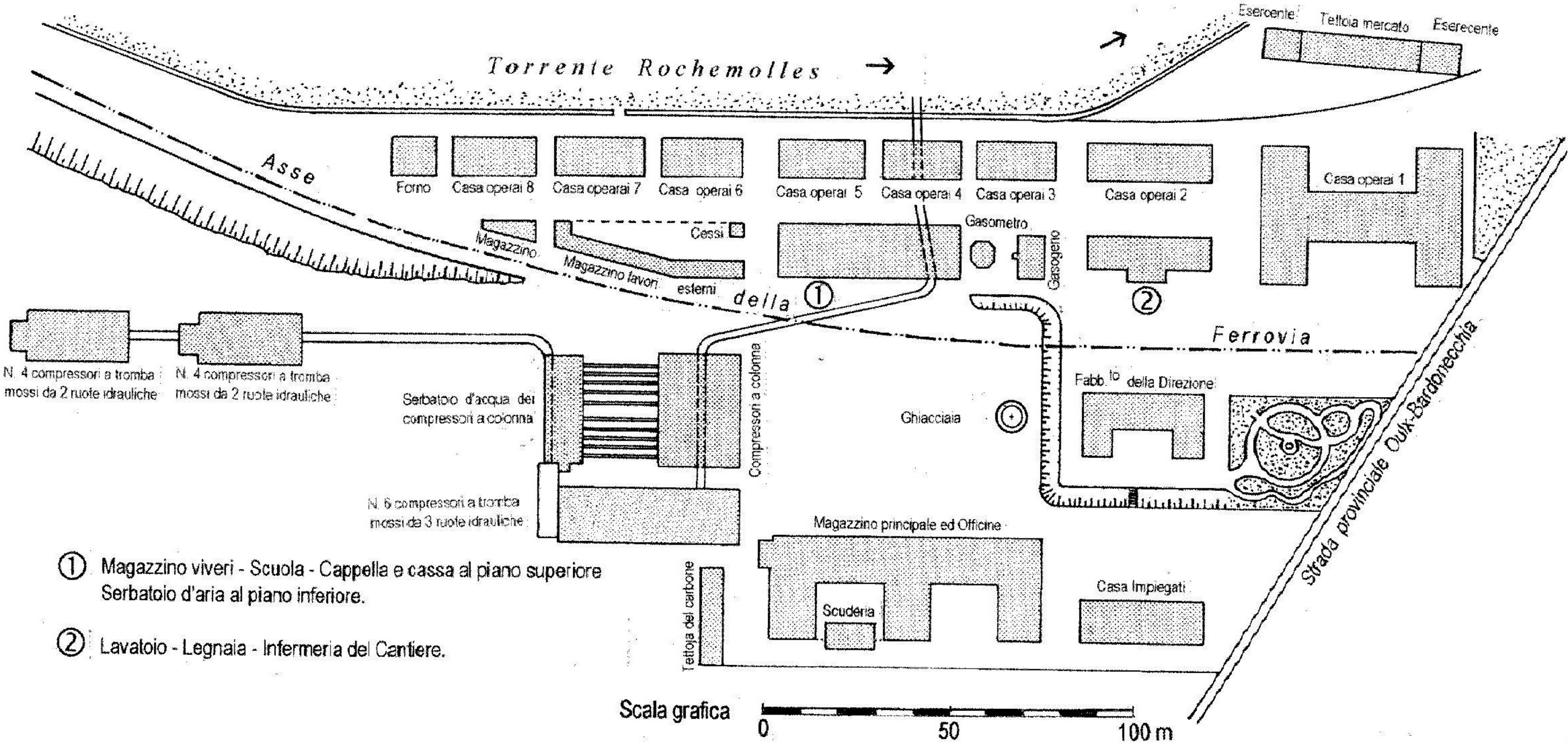


Drilling machine designed by G. Sommelier for excavating the Frejus Railway Tunnel 130 years ago

# Necessity stimulates Innovation




**Historical FREJUS Tunnel - *Scheme of the construction sequence***




**General scheme of the worksite logistics in Bardonecchia (around 1865)**

**The main work done so far by the ITA WG 17 was to understand better - with the help of the entire tunneling community - the worldwide trends in the planning, implementation, operation and maintenance of major infrastructure projects involving long tunnels at great depths.**

*QA photos*

# First Report of ITA WG17 "LONG TUNNELS AT GREAT DEPTH"

1. **Introduction**
2. **Project specifications**
3. **Ground conditions**
4. **Safety and environment**
5. **Design requirements**
   - 5.1 Technical approach
   - 5.2 Characteristics of the various options through conceptual and preliminary designs
   - 5.3 Constructability analysis of each design-construction-investment option
   - 5.4 Comparison of configuration and method options
   - 5.5 Comparison of alignments
6. **Tunnel construction**
   - 6.1 Tunnel excavation
   - 6.2 Tunnel support
   - 6.3 Ventilation during construction
   - 6.4 Haulage and transportation equipment
   - 6.5 Reuse of excavated materials
   - 6.6 Concrete
7. **Special conditions for railway tunnels**
8. **Special conditions for road tunnels**
9. **Risk assessment and management**
10. **References**

# The attained goals

**The tunnelling world has witnessed steady incremental improvement in tunnel construction techniques, especially mechanized excavation methods.**

**In the area of mechanized tunnelling the case-histories presented in this Congress emphasize the huge improvements achieved:**

- **the diameter of the tunnels keeps increasing;**
- **the performance of TBMs are constantly improving;**
- **the length of a drive by a single TBM is also increasing.**

**The first report prepared by the WG17 was set to meet the following specific objectives:**

- ***to report the state-of-the-art of the field,***
- ***to provide a checklist of the problems involved,***
- ***to recommend an approach or a methodology for resolving the major problems in the checklist.***

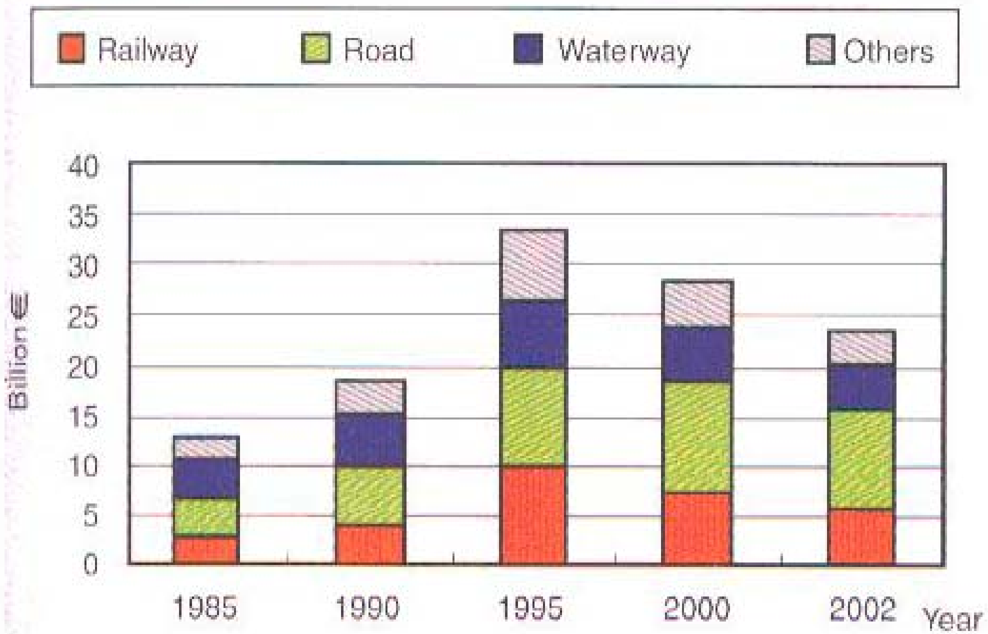
**The feedback and advice from the professional, diversified and qualified audience of this lecture will be a valid contribution for the continuation of the works by WG17.**

| Tunnel Name | Type | Country | Opening | Length [km] | Diameter [m] | Notes |
|---|---|---|---|---|---|---|
| **TUNNELS IN OPERATION** | | | | | | |
| **Wanjiazhai** | hydraulic | China | 2001 | 88.7 | 4.9 | 4 tunnels excavated with 4 double-shield telescopic TBMs |
| **Seikan** | railway | Japan | 1988 | 53.8 | 9.6 | 23 .3 km of submarine section; 240m beneath the sea level |
| **Channel** | railway | UK - France | 1994 | 52 | | 11 TBMs |
| **Laerdal** | road | Norway | 2000 | 24.5 | | NATM |
| **Sempione** | railway | Italy – CH | 1922 | 19.8 | | |
| **Vereina** | railway | Switzerland | 2001 | 19 | 7.64 | 9414m TBM bored in 22 months |
| **Qinling** | railway | China | 1999 | 18 | | Twin tunnels, D&B for one tube, 2 TBMs for the second tube |
| **St. Gotthard** | road | Switzerland | 1980 | 17 | | |
| **Frejus** | railway | Italy - France | 1871 | 13.6 | | |
| **Pinglin** | road | Taiwan | 2004 | 12.9 | 11.8 | 3 DS TBMs |
| **North Cape** | road | Norway | 1999 | 7 | | 212m beneath the sea level |
| **Great Belt** | railway | Denmark | 2000 | 7 | | |

# Some challenging international projects

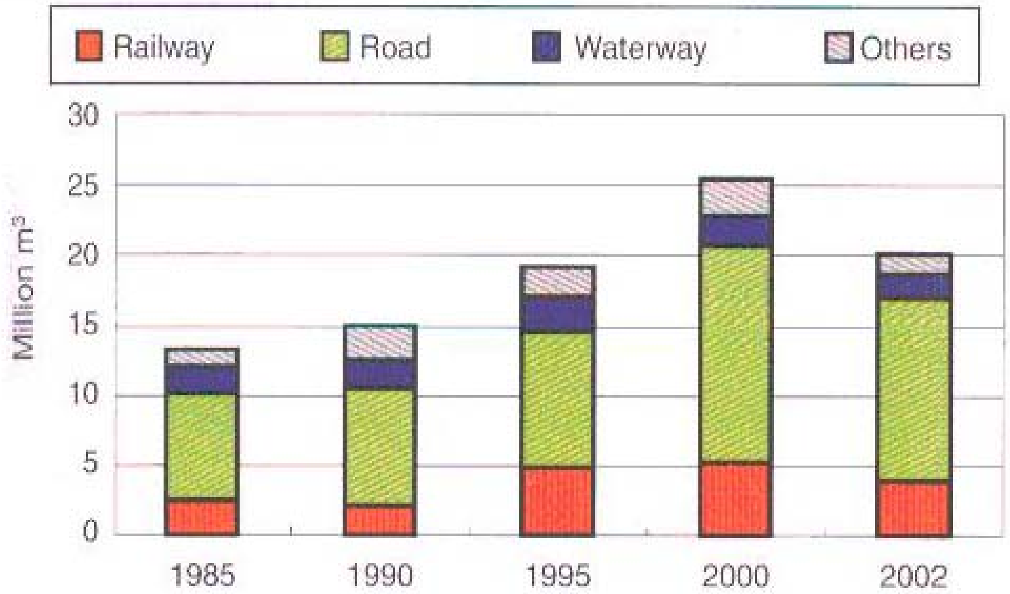
| Tunnel Name | Type | Country | Started | Length [km] | Diameter [m] | Notes |
|---|---|---|---|---|---|---|
| **TUNNELS UNDER CONSTRUCTION** | | | | | | |
| **Gotthard Base** | | Switzerland | 1999 | 57 | 9.5 | 90% of the length with 8 TBMs |
| **Lotschberg Base** | | Switzerland | 1999 | 36 | 9.5 | |
| **Guadarrama** | railway | Spain | 2002 | 22 | 9.5 | Under construction by 4 TBMs |
| **Hida** | road | Japan | | 10.75 | 12.84 + 4.5 | Tunnel + emergency tunnel |
| **Pajares** | railway | Spain | 2004 | 25 | 10 | |

## Trend of Amount in Tunnel Works under Contract

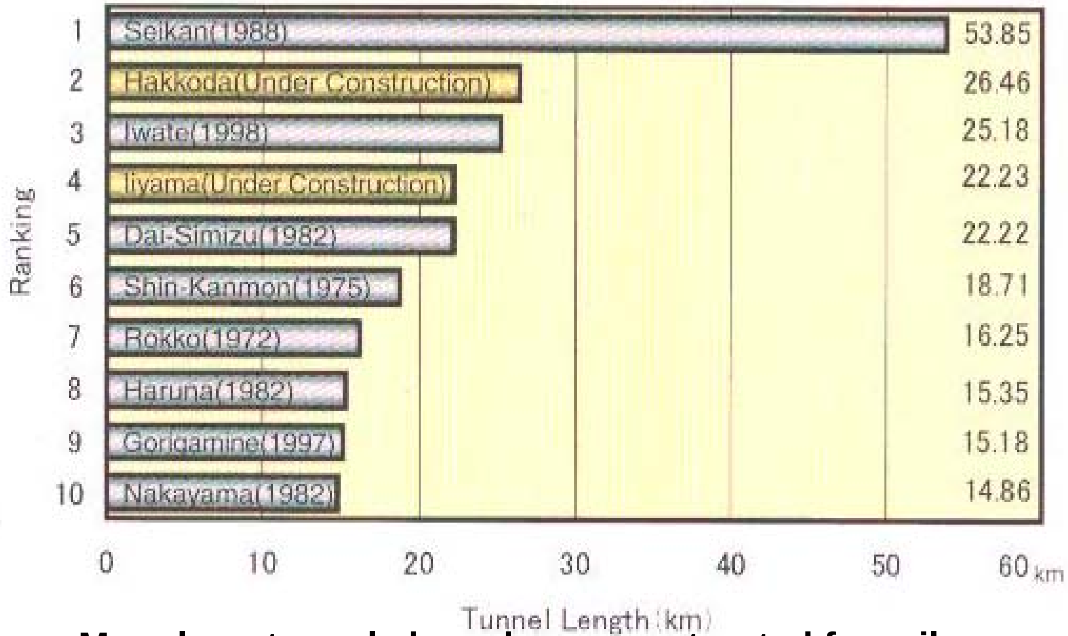



**In 2000 alone, the total length of tunnels under construction was as much as 1178km**

## Trend of Excavated Volume in Tunnel Works

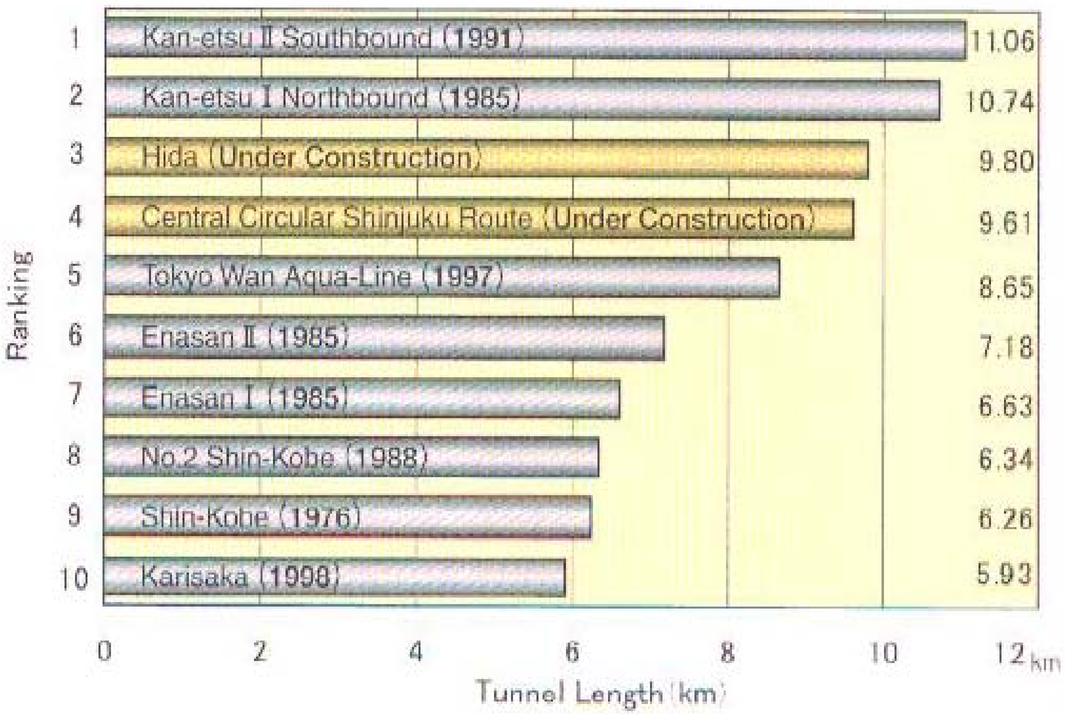



## Long Railway Tunnels in Japan




**More long tunnels have been constructed for railways than for roads**

## Long Road Tunnels in Japan



Many technological innovations have been introduced in tunnel boring machines over the last years.

Each innovation has been originated by the requirement of minimizing and controlling certain risks. Hence, an innovation is achieved through a Risk Management process.

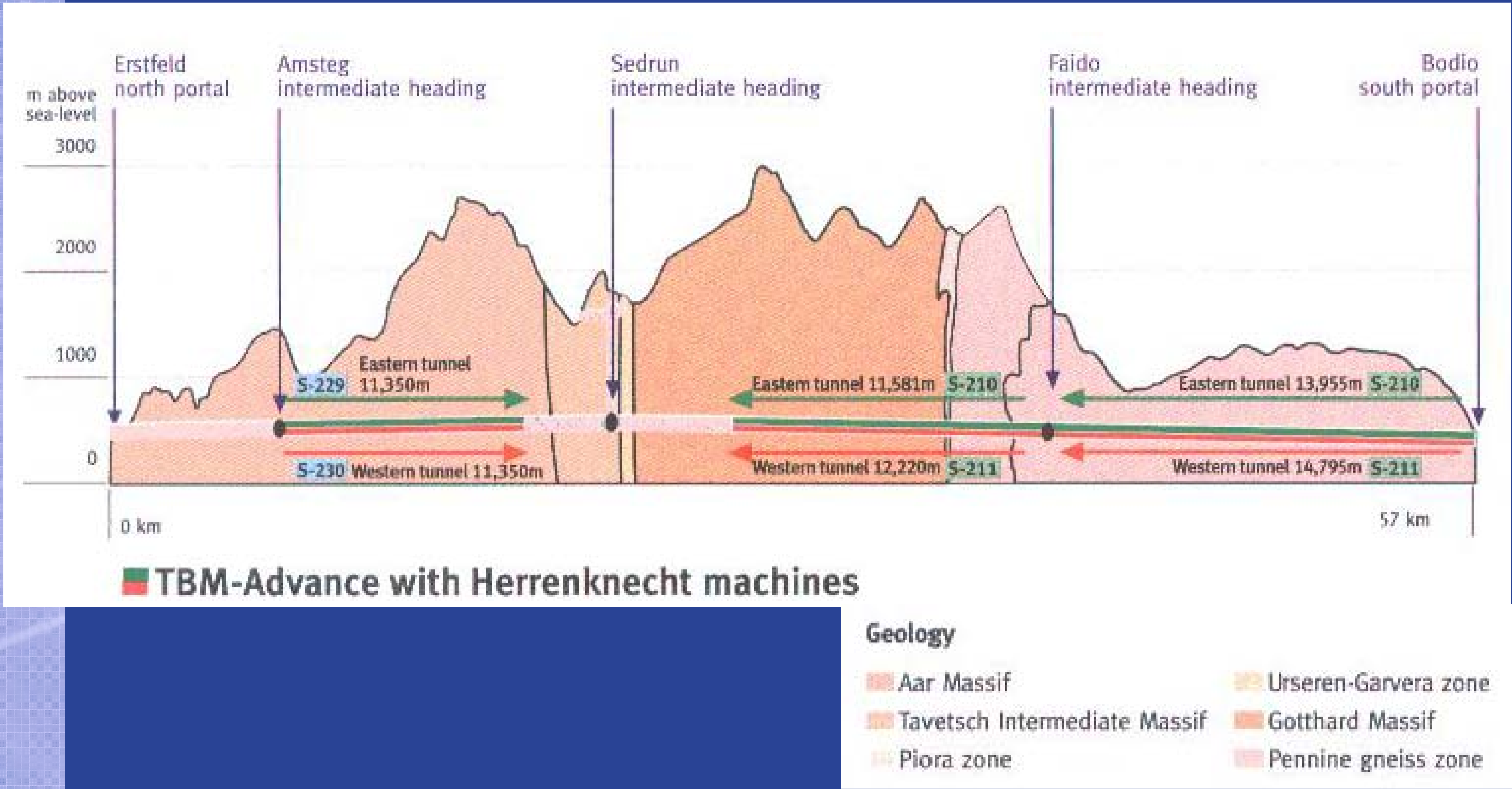
The success of an innovation depends on two main factors:

- investment
- the synergy among the new Actors: not only Owner, General Contractor and Designer, but also Contractor for the Special Works and TBM Manufacturer

# Tunnels in the stage of planning and feasibility studies

| Project Name | Type | Country | Length | Notes |
|---|---|---|---|---|
| **TUNNELS IN PLANNING AND FEASIBILITY STUDY** | | | | |
| **Brenner Base Tunnel** | railway | Austria – Italy | 54 km | |
| **Lyon-Turin Base Tunnel** | railway | France - Italy | 52 km | |
| **California High Speed** | railway | USA | 2x100 km | |
| **Gibraltar Strait Crossing** | railway | Spain - Marocco | 50 km | |
| **Nusantara Tunnel** | road | Indonesia | 2x33 km | |
| **Chongming Tunnel** | road | China | 2x8 km | Shall be the largest bored tunnel in the world (15.2m diameter) |
| **Brightwater System** | hidraulic | USA | 31 km | |
| **Hong Kong Drainage Tunnels** | hidraulic | Hong Kong | 20 km | |
| **South-North Water Transfert Scheme** | hidraulic | China | 244.1 km | 7 tunnels, 3 of them being longer than 50 km |

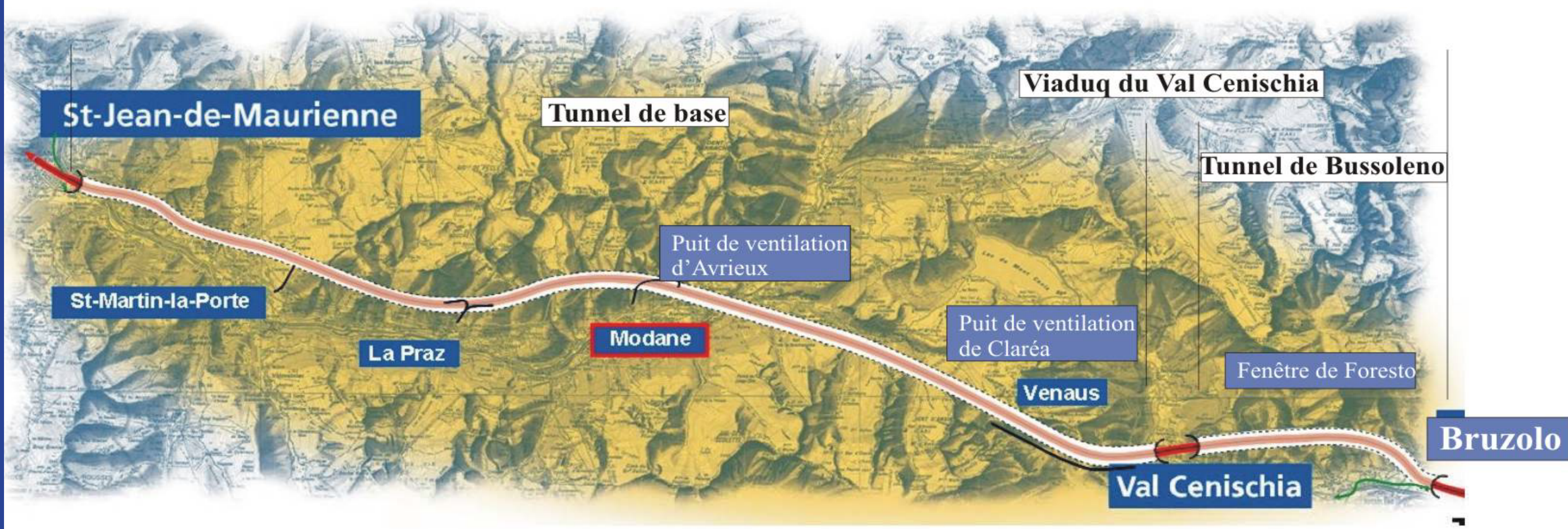
# The new St. Gotthard Tunnel



# The new railway link between Turin and Lyon

Cartografia del tracciato della sezione internazionale – tratta comune italo francese

Figure 2 : Le tunnel de base (53 km) et le tunnel de Bussoleno (12km) de la section commune italo - française.

