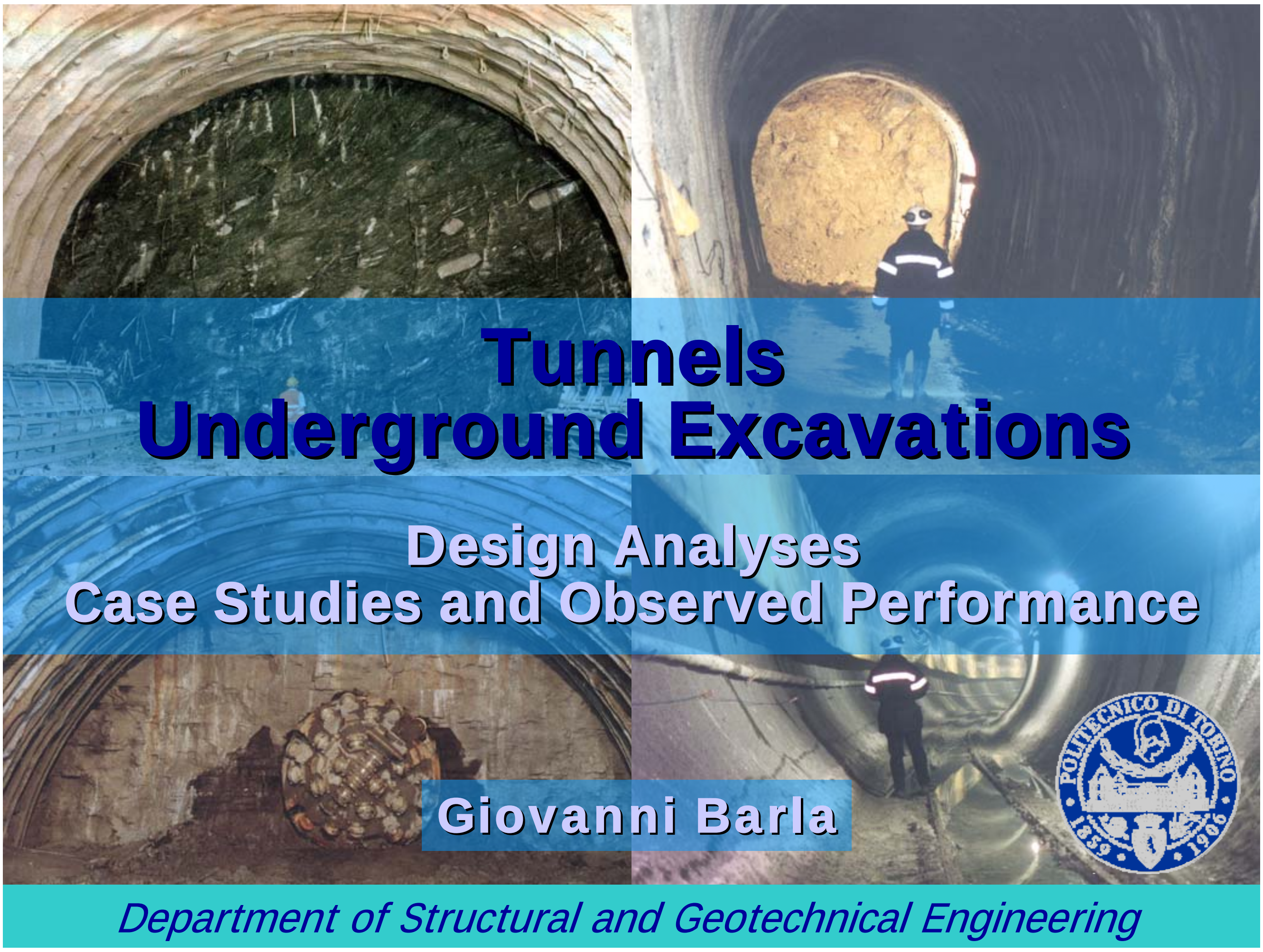
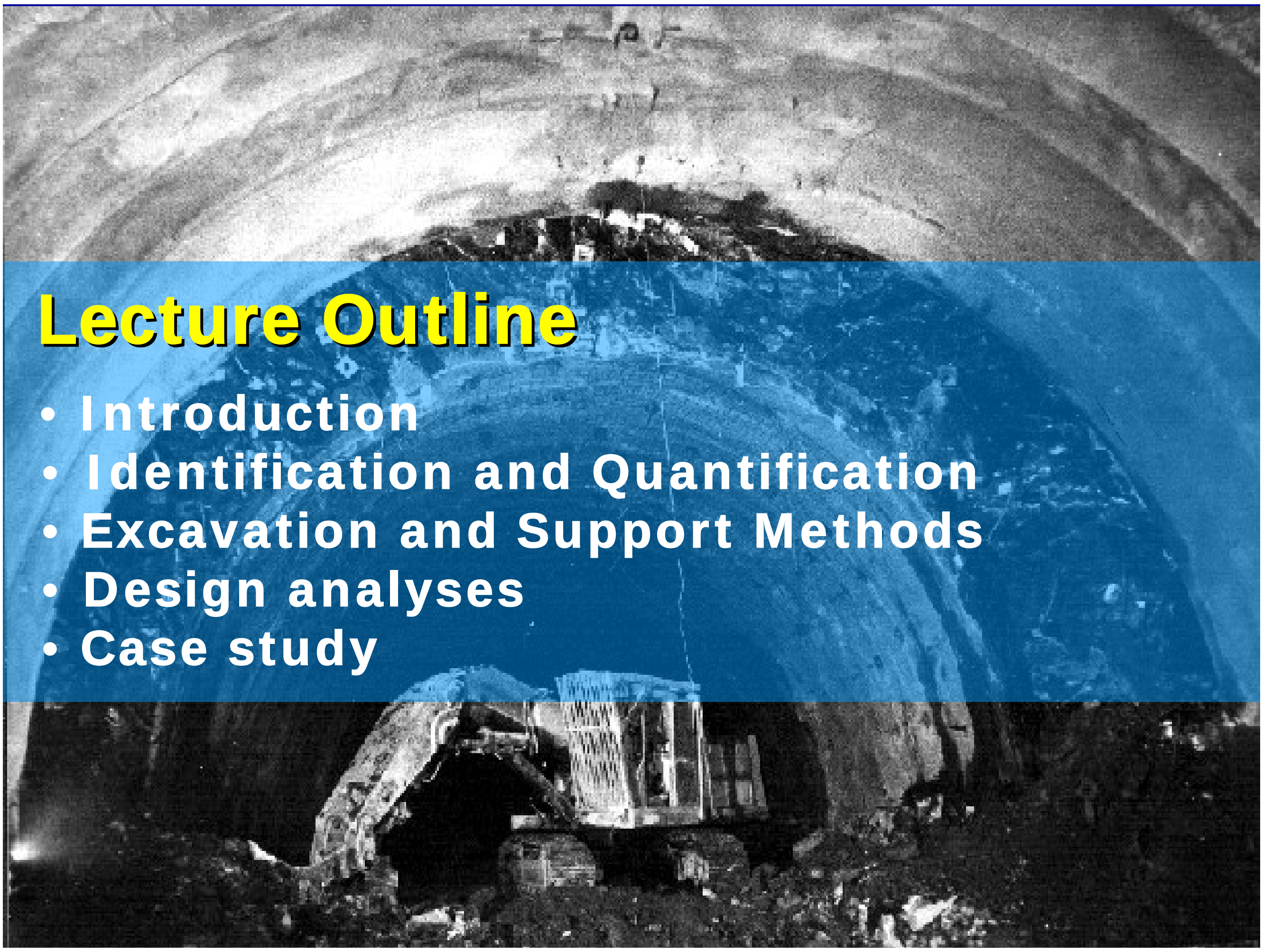

Tunnels
Underground Excavations
Design Analyses
Case Studies and Observed Performance
Giovanni Barla
POLITECNICO DI TORINO
1859
1906
Department of Structural and Geotechnical Engineering


Lecture 3: Tunnelling under
Squeezing Conditions



Lecture Outline

- Introduction
- Identification and Quantification
- Excavation and Support Methods
- Design analyses
- Case study

The term "squeezing rock" originates from the pioneering days of tunnelling through the Alps

It was associated with deformations, damage or destruction of the timber supports used

SQUEEZING

SQUEEZING stands for large time - dependent convergence during tunnel excavation. It takes place when a particular combination of induced stresses and material properties pushes some zones around the tunnel beyond the limiting shear stress at which creep starts. Deformation may terminate during construction or continue over a long period of time

SQUEEZING

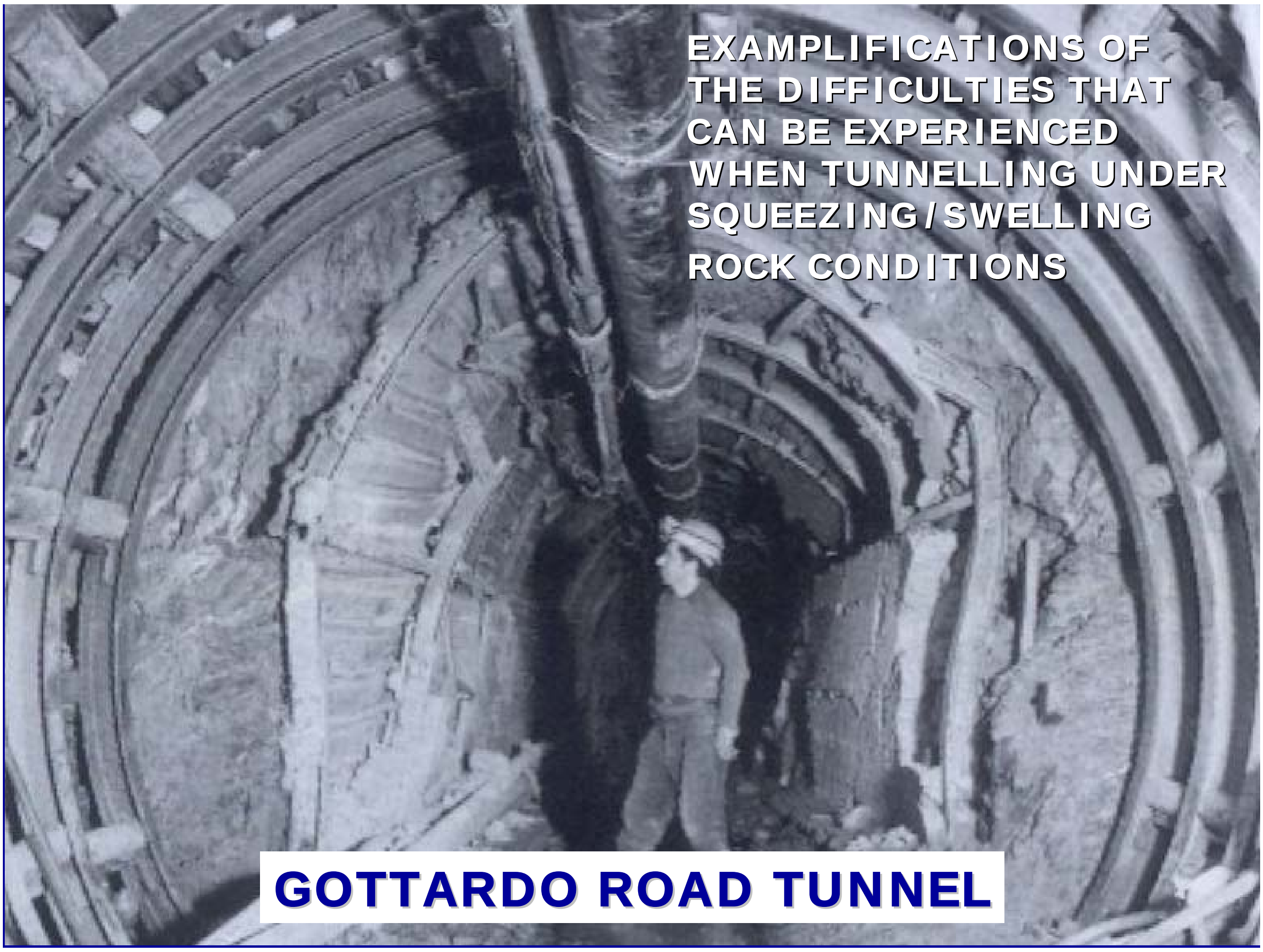
SQUEEZING is closely related to the excavation and support techniques which are adopted. If the support installation is delayed, the rock mass moves into the tunnel and a stress redistribution takes place around it. On the contrary, if deformation is restrained, squeezing will lead to long-term load build-up of rock support

SQUEEZING

The ***tunnel convergence***, the **face extrusion**, the ***rate of deformation*** and the extent of the ***yielding zone*** around the tunnel depend on the geological and geotechnical conditions, the in situ state of stress relative to the rock mass strength, the ground water flow and pore pressure, and the rock mass properties

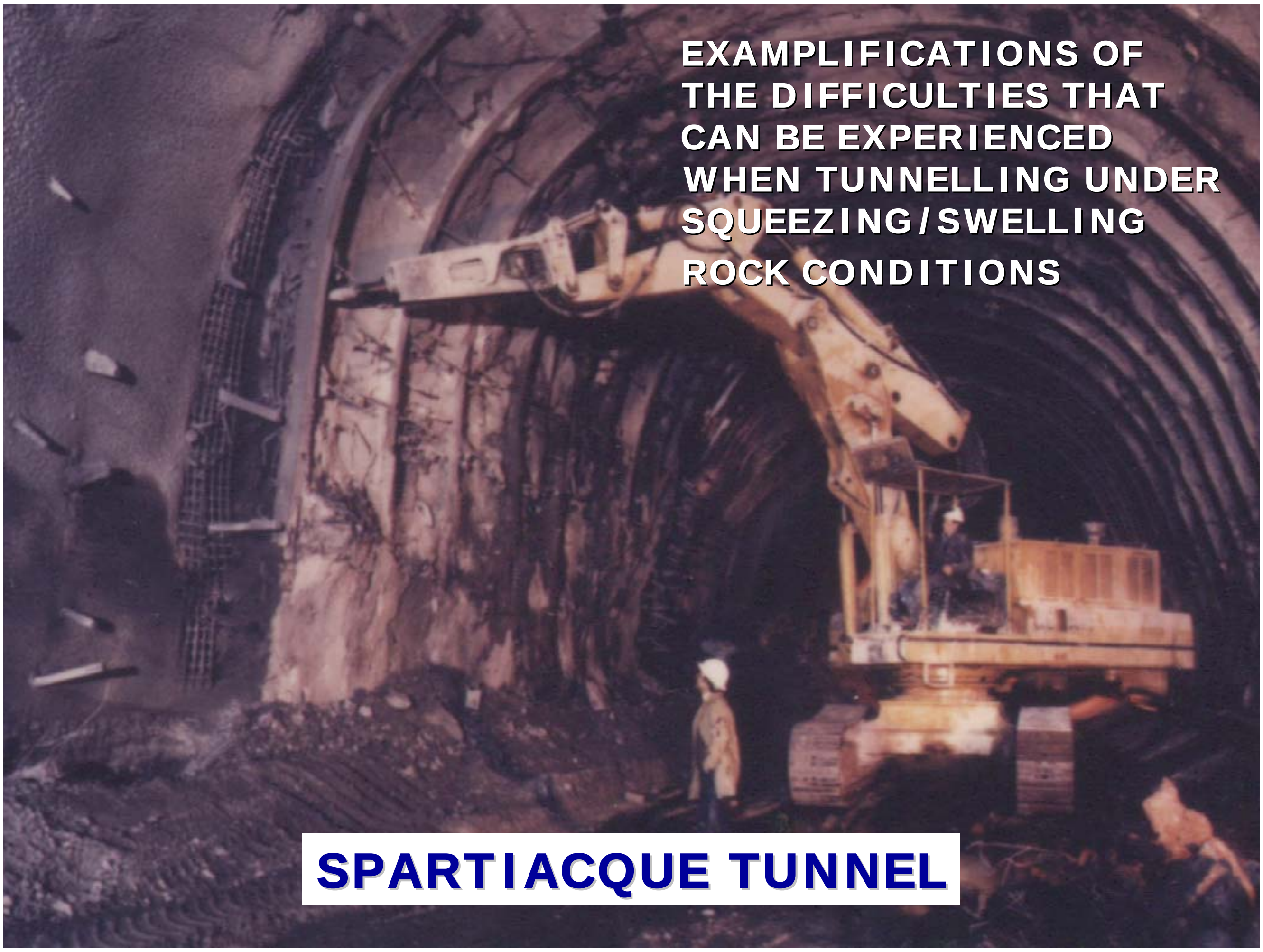
SQUEEZING

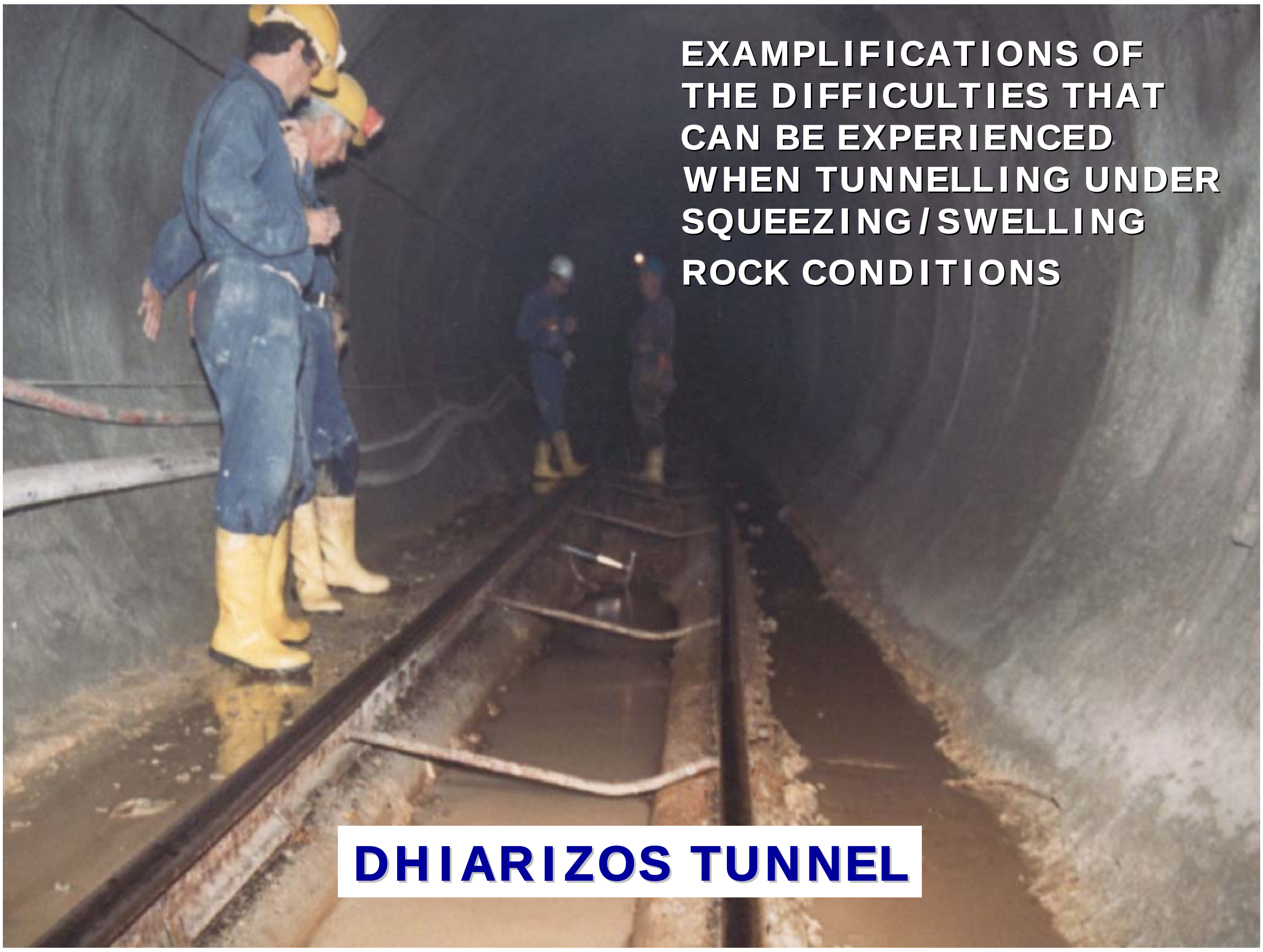
The **large deformations** associated with squeezing may also occur in rocks susceptible to ***swelling.*** Although the causes resulting in either a behaviour or the other one are different, it is often difficult to distinguish between squeezing and swelling, as the two phenomena may occur at the same time and induce similar effects

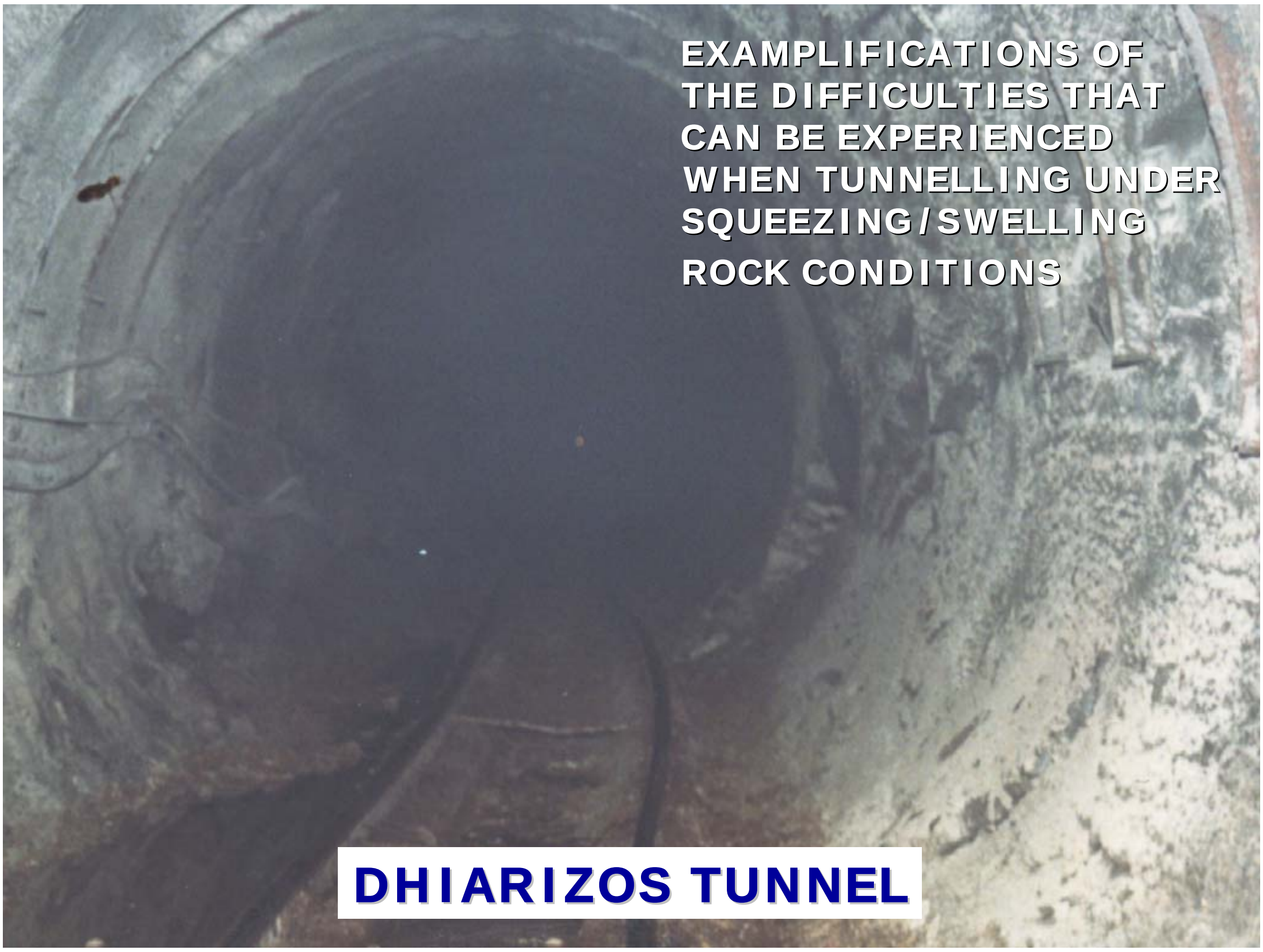

EXAMPLIFICATIONS OF THE DIFFICULTIES THAT CAN BE EXPERIENCED WHEN TUNNELLING UNDER SQUEEZING/SWELLING ROCK CONDITIONS
GOTTARDO ROAD TUNNEL

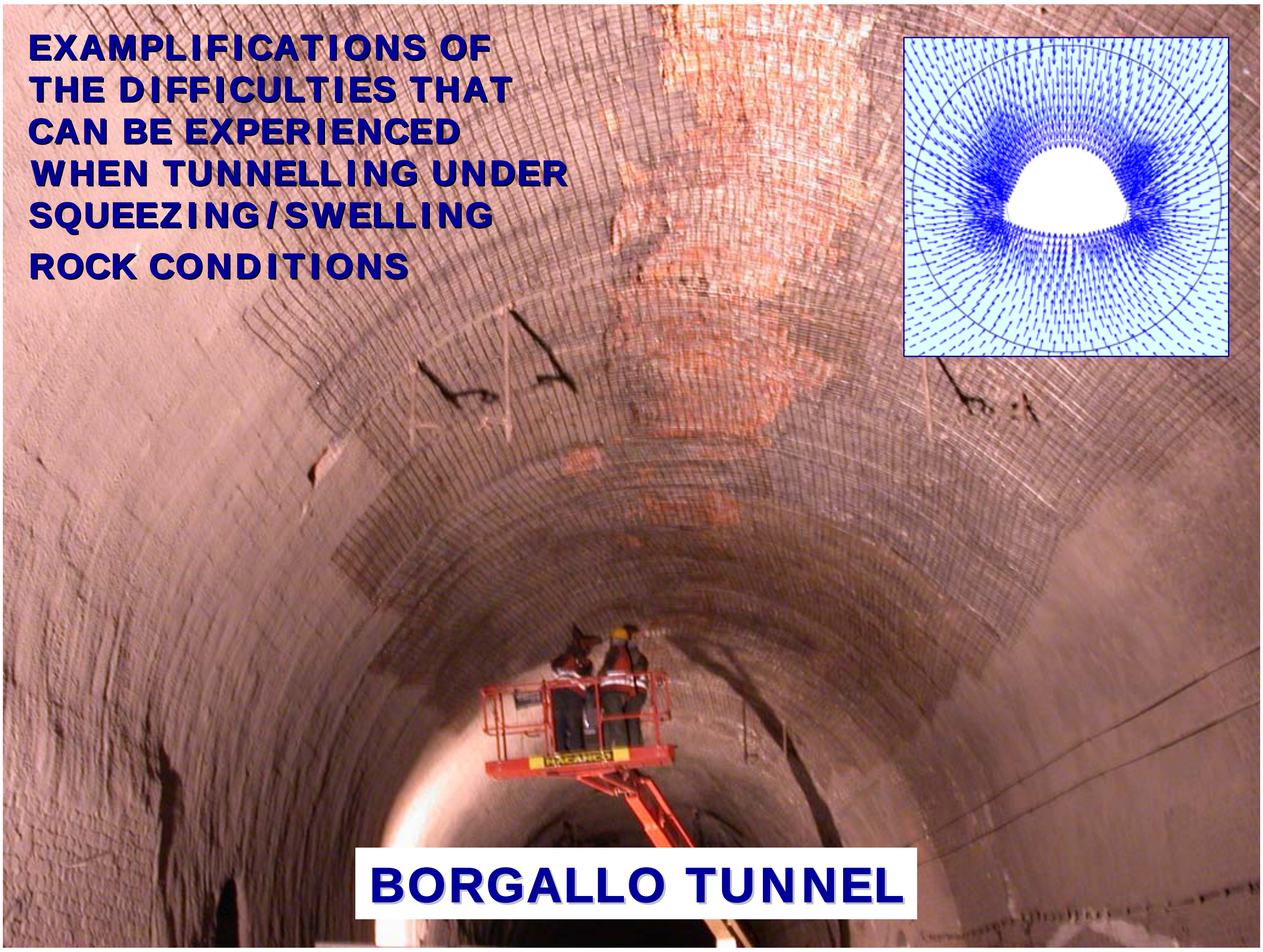

EXAMPLIFICATIONS OF THE DIFFICULTIES THAT CAN BE EXPERIENCED WHEN TUNNELLING UNDER SQUEEZING/SWELLING ROCK CONDITIONS
SAN DONATO RAILWAY TUNNEL


EXAMPLIFICATIONS OF THE DIFFICULTIES THAT CAN BE EXPERIENCED WHEN TUNNELLING UNDER SQUEEZING / SWELLING ROCK CONDITIONS
SAN DONATO RAILWAY TUNNEL


EXAMPLIFICATIONS OF THE DIFFICULTIES THAT CAN BE EXPERIENCED WHEN TUNNELLING UNDER SQUEEZING / SWELLING ROCK CONDITIONS
SPARTIACQUE TUNNEL


EXAMPLIFICATIONS OF
THE DIFFICULTIES THAT
CAN BE EXPERIENCED
WHEN TUNNELLING UNDER
SQUEEZING / SWELLING
ROCK CONDITIONS
DHIARIZOS TUNNEL


EXAMPLIFICATIONS OF
THE DIFFICULTIES THAT
CAN BE EXPERIENCED
WHEN TUNNELLING UNDER
SQUEEZING / SWELLING
ROCK CONDITIONS
DHIARIZOS TUNNEL



EXAMPLIFICATIONS OF THE DIFFICULTIES THAT CAN BE EXPERIENCED WHEN TUNNELLING UNDER SQUEEZING / SWELLING ROCK CONDITIONS

ORTE TUNNEL

Different Methods...

1. Jethwa et al. 1984
2. Singh et al. 1992
3. Aydan et al. 1993
4. Goel et al. 1995
5. Hoek and Marinos 2000

Methods...based on different parameters such as:

Rock Mass Quality Q

Rock Mass Number N (Q for SRF=1)

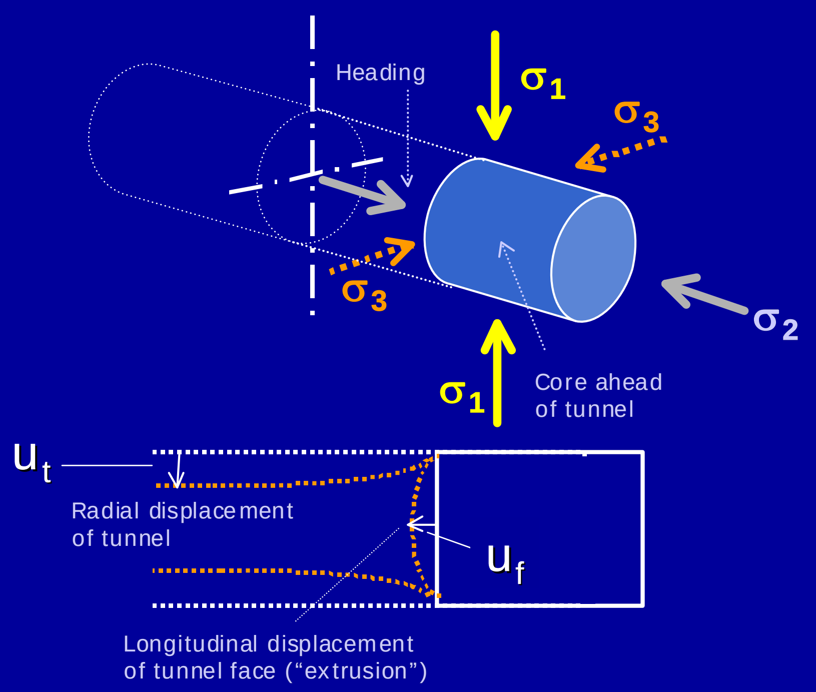
Tunnel Depth H

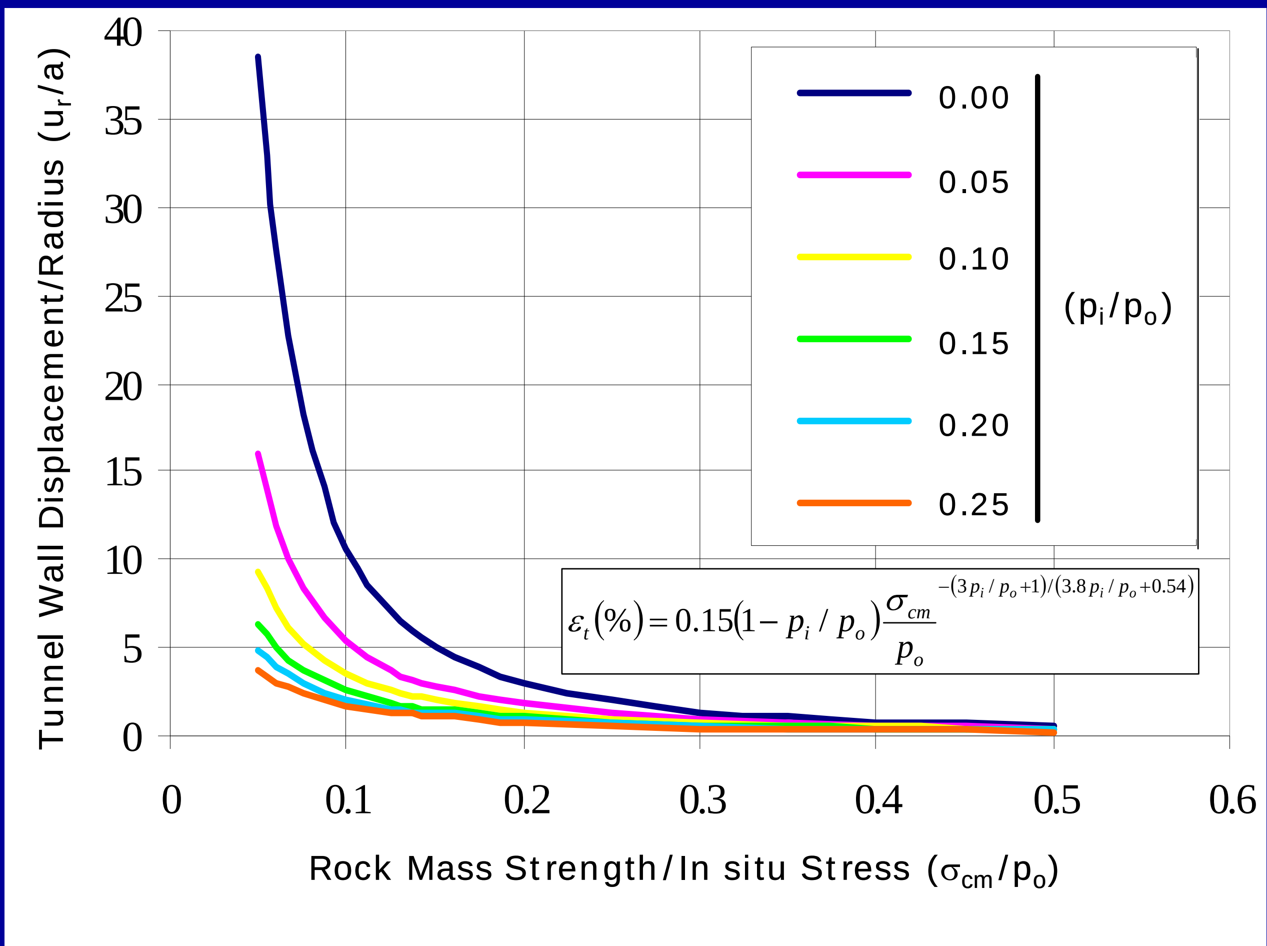
Rock Mass Strength / In situ stress (σ_{cm} / p_o)

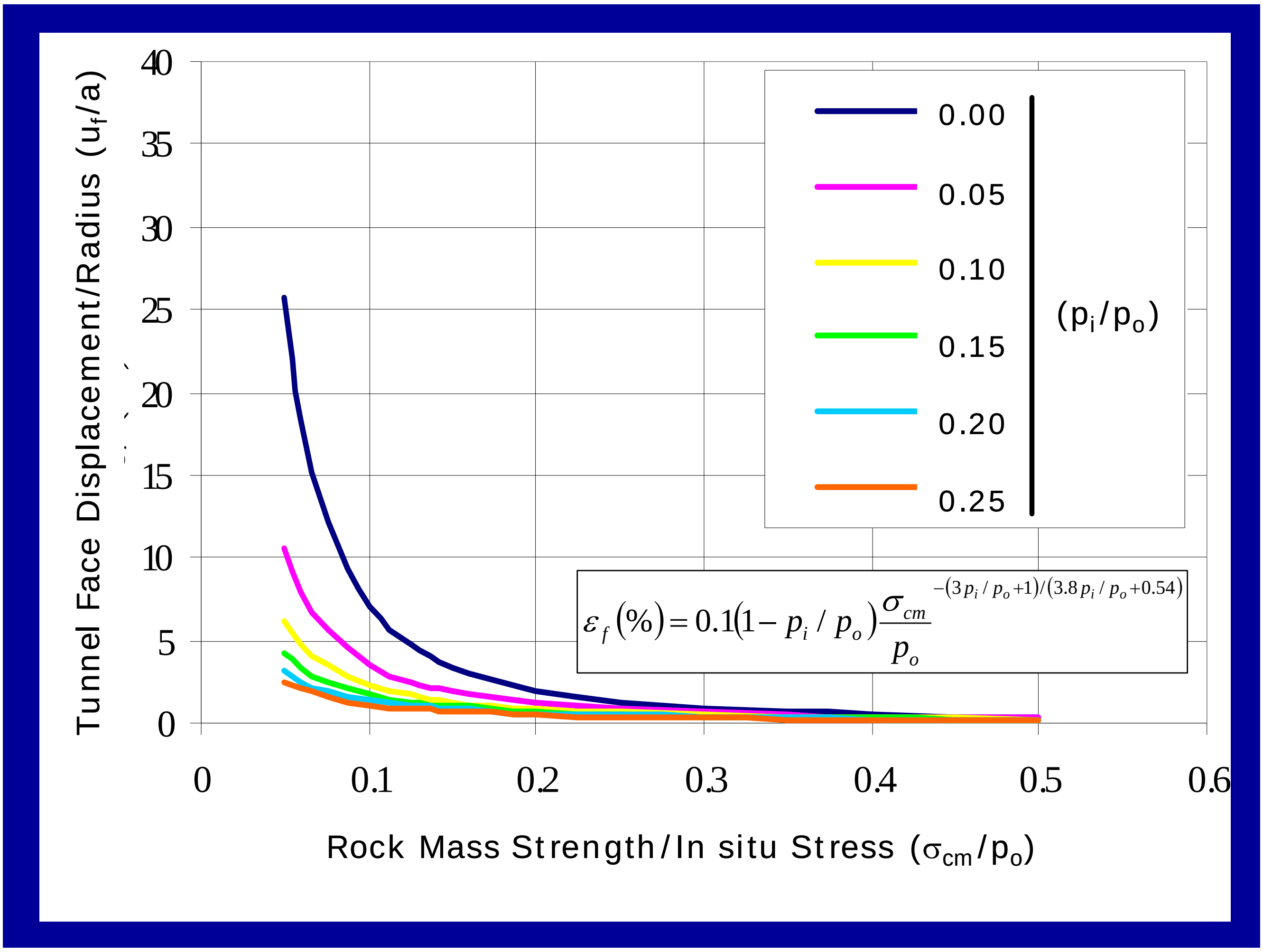
Intact Rock Strength / In situ stress (σ_{ci} / p_o)

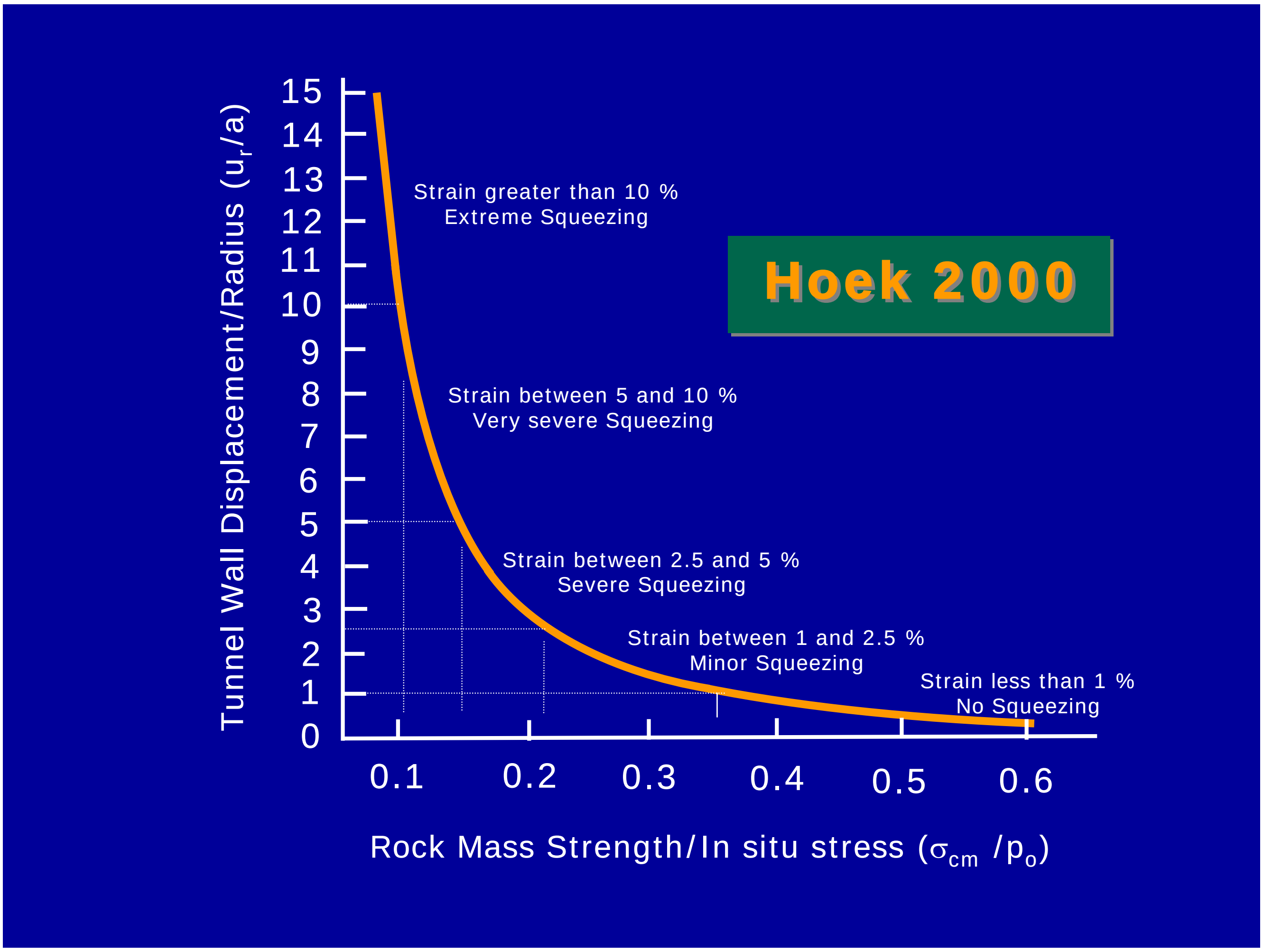
To be discussed: Hoek and Marinos

Tunnel Response during face advances



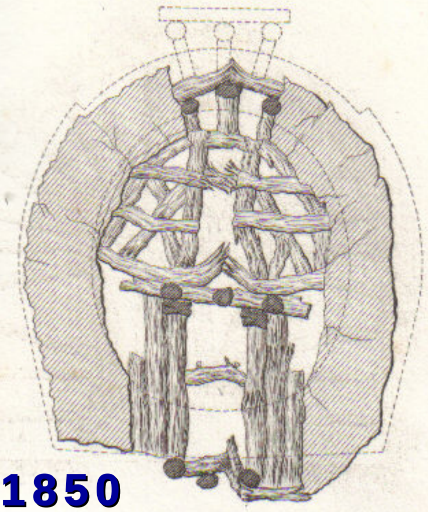



Tunnel Face Displacement/Radius (u_f/a)
Rock Mass Strength/In situ Stress (σ_{cm}/p_o)
0.00
0.05
0.10
0.15
0.20
0.25
(p_i/p_o)
$$\varepsilon_f(\%) = 0.1(1 - p_i/p_o)\frac{\sigma_{cm}}{p_o}^{-(3p_i/p_o+1)/(3.8p_i/p_o+0.54)}$$


Tunnel Wall Displacement/Radius (u_r/a)
Rock Mass Strength/In situ stress (σ_{cm}/p_o)
Hoek 2000
Strain greater than 10 %
Extreme Squeezing
Strain between 5 and 10 %
Very severe Squeezing
Strain between 2.5 and 5 %
Severe Squeezing
Strain between 1 and 2.5 %
Minor Squeezing
Strain less than 1 %
No Squeezing

The question in tunnelling

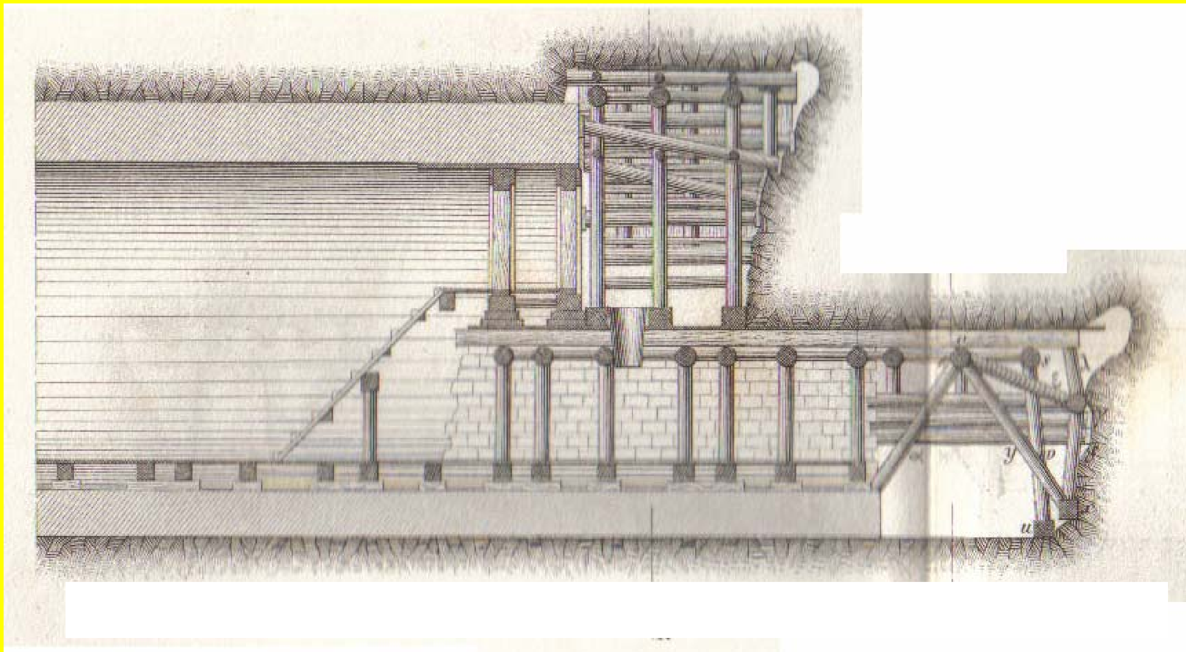
How to avoid the tunnel wooden support failure, if not the tunnel collapse?



1850

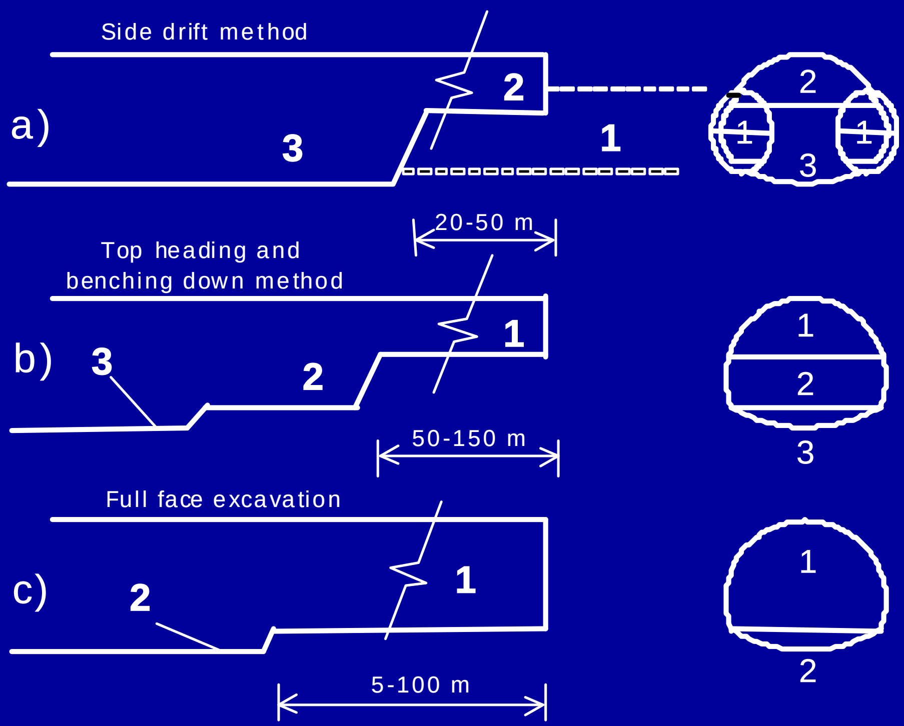
1985

"Capolavori di Minuseria" (Politecnico di Torino)



→ Italian Method

Excavation and support methods: the "past"

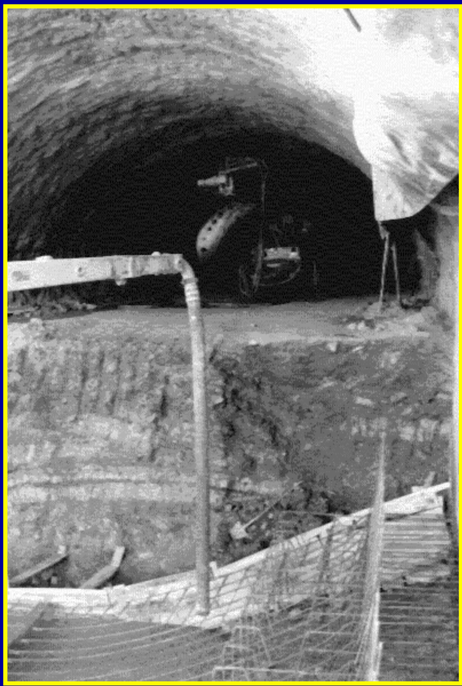


Excavation and support methods: the "present"

One of the above methods generally applied for construction of tunnels with span greater than 10 m (typically 100 m^2 cross section or greater, up to 160 m^2)

Even for shallow transportation tunnels, the full face method tends to be favored with respect to the other two methods. This is certainly the case in Italy

The tunnel is driven ahead by relying on reinforcement of the face and of the ground surrounding the heading. Frequent use is made of fiberglass elements



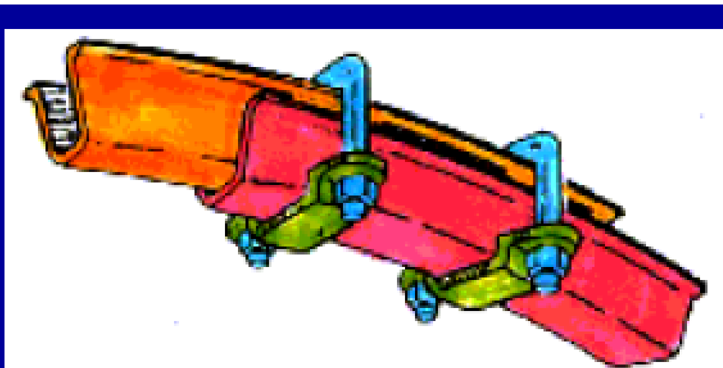
Top heading and benching down method

Full face excavation method

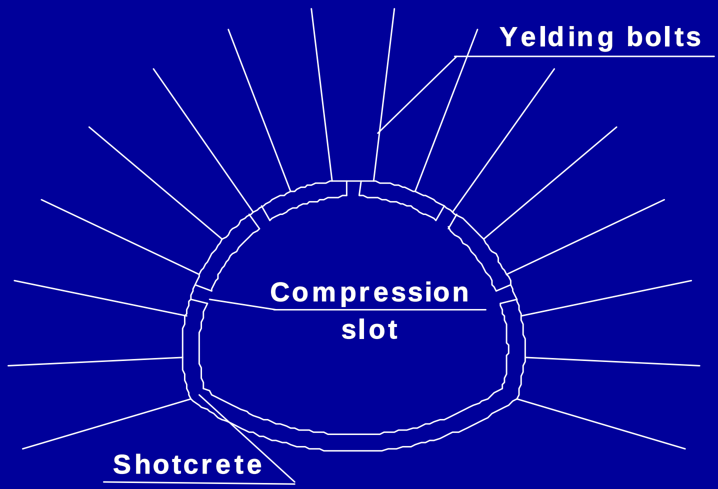

MARINASCO TUNNEL


MARINASCO TUNNEL

MARINASCO TUNNEL



USE OF: Yielding Steel Ribs

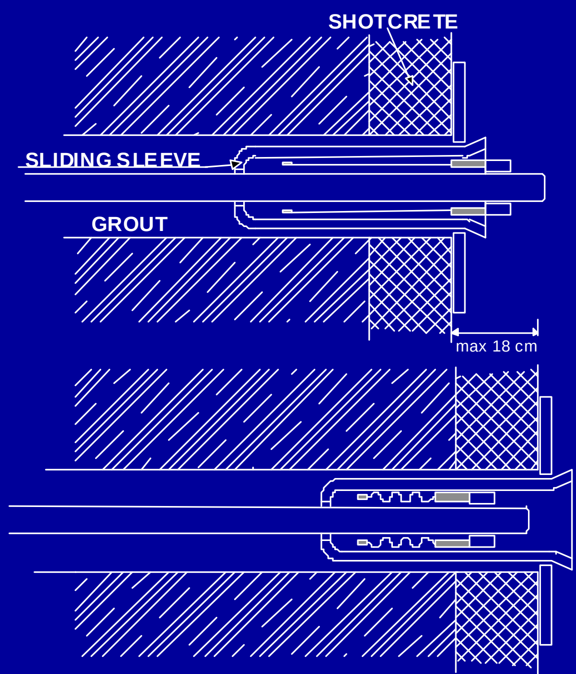


USE OF:

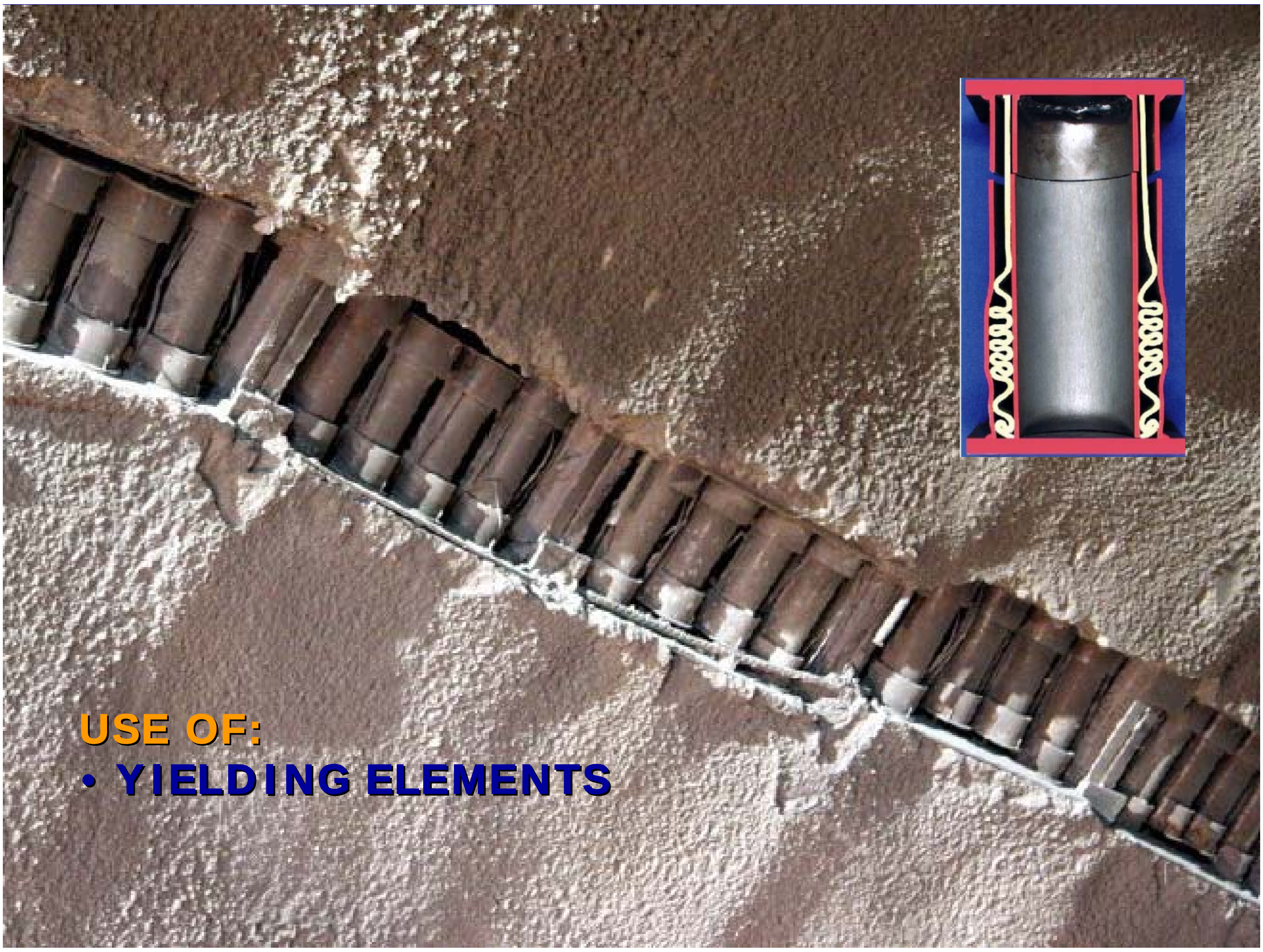
- **YIELDING STEEL RIBS**
- **YIELDING BOLTS**
- **LINING STRESS CONTROLLERS**

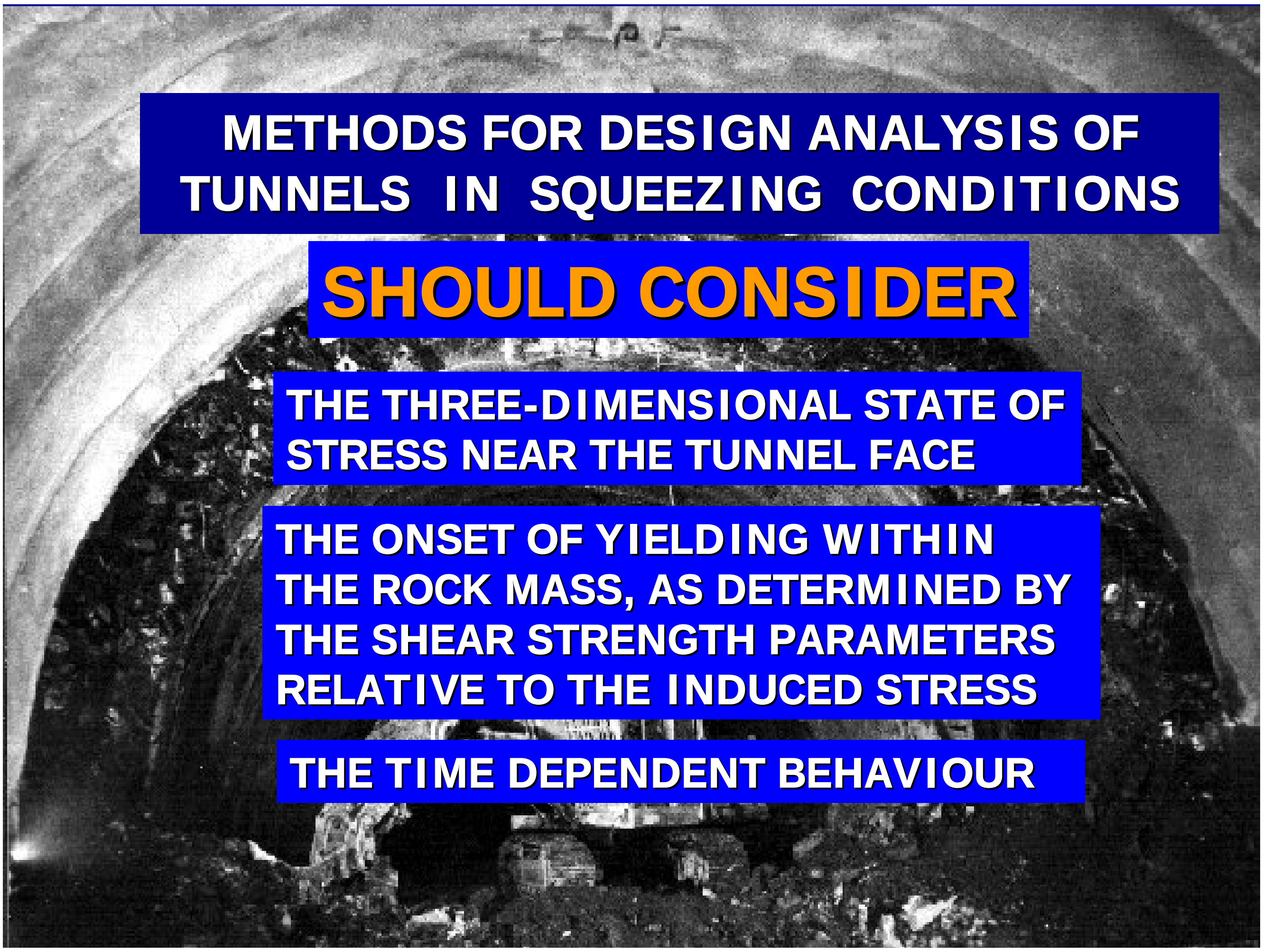
Before convergence

Following convergence

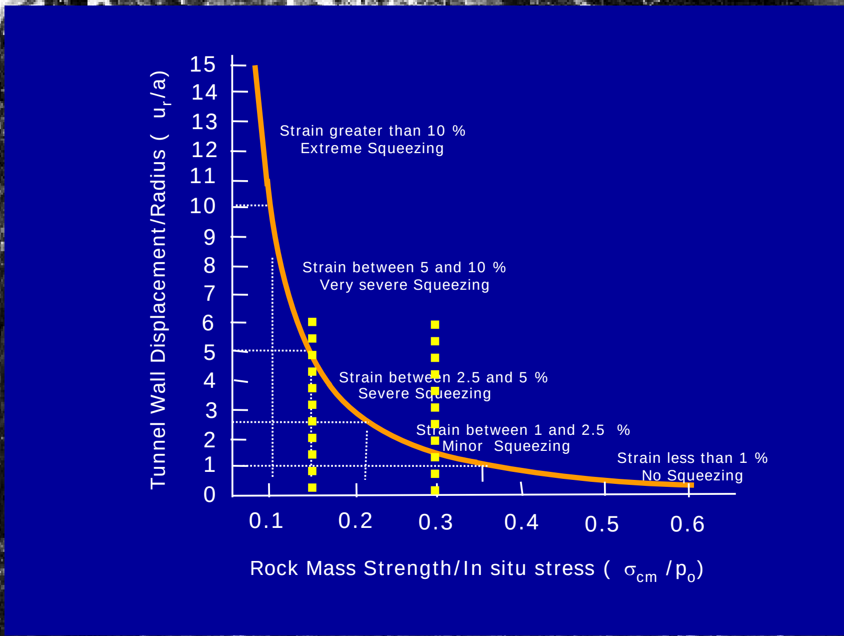


Yielding Bolts

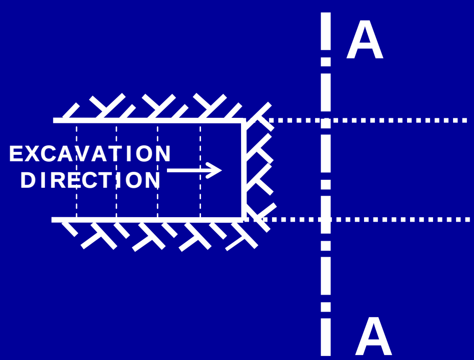

USE OF:
• YIELDING ELEMENTS

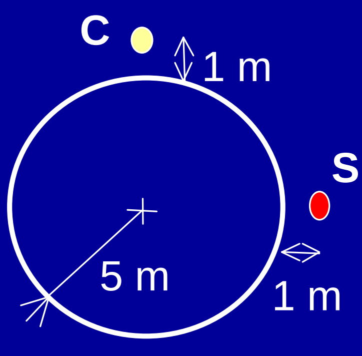

METHODS FOR DESIGN ANALYSIS OF TUNNELS IN SQUEEZING CONDITIONS
SHOULD CONSIDER
THE THREE-DIMENSIONAL STATE OF STRESS NEAR THE TUNNEL FACE
THE ONSET OF YIELDING WITHIN THE ROCK MASS, AS DETERMINED BY THE SHEAR STRENGTH PARAMETERS RELATIVE TO THE INDUCED STRESS
THE TIME DEPENDENT BEHAVIOUR

The use of numerical analyses is advisable when the rock mass strength/in situ stress ratio is below 0.3 and it is highly recommended if this ratio falls below about 0.15, when the stability of the tunnel face may become a critical issue

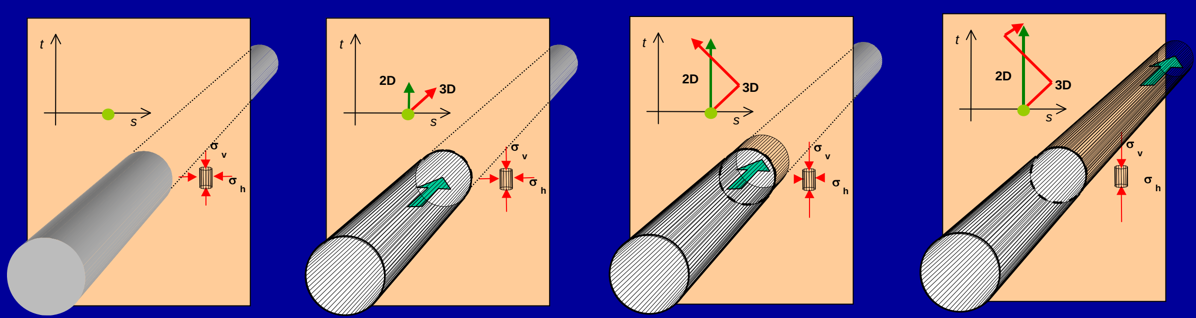


3D Analyses advisable





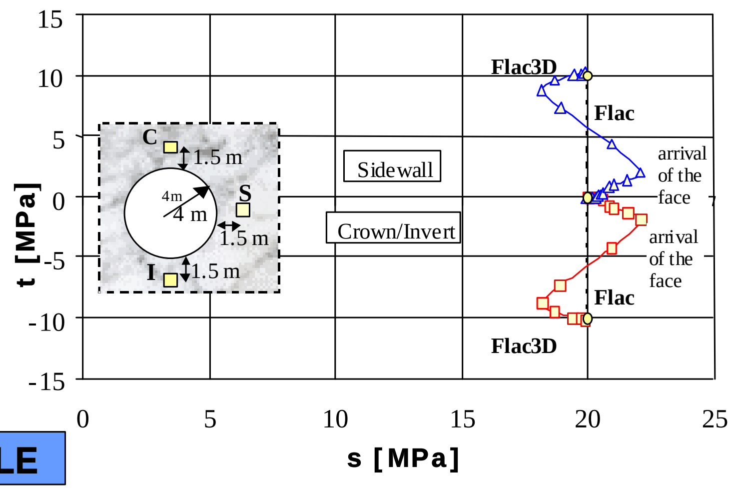
Longitudinal Section **Transversal Section A- A**



Methods for Design Analysis

3D Analyses advisable

INFLUENCE OF 3D CONDITIONS



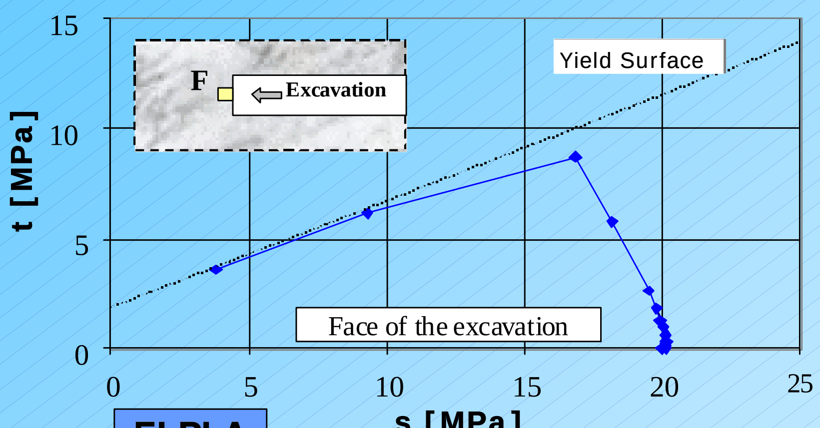
ILE

STRESS PATH AT POINT
C (crown), I (invert), S (sidewall)

Methods for Design Analysis

3D Analyses advisable

INFLUENCE OF 3D CONDITIONS

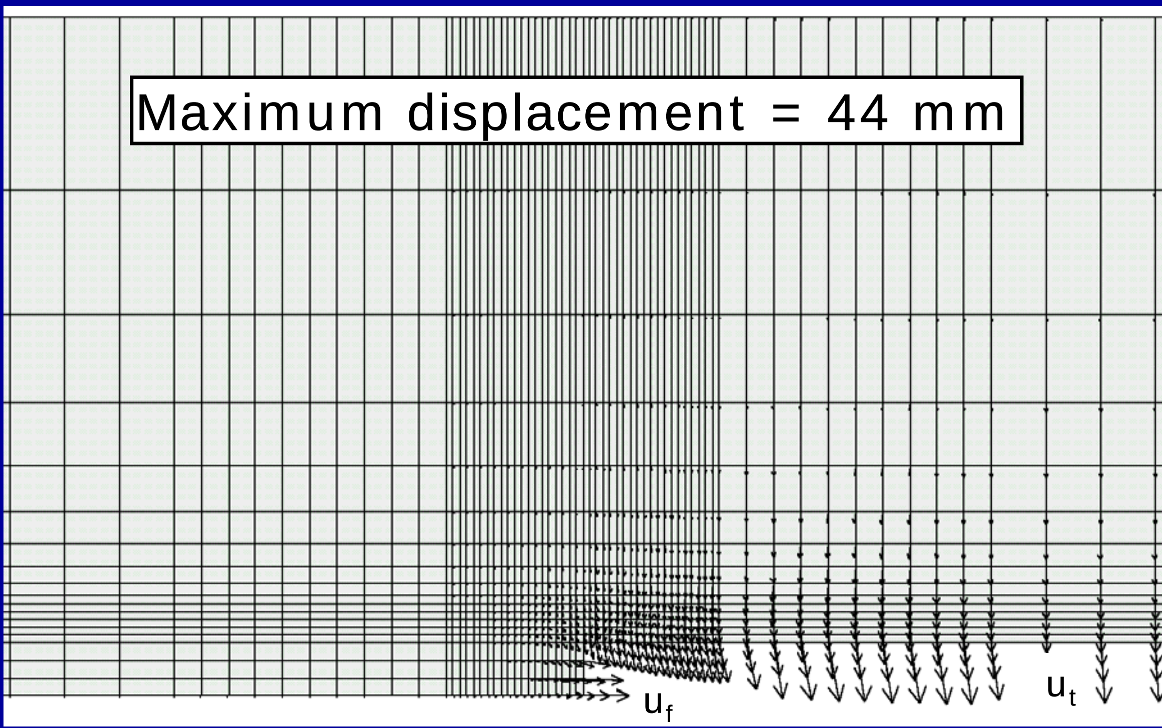


ELPLA

STRESS PATH AT POINT F
(FACE OF THE EXCAVATION)

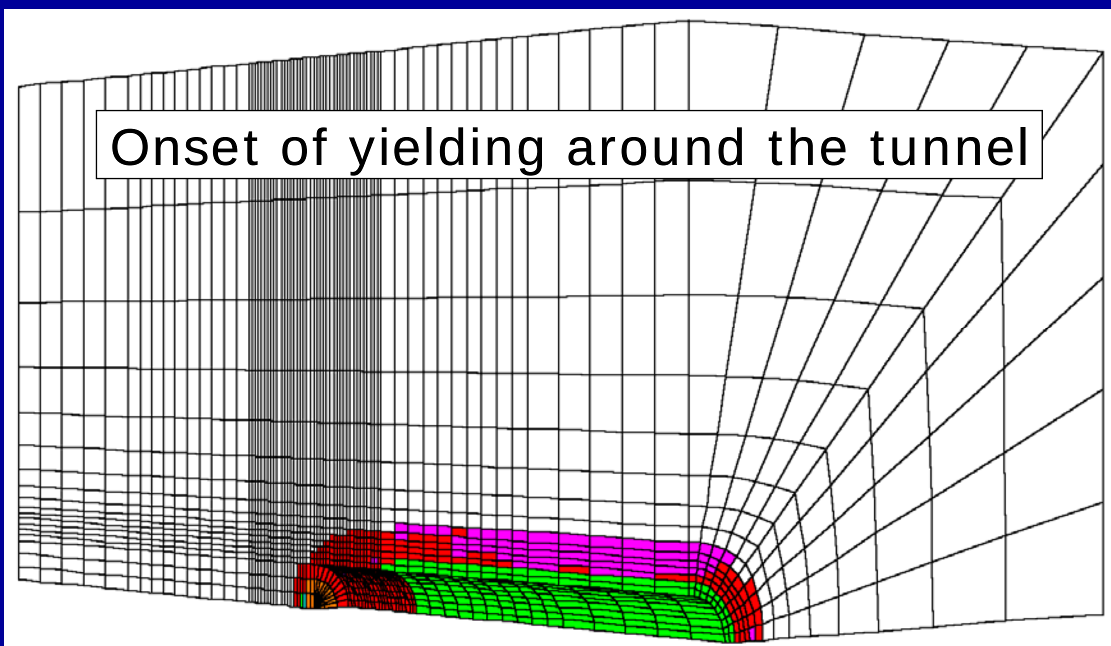
Methods for Design Analysis

3D Analyses advisable



Methods for Design Analysis

3D Analyses advisable



Methods for Design Analysis

SIMPLIFIED METHODS OF ANALYSIS AND DESIGN OF TUNNELS IN SQUEEZING CONDITIONS

CONSIDER

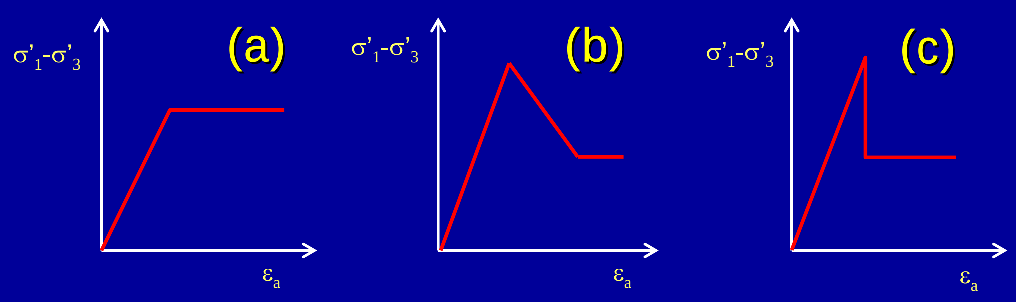
- THE ONSET OF YIELDING WITHIN THE ROCK MASS, AS DETERMINED BY THE SHEAR STRENGTH PARAMETERS RELATIVE TO THE INDUCED STRESS

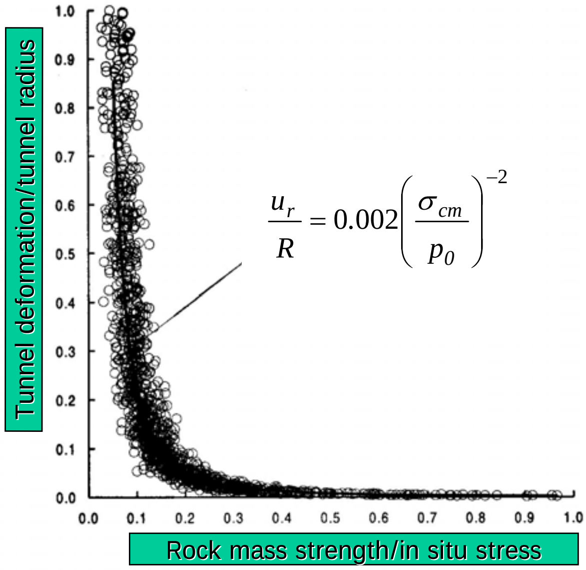
- Elasto-plastic closed form solutions for rock mass response to excavation of a circular tunnel can be used

If the rock mass is assumed to behave as an elasto-plastic isotropic medium, the following models can be adopted:

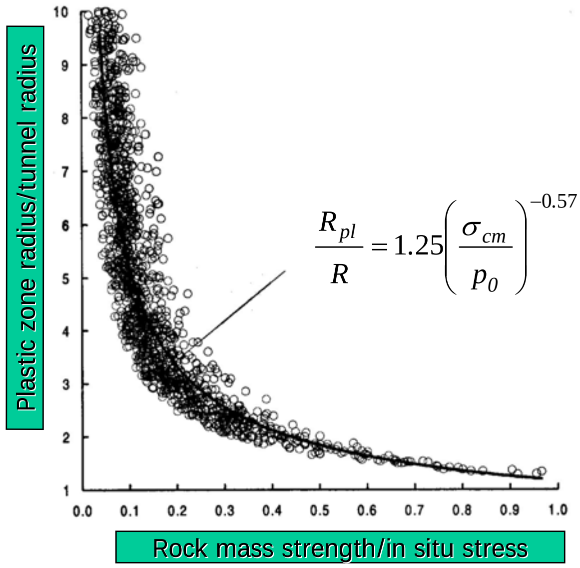
- Elastic perfectly plastic (a)
- Elasto-plastic with strain softening behaviour (b)
- Elasto-plastic, with brittle behaviour (c)

(e.g.Brown et al.,1983;....Carranza-Torres and Fairhurst,1999)





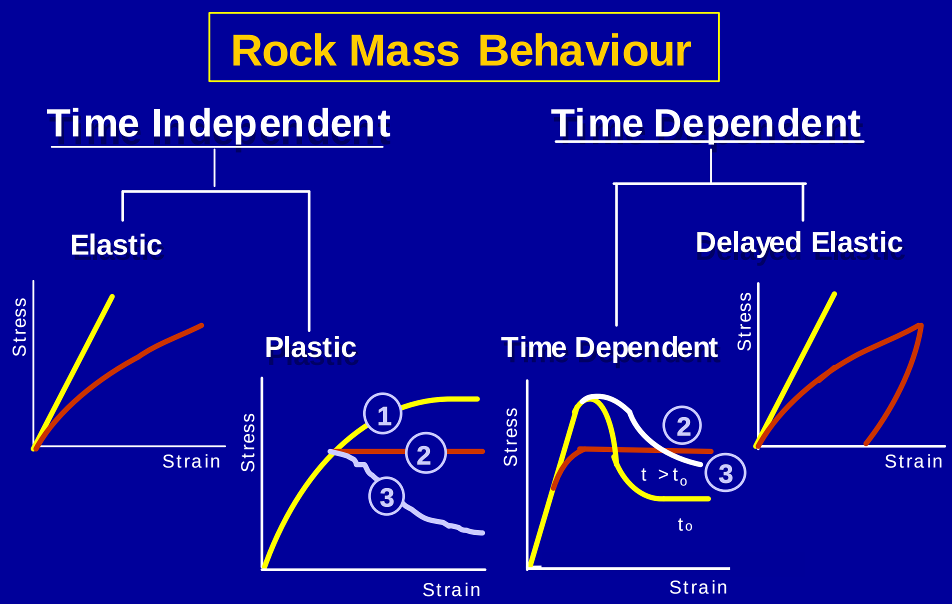
$$\frac{u_r}{R} = 0.002\left(\frac{\sigma_{cm}}{p_0}\right)^{-2}$$



$$\frac{R_{pl}}{R} = 1.25\left(\frac{\sigma_{cm}}{p_0}\right)^{-0.57}$$

BASED UPON THE ABOVE SOLUTIONS DIMENSIONLESS PLOTS CAN BE DERIVED FROM THE RESULTS OF PARAMETRIC STUDIES WHERE THE INFLUENCE OF THE VARIATION IN THE INPUT PARAMETERS ARE STUDIED BY THE MONTE CARLO ANALYSIS, UNDER THE ASSUMPTION OF ELASTIC PERFECTLY PLASTIC BEHAVIOUR OF THE ROCK MASS, WITH ZERO VOLUMETRIC CHANGE (HOEK,1998,1999)

Time - dependent behaviour

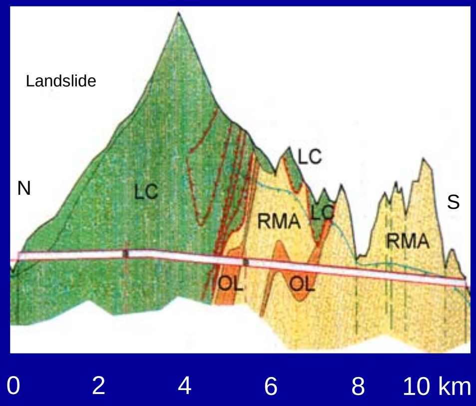


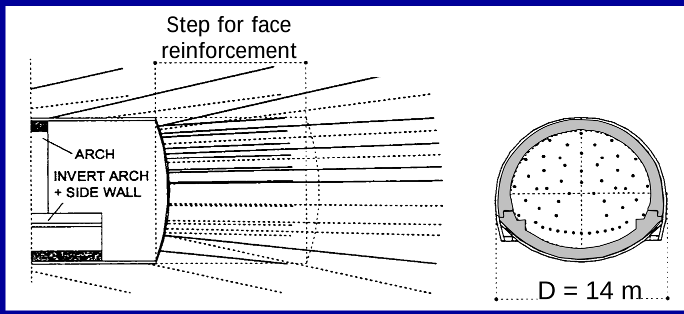
1 - Strain - hardening
2 - Perfectly plastic
3 - Strain softening

• Time - dependent post peak behaviour
• Time - dependent peak and ultimate strength

Methods for Design Analysis

RATICOSA TUNNEL





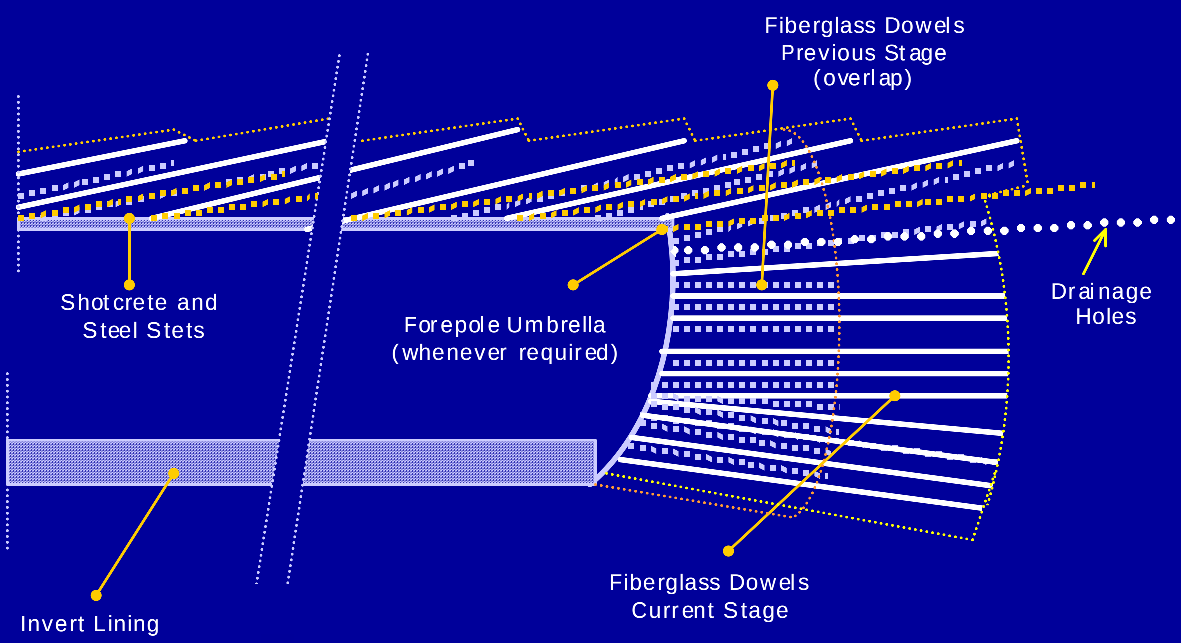
EXCAVATION OF LARGE SPAN TUNNELS BY THE FULL FACE METHOD WITH GROUTED FIBERGLASS DOWELS IN FACE

RATICOSA TUNNEL - Clay-Shales

(BOLOGNA - FIRENZE HIGH SPEED RAILWAY LINE)

COURTESY OF ROCKSOIL - CAVET - ITALFERR

Full Face Excavation / Support / Reinforcement Sequence Through Weak Rock (Monghidoro Flysch)



Full Face Excavation / Support / Reinforcement Sequence Through Weak Rock

Schematic Illustration - not to scale

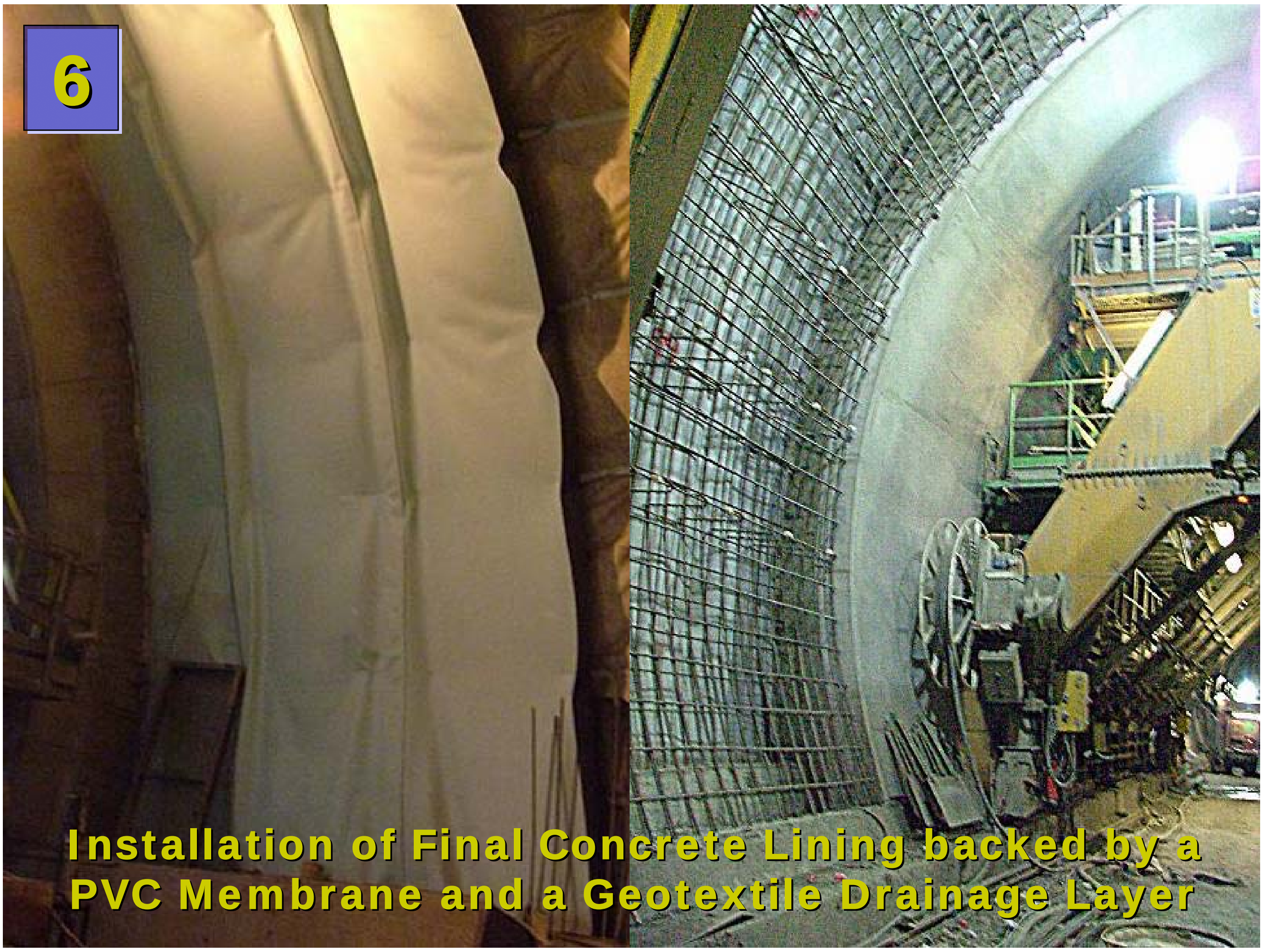

1
SCI
EX255
Mucking-Out with face stabilisation completed and prior to new face advance stage (typically 1 m)


2
Steel Sets installed as close to the face as possible
Optical Target for Convergence Measurements
Hole in the face to be drilled
Fiberglass Dowell being grouted
Drilling Unit for Installation of Fiberglass Face Reinforcement


3
Installation of Heavy Steel Sets
as close to the face as possible
followed by Application of Shotcrete

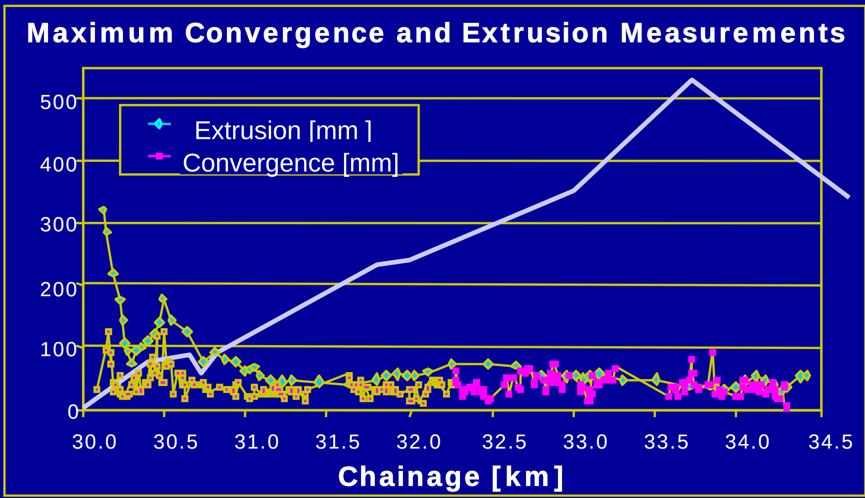

4
Installation of Invert Struts close to the face
to control floor heave and to “close the ring”

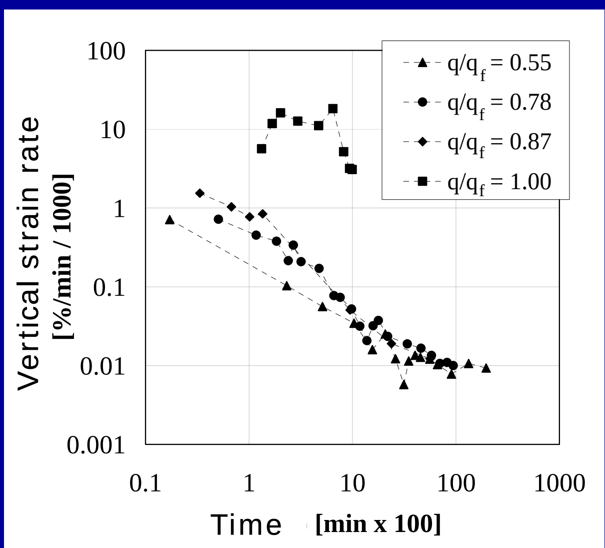

5
Invert Reinforced Concrete Lining
installed as close to the face as possible


6
Installation of Final Concrete Lining backed by a
PVC Membrane and a Geotextile Drainage Layer

Lesson Learnt: Extrusion measurements more relevant than convergence measurements for understanding rock mass response

(Case Study: Raticosa Tunnel)

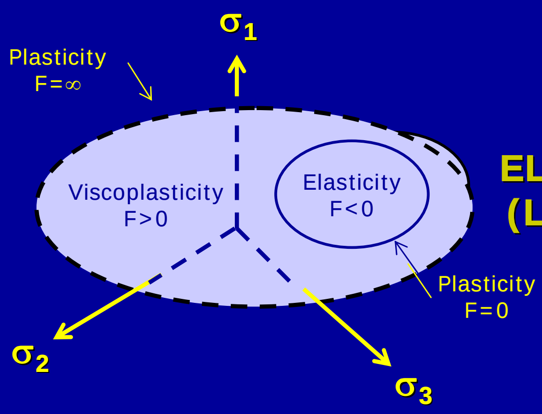




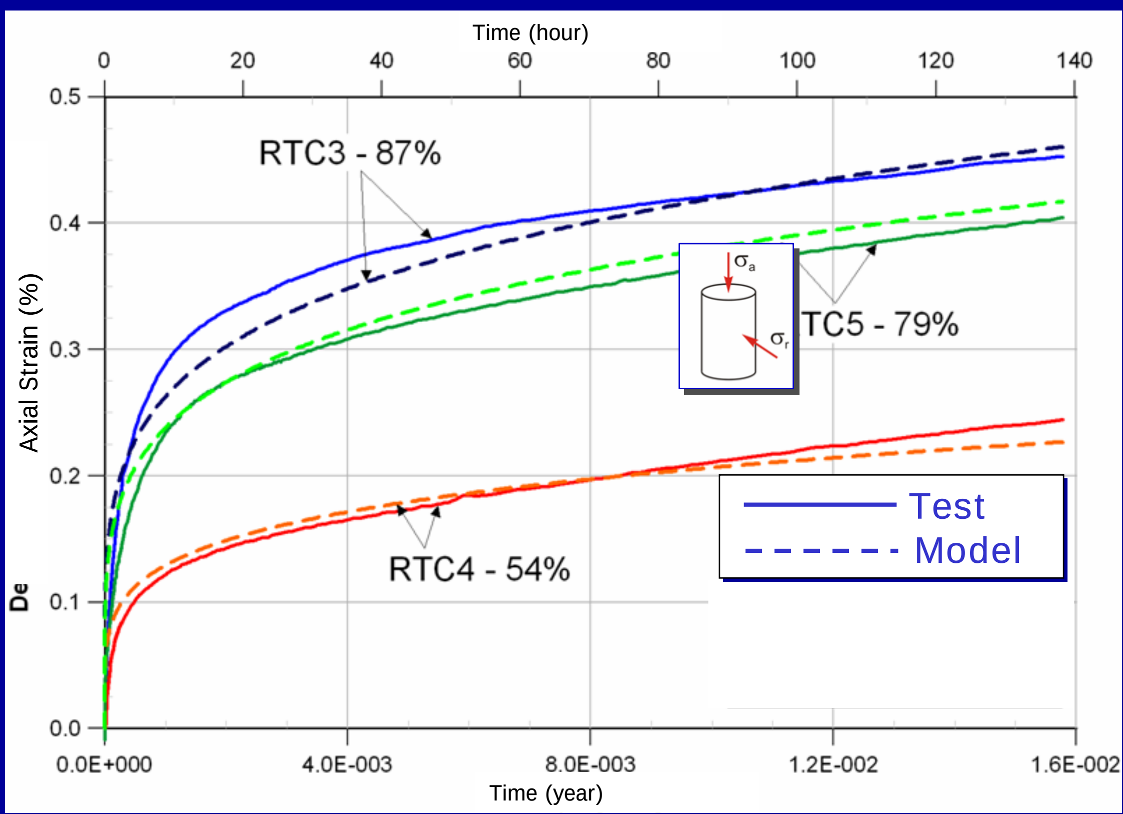
Creep Tests in undrained conditions on clay-shales for the study of time dependent response of tunnel face

(q / q_f = mobilised strength)

ELASTO-VISCOPLASTIC MODEL (Lemaitre and Chambon, 1996)

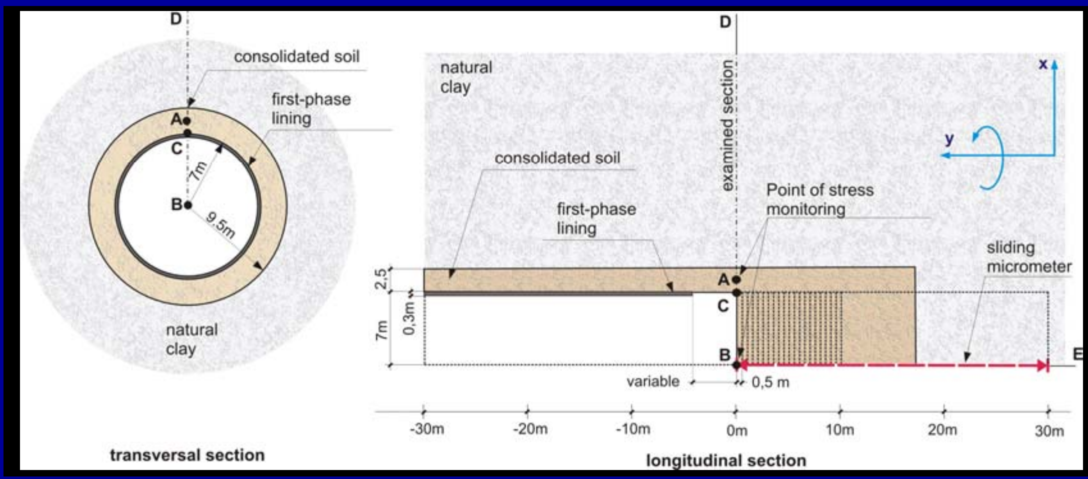


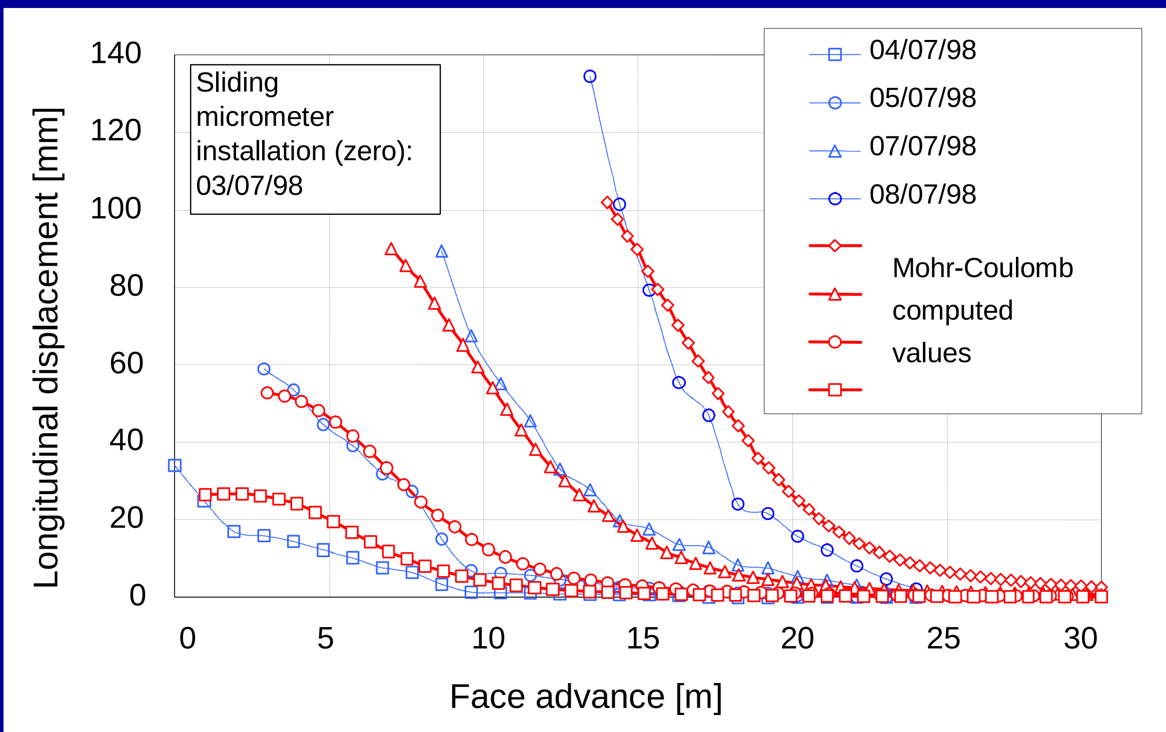
The viscoplastic strains depend on the deviatoric stress state only and do not induce volumetric strains



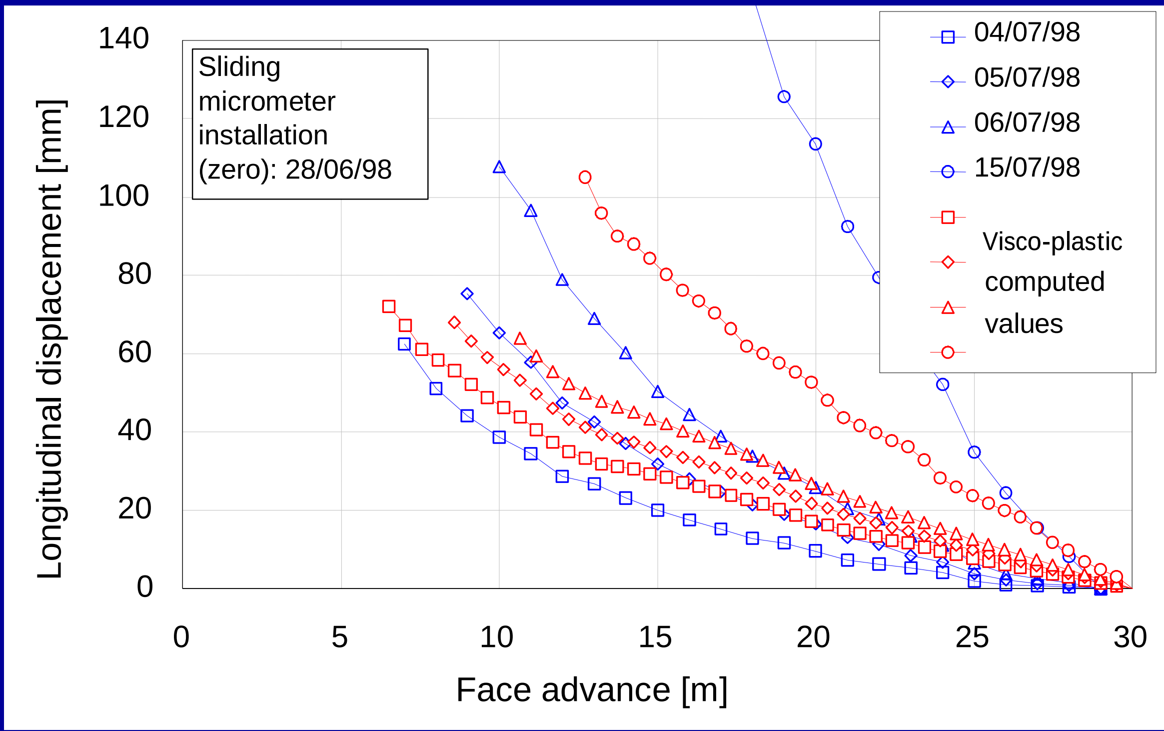
- axis-symmetric conditions
- circular cross section
- initial state of stress constant and isotropic
- coupled analysis in undrained conditions
- two cases considered:

- Osteria Access Adit (depth = 148 m)
  Mohr-Coulomb elasto-plastic perfectly plastic model
- Raticosa Tunnel (depth = 50 m)
  Elasto visco-plastic model





Osteria Access Adit



Raticosa Tunnel

Tunnels
Underground Excavations

Design Analyses
Case Studies and Observed Performance

Giovanni Barla

Department of Structural and Geotechnical Engineering