



The 3rd Training course
TUNNELLING IN URBAN AREA
Prague, 4-5th May 2007

Numerical modelling in tunnels

TRAINING MATERIAL PREPARED BY

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(Mott MacDonald, Czech Republic)



1

Introduction

2

Chapter 1 - Sequential excavation tunnel support structural elements

3

Chapter 2 - Numerical models of tunnels and reality – constitutive laws

4

Chapter 3 - Settlement above shallow tunnels

5

Conclusions



1

2

3

4

5

Shotcrete

does not mean
NATM

Numerical modelling in tunnels

1

2

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5

Selection of tunnel support structural elements

- ground
- excavation method
- demand for control of deformation - settlement



1

Ground

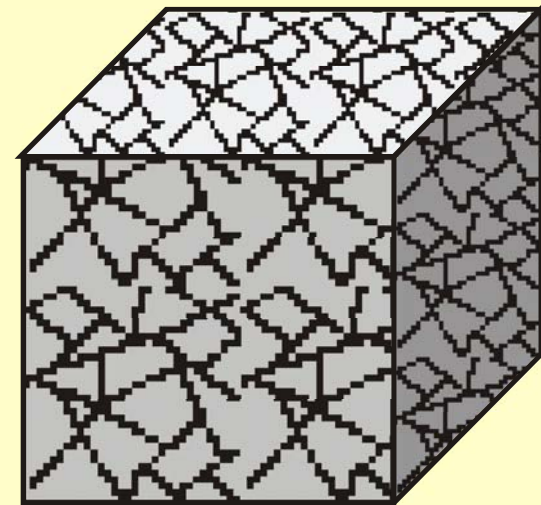
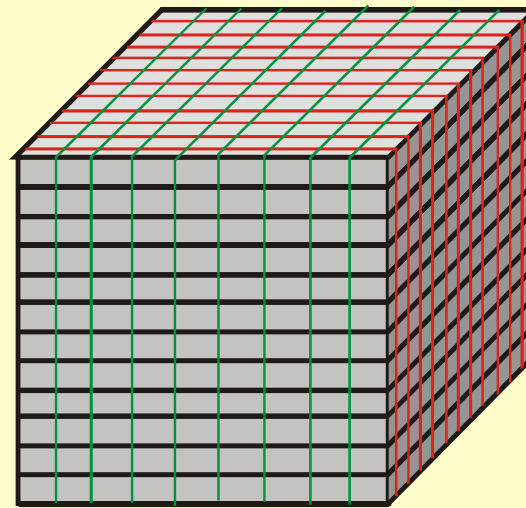
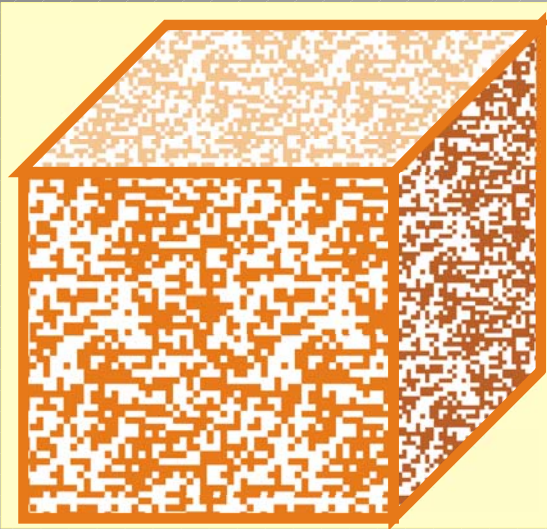
2

Soils

R.M. with less than 4 systems of discontin.

R.M. with more than 4 systems of discontin.

3



4

5

Continuum

Discontinuum

Continuum

• Numerical methods

• Numerical methods

• Numerical methods

+

• **Structural analysis !!**



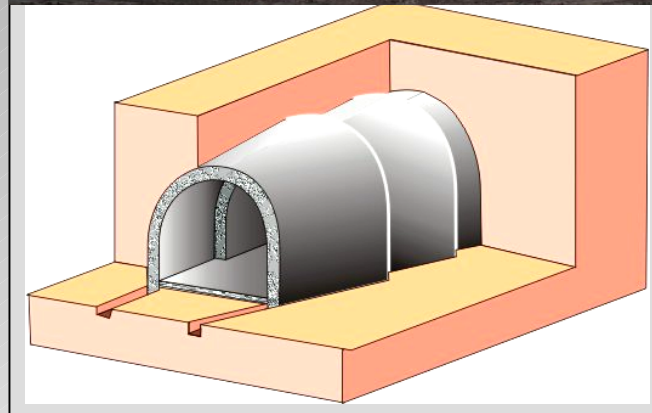
Excavation method

Introduction

Segment lining



Perforex



Shotcrete



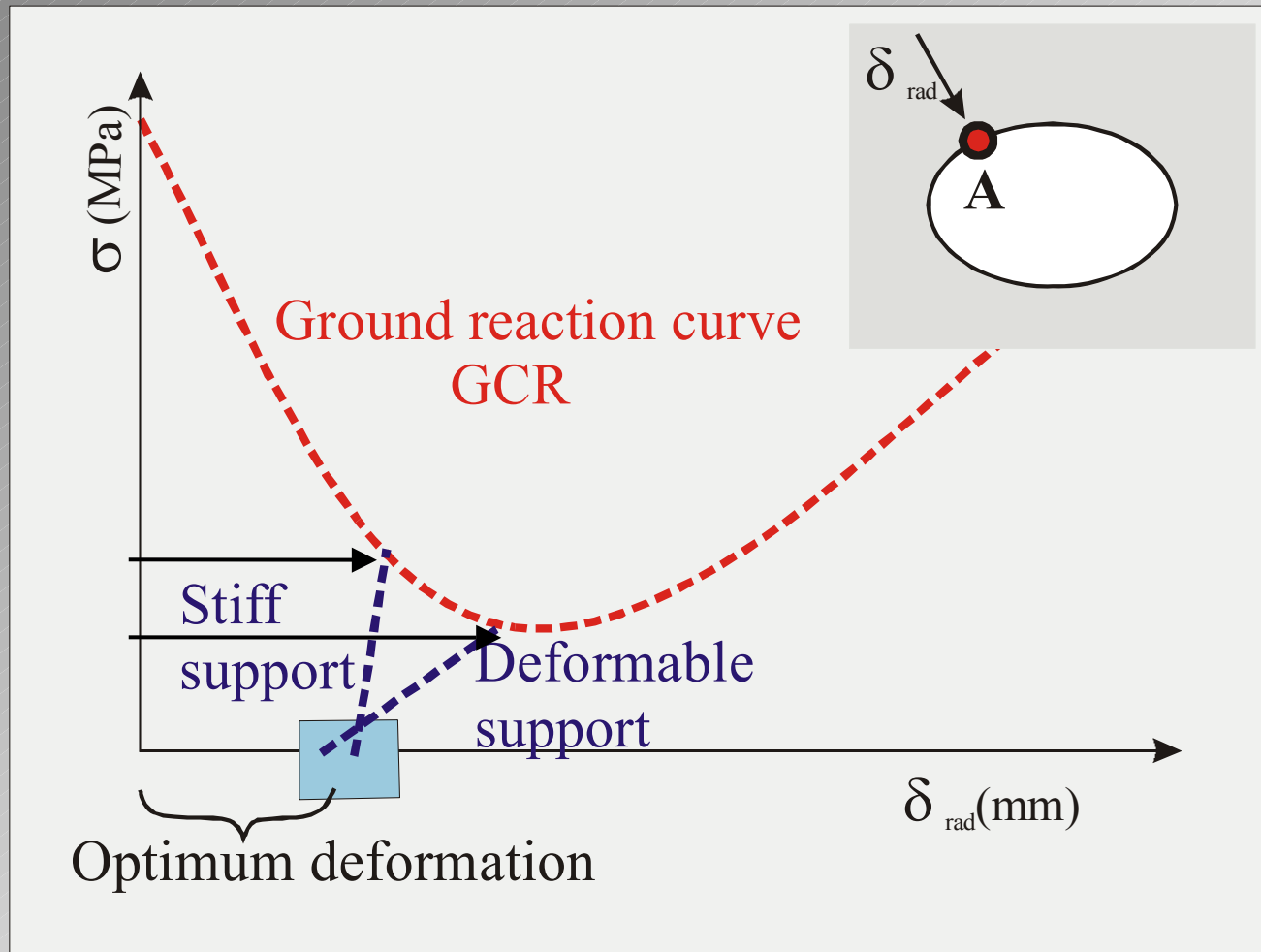
•TBM

•Perforex

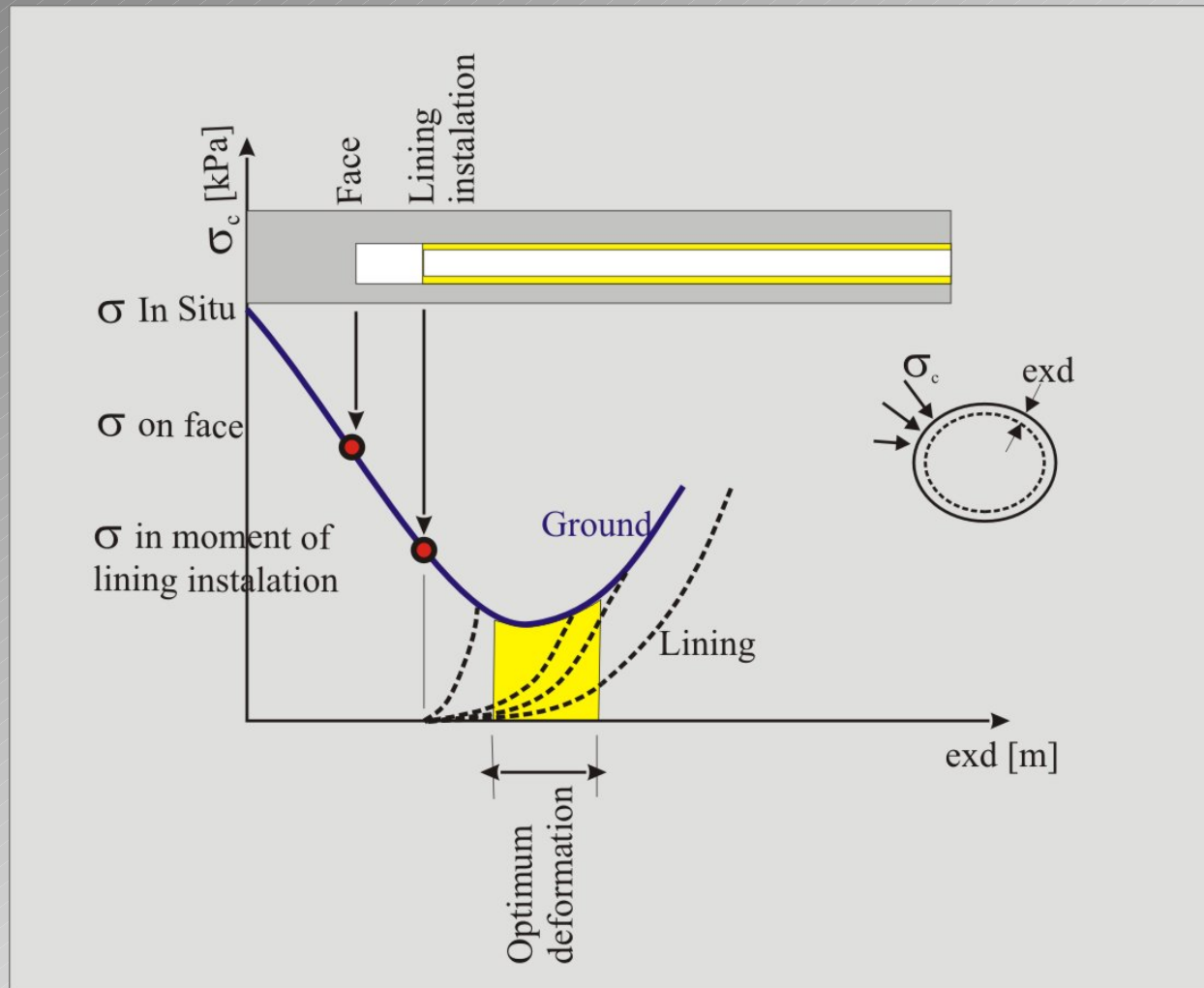
•NATM

Numerical modelling in tunnels

Control of deformation



Timing of support installation



1

2

Sequential excavation tunnel support structural elements

3

4

- shotcrete
- rock bolts

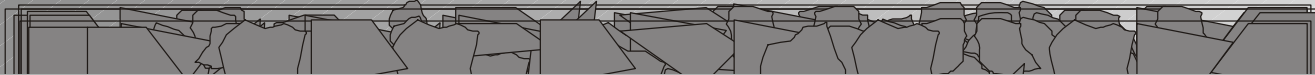
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1

Shotcrete membrane effect

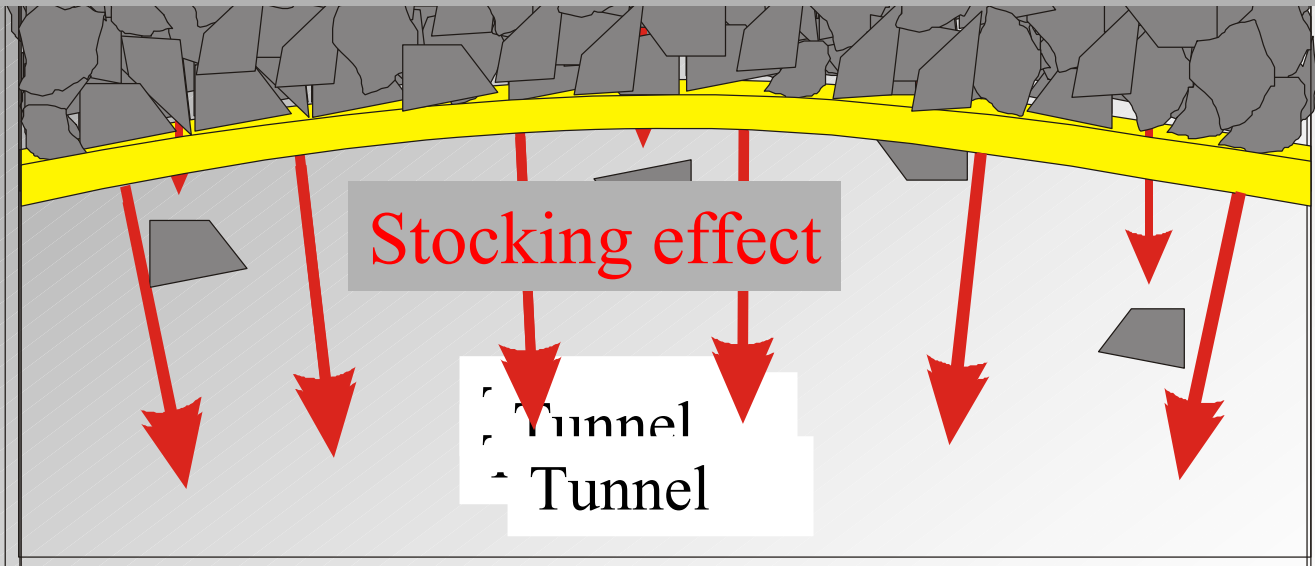
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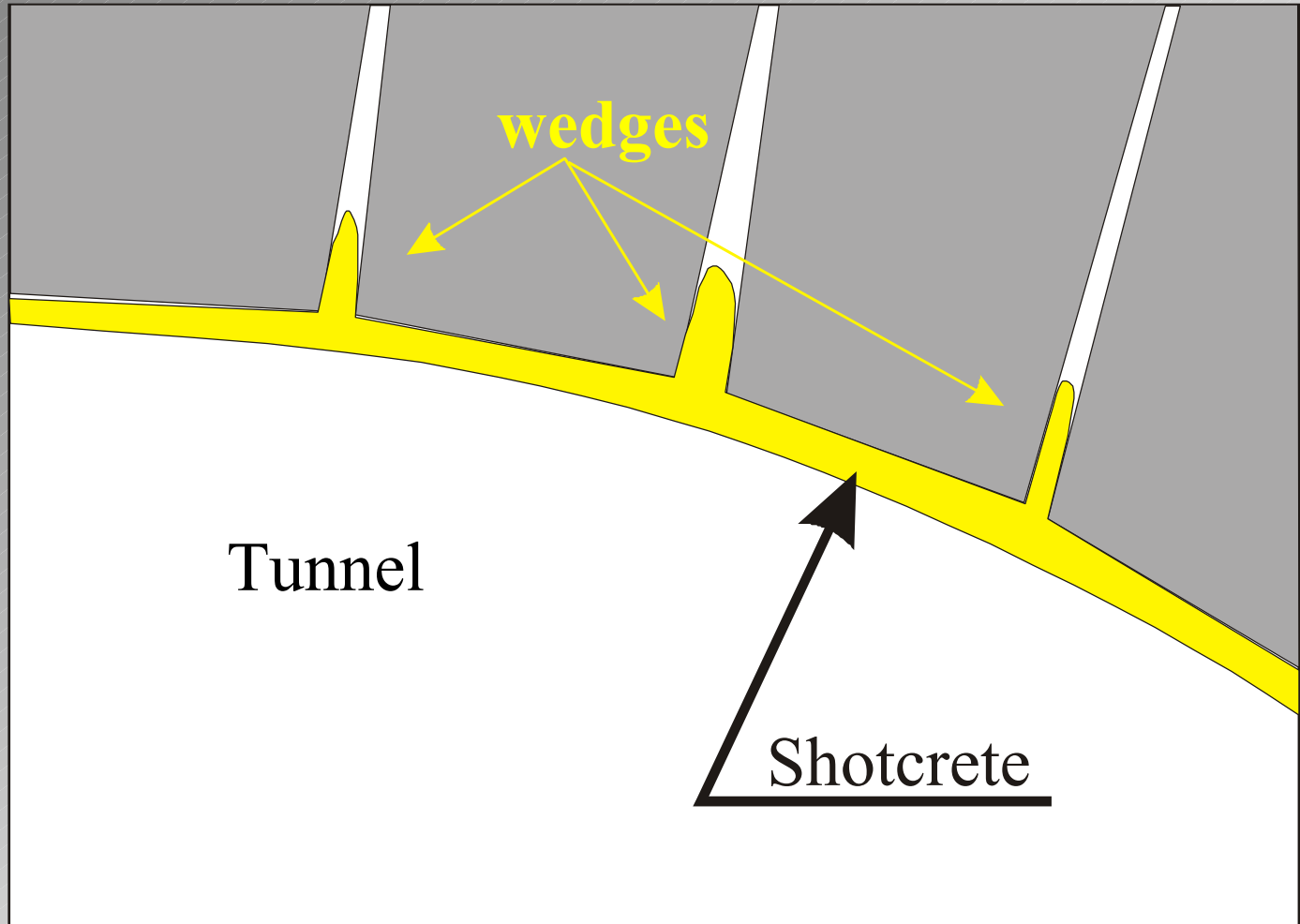
How do mechanical properties of the rock mass in the vicinity of an opening change?????????
discontinuities and cracks tend to close.

4

5



Shotcrete – wedge effect



1

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5



1

Shotcrete – shear strength and the strength of adhesion

2

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4

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Magnitude of adhesion is estimated to be close to 3MPa



Shotcrete thickness $< 3\text{cm}$

Shotcrete thickness $> 3\text{cm}$



1

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Rock bolts

US Tunnel engineering handbook –

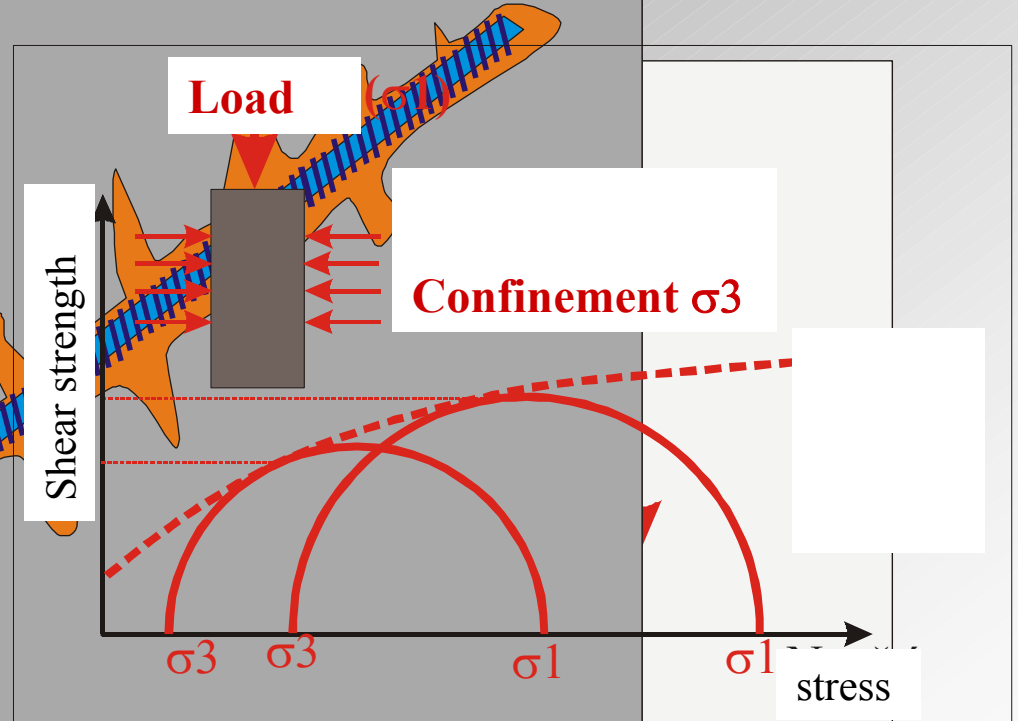
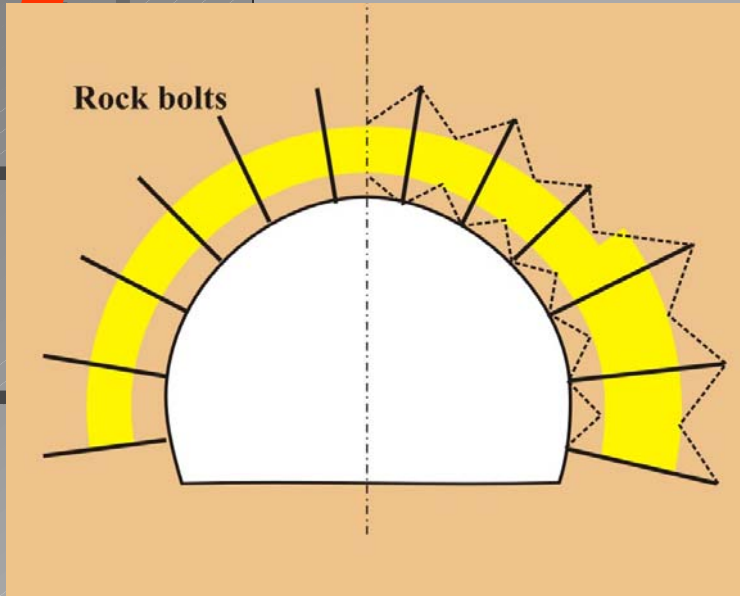
Rock bolt is the general term that includes rock bolts, rock dowels and cable tendons.



Rock bolts

1

2



5

Rock arch for
the rock bolts

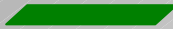
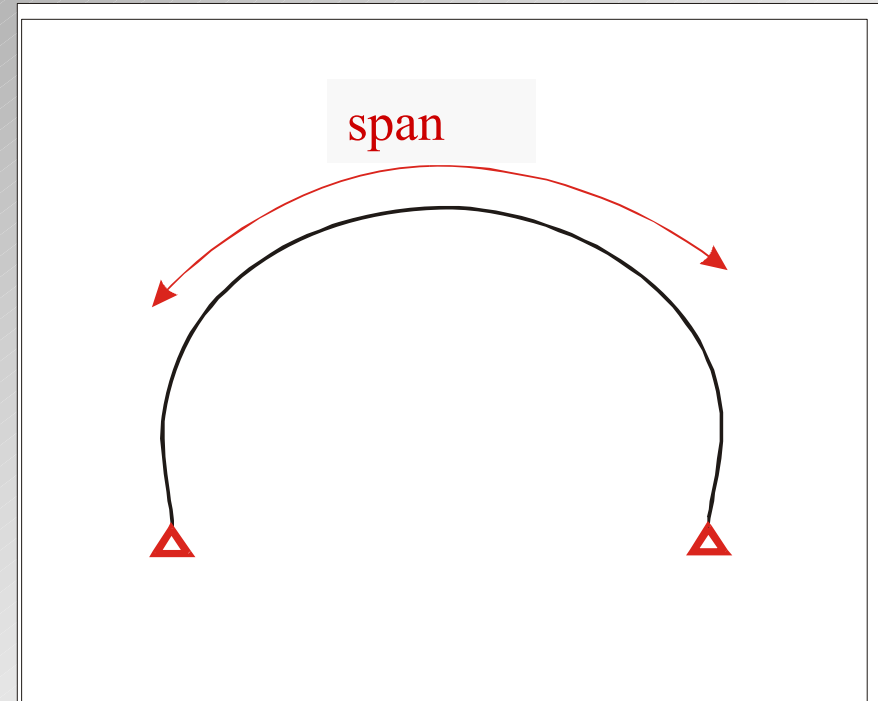
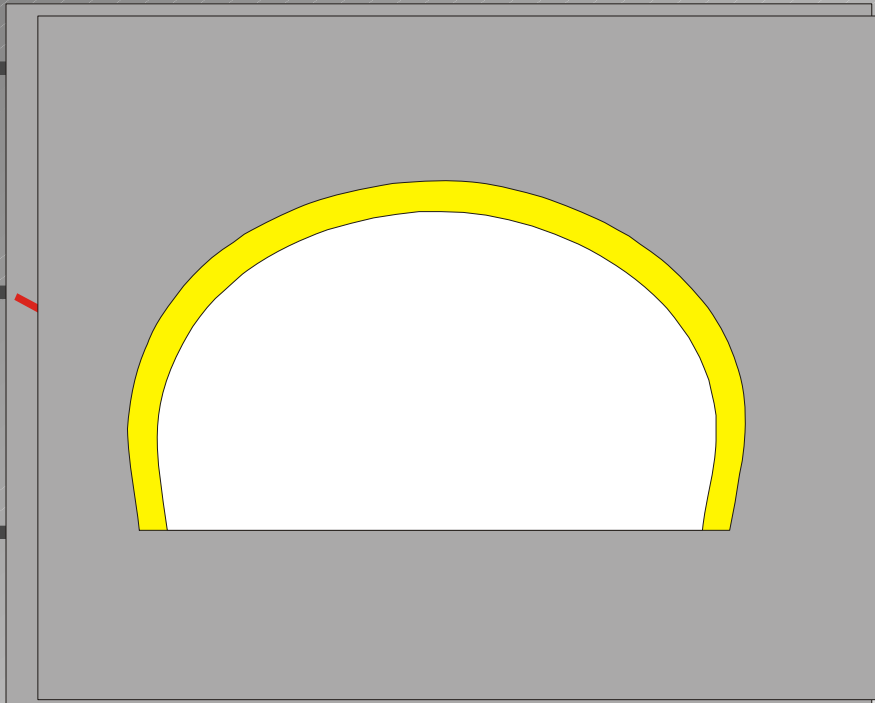
tion.



1

2

Shotcrete and rock bolts



1

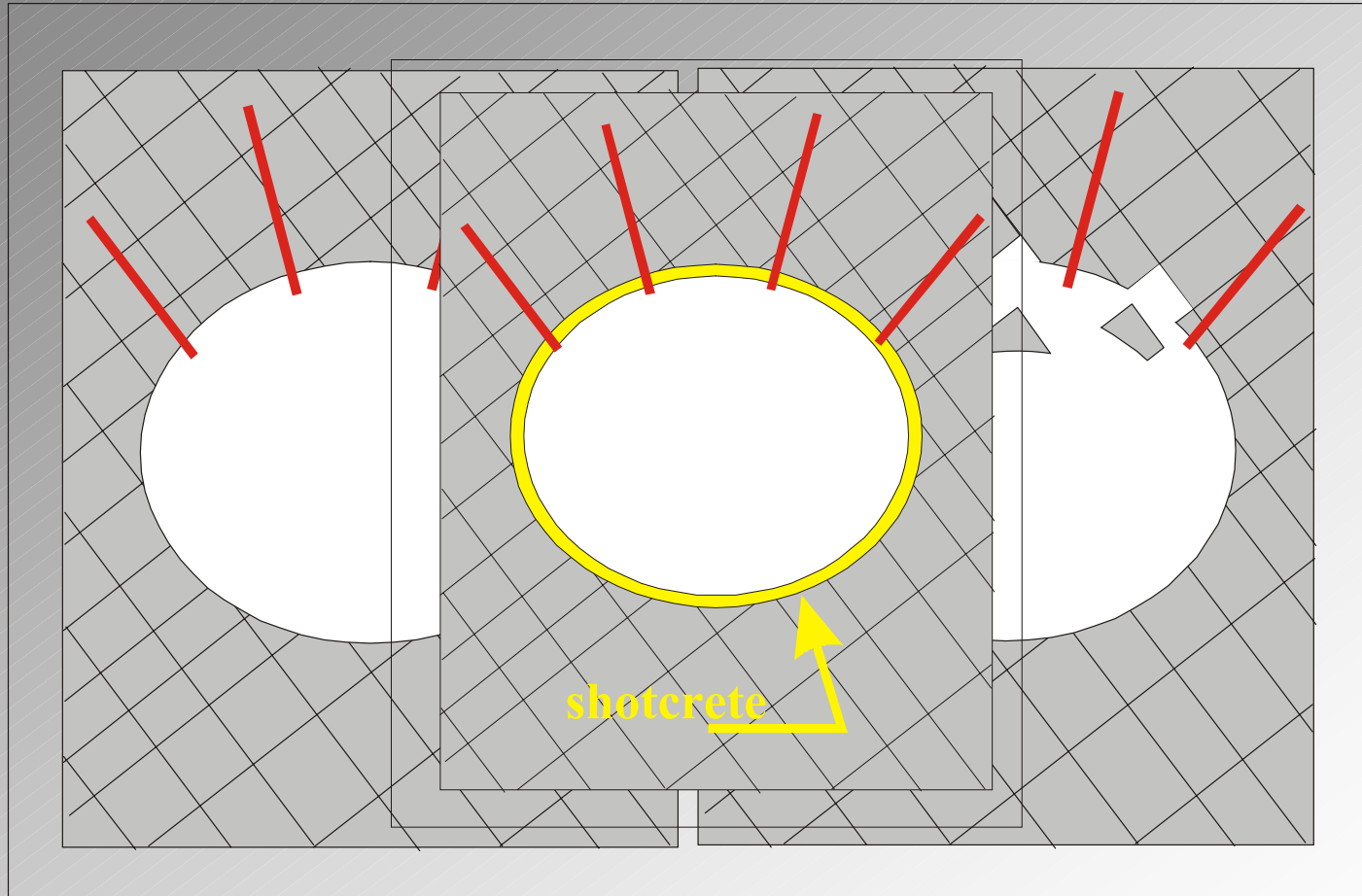
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Shotcrete and rock bolts



Dulles international airport

1

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Numerical modelling in tunnels





1

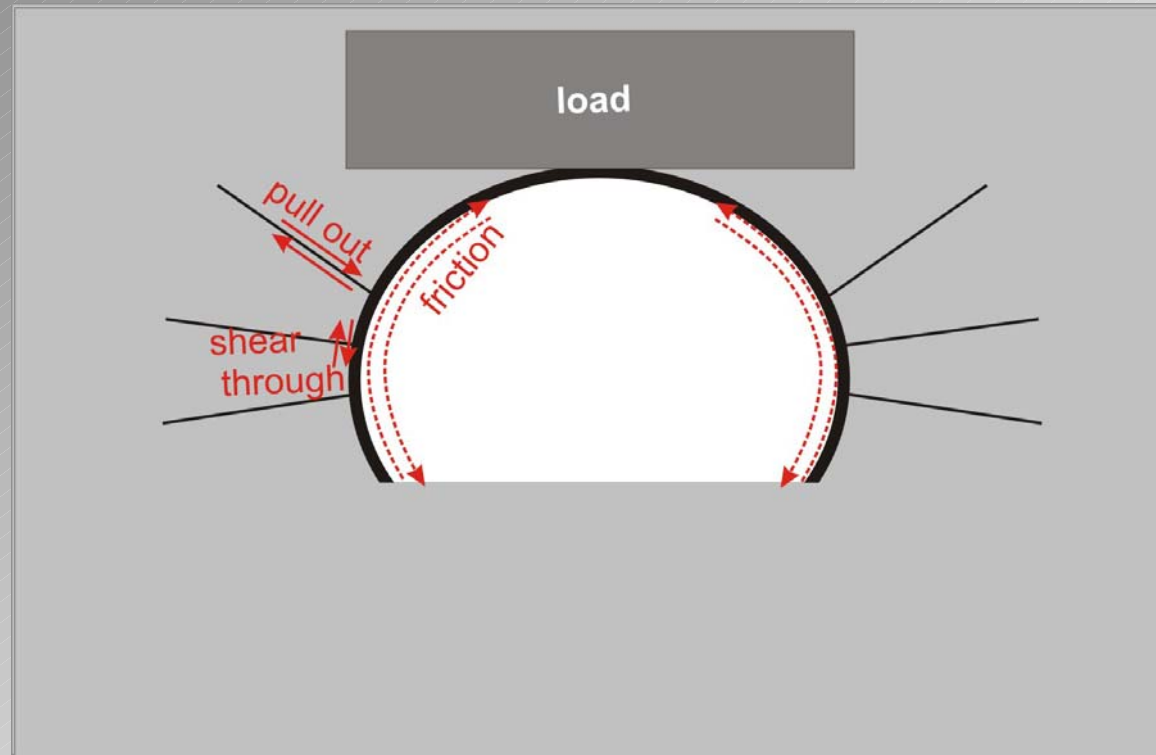
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Dulles static calculation



1

Perforex tunnels

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Numerical modelling in tunnels



1

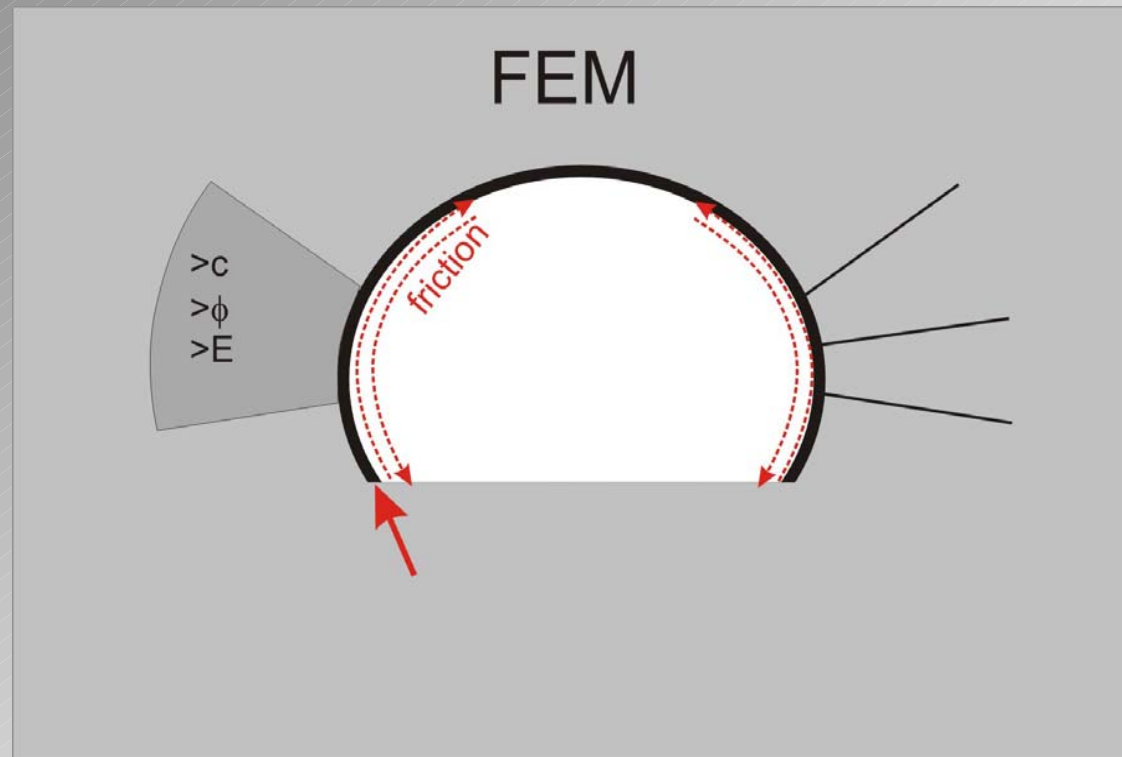
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Perforex static calculation



1

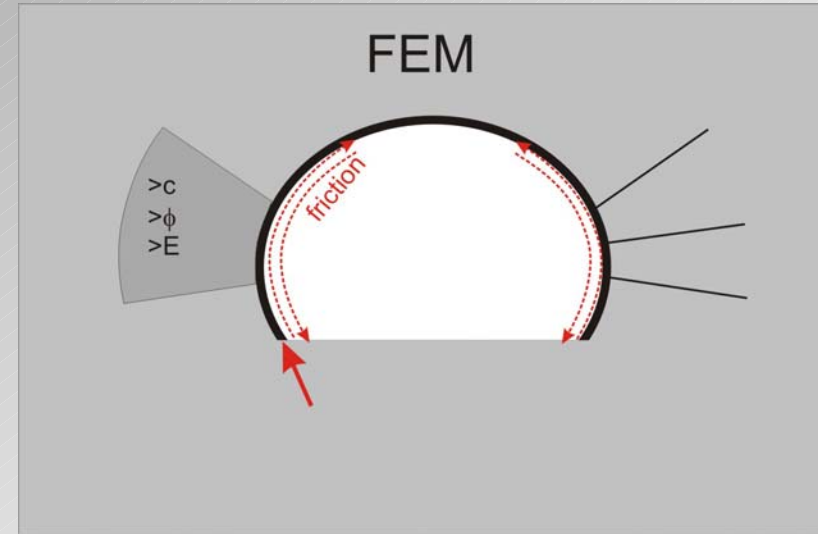
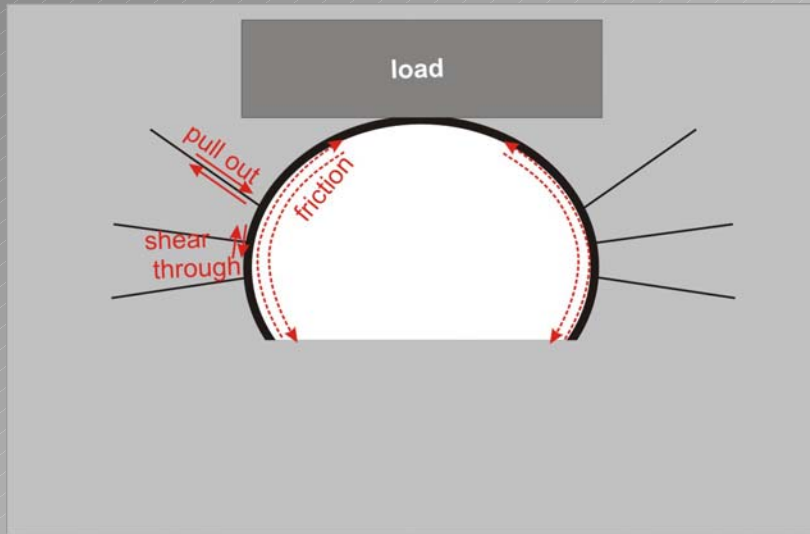
2

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5

Which is better

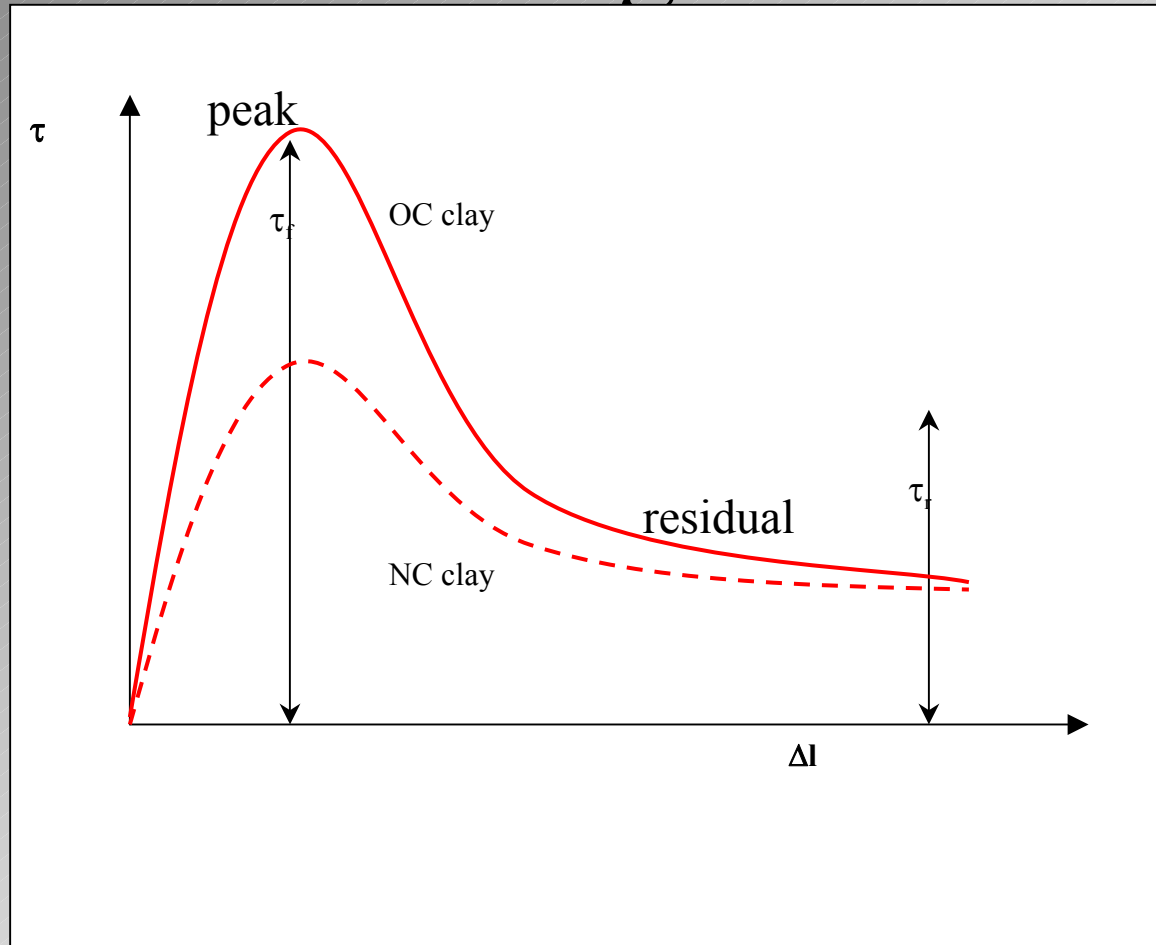


OK
OK

Claystone
Clay

OK+
XXXXXXXXXX

Deformation and mobilized strength



Numerical modelling in tunnels

1

2

Mobilised strength

Claystone

Clay

3

- Short def. path
- All components together
- Rock self supporting
- Footing bearing capacity sufficient

- Long def.path
- Components gradually
- Time dependent loading
- Non of the components itself sufficient

4

5



1

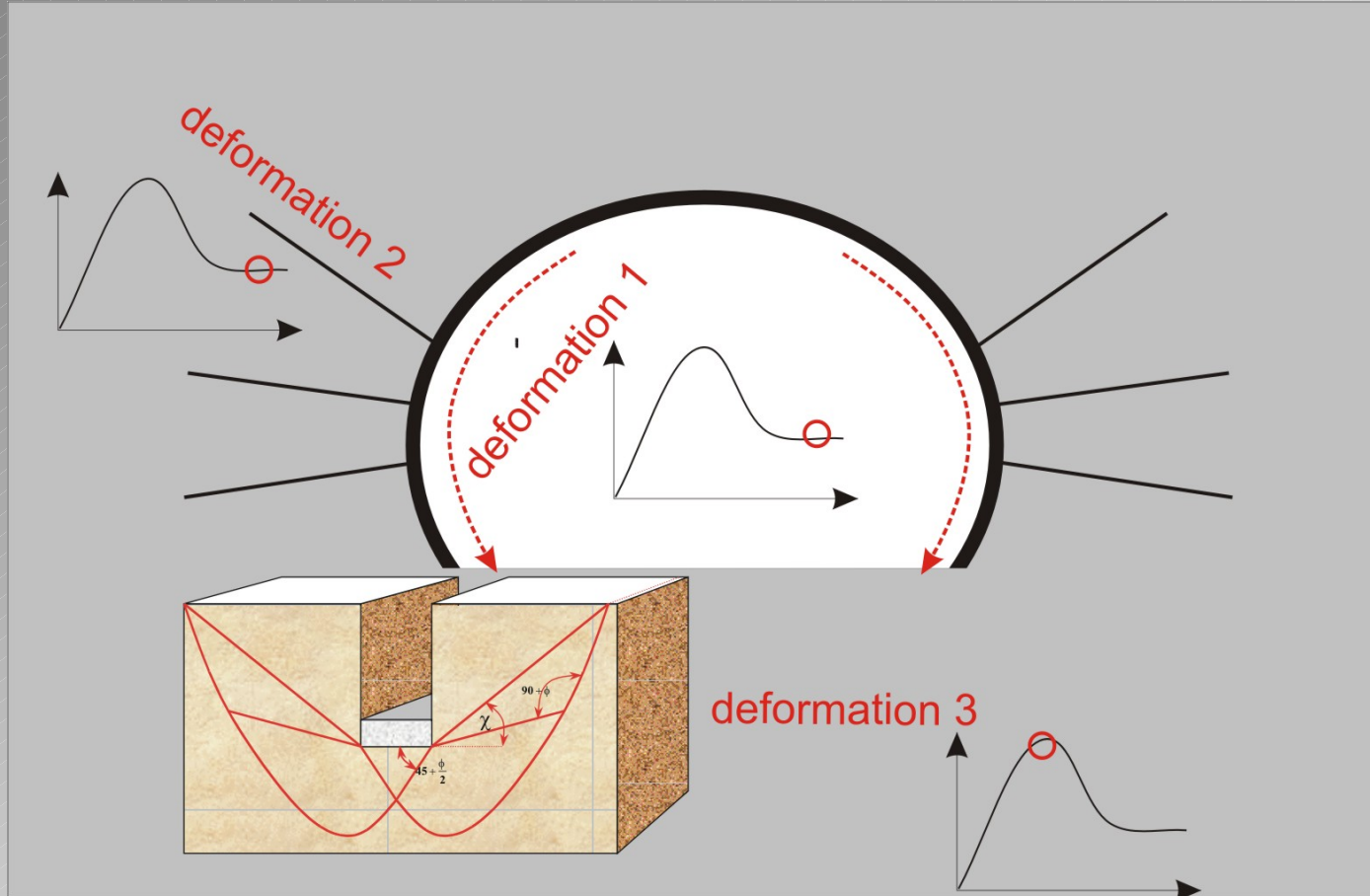
2

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Potential collapse



Numerical modelling in tunnels



1

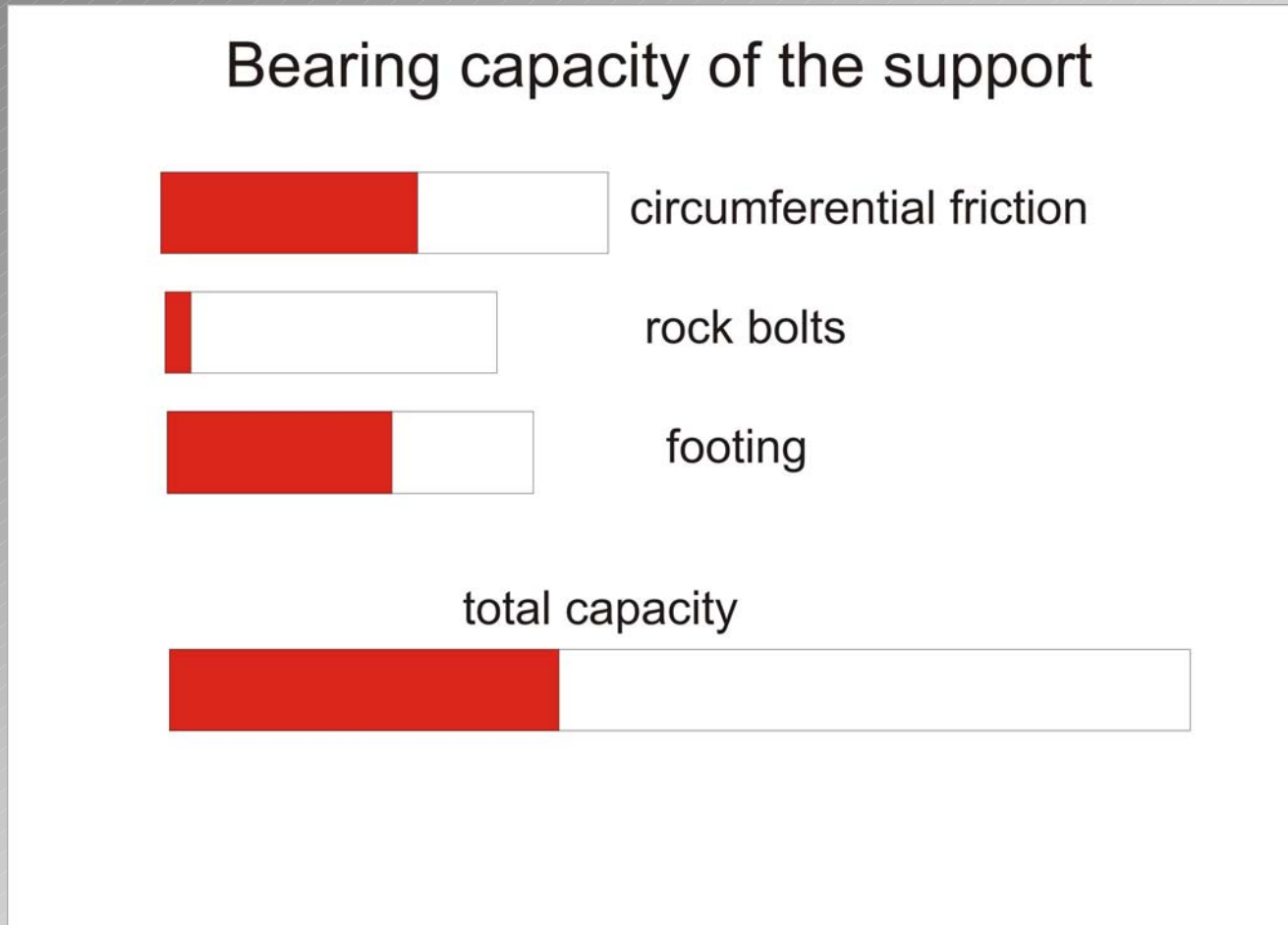
Bearing capacity of the support

2

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1

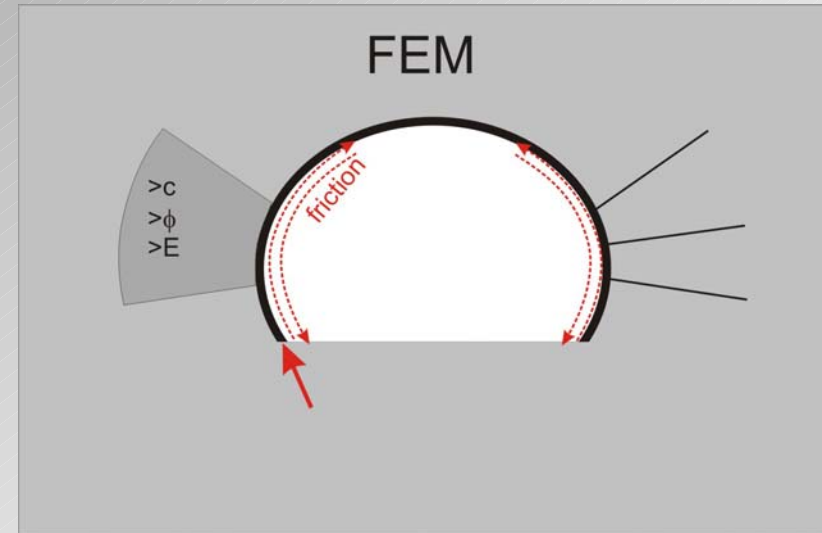
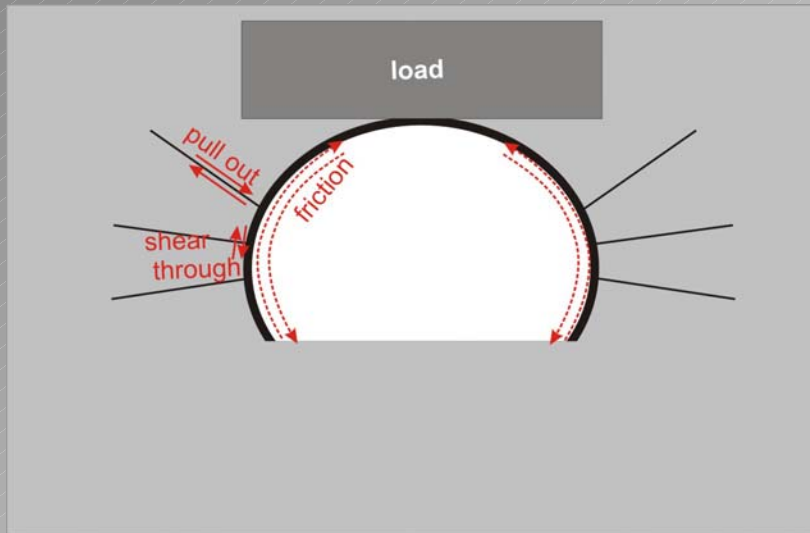
2

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4

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Which is better



1

2

Numerical models of tunnels and reality - constitutive laws

3

- constitutive laws

4

- Shotcrete
- rockbolts

5



1

Do numerical models provide us with information about:

2

3

- immediate crown stability during excavation?

4

- immediate face stability during excavation?
- loads that the support shall be dimensioned for?

5

- deformations that should be expected?



1

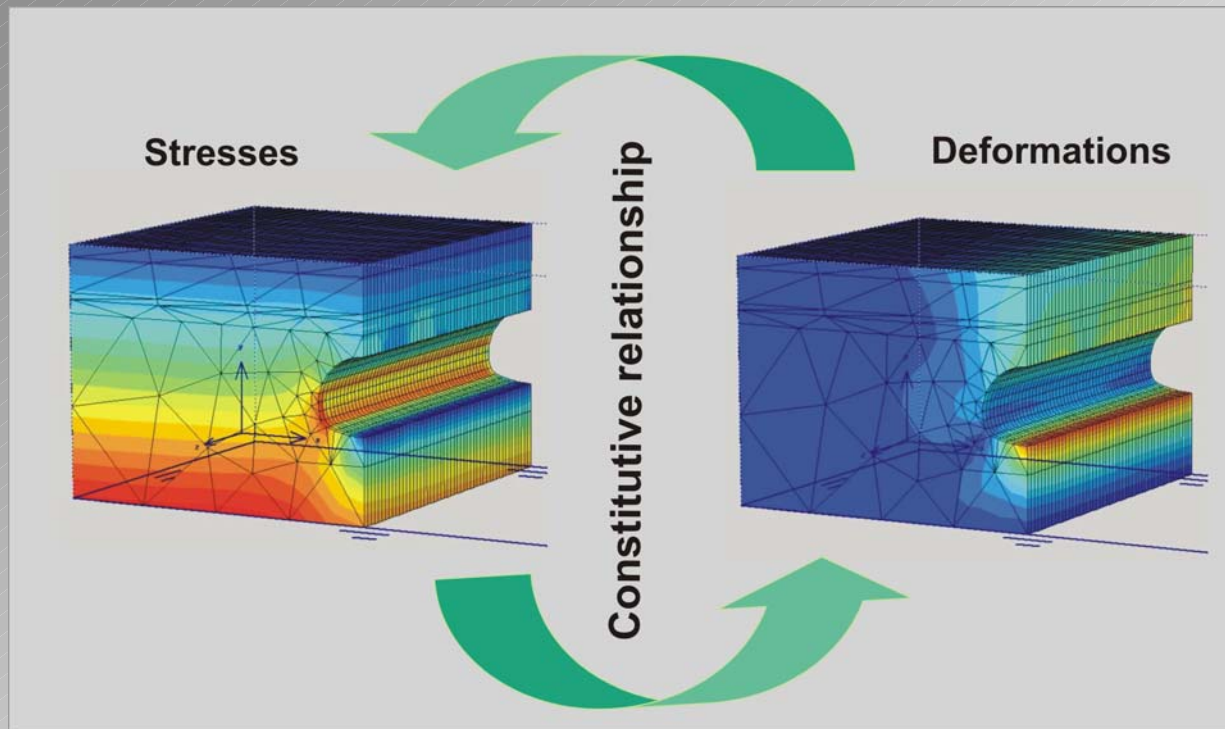
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Constitutive laws



Constitutive laws

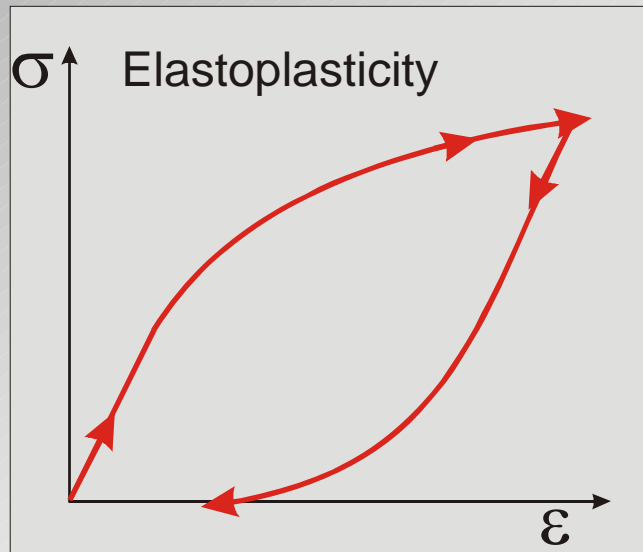
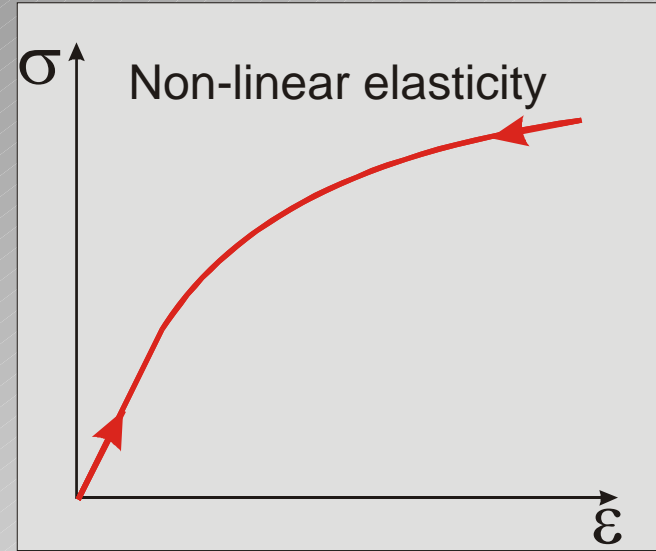
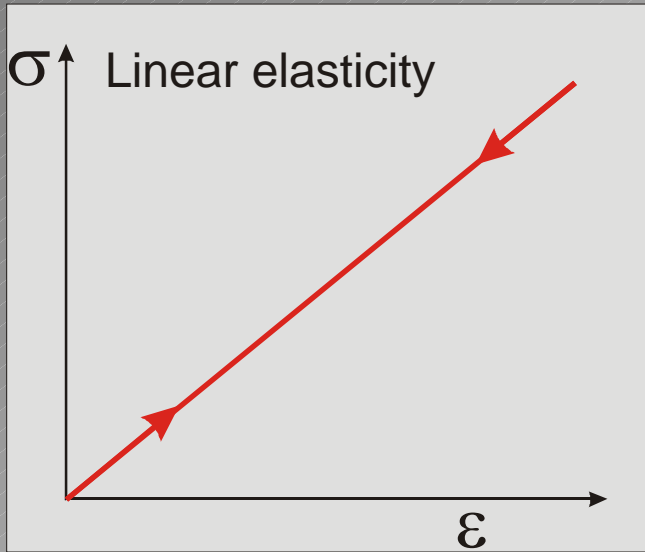
1

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Numerical modelling in tunnels



Elastoplasticity