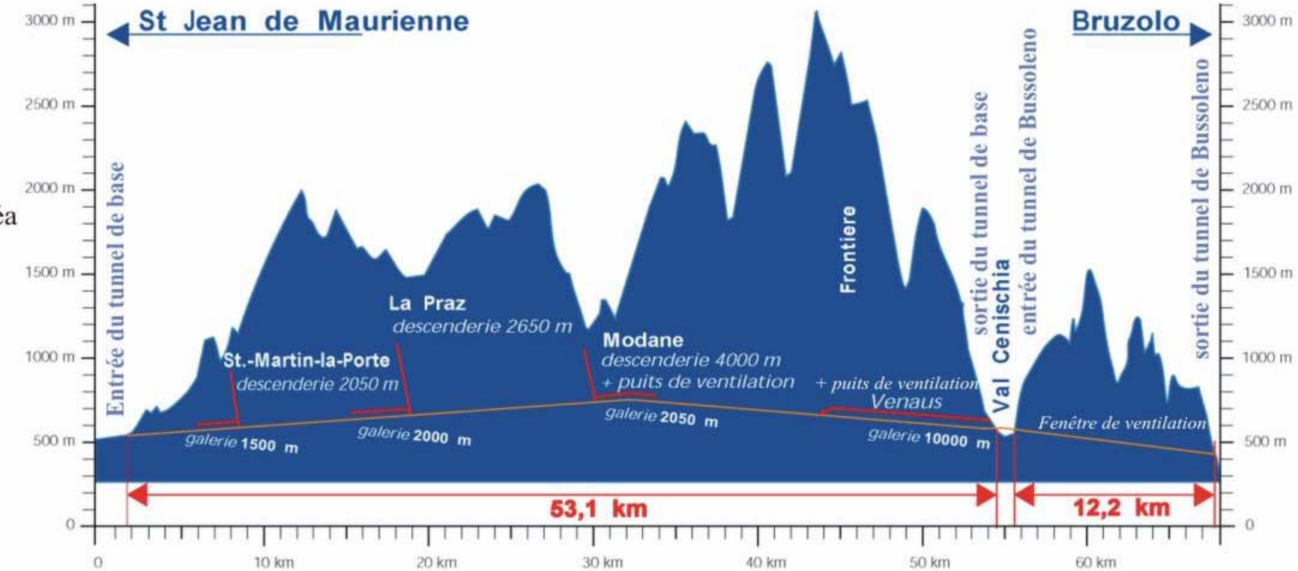



**Les ouvrages secondaires :**

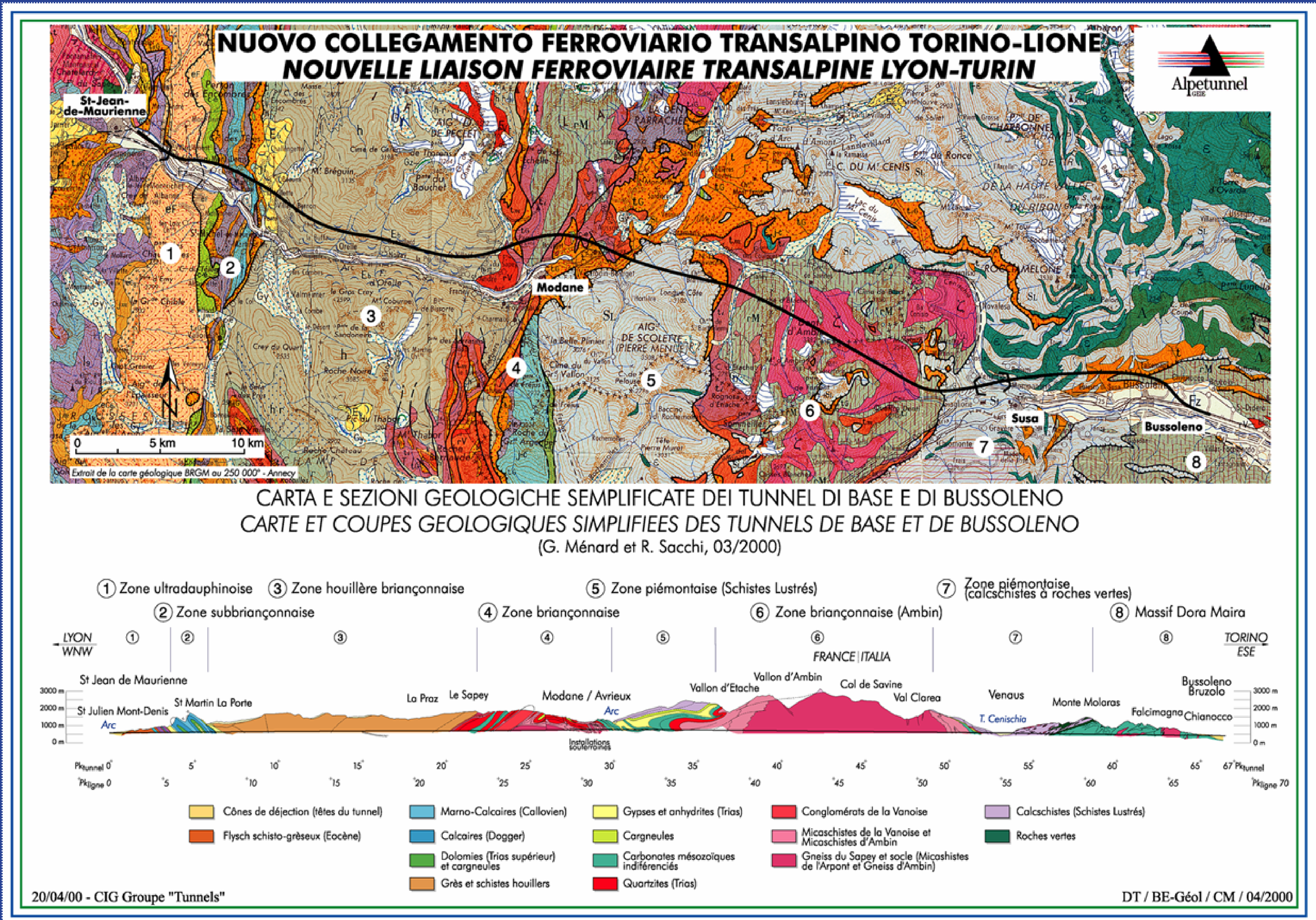
Galeries de Modane, La Praz,
St Martin La Porte et Venaus,

Puits de ventilation d'Avrieux et de Claréa

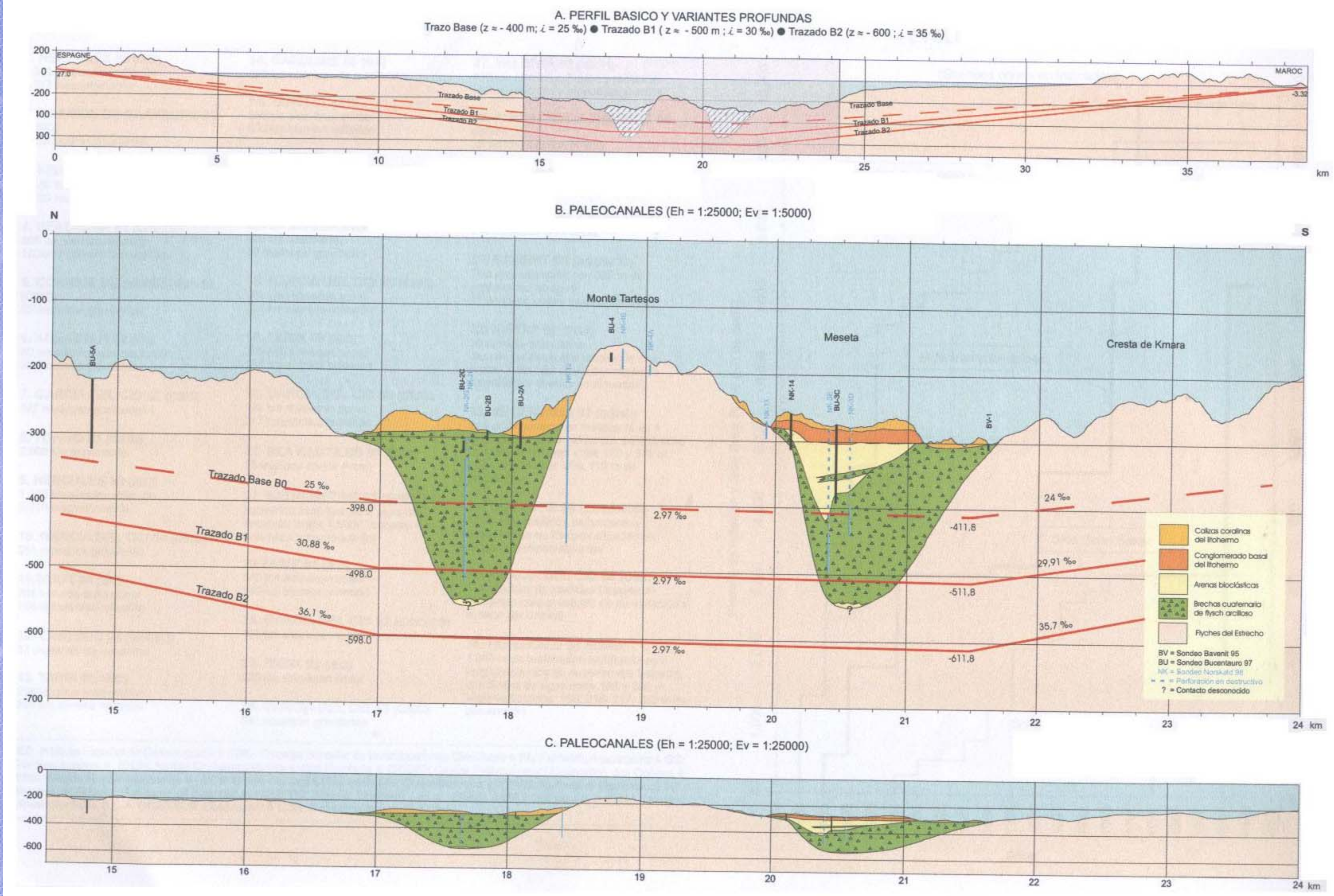
Fenêtre de Foresto



# The new railway link between Turin and Lyon



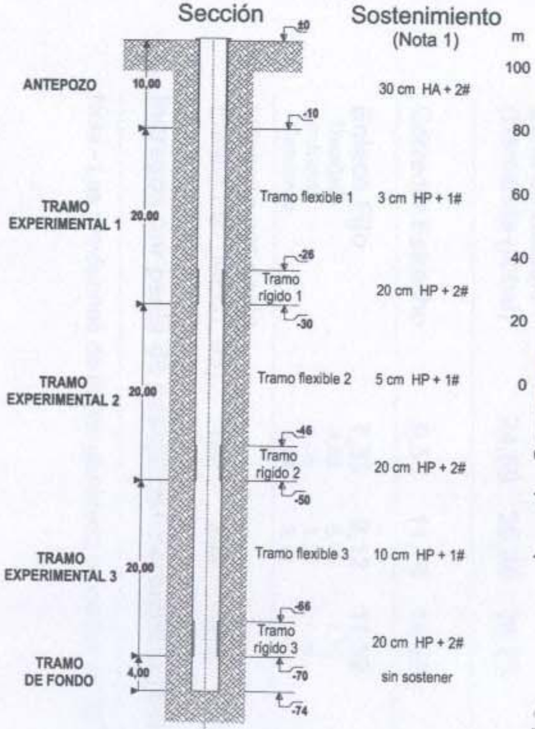
# Gibraltar Strait Crossing



# Fig. 6. OBRAS EXPERIMENTALES DE BOLONIA Y TARIFA

## POZO DE BOLONIA

Profundidad: 74 m • Diámetro: 3,5 m • Perforación: martillo manual
Instrumentación: 26 x C2 + 4 x ER + 3 x EC + 3 x PC (Nota 2)

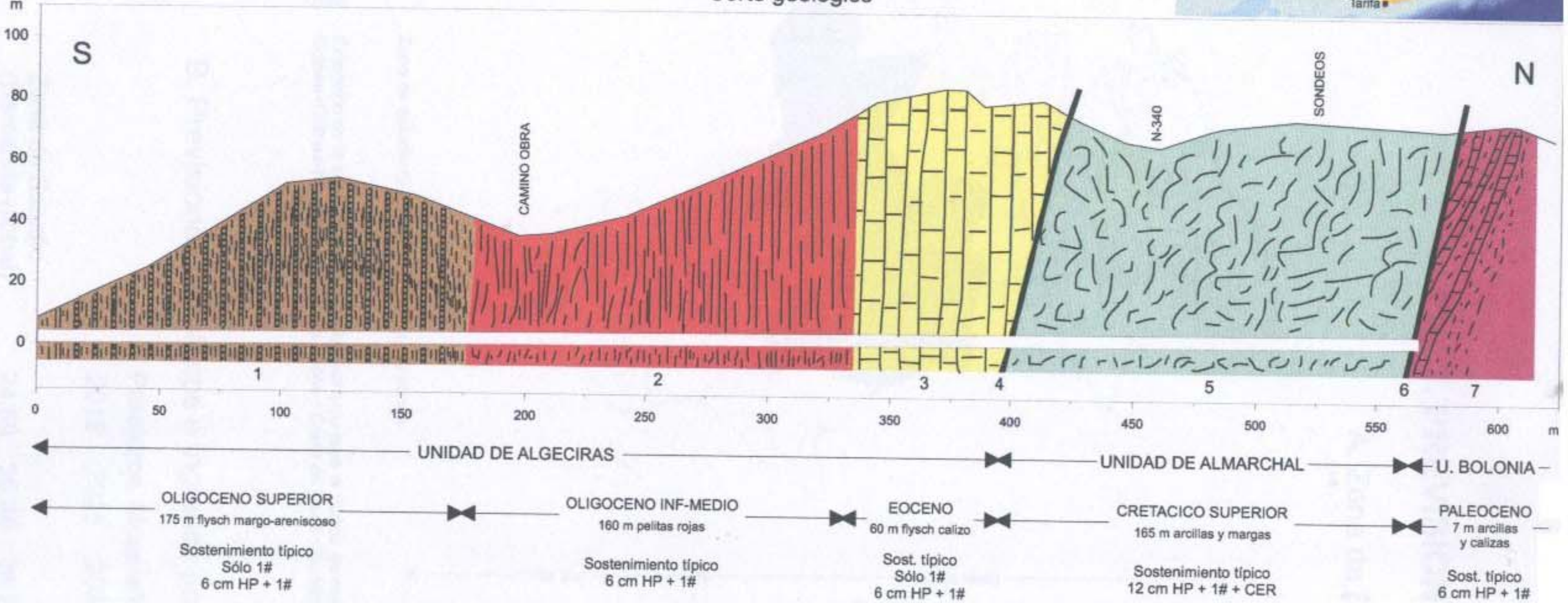




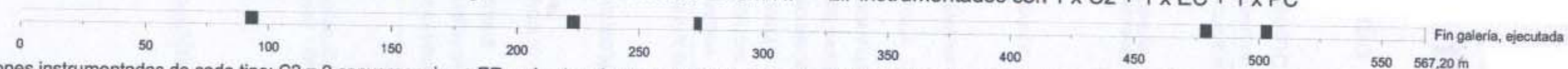
## GALERIA DE TARIFA

Longitud: 567,20 m • Diámetro: 3,80 m • Perforación: TBM sin escudo
Instrumentación: 62 x C2 + 10 x ER + 5 x EC + 5 x PC (Nota 2)

Corte geológico




Situación de los anillos rígidos con sostenimiento 20 cm HP + 2# instrumentados con 1 x C2 + 1 x EC + 1 x PC




Nota 1. La instrumentación se indica en nº de secciones instrumentadas de cada tipo: C2 = 2 convergencias • ER = 4 extensómetros radiales • EC = 4 extensómetros circunferenciales •PC = 4 células de presión radiales.
Nota 2. Los sostenimientos, en espesor en cm de HA (hormigón armado) o de HP (hormigón proyectado con fibra de acero) • Número de mallas de 100 x 100 mm x Ø 8 mm (#) • Cerchas UPE 120 por metro (CER).

*Pozo de Bolonia. Al fondo el cerro de San Bartolomé*

*Tuneladora Ø 3,80 m utilizada en la Galería de Tarifa*

*Galería de Tarifa. Tramo de flysch margo-areniscoso*

## Behavior of the rock mass upon excavation and heterogeneity of ground in the face

Stability of the excavation face and of the cavity

Rock wedges

Yielding and plastic zone

Failure of the walls under the grippers

Squeezing

Swelling

Sticky behavior

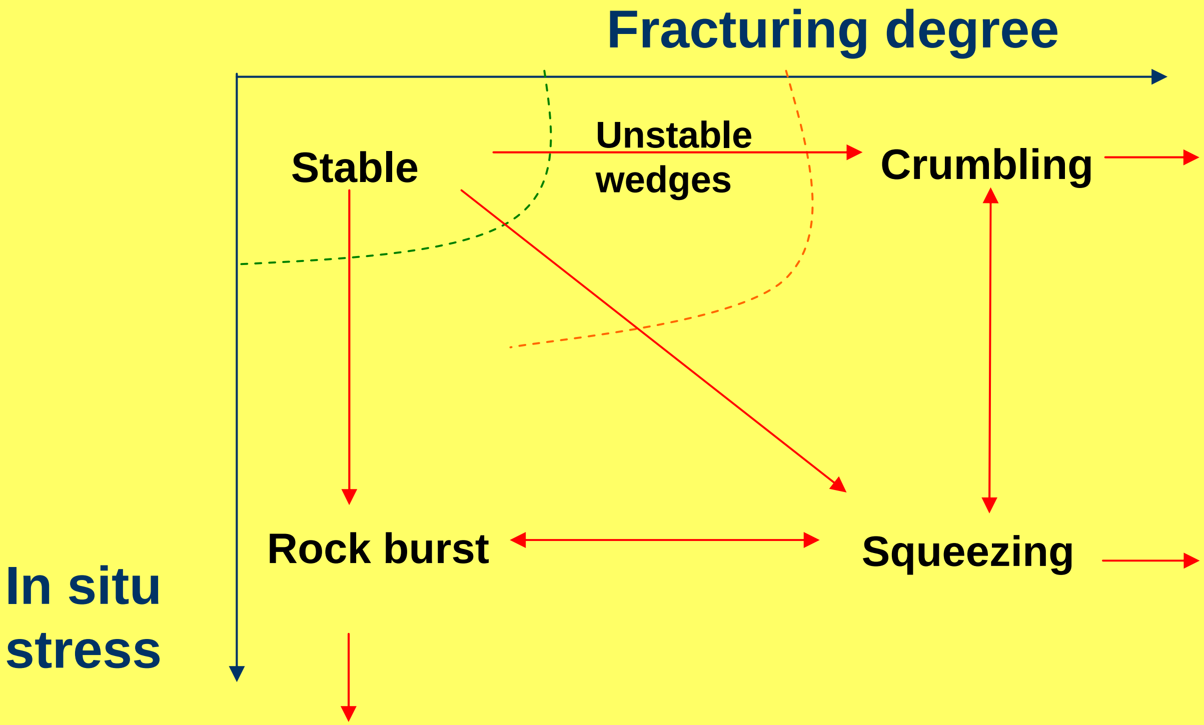
Water inflow

Gas inflow

**S.S.1 - S.Niccolò Pilot Tunnel (1991-1992)**
***Squeezing behavior / collapse of the reaction zone beneath the grippers***

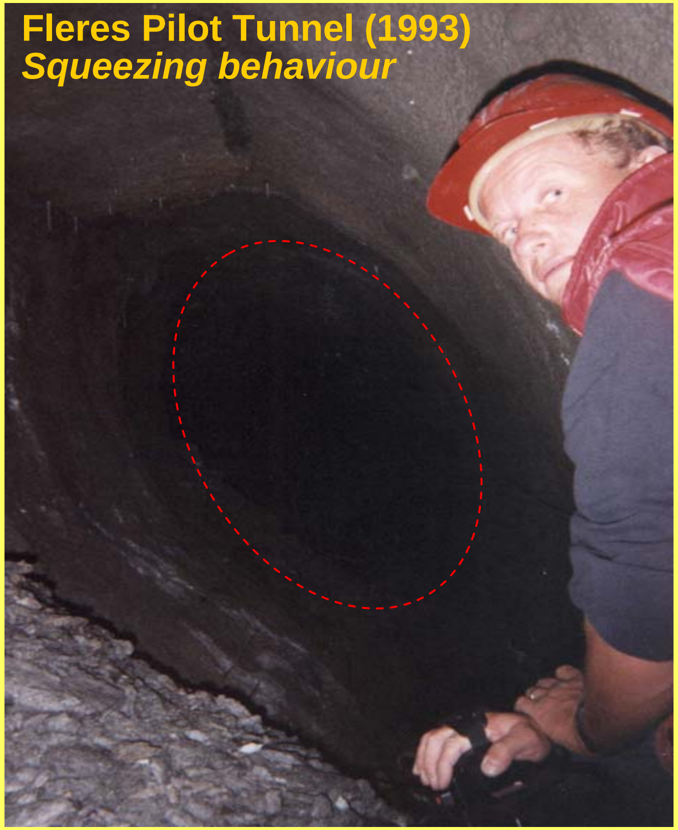
# The deformation phenomena

(most frequent condition)




**Pont Ventoux Hydroelectric Power Plant**
*Crumbling behavior in a fault zone: heavy support behind the head of the TBM (from Barla and Pelizza, 2000)*

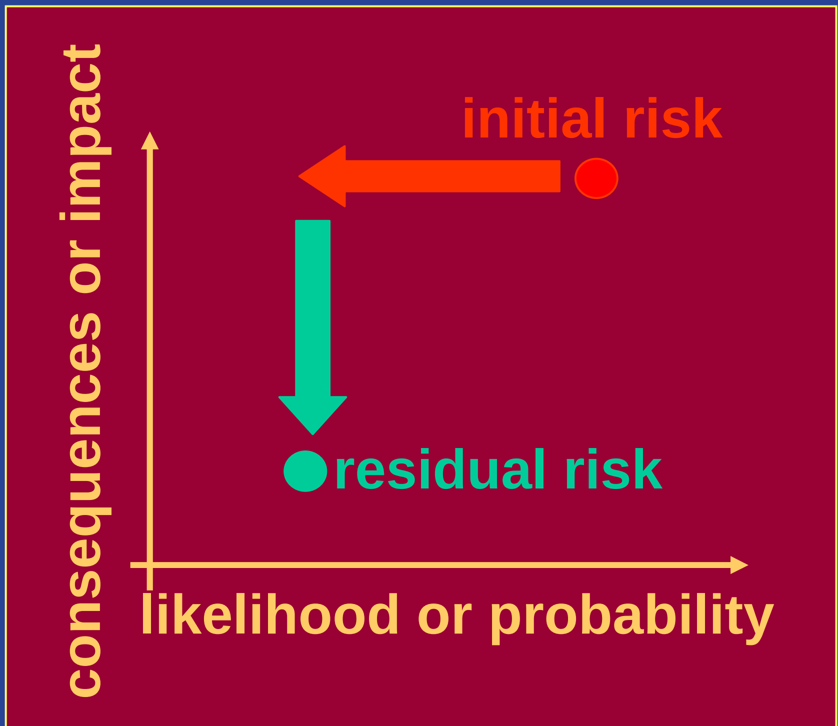
**St. Gotthard Tunnel**
*Rock burst*



**Fleres Pilot Tunnel (1993)**
*Squeezing behaviour*

**No construction project is risk free. Risk can be managed, minimized, shared, transferred, or simply accepted, but it cannot be ignored.**

**Realistically, not all risks associated with underground construction can be entirely avoided or mitigated.**




**HAZARD** is an event that may cause damage, and is associated with a probability of occurrence and losses.

**RISK** is generally defined as the product of the probability of occurrence and the resulting losses (impact, consequence).

**RESIDUAL RISK** is the risk remaining after primary-risk response.

## Risk should be properly managed by:

- risk identification,
- risk quantification,
- definition of the responses to risk

**LEGEND – Risk Scale**

- Negligible
- Low
- Medium
- High

| | | PROBABILITY | | | | |
|---|---|---|---|---|---|---|
| | | Negligible | Unlikely | Likely | Probable | Very likely |
| IMPACT | Very high | | Face instability | | Rockbursts<br>Squeezing conditions | |
| | High | | Lowering of the | | Water Inflow | |
| | Medium | | groundwater table | | | |
| | Low | | | Inadequate | | |
| | Very low | | | support capacity | | |

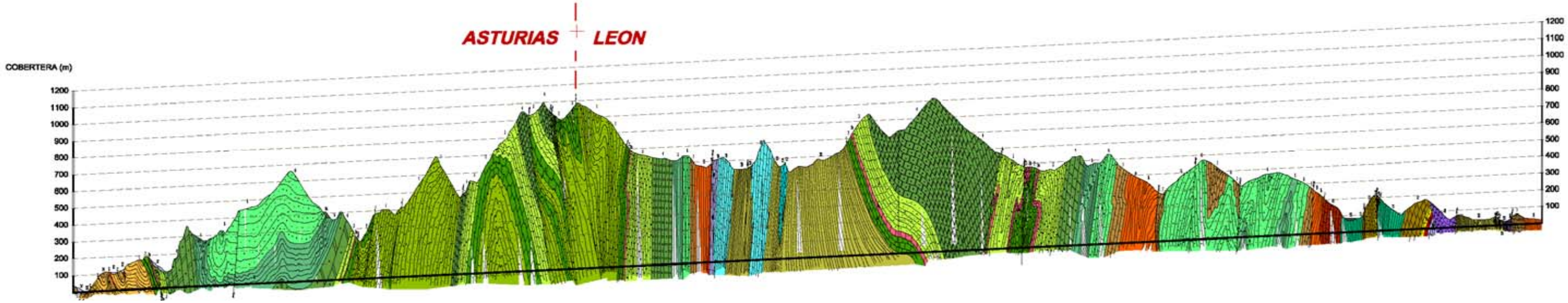
# Risk Quantification

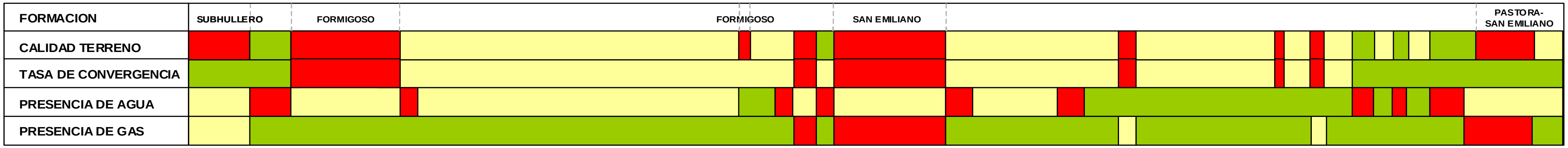
GEODATA

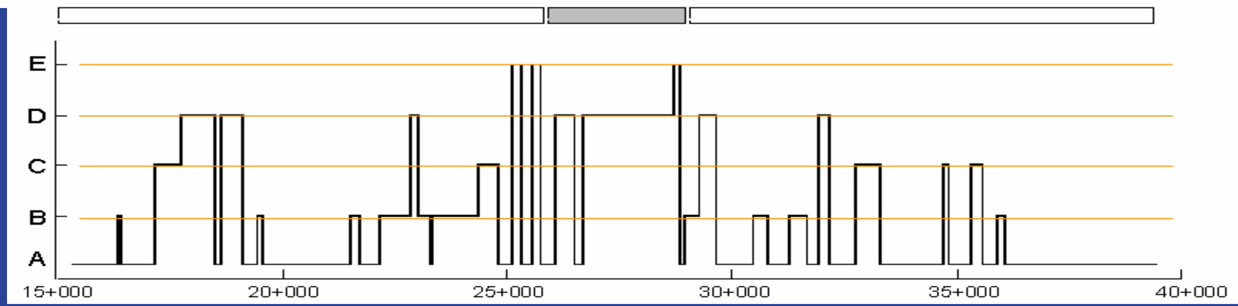
LÍNEA FFCC LEÓN-GIJÓN - VARIANTE DE PAJARES - TÚNEL DE BASE

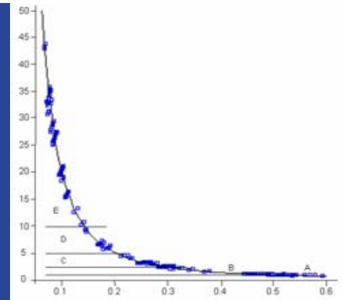
Esquema constructivo y diagrama de ejecución (plazos probabilisticos)

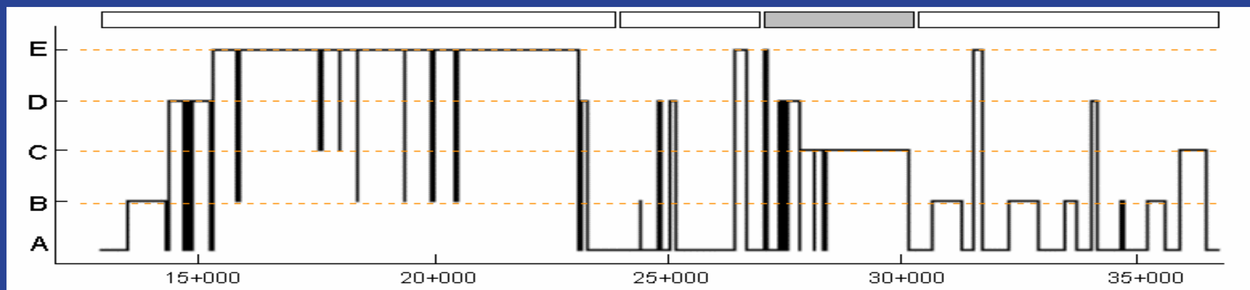
Solución base del Estudio Informativo

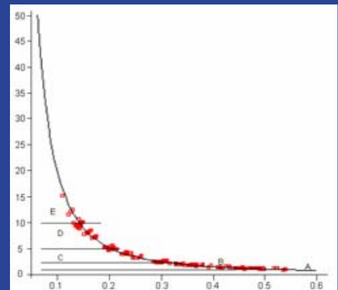


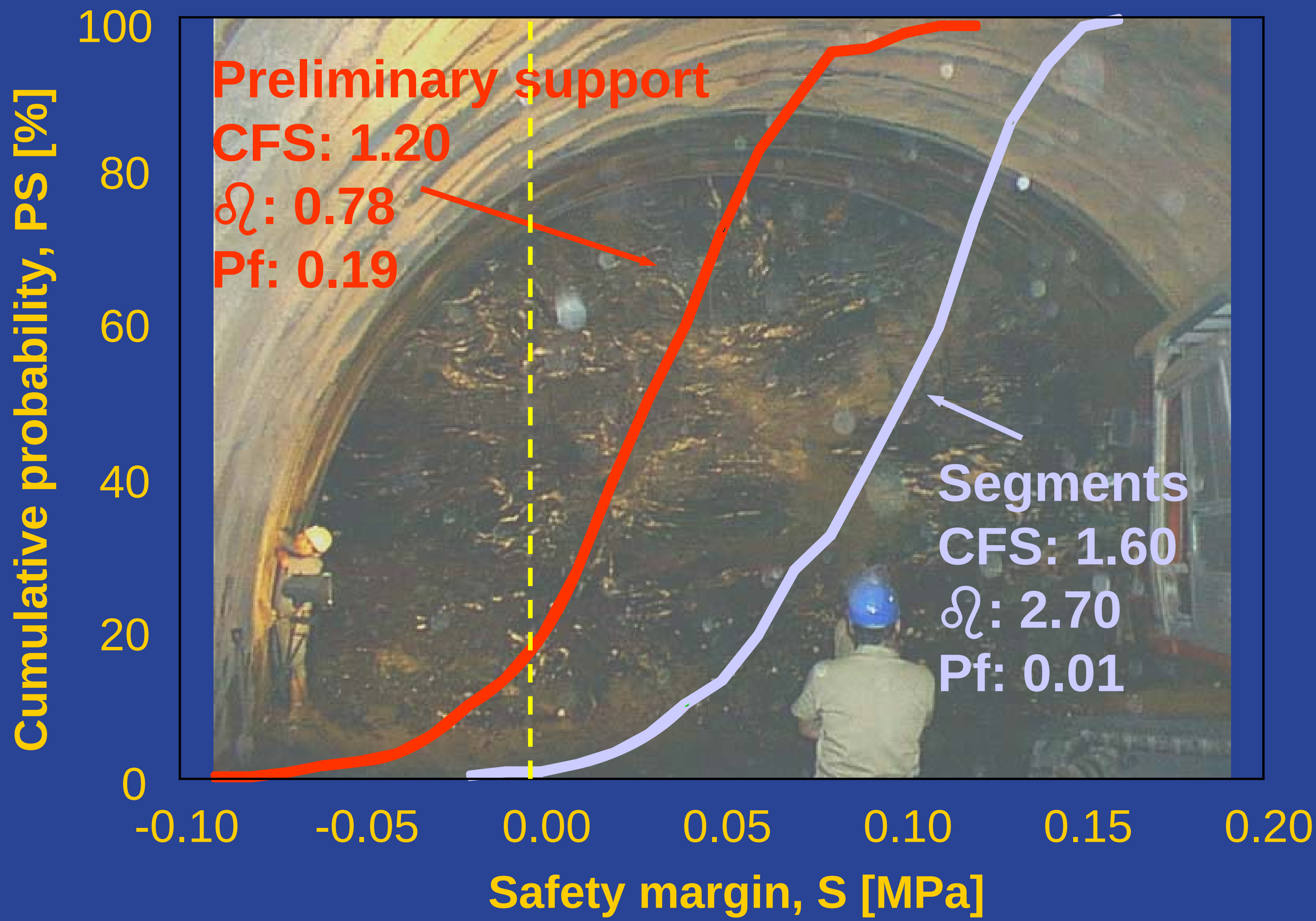





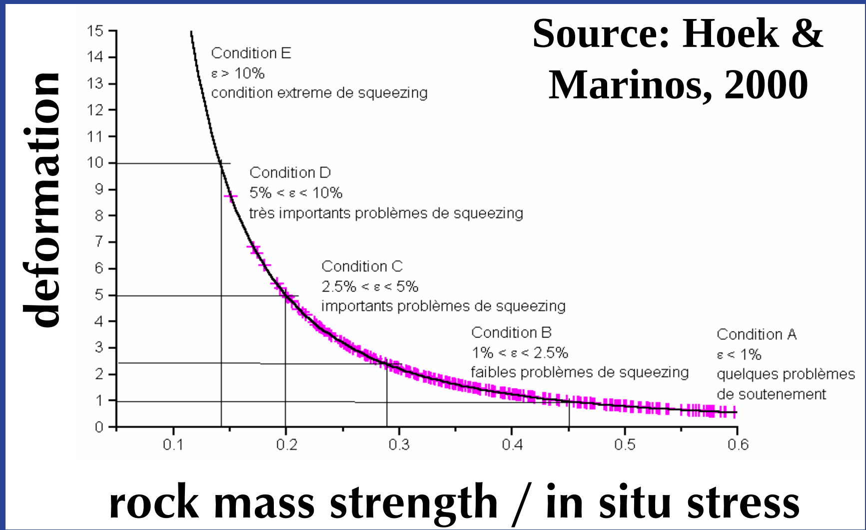



# Example of quantifying the probability of failure

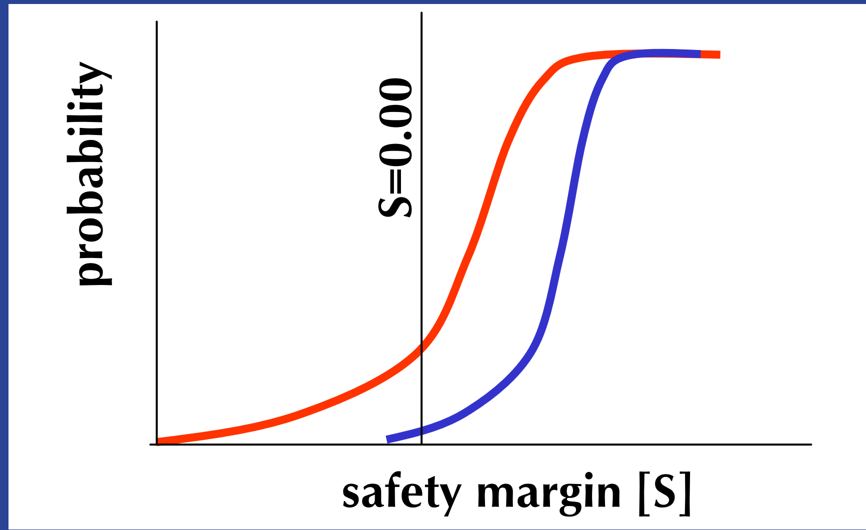


# Risk Quantification

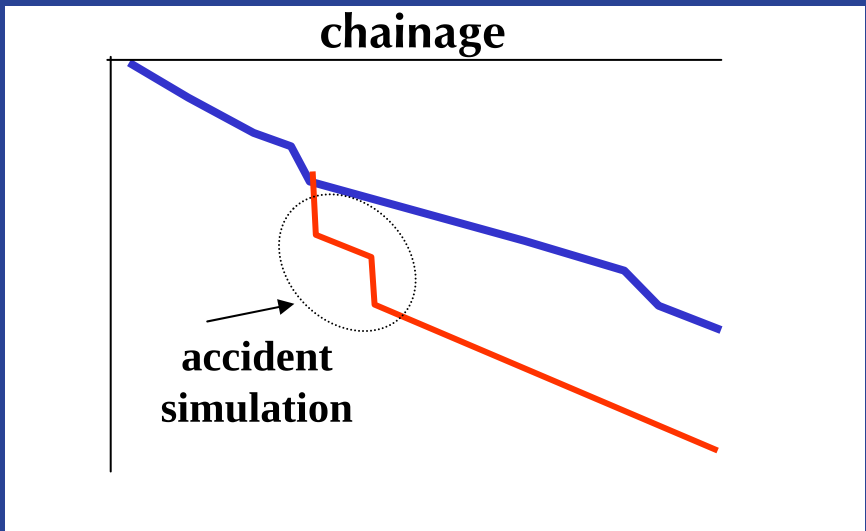
## Evaluation of rock mass behavior



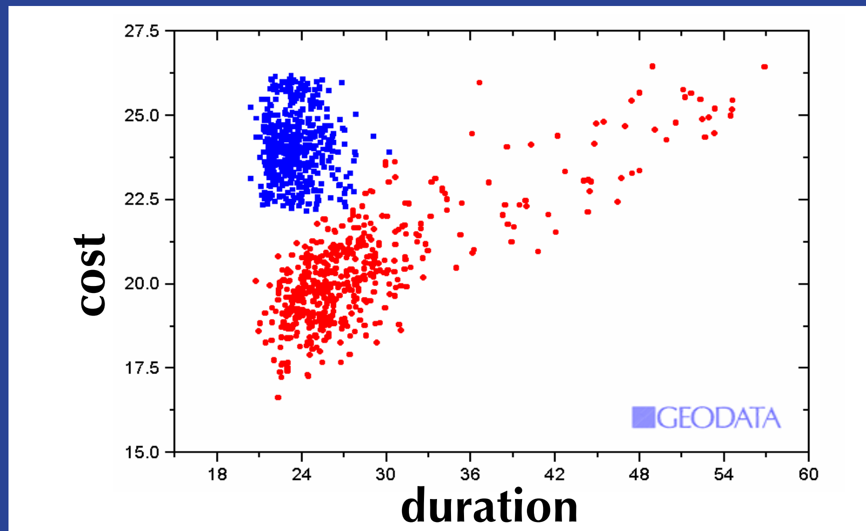

## Evaluation of section capacity



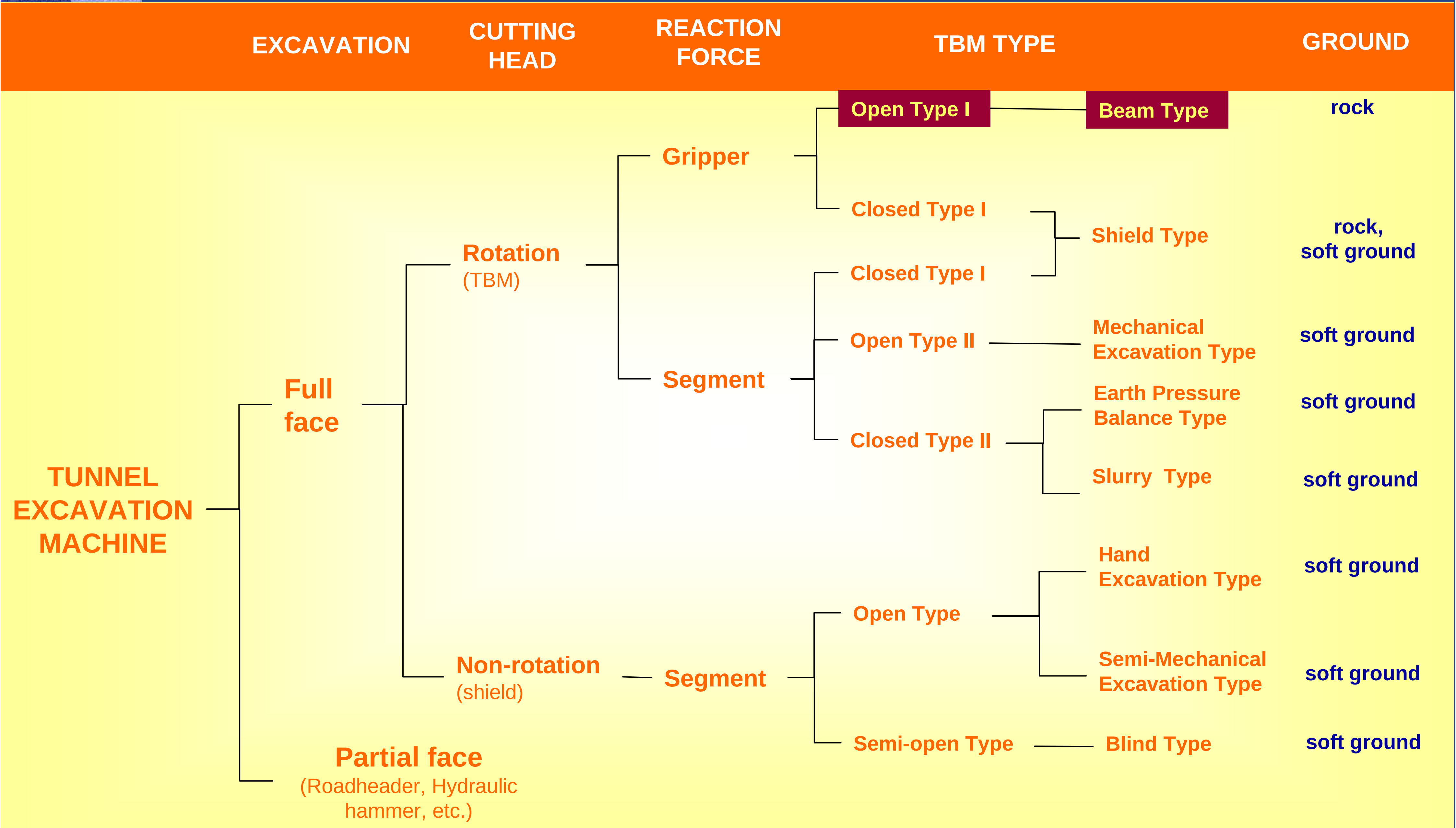

## Simulation of structural inadequacy




## Distribution of time and cost

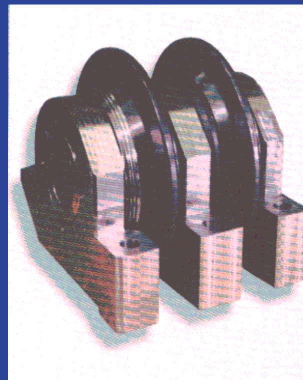


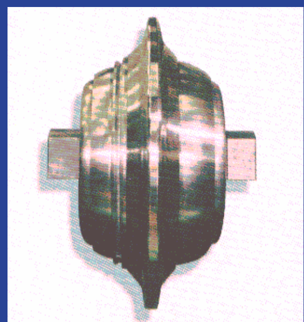
# Classification of tunnel excavation machines (ITA WG14, 2000)

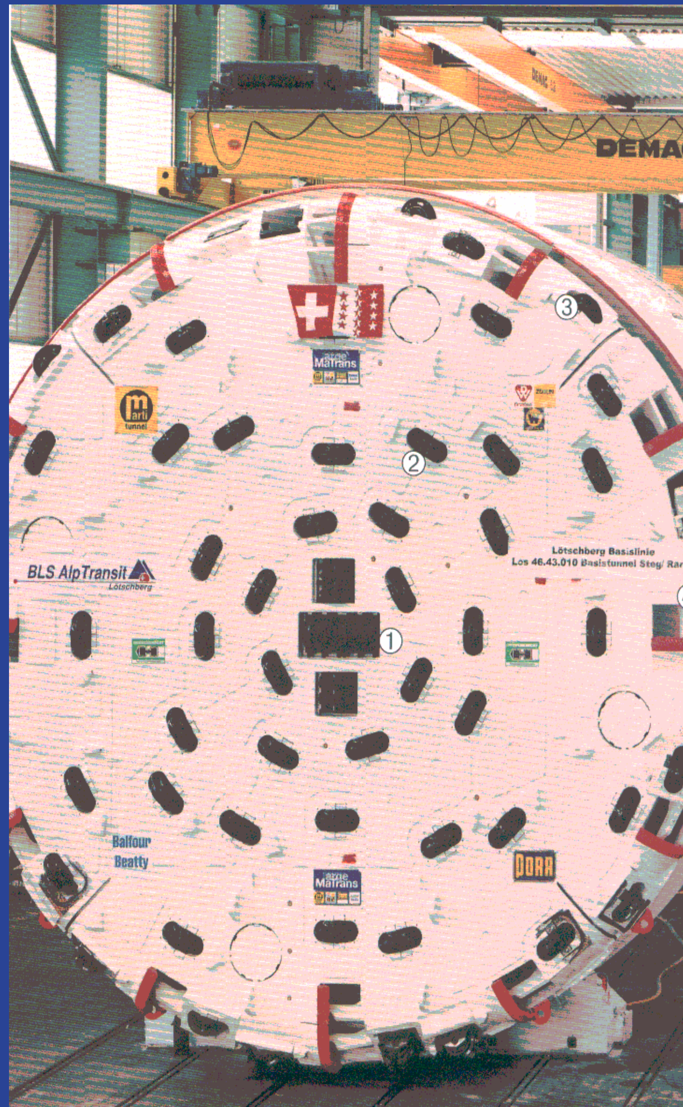


# Open gripper TBMs

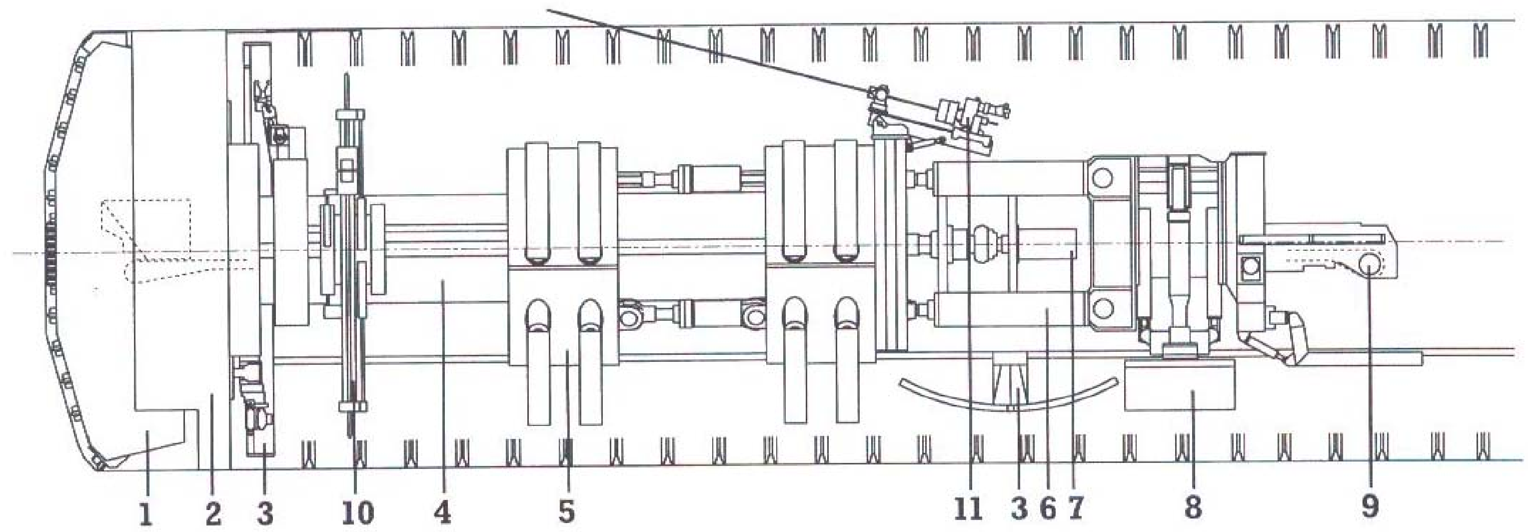
**The family of open TBMs is developed for excavating in rock.**
**The thrusting force is obtained by reacting on the grippers.**
**The head is equipped with cutting disks.**

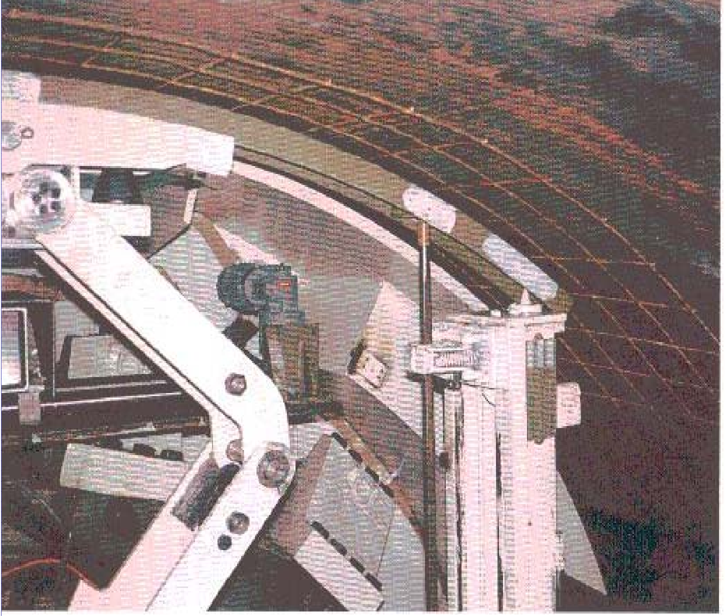




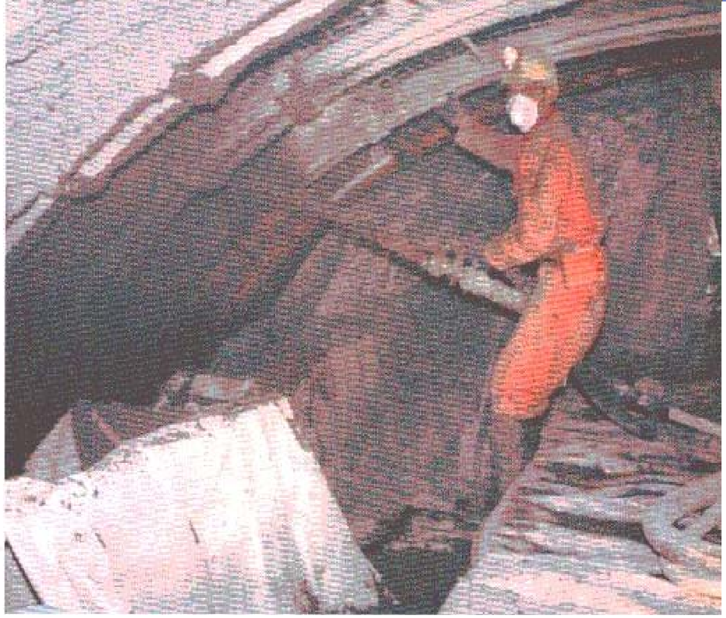
# Open TBMs




**1.** Cutter head **2.** Cutter head shield, hydraulically adjustable **3.** Support installation system and transport system **4.** Inner kelly **5.** Outer kelly, two-piece, with grippers and adjusting cylinders **6.** Thrust cylinder **7.** Cutter head drive **8.** Rear support **9.** Belt conveyor **10.** Roof-bolting drill **11.** Probe drill



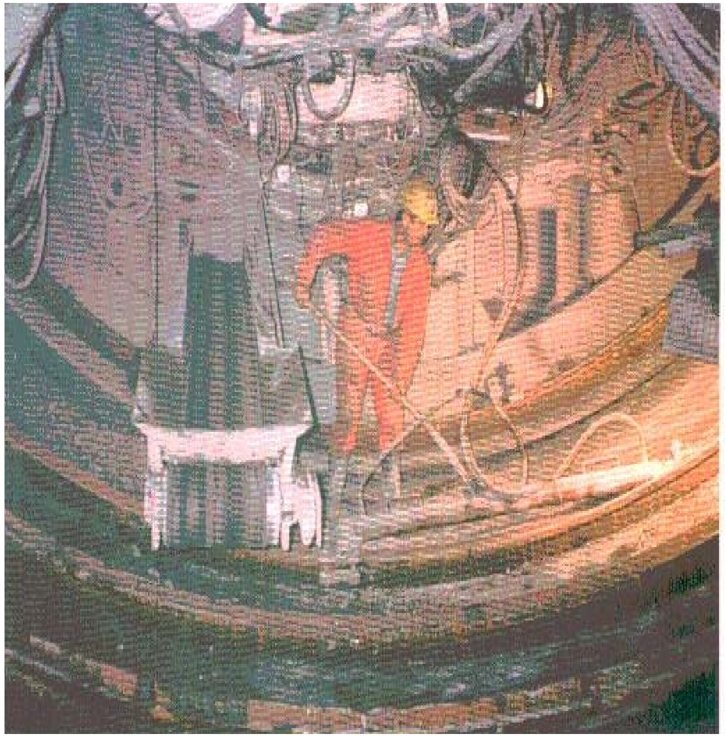
Ribs and wire-mesh support are mechanically installed directly behind the cutter head



Shotcreting can start immediately behind the cutter head

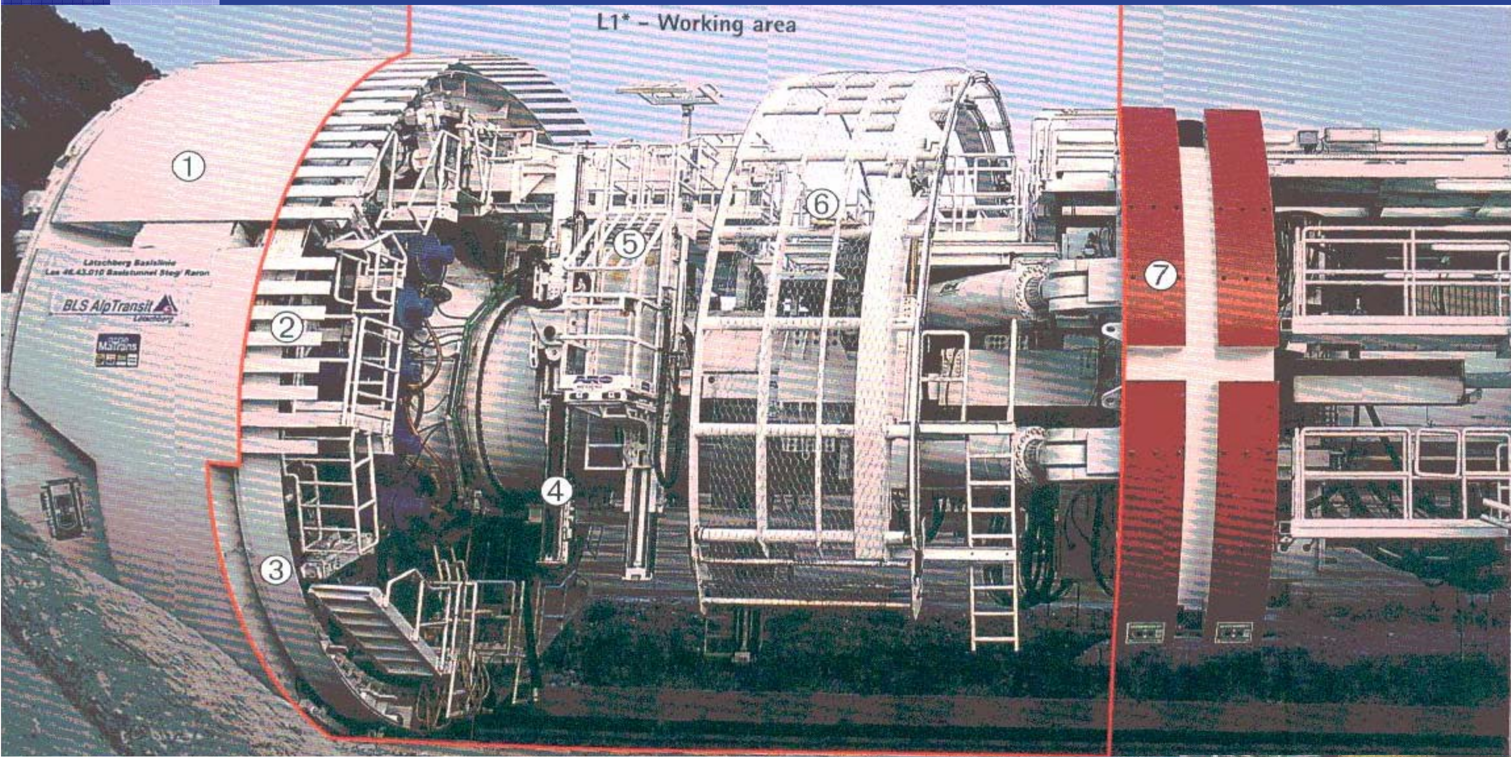
Space is available on the machine for fitting of wire-mesh support and ring beams

The support rings installed are bridged to avoid damage; the geometry of the grippers is tailored to this.

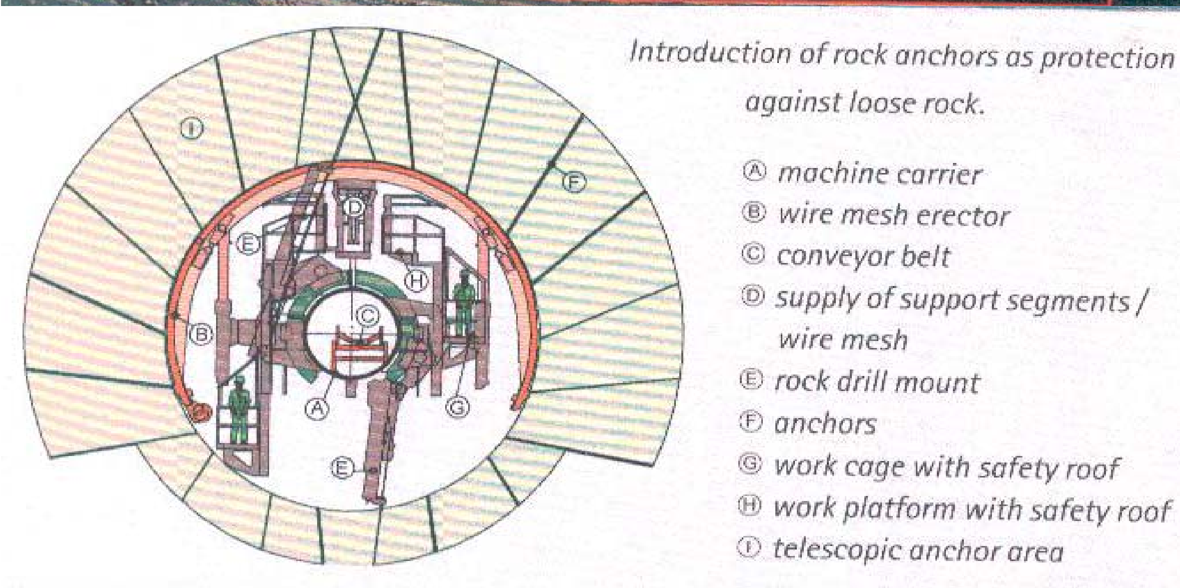


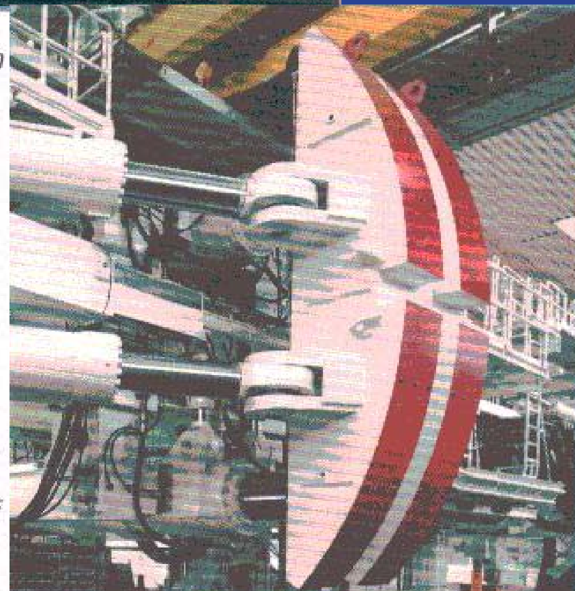
The clearance underneath the machine allows invert cleaning and transport of invert segments.

# Open TBMs – the working zone




The requirement of stabilizing the tunnel immediately behind the cutting head, when excavating in fractured rock, led to the development of effective and versatile systems for the installation of the support.

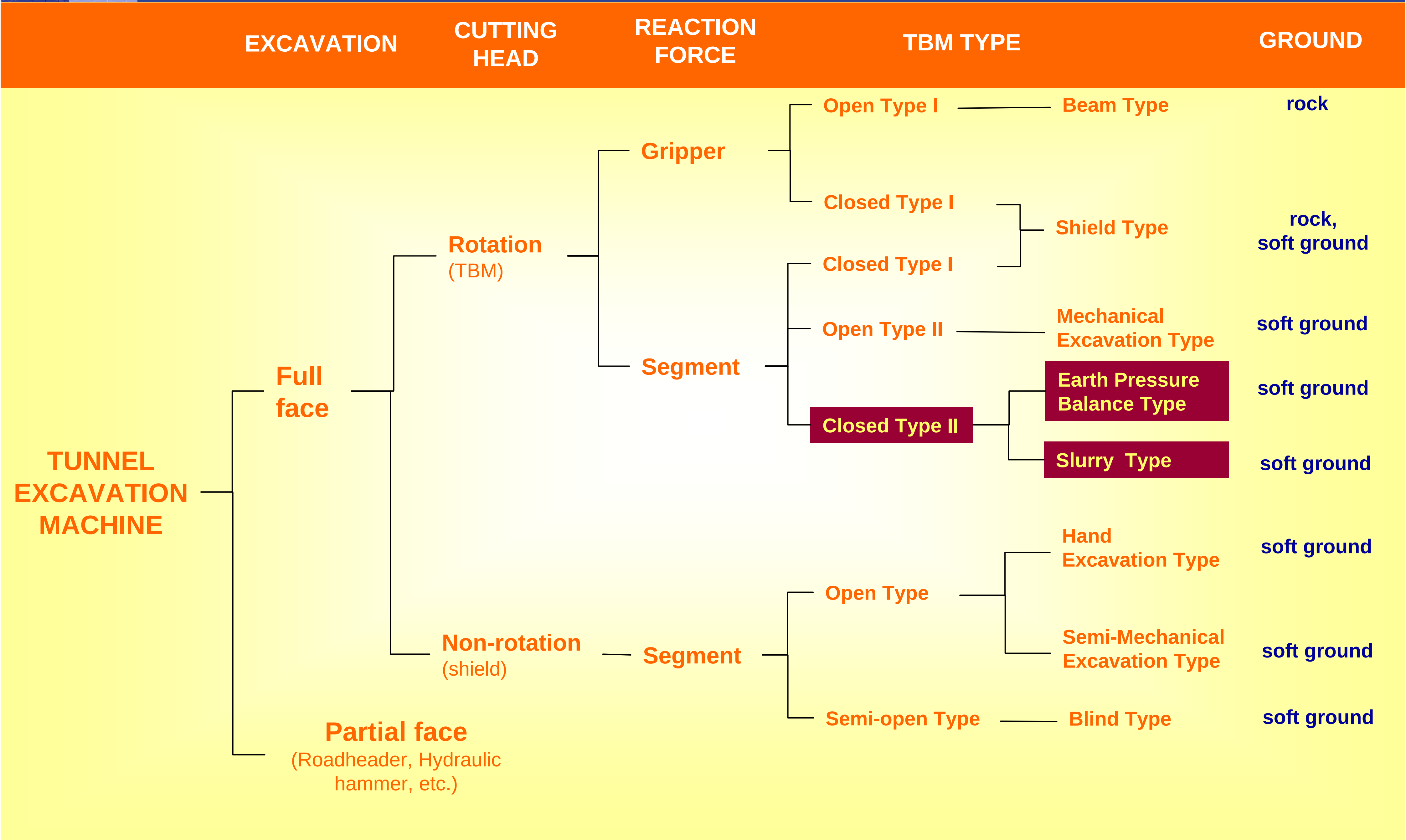


The only means of face support is mechanical


TBM Herrenknecht - Lötschberg Base Tunnel ($\phi$=9.43m)

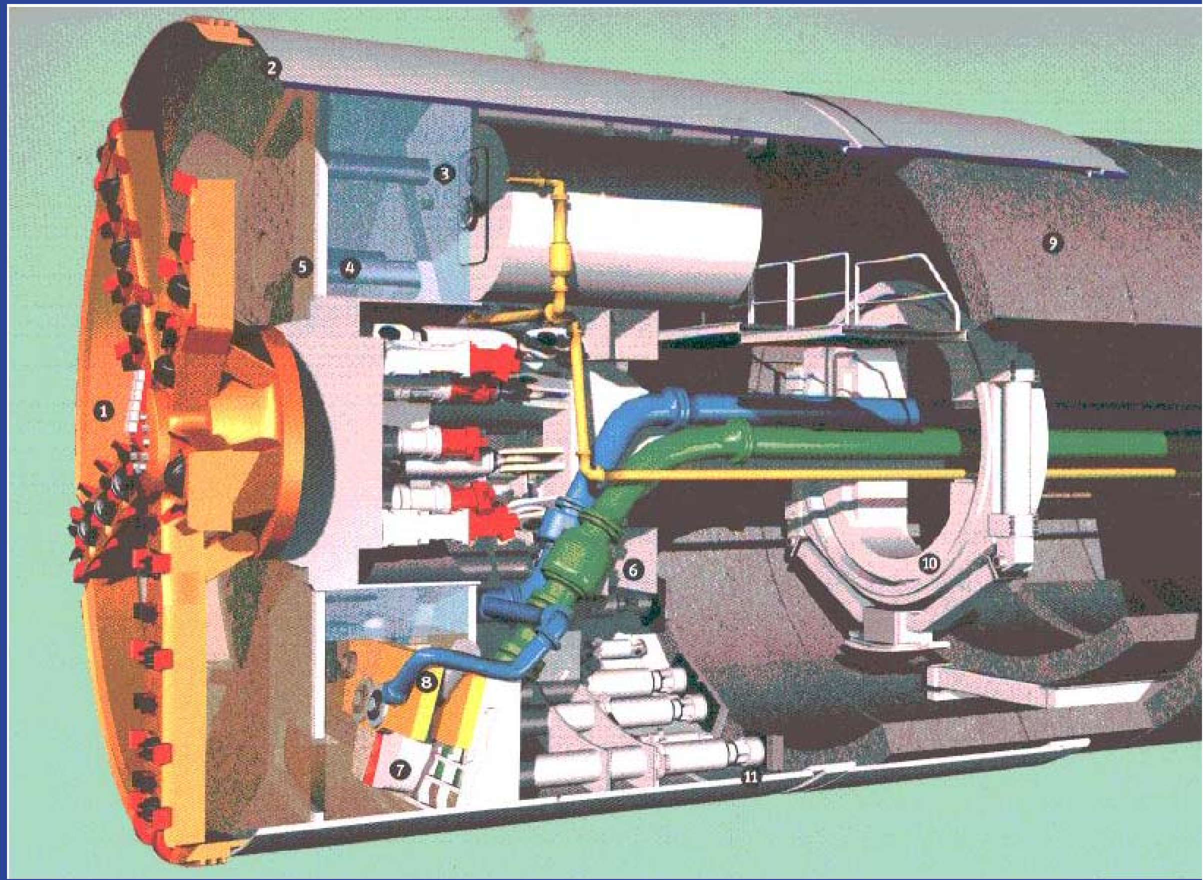
# Classification of tunnel excavation machines (ITA WG14, 2000)

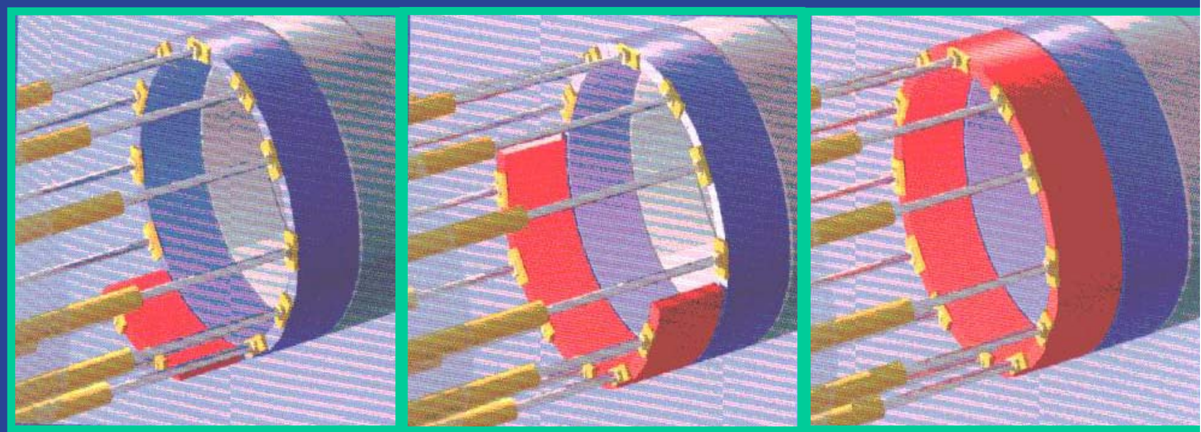


# Slurry Shield

Another category of excavation machines is developed for poor geological conditions, the so-called closed shields, equipped for pressurizing the excavation face.

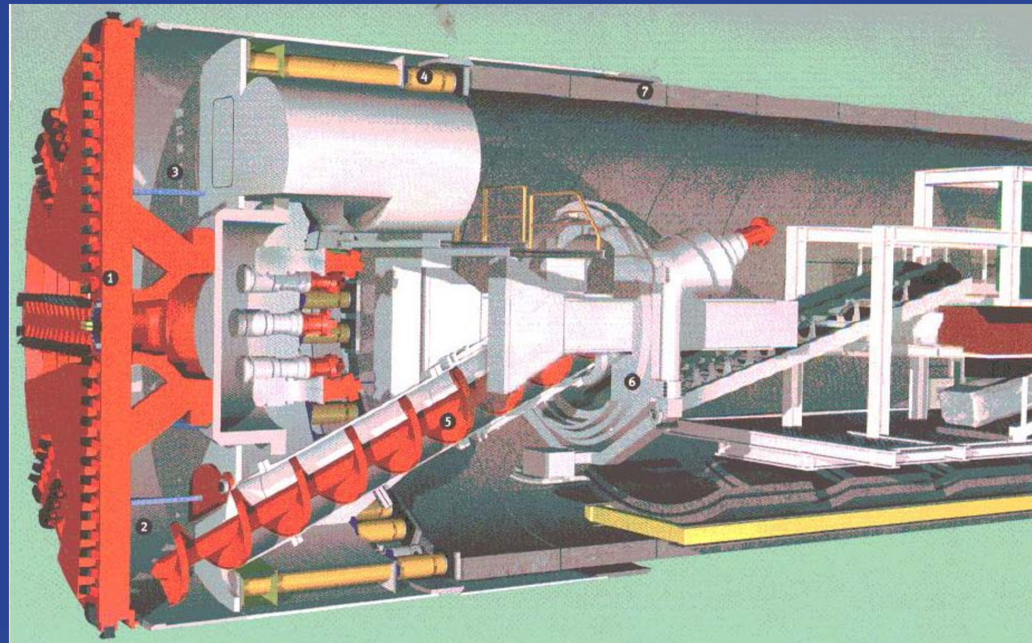
Advanced technologies guarantee the hydraulic tightness towards the inside of the shield creating the possibility of working with non-mechanical means of face support: Slurry shields and EPB Shields.

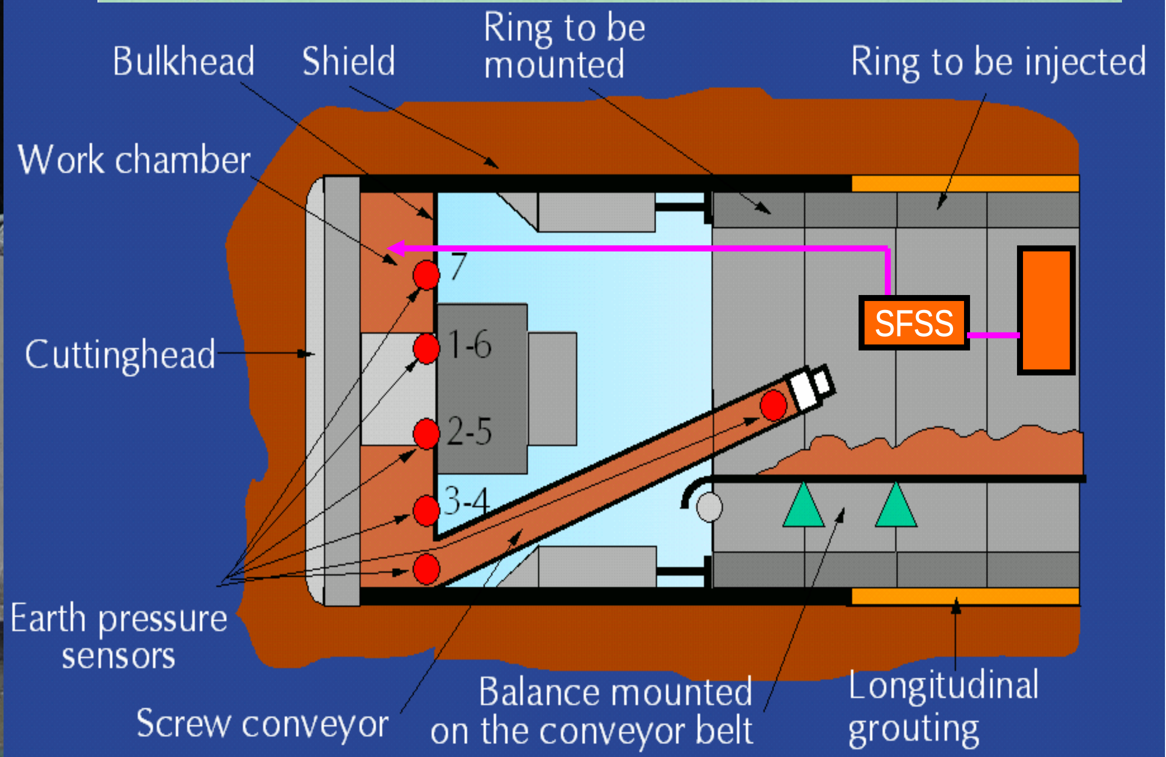




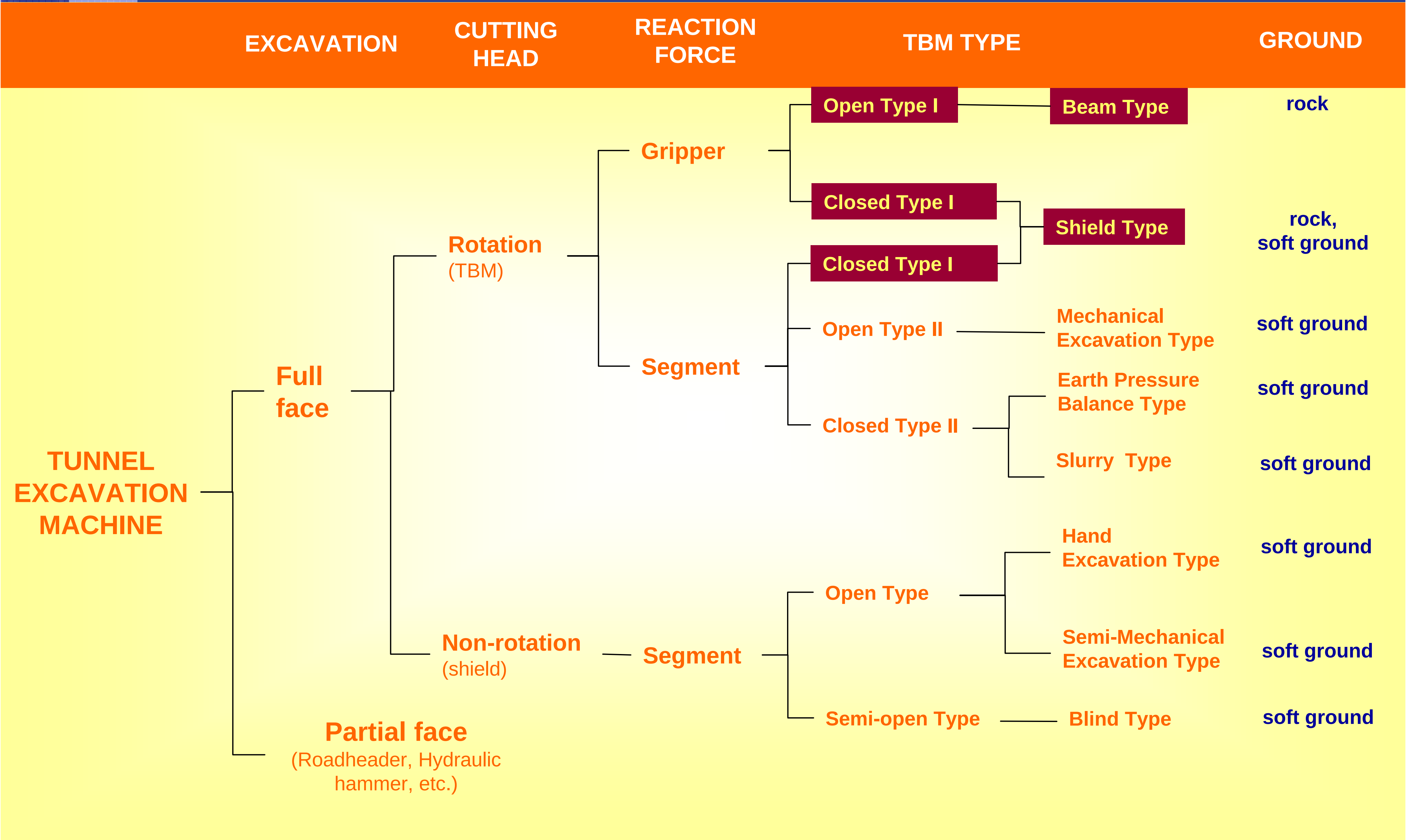
# Earth Pressure Balance

One of the two Herrenknecth EPB-TBMs used for excavating the 7km of tunnels of Porto Metro



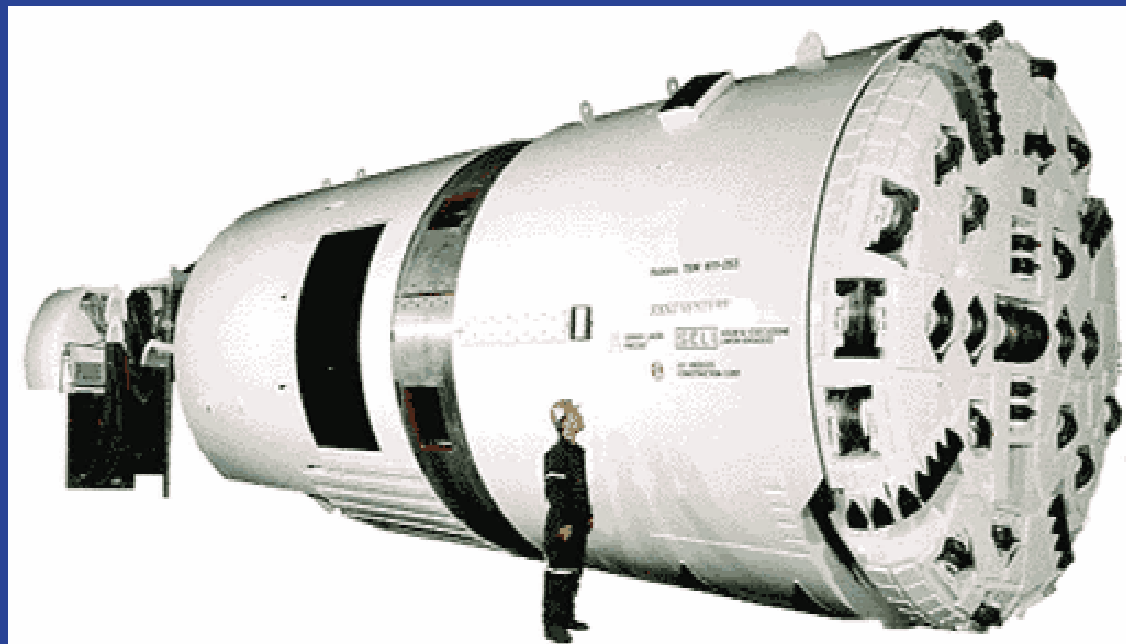


# Classification of tunnel excavation machines (ITA WG14, 2000)



a) open

b) shielded

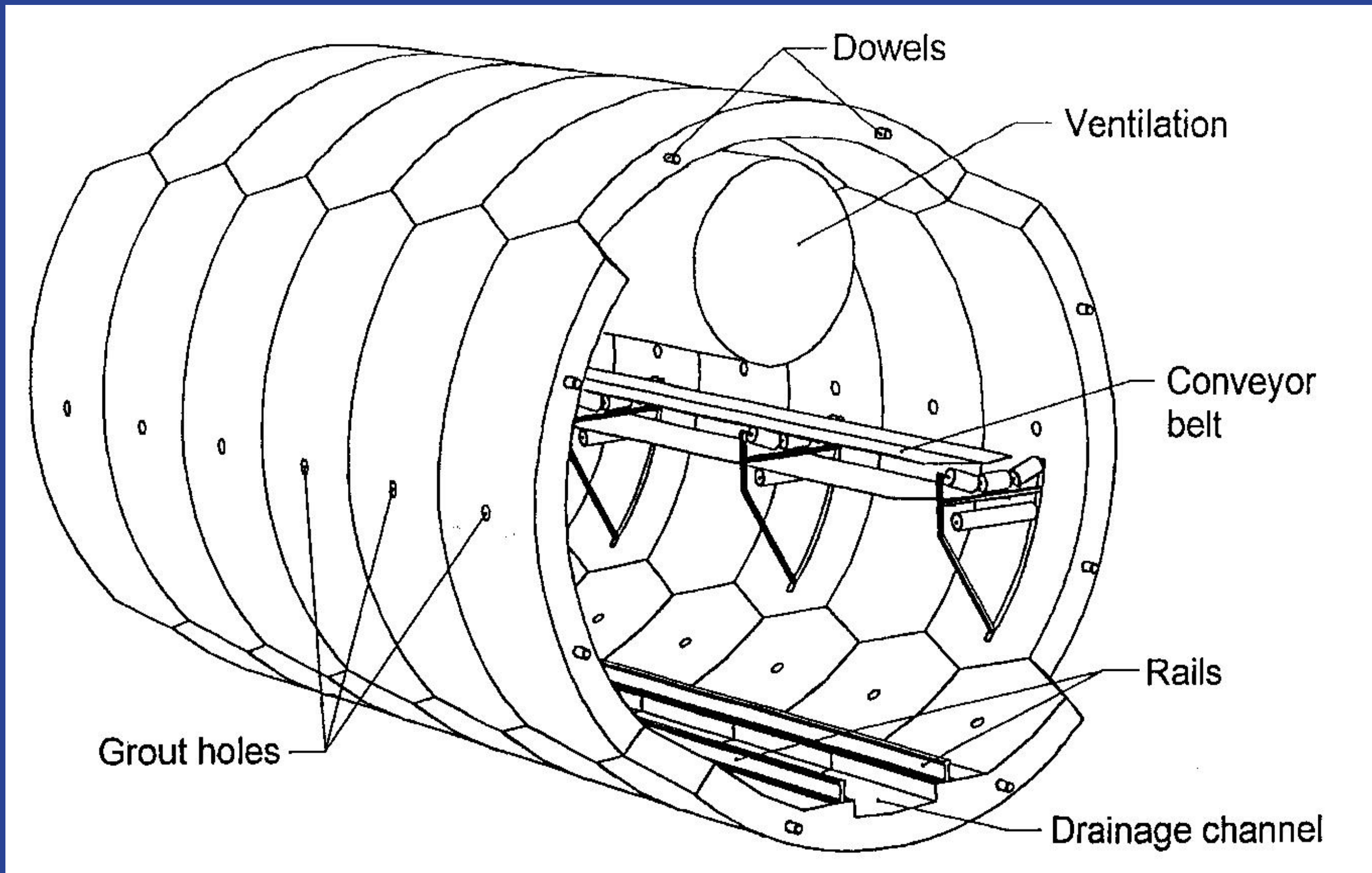


c) Double shield Robbins TBM

**The first significant hybrid machine is a double-shield TBM produced by Robbins in the early ’80: grippers + lining installed under the protection of a shield.**

# Rapid lining installation for straight tunnels: the hexagonal segments

**With the offset in the circumferential joints it is possible to erect half of a ring while the TBM is thrusting its gripping units against the second half of the previously installed ring.**



# Possible solutions

**Fracturing degree**

**In situ stress**

**Stable**

**Unstable wedges**
- bolts in L1
- wire-mesh in L1, if required

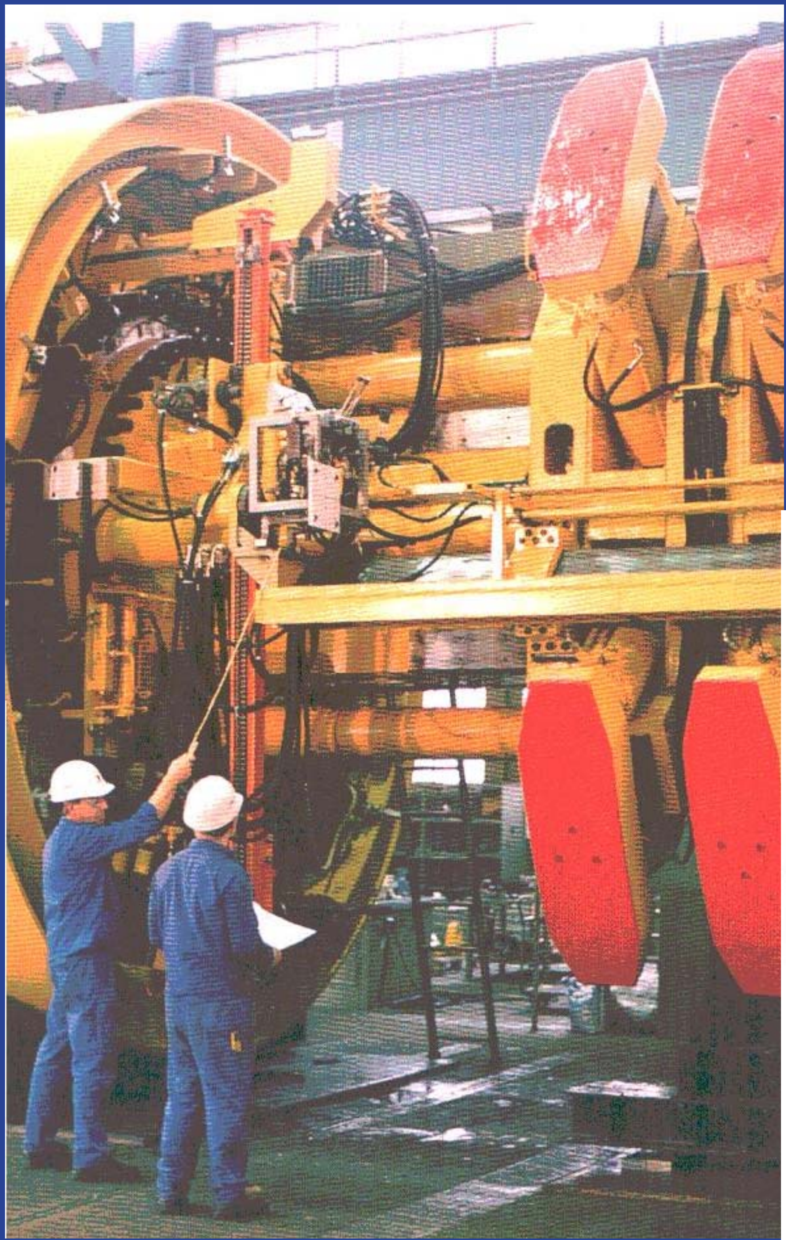
**Crumbling**
- plane head
- small protection shield
- pre-reinforcement in advance
- drainage system
- ribs + wire-mesh in L1
- shotcrete in L1/L2

**Rock burst**
- convex head
- small protection shield
- bolts + wire-mesh in L1
- deformable support
- shotcrete in L2

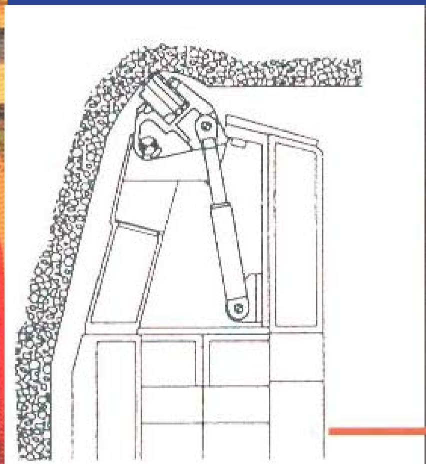
**Squeezing**
- plane head
- overcutting
- requalification of the rock mass ahead
- bolts in L1
- short shield/absent/ with loopholes
- conical shield
- bentonite injections
- deformable support
- extended gripper surfaces/thrust on segments
- shotcrete in L2

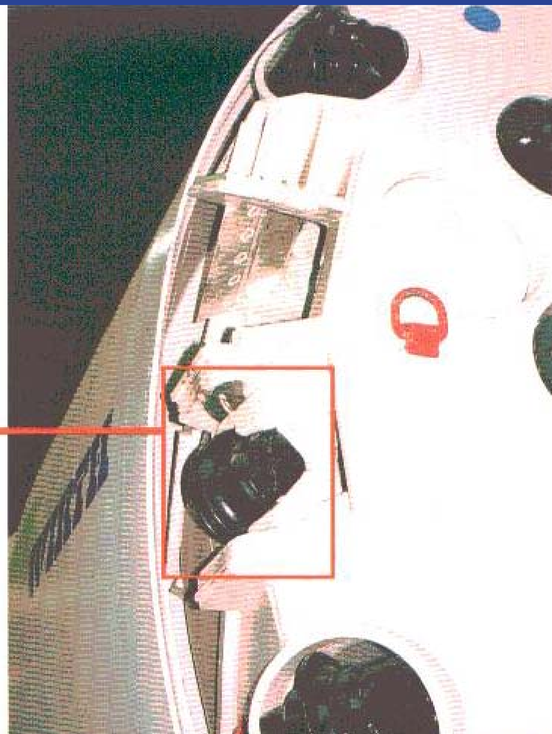
LEGEND: **Open TBM** **Double shield**

**The innovations are effective when a multidisciplinary approach is activated**

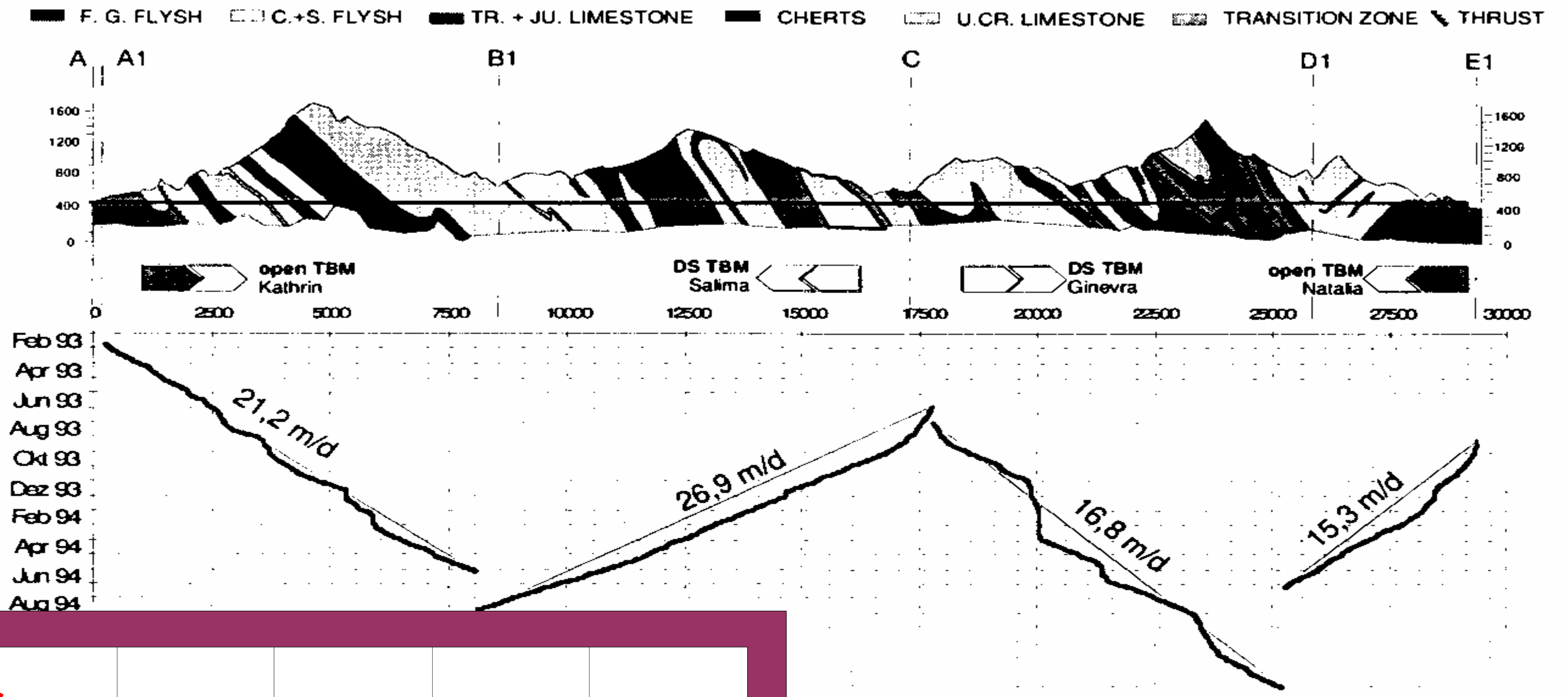


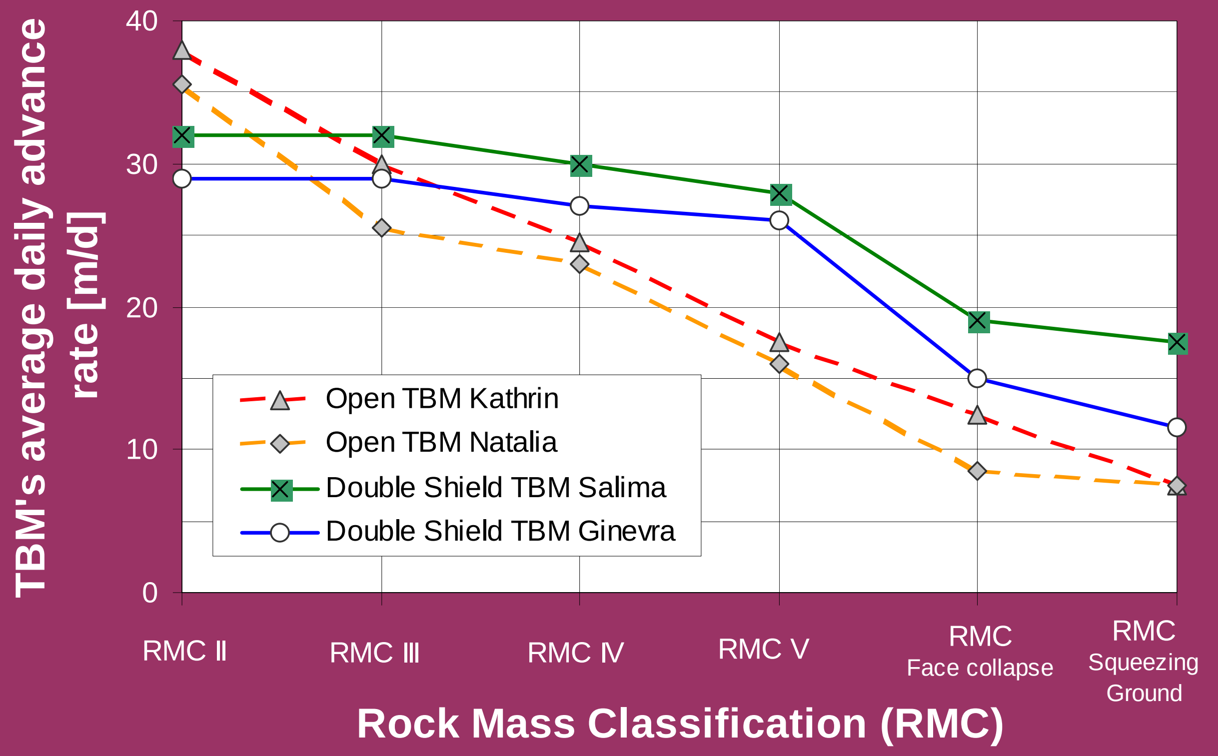
**Hydraulically adjustable enlarging cutters make it possible to increase the bore diameter as and when required**





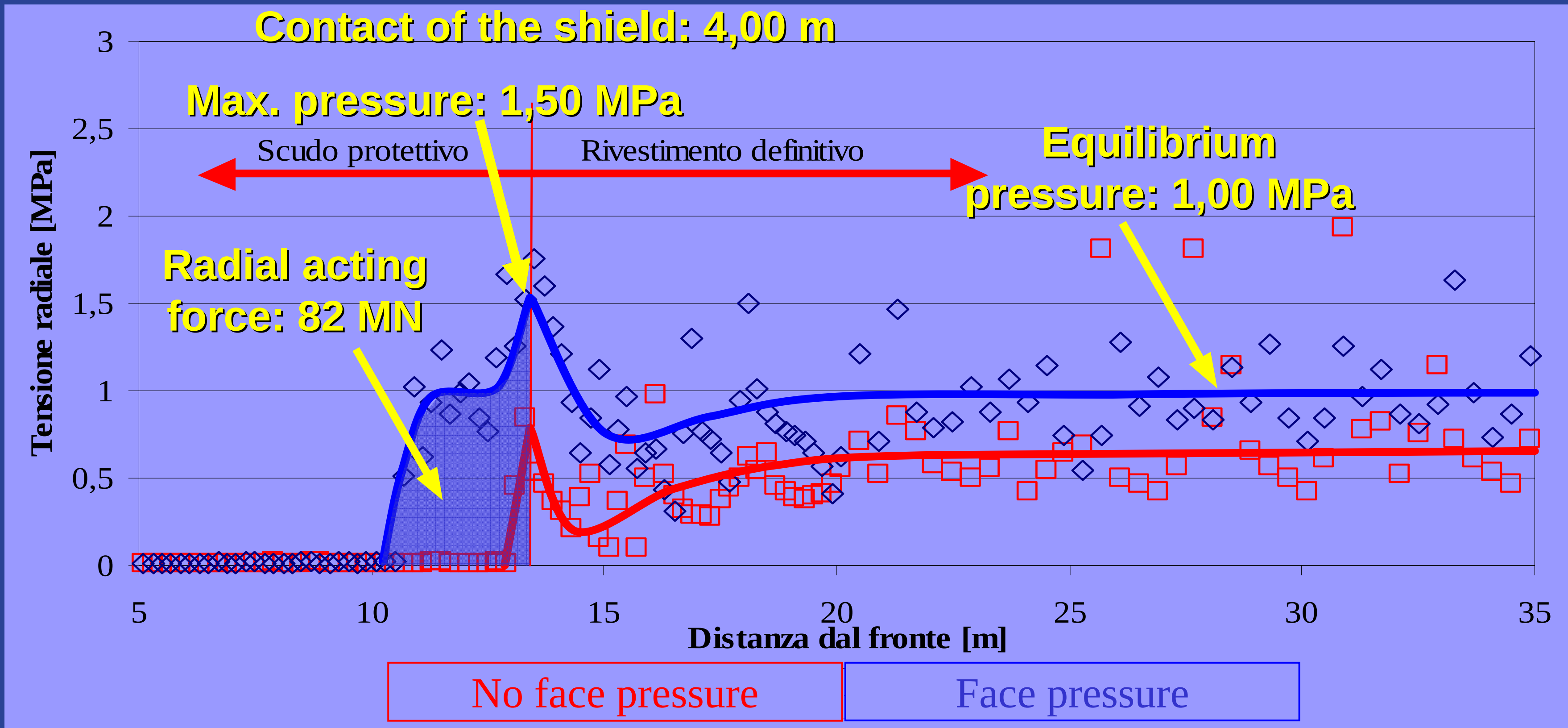
# Short double shield




# Evinos Tunnel – Greece

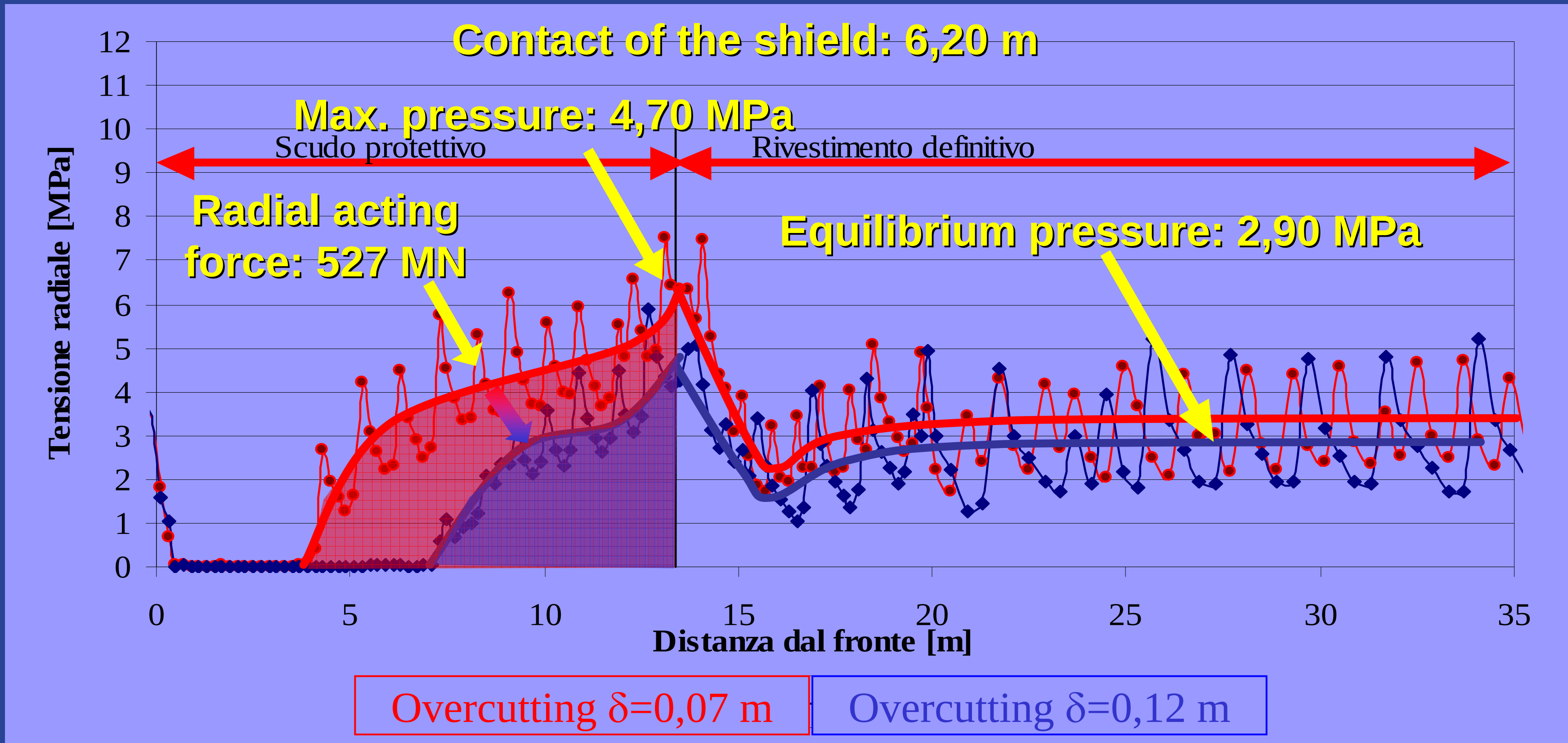
# The model takes into account the pressure of the cutting head



## Variation induced from considering the pressure of the face

| | Non-considered pressure | | Considered pressure |
|---|---|---|---|
| Contact of the shield | 0,40 m | ⇨ | 4,00 m |
| Max. pressure acting on the shield | 0,77 MPa | ⇨ | 1,50 MPa |
| Radial force acting on the shield | (5 MN) | ⇨ | 82 MN |
| Equilibrium pressure cavity – final lining | 0,65 MPa | ⇨ | 1,00 MPa |

# Modelling at greater depth: increase of the overcutting



## Variation induced by increasing the overcutting

| | Depth h=600 m ocercutting $\delta$=0,07 m | | Depth h=600 m overcutting $\delta$=0,12 m |
|---|---|---|---|
| Contact of the shield | 9,40 m | ⇨ | 6,20 m |
| Max. pressure acting on the shield | 6,30 MPa | ⇨ | 4,70 MPa |
| Radial force acting on the shield | 1082 MN | ⇨ | 527 MN |
| Equilibrium pressure cavity – final lining | 3,35 MPa | ⇨ | 2,90 MPa |

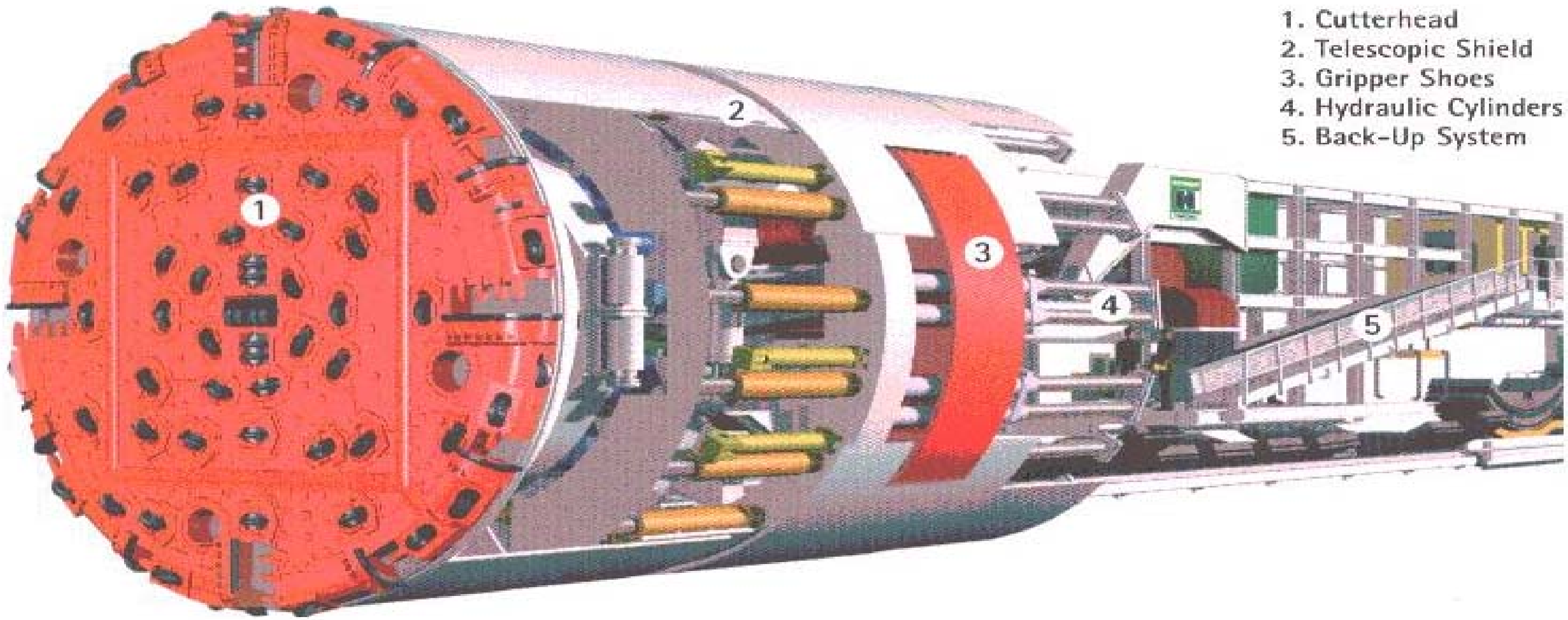
# Double shield TBM with extended surface of the grippers

## GUADARRAMA TUNNEL

**Tunnel project:**
Guadarrama, Spain · Railway tunnel
Tunnel length: 2 x 14,500m
Geology: granite, gneiss, fault zones

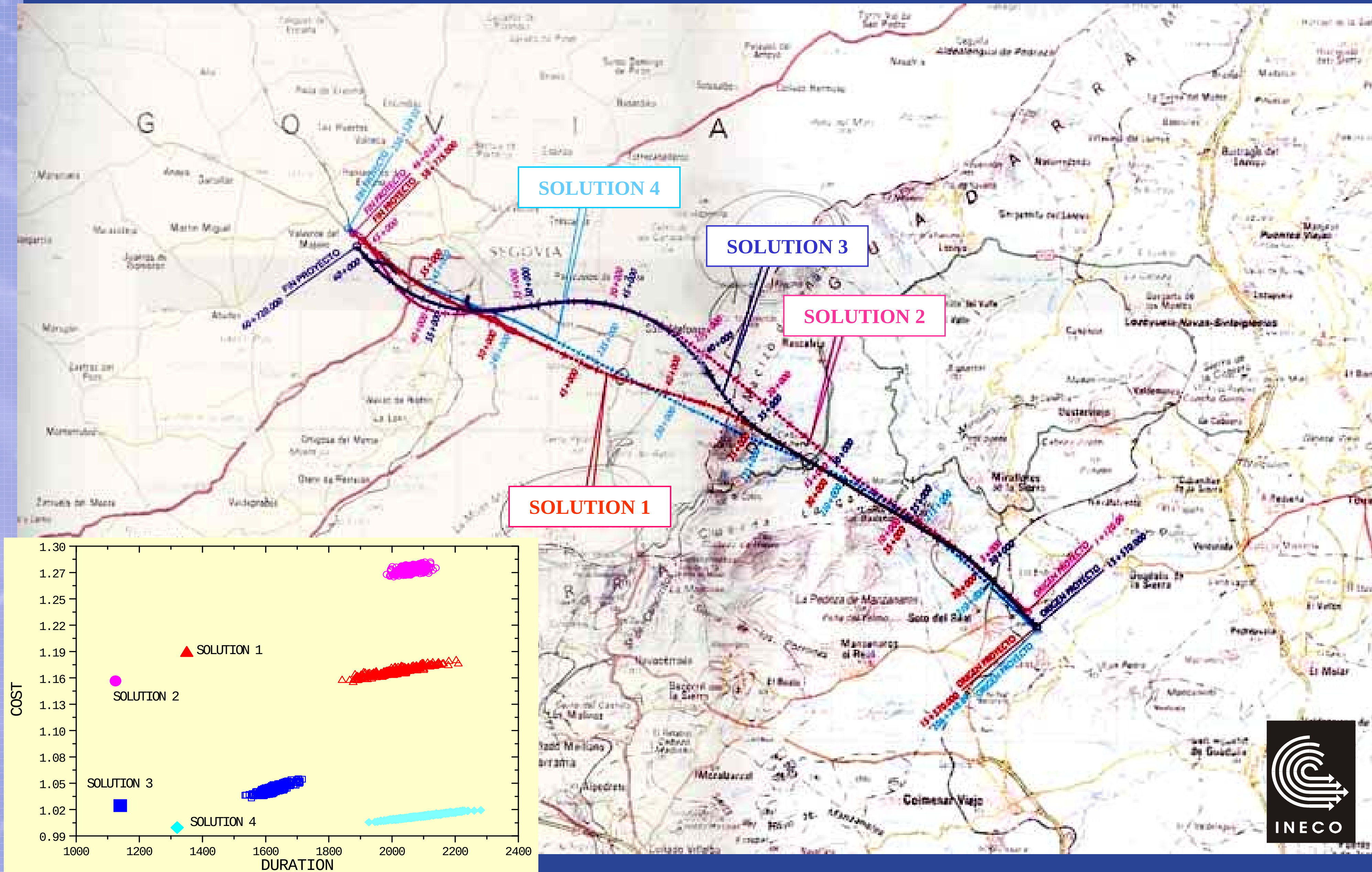
**Machine data:**
2 x Hard Rock Double Shield TBM, Ø 9.51m,
Cutterhead power 5,500kW, Weight 1,650t,
Length 220m

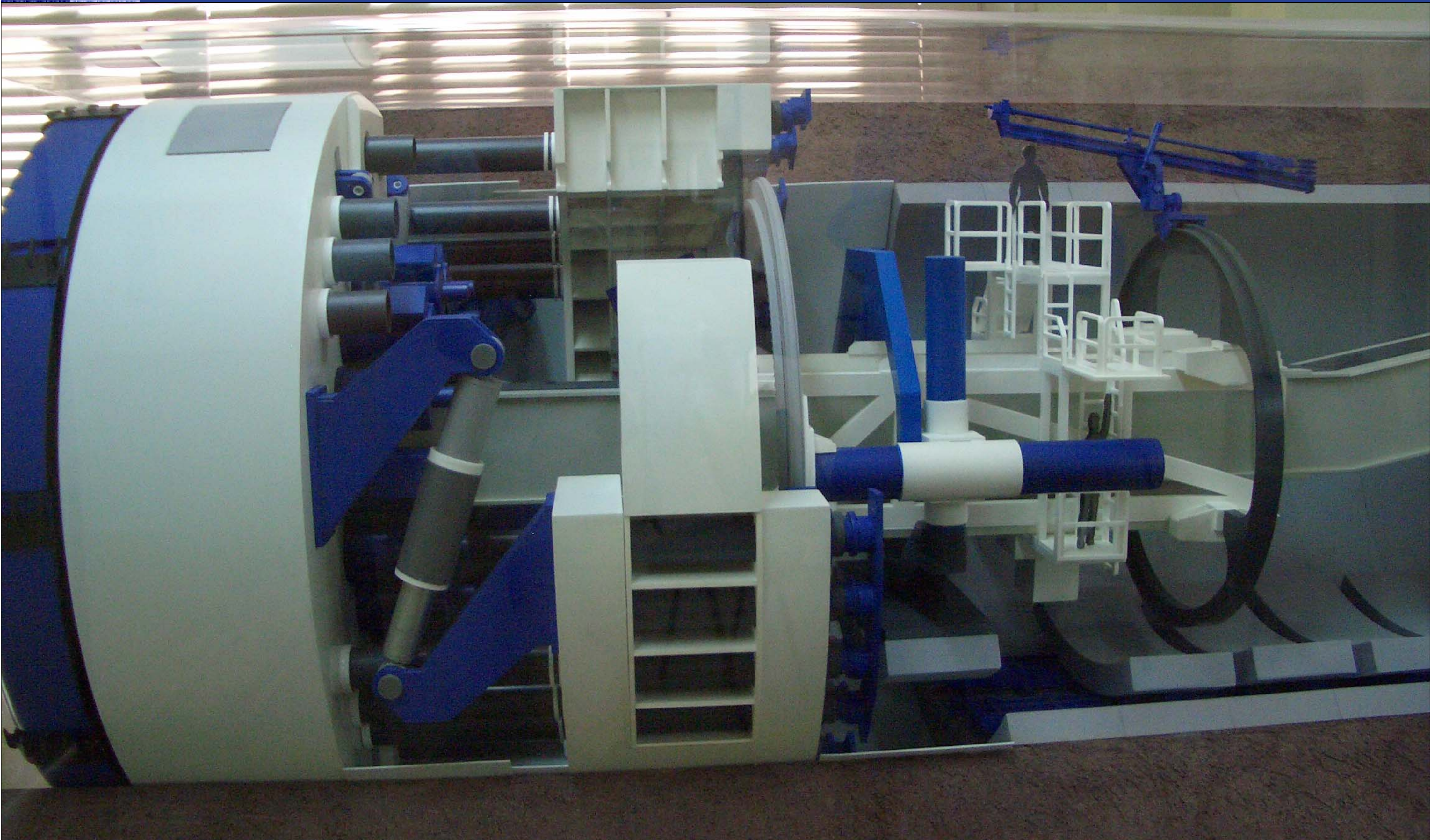
**Contractor / JV:**
S-201: FCC, ACS, Ferrovial
S-202: Comsa, Dragados, Necso, Ohl, Sacyr



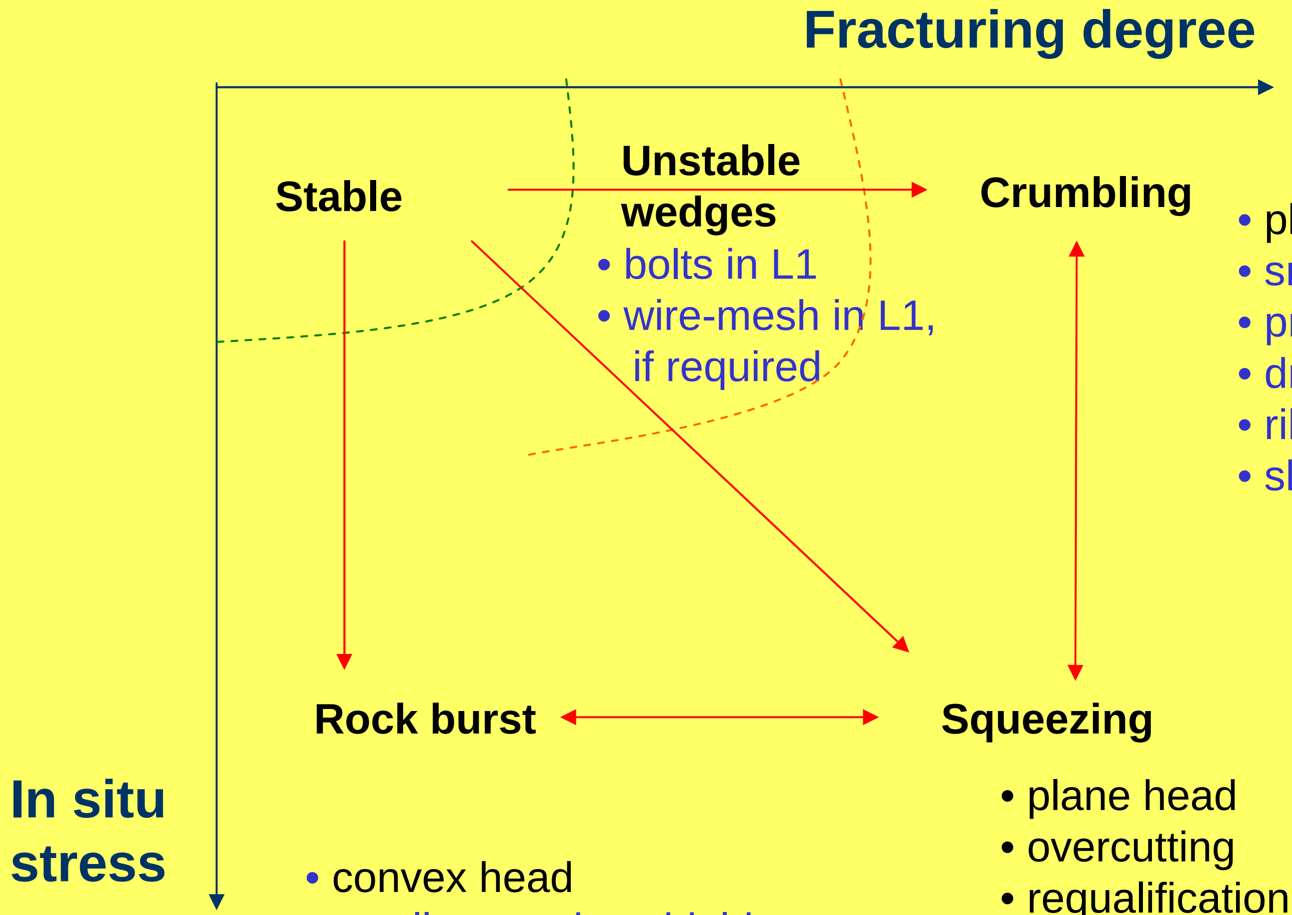

1. Cutterhead
2. Telescopic Shield
3. Gripper Shoes
4. Hydraulic Cylinders
5. Back-Up System

# High-speed railway Madrid-Segovia: Guadarrama Tunnel





# Possible solutions




**Unstable wedges**
- bolts in L1
- wire-mesh in L1, if required

**Crumbling**
- plane head
- small protection shield
- pre-reinforcement in advance
- drainage system
- ribs + wire-mesh in L1
- shotcrete in L1/L2

**Rock burst**
- convex head
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**Squeezing**
- plane head
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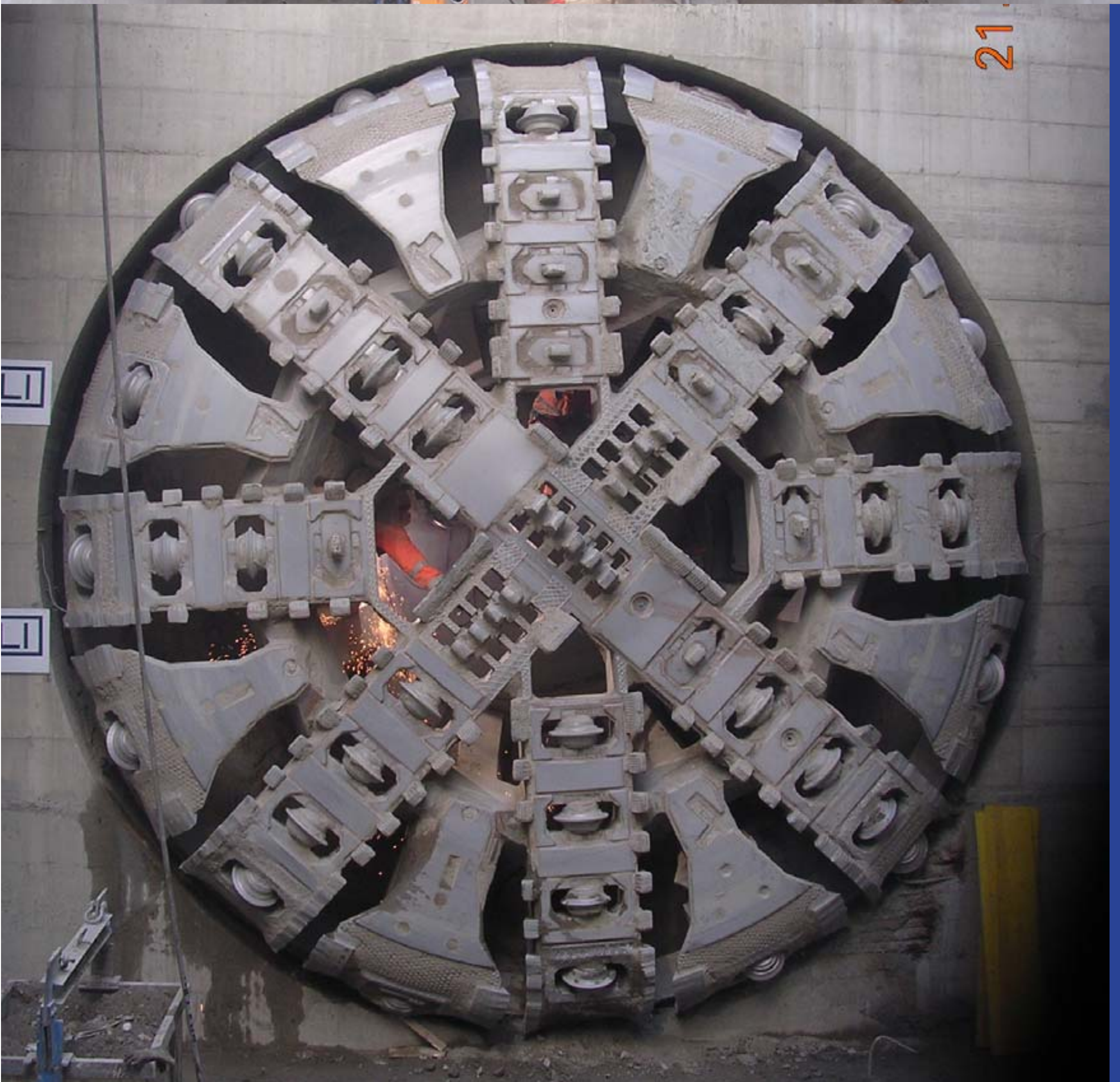
- bolts in L1
- short shield/absent/ with loopholes
- conical shield
- bentonite injections
- deformable support
- extended gripper surfaces/thrust on segments
- shotcrete in L2

LEGEND: **Open TBM** **Double shield**

**Both the infrastructure market and the complexity of the new frontiers do offer huge opportunities for further developments in the field of tunnelling in rock, especially with reference to deep and long tunnels.**

**As an example, the following point can be mentioned:**

- **improve the exploration ahead of the excavation face;**
- **manage excessive convergences;**
- **supply high counter-pressures to the tunnel face.**


21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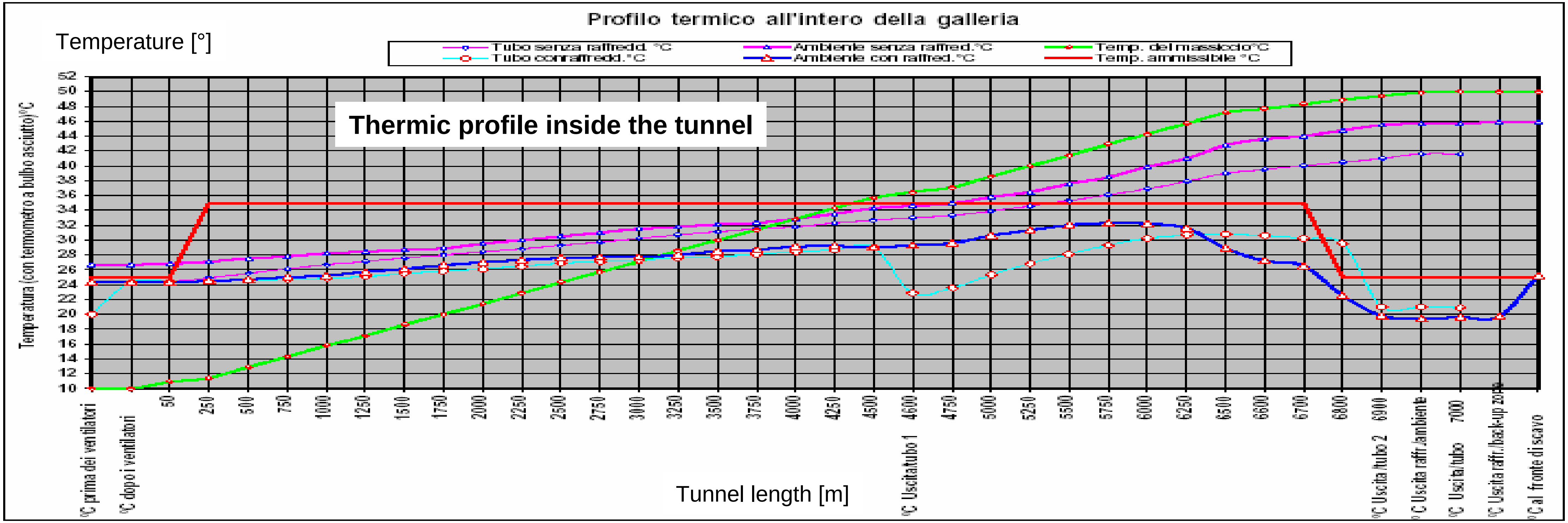
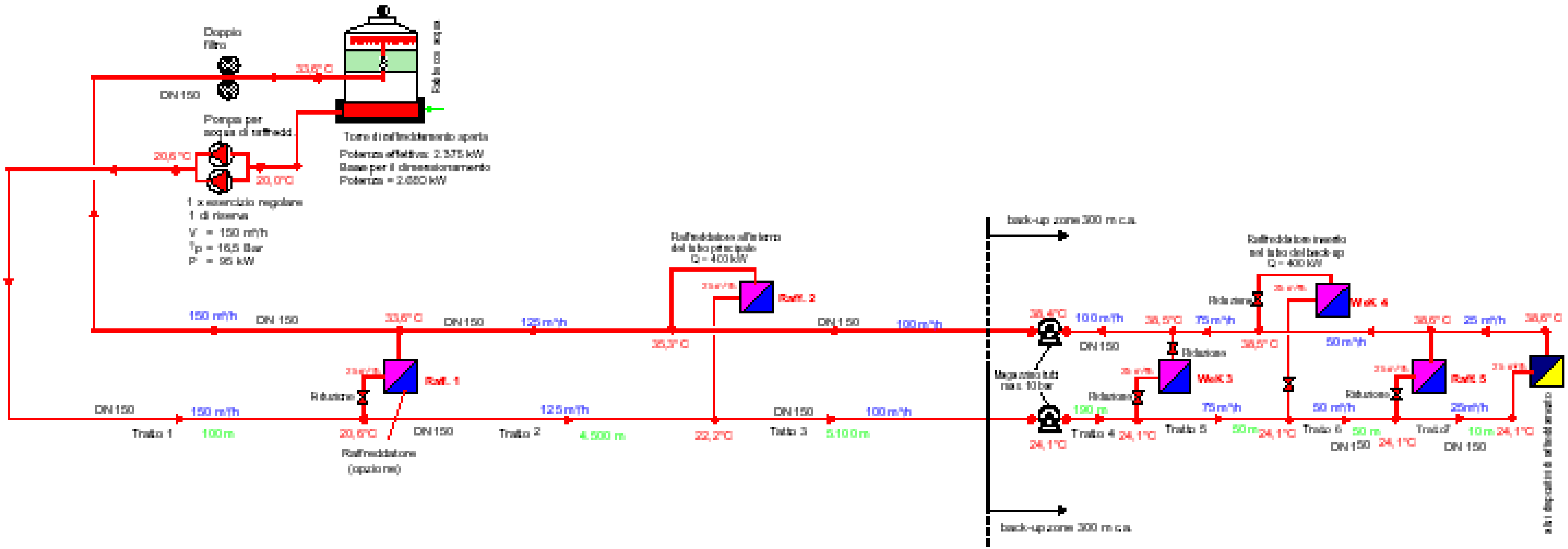
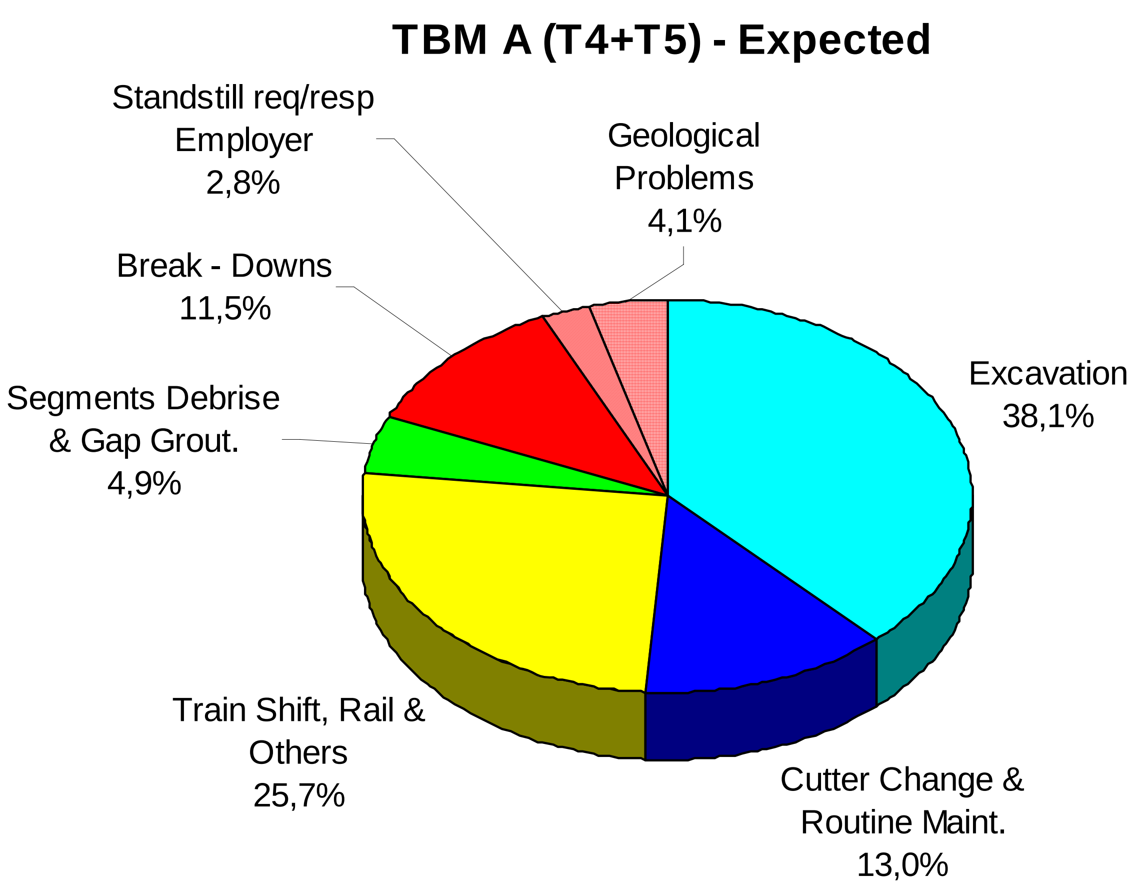


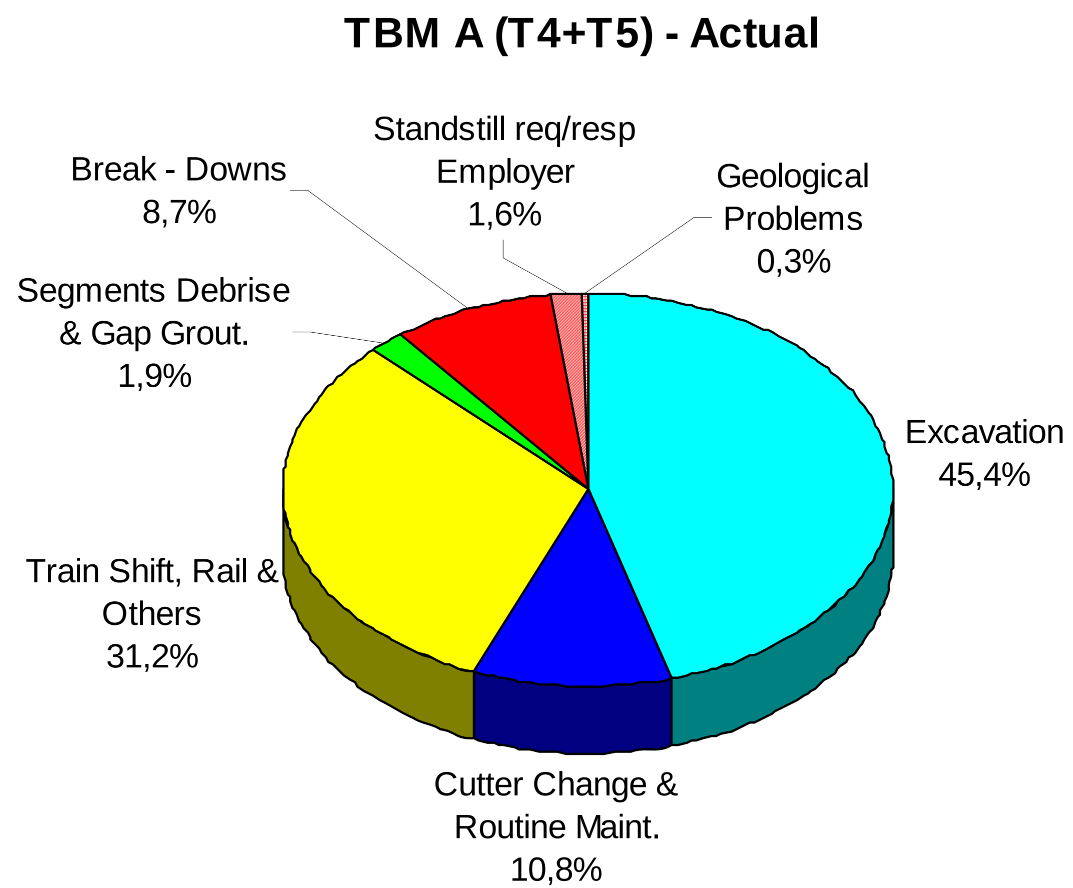
Profilo termico all'intero della galleria
Temperature [°]
Tubo senza raffredd. °C
Tubo con raffredd. °C
Ambiente senza raffred. °C
Ambiente con raffred. °C
Temp. del massiccio °C
Temp. ammissibile °C
Thermic profile inside the tunnel
Temperatura (con termometro a bulbo asciutto) °C
°C prima dei ventilatori
°C dopo i ventilatori
°C Uscita tubo 1
°C Uscita tubo 2
°C Uscita raffr./ambiente
°C Uscita tubo
°C Uscita raffr./back-up zone
°C al fronte di scavo
Tunnel length [m]

Doppio filtro
DN 150
33,6° C
Torre di raffreddamento aperta
Potenza effettiva: 2.375 kW
Base per il dimensionamento
Potenza = 2.880 kW
Pompa per acqua di raffredd.
20,6° C
20,0° C
1 x esercizio regolare
1 di riserva
V = 150 m³/h
Raffreddatore all'interno del tubo principale
Q = 400 kW
Raff. 1
Raff. 2
WaK 3
WaK 4
Raff. 5
Riduzione
Raffreddatore (opzionale)
Tratto 1
Tratto 2
Tratto 3
Tratto 4
Tratto 5
Tratto 6
Tratto 7
back-up zone 300 m c.a.
Raffreddatore inserito nel tubo del back-up
Q = 400 kW

# The importance of the logistics and of the "auxiliary" equipments




**WANJIAZHAI - China**

# RMP: Risk quantification - Evaluation of alternatives with respect to management of unfavorable conditions

LÍNEA FFCC LEÓN-GIJÓN - VARIANTE DE PAJARES - TÚNEL DE BASE

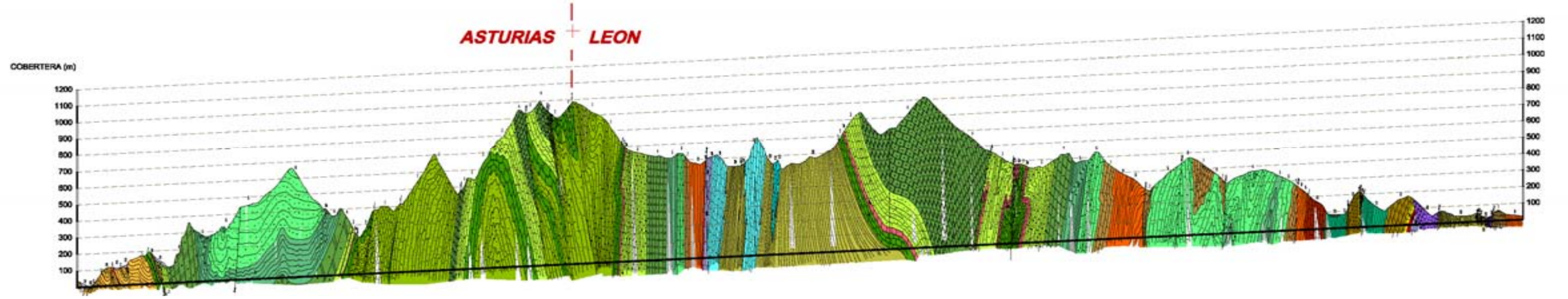
Esquema constructivo y diagrama de ejecución (plazos probabilisticos)

Solución Alternativa 1 (Fig. 2)

GEODATA

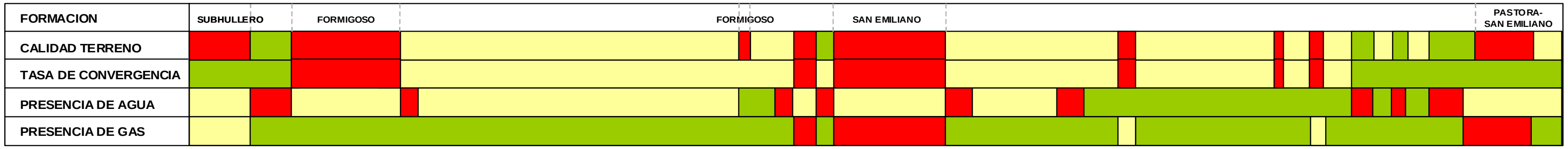
**RESUMEN LITOLOGIAS**

| | |
|---|---|
| Calizas y Dolomias: | 20% |
| Pizarras, Lutitas y Limolitas: | 40% |
| Areniscas y Conglomerados: | 30% |
| Cuarcitas: | 8% |
| Margas: | 2% |




**LEYENDA**

- Cond. favorables
- Cond. medias
- Cond. desfavorables




**VELOCIDADES DE AVANCE**

| | |
|---|---|
| TBM en roca buena/media: | 10.0-20.0m/día |
| TBM en roca mala: | 5.0-10.0m/día |
| TBM en sentido descend.: | 5.0-15.0m/día |
| CONV en roca buena: | 5.0-6.0m/día |
| CONV en roca media: | 2.5-3.0m/día |
| CONV en roca mala: | 1.5-2.0m/día |
| POZO en cualquier roca: | 2.0-2.5m/día |
| GALERIA en cualquier roca: | 6.0-7.0m/día |

**TRABAJOS PRELIMINARES**

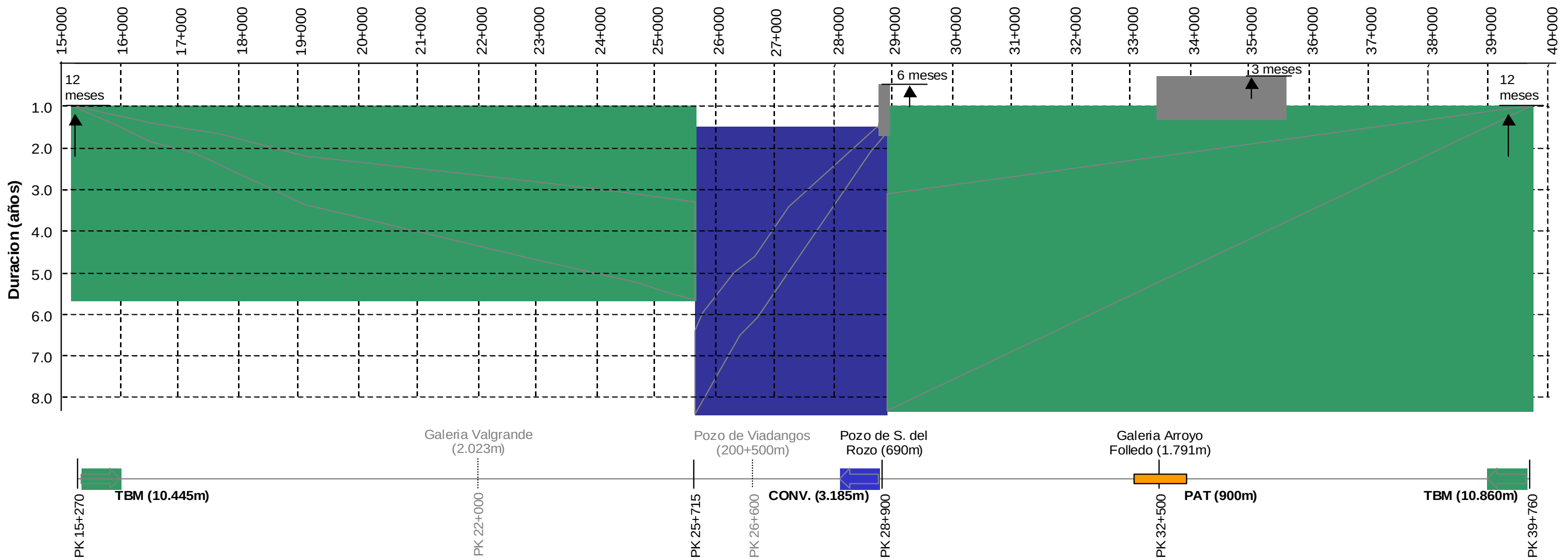
| | |
|---|---|
| Instalaciones y boquilla pozo/túnel: | 6 meses |
| Instalaciones y boquilla galeria: | 3 meses |
| Montaje TBM en pozo o galeria: | 6 meses |
| Orden, construccion y montaje TBM: | 12 meses |

**DÍAS DE TRABAJO**

24 dias/mes

**NOTAS**

1. El modelo geologico de este esquema ha sido elaborado por la UTE INECO-Geoconsult
2. Los avances se refieren al solo ciclo de excavación y soporte
3. No se ha considerado la construcción del PAT y de otras obras auxiliarias (galerias de conexión, refugios, etc.)
4. Los accesos marcados en gris no son utilizados

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# RMP: Risk quantification - Evaluation of alternatives with respect to management of unfavorable conditions

LÍNEA FFCC LEÓN-GIJÓN - VARIANTE DE PAJARES - TÚNEL DE BASE

Esquema constructivo y diagrama de ejecución (plazos probabilisticos)

Solución base del Estudio Informativo (Fig. 1)

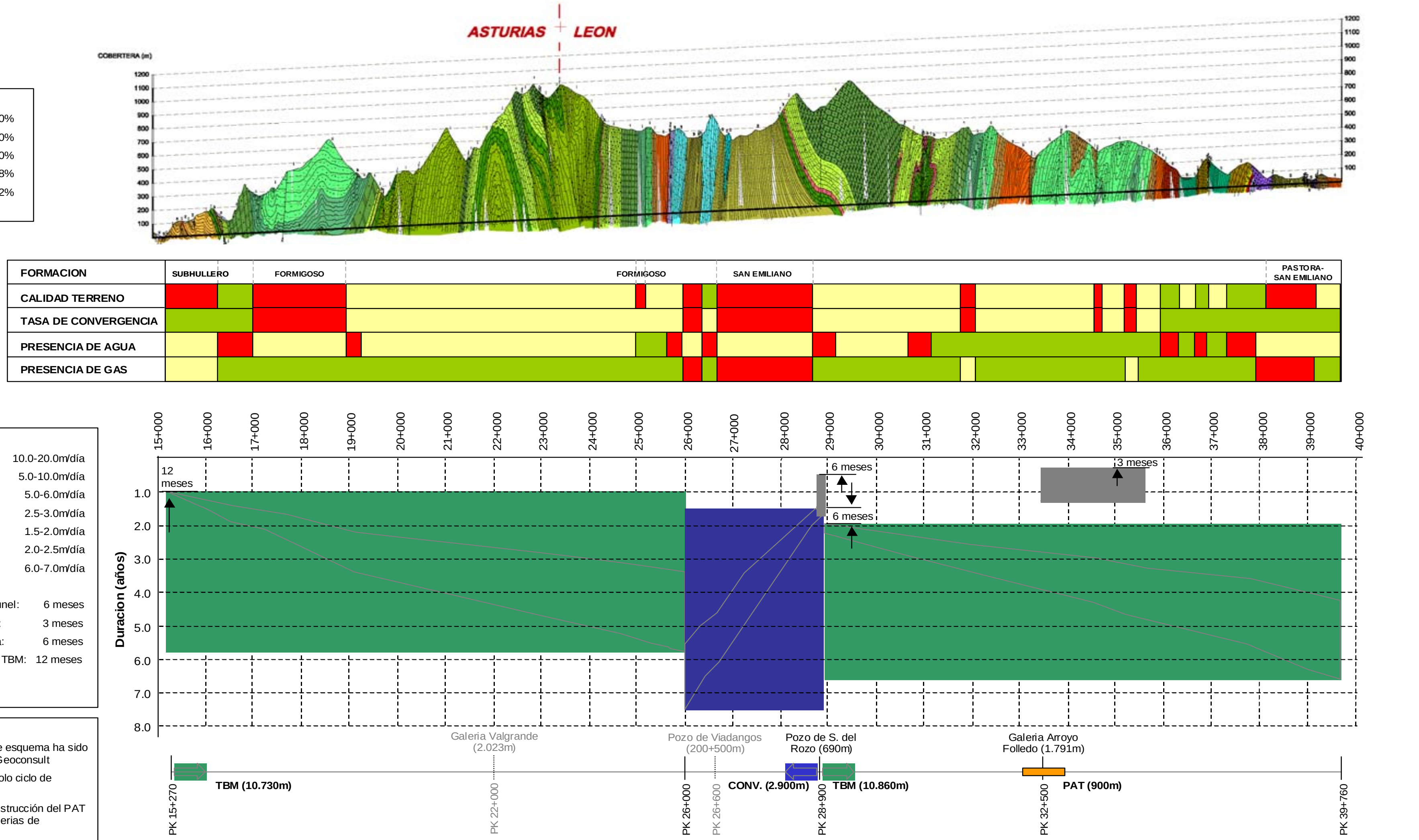
GEODATA

**RESUMEN LITOLOGIAS**

| | |
|---|---|
| Calizas y Dolomias: | 20% |
| Pizarras, Lutitas y Limolitas: | 40% |
| Areniscas y Conglomerados: | 30% |
| Cuarcitas: | 8% |
| Margas: | 2% |

**LEYENDA**

- Cond. favorables
- Cond. medias
- Cond. desfavorables




**VELOCIDADES DE AVANCE**

| | |
|---|---|
| TBM en roca buena/media: | 10.0-20.0m/día |
| TBM en roca mala: | 5.0-10.0m/día |
| CONV en roca buena: | 5.0-6.0m/día |
| CONV en roca media: | 2.5-3.0m/día |
| CONV en roca mala: | 1.5-2.0m/día |
| POZO en cualquier roca: | 2.0-2.5m/día |
| GALERIA en cualquier roca: | 6.0-7.0m/día |

**TRABAJOS PRELIMINARES**

| | |
|---|---|
| Instalaciones y boquilla pozo/túnel: | 6 meses |
| Instalaciones y boquilla galeria: | 3 meses |
| Montaje TBM en pozo o galeria: | 6 meses |
| Orden, construccion y montaje TBM: | 12 meses |

**DÍAS DE TRABAJO**

24 dias/mes

**NOTAS**

1. El modelo geologico de este esquema ha sido elaborado por la UTE INECO-Geoconsult
2. Los avances se refieren al solo ciclo de excavación y soporte
3. No se ha considerado la construcción del PAT y de otras obras auxiliares (galerias de conexión, refugios, etc.)
4. Los accesos marcados en gris no son utilizados

# RMP: Risk quantification - Evaluation of alternatives with respect to management of unfavorable conditions

LÍNEA FFCC LEÓN-GIJÓN - VARIANTE DE PAJARES - TÚNEL DE BASE

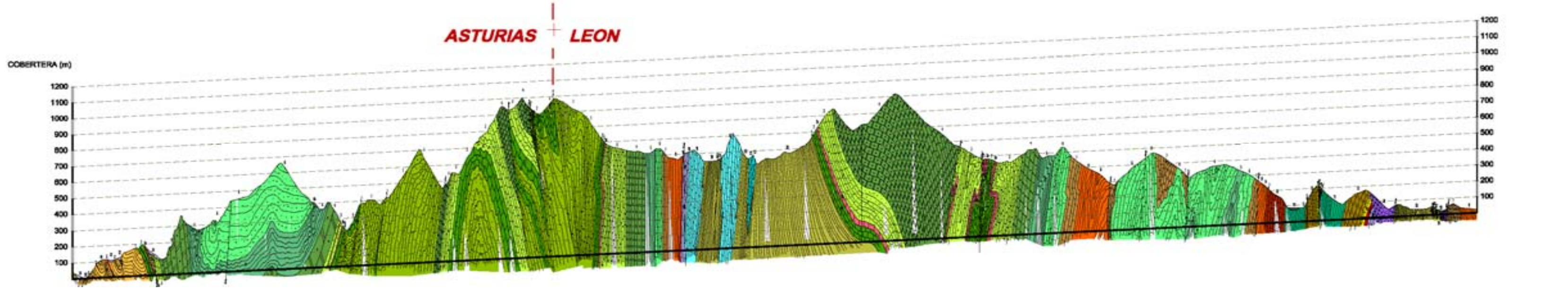
Esquema constructivo y diagrama de ejecución (plazos probabilisticos)

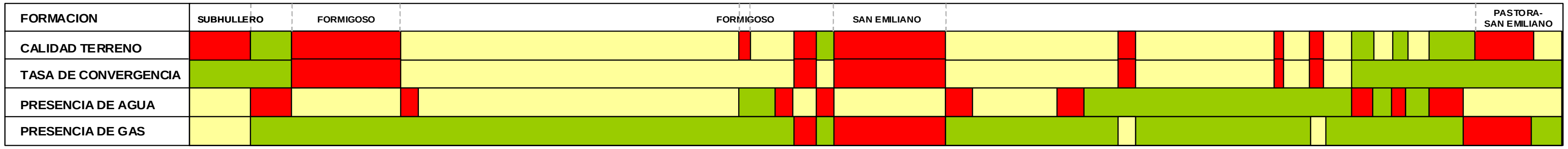
Solución Alternativa 2 (Fig. 3)

GEODATA

**RESUMEN LITOLOGIAS**

| | |
|---|---|
| Calizas y Dolomias: | 20% |
| Pizarras, Lutitas y Limolitas: | 40% |
| Areniscas y Conglomerados: | 30% |
| Cuarcitas: | 8% |
| Margas: | 2% |




**LEYENDA**

- Cond. favorables
- Cond. medias
- Cond. desfavorables

**VELOCIDADES DE AVANCE**

| | |
|---|---|
| TBM en roca buena/media: | 10.0-20.0m/día |
| TBM en roca mala: | 5.0-10.0m/día |
| CONV en roca buena: | 5.0-6.0m/día |
| CONV en roca media: | 2.5-3.0m/día |
| CONV en roca mala: | 1.5-2.0m/día |
| POZO en cualquier roca: | 2.0-2.5m/día |
| GALERIA en cualquier roca: | 6.0-7.0m/día |

**TRABAJOS PRELIMINARES**

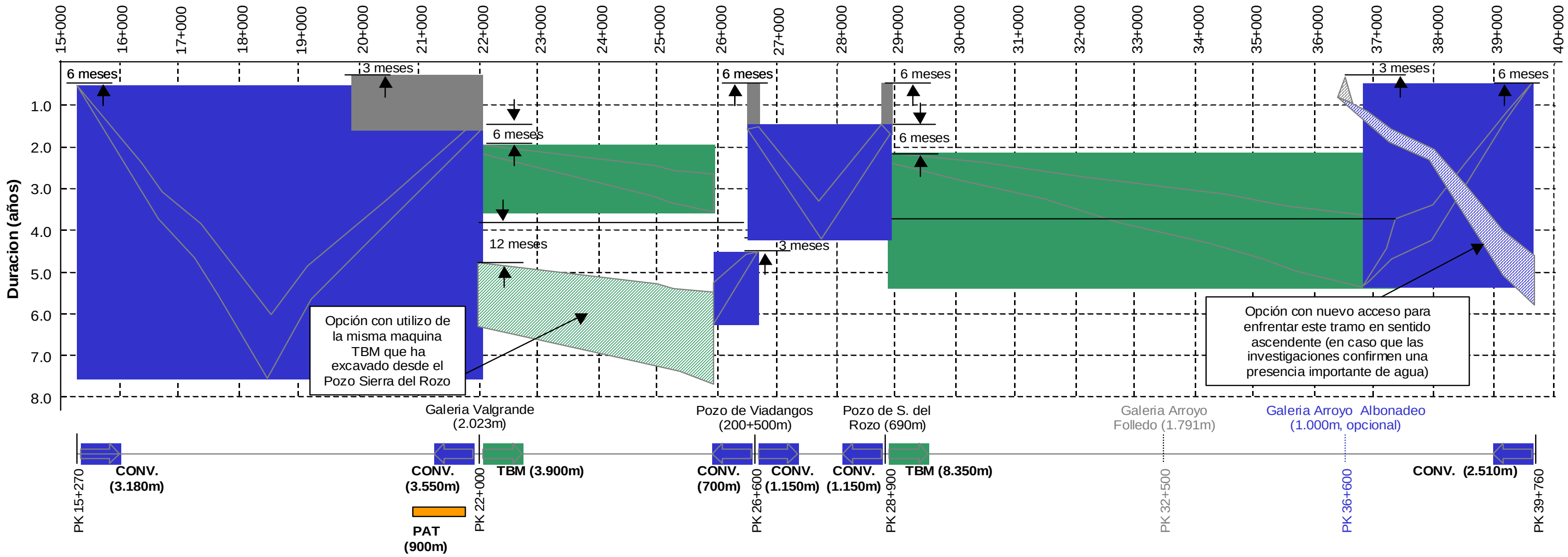
| | |
|---|---|
| Instalaciones y boquilla pozo/túnel: | 6 meses |
| Instalaciones y boquilla galeria: | 3 meses |
| Montaje TBM en pozo o galeria: | 6 meses |
| Orden, construccion y montaje TBM: | 12 meses |

**DÍAS DE TRABAJO**

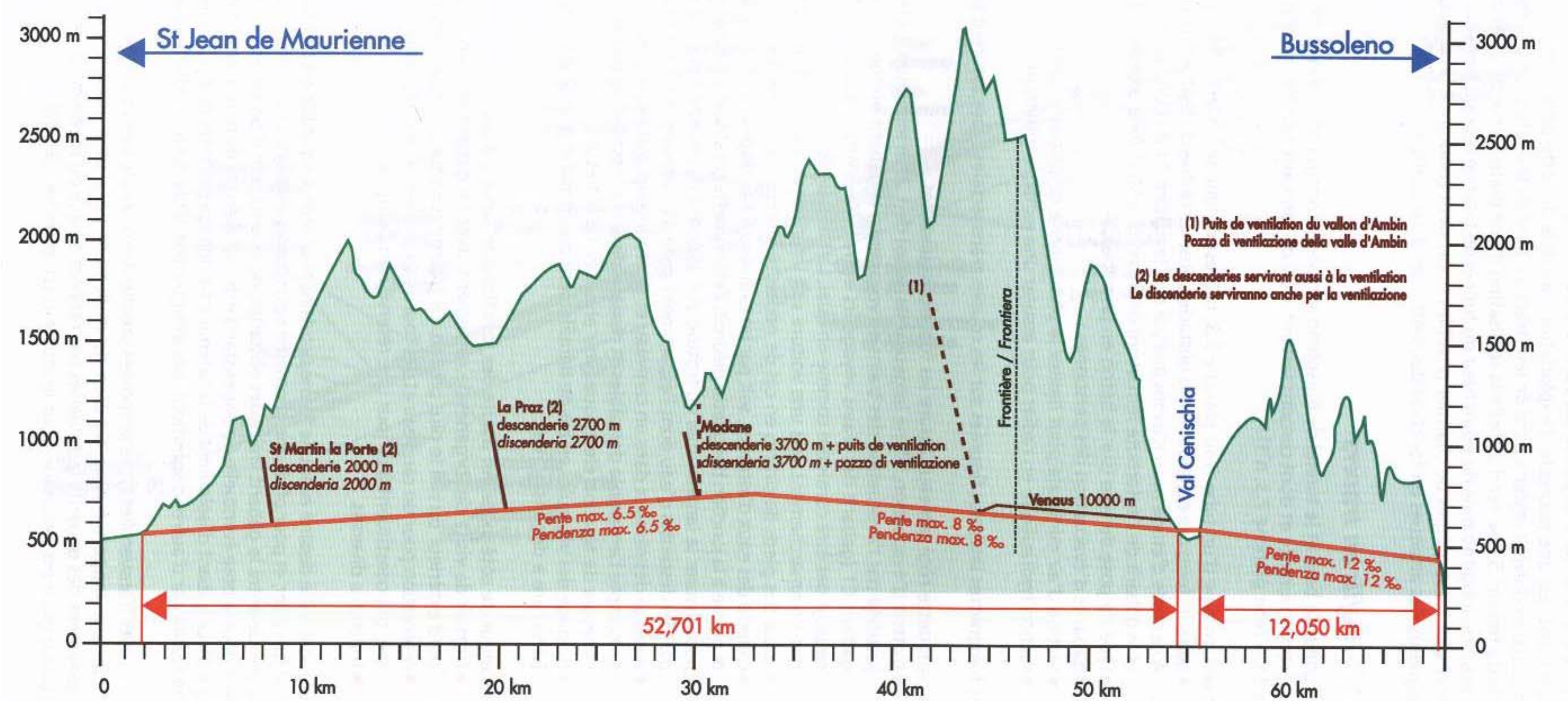
24 dias/mes

**NOTAS**

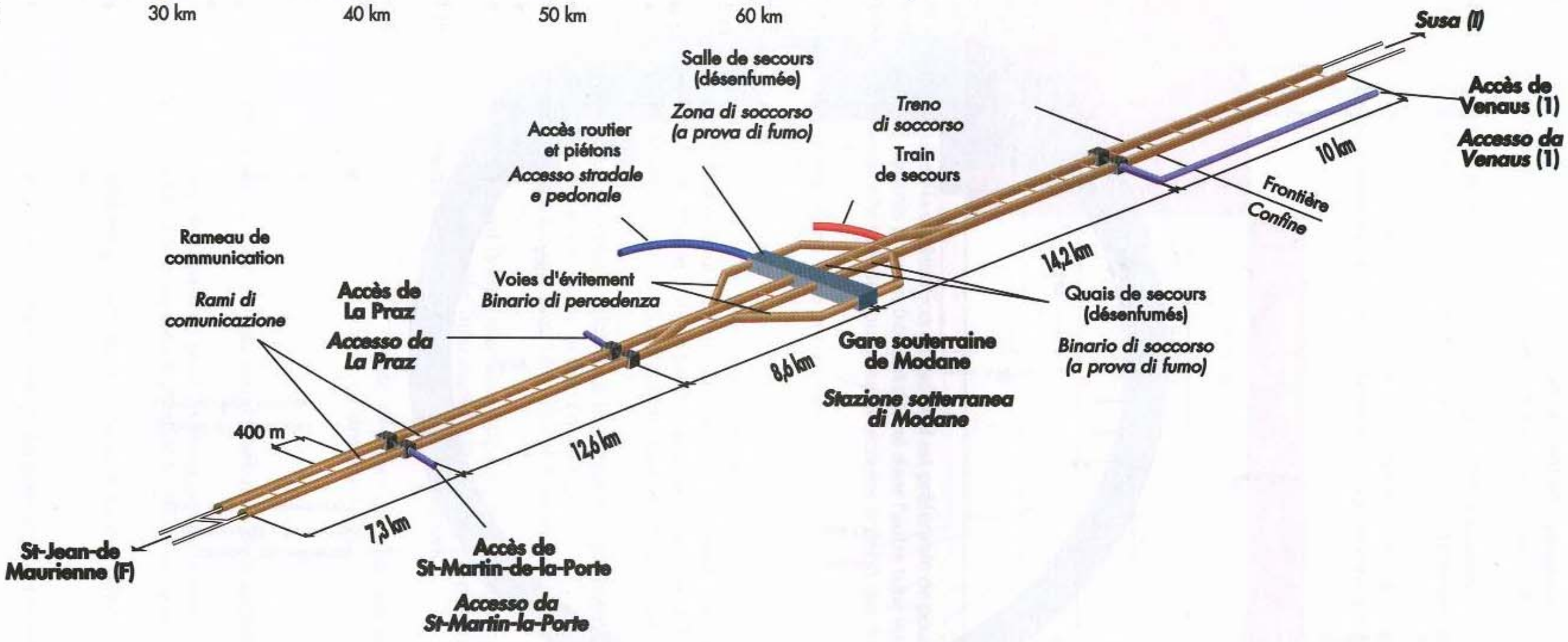
1. El modelo geologico de este esquema ha sido elaborado por la UTE INECO-Geoconsult
2. Los avances se refieren al solo ciclo de excavación y soporte
3. No se ha considerado la construcción del PAT y de otras obras auxiliares (galerias de conexión, refugios, etc.)
4. Los accesos marcados en gris no son utilizados



# Lyon – Turin Base Tunnel: Schematic profile



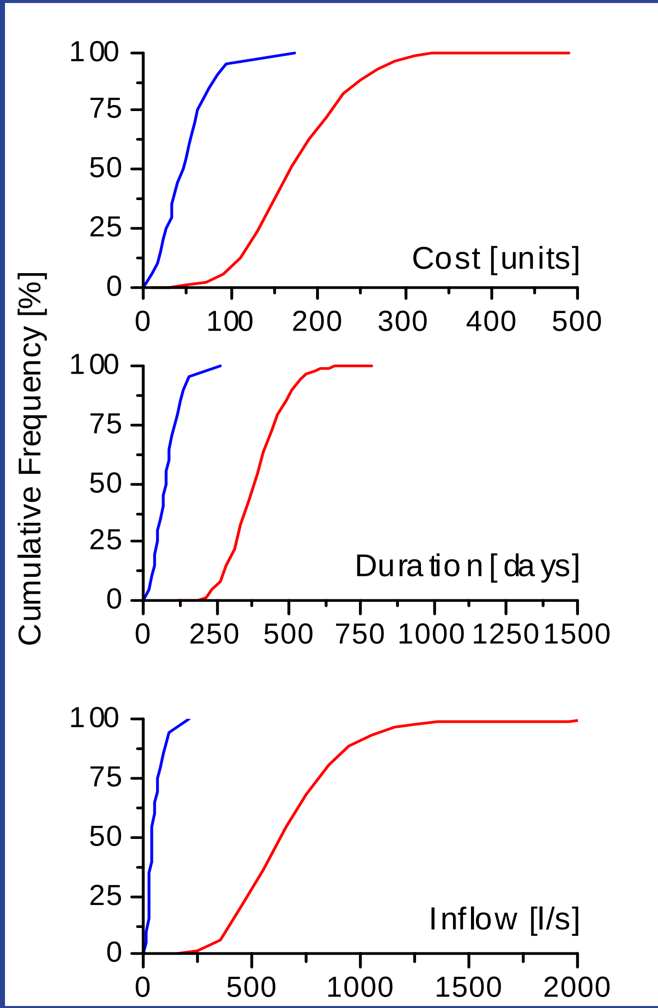

**Source: CIG - Rapport du Groupe de travail - Tunnel, 12/2000**

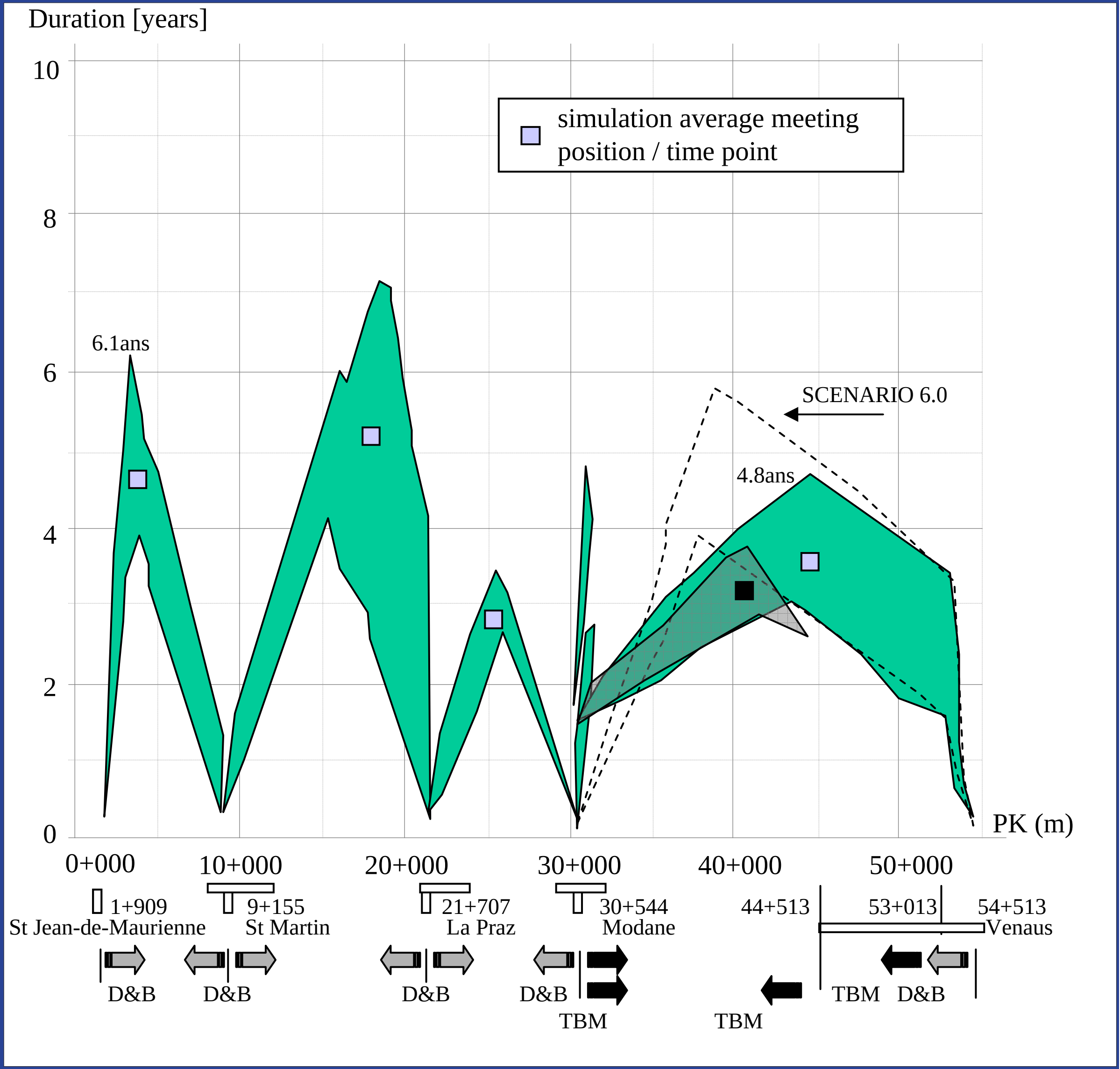


# RMP: Risk quantification - Evaluation of alternatives with respect to management of unfavorable conditions

## High-capacity 52km-long railway link

### Distribution of additional cost, duration, and inflow due to unforeseen geologic conditions

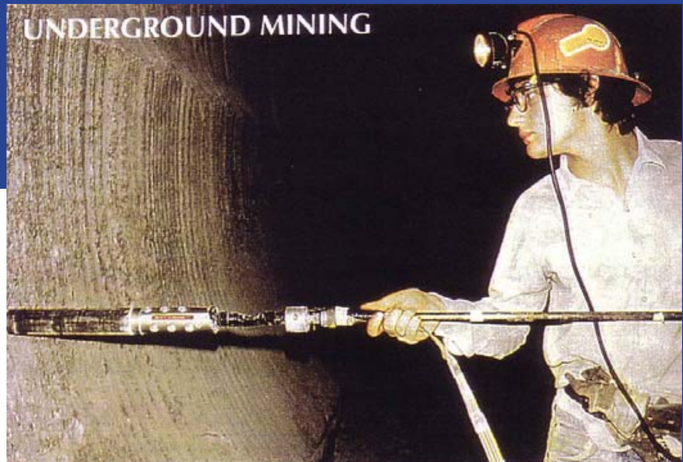



Source: B & G - GEODATA, 11/2000

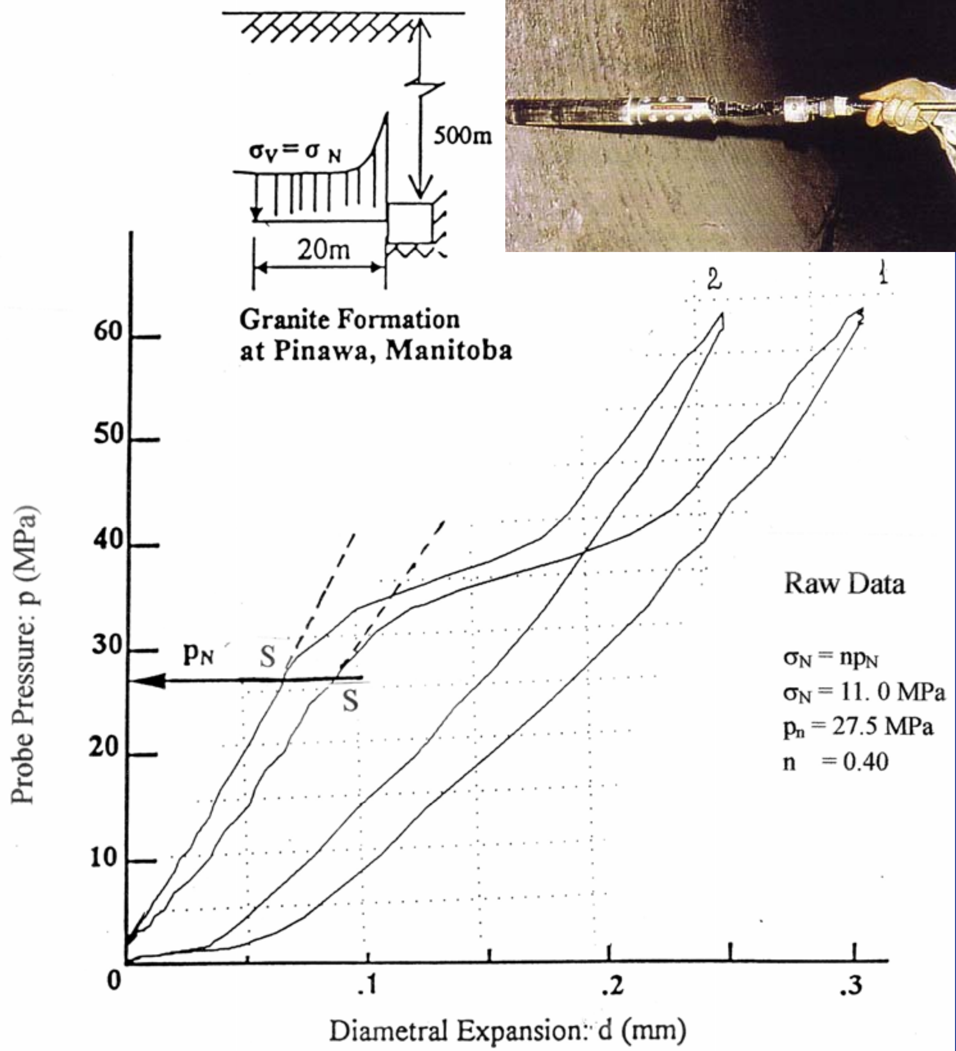
# SERATA STRESS TECHNOLOGY (SST)

*Underground Research Laboratory (URL) of Canada Atomic Energy*

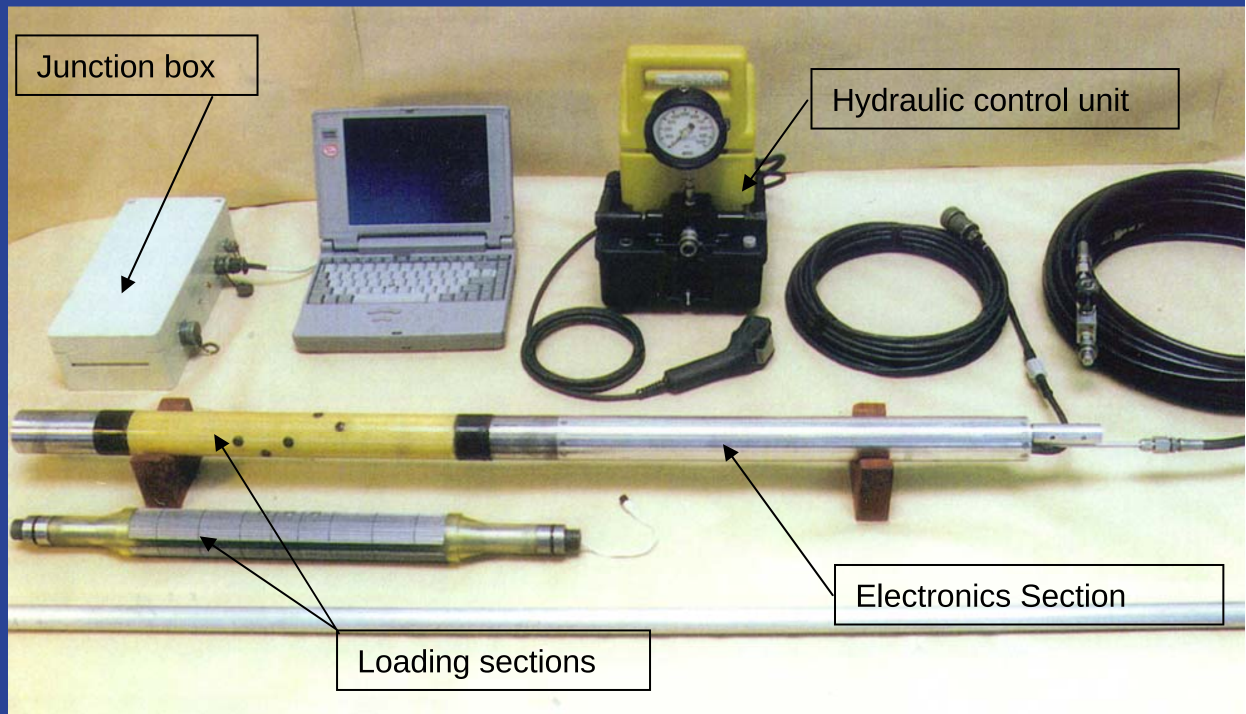



Allows to determine the initial stress and the elasticity characteristics of the material (key parameters for deep tunnels and for mechanized tunneling) with a unique test.

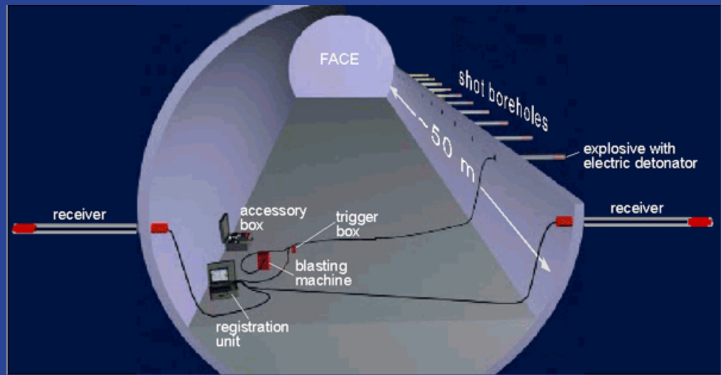
Testing is quick and induces limited interference with the tunneling operations.

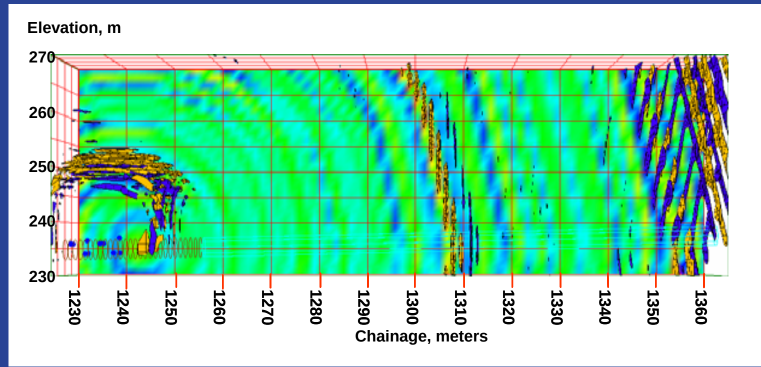



Limited execution time (15-20 min. / test)



# Exploration ahead of the tunnel face: TSP e TRT

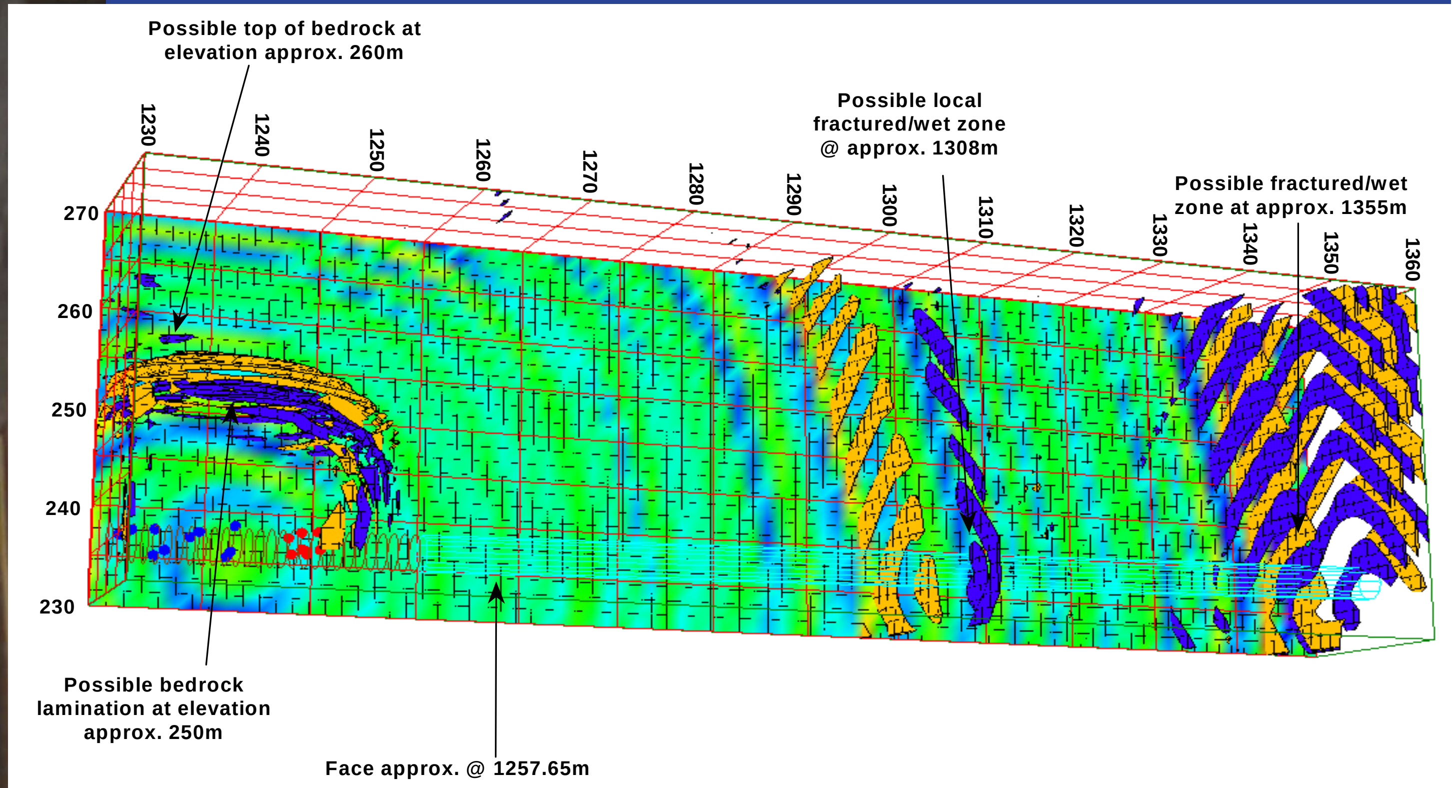



| | **TSP (Amberg)**<br>**Tunnel Seismic Prediction** | **TRT (NSA)**<br>**Tunnel Reflection Tomography** |
|---|---|---|
| **Energy source** | Explosive | Magnetic restrictive System (Etrema)<br>Explosive, sledge hammer |
| **Test duration** | 3 hours<br>plus time for the boring 26 holes | 4 to 5 hours |
| **Test depth** | 100 to 200m<br>Limited depth in case of TBM excavation | 50 to 150m in whatever excavation and site conditions |
| **Results** | One-dimensional profile of the elastic characteristics of the rocks.<br>Delimitation and characteristics of the main reflectors (position, dip and strike angle) | Tomographical image with 2D and 3D of the reflection coefficient |

# Exploration ahead of the tunnel face - TRT

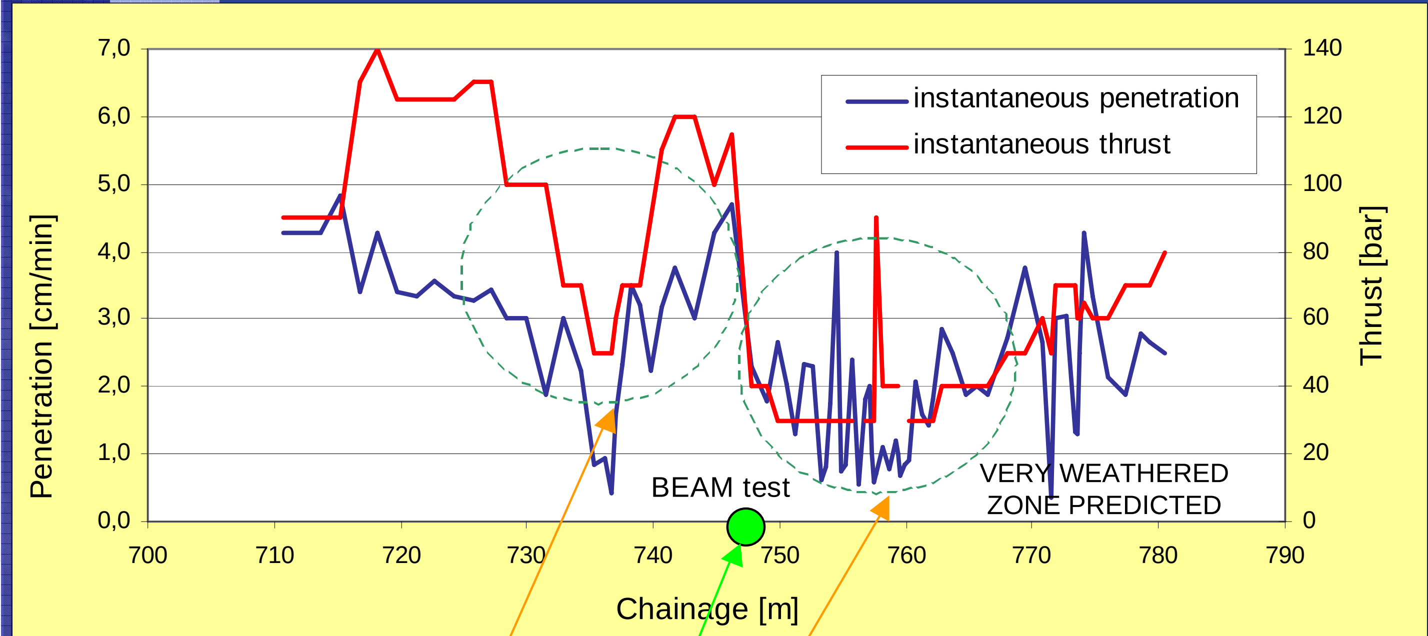
## TRT – 3D results



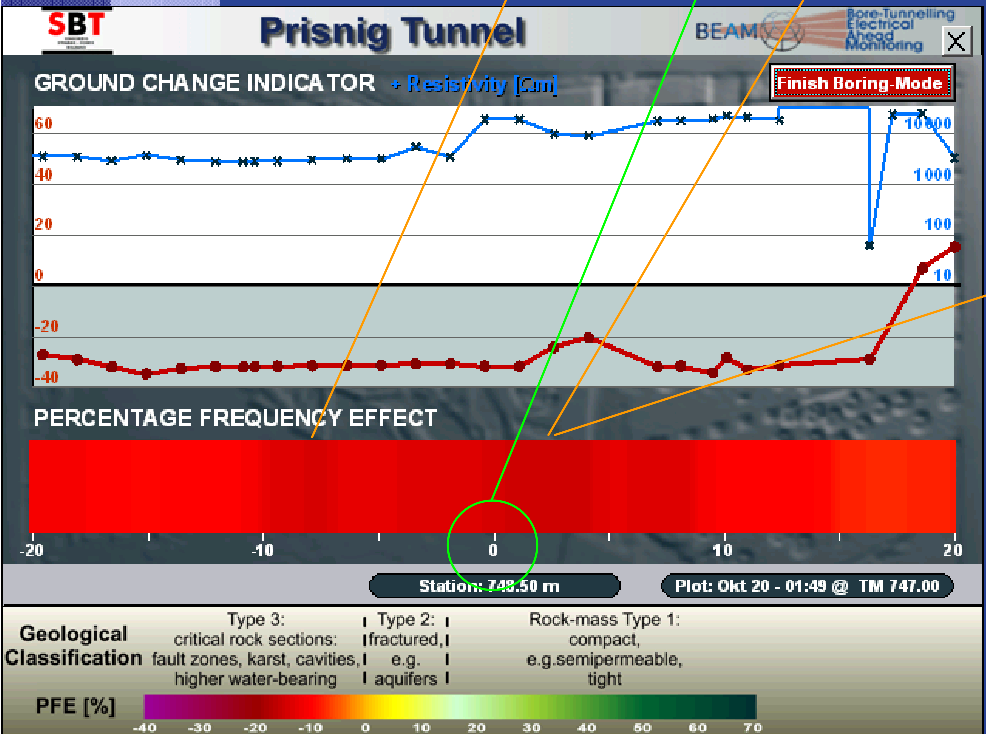

The *TRT test* provides **great versatility** since more than one type of **energy source** can be used: **explosive charges** (deep level of investigation and signals with quite high frequency); **mechanical methods** (impact masses); new **electro-mechanical methods** (very low impact on site activities whilst giving a good level of penetration and high frequency signals).

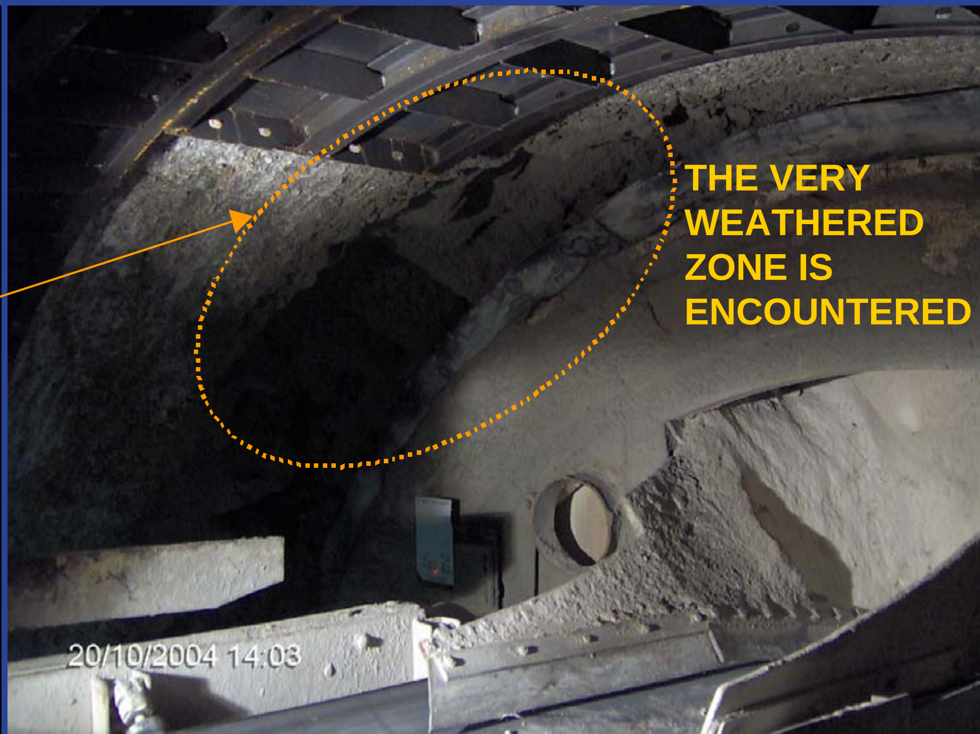
## TRT - Supply of energy inside the TBM

# Exploration with Bore-tunnelling Electrical Ahead Monitoring - BEAM

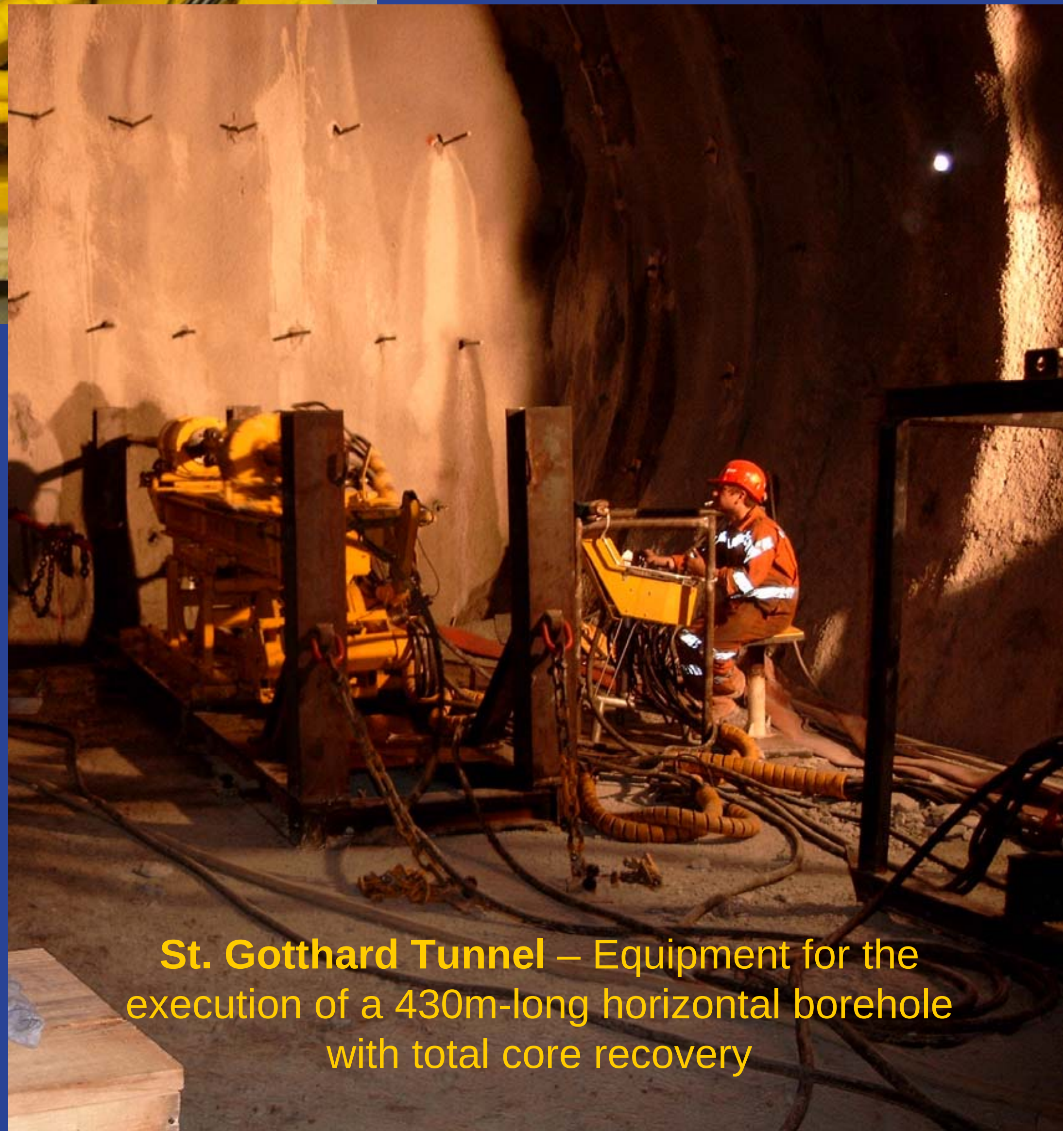



BEAM is a focused-electrical frequency domain induced polarization method to explore fore-field and perimeter ground while TBM drives.
It allows the early detection and location of rock changes due to continuous automatic measurement of electrical parameters.
The monitoring current beam is forced to penetrate the ground ahead of the face up to a distance of several times the tunnel diameter



# DIAMEC drilling device

**St. Gotthard Tunnel** – Equipment for the execution of a 430m-long horizontal borehole with total core recovery

# Beilage Vorauserkundungsrapport Kernbohrung EST SW Nr. 9: Erkundung Urseren-Garvera-Zone Stand 04.11.2004

**Legende**
**Geologische Aufnahme: Bandaufzeichnung**

- Gneise
- Schiefergneise
- Schiefer
- Serpentinit

**Legende**
**Aufnahme Bohrungen im TZM Süd**

- Gneise
- Schiefergneise
- Schiefer
- Kernverlust

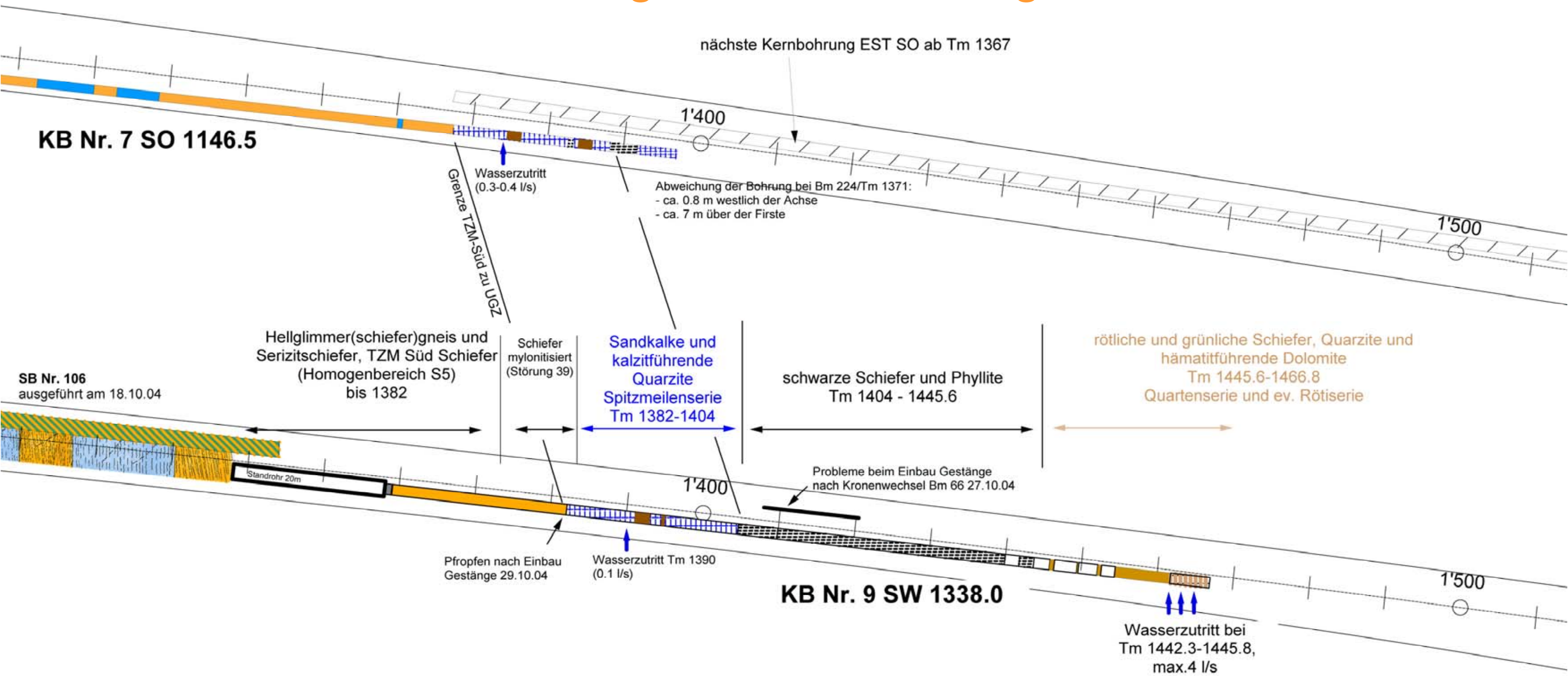
**Legende**
**Aufnahme Bohrungen in der Urseren-Garvera-Zone**

Spitzmeilenserie
- Sandkalk
- Kalkschiefer
- Quarzit

Prodkammserie
- schwarze Schiefer, z.T. Kalkschiefer

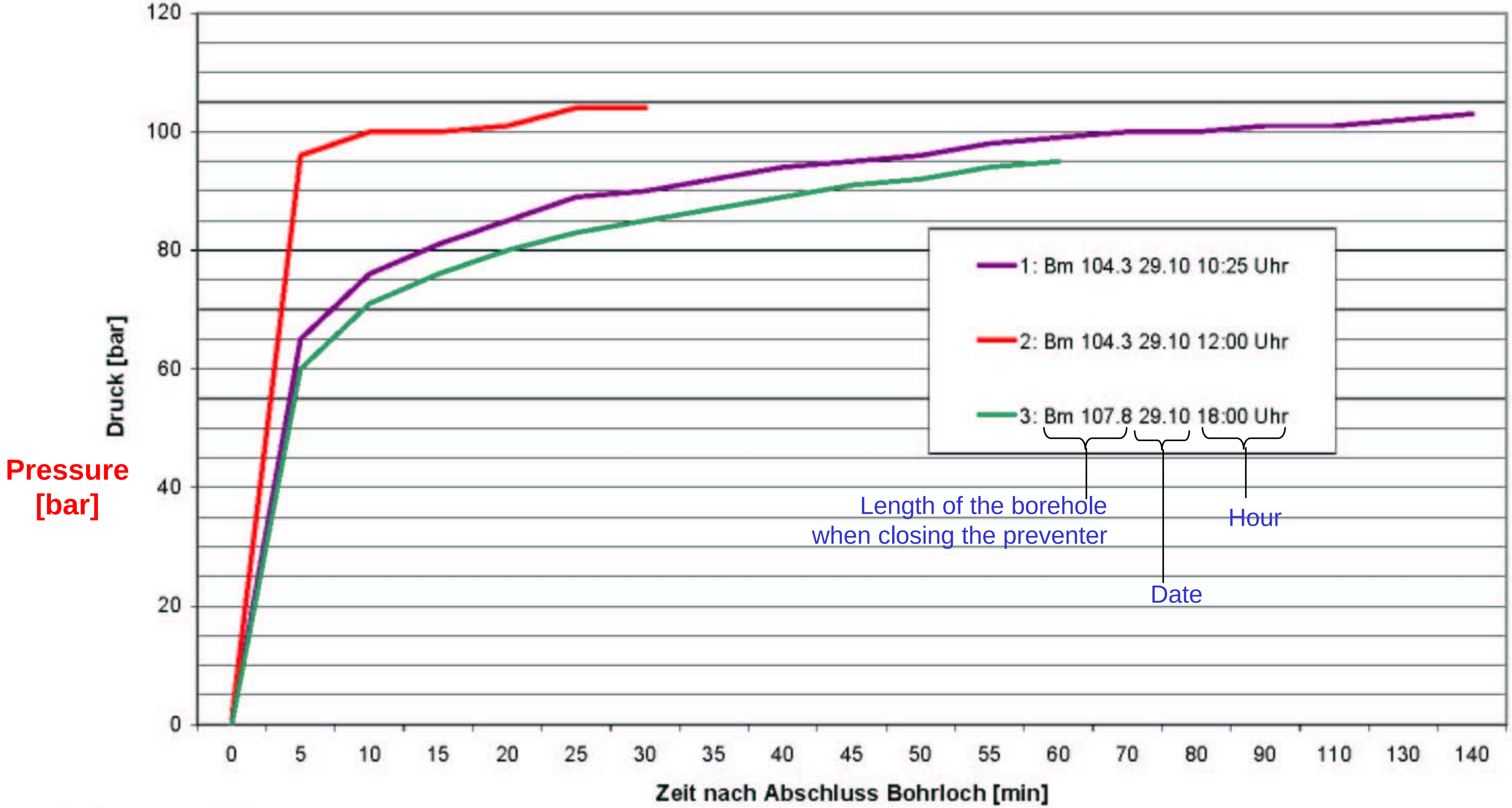
Quartenserie
- quarzreiche, dolomitische Schiefer, grünlich, rötlich
- hämatitführende Dolomite

## Long horizontal drilling at St.Gotthard Tunnel



**Test for measuring the water pressure**

**Druckhöhenversuche KB Nr. 9 EST SW ab Tm 1338**




**Delay after the closure of the preventer [min]**

# Gibraltar Strait Crossing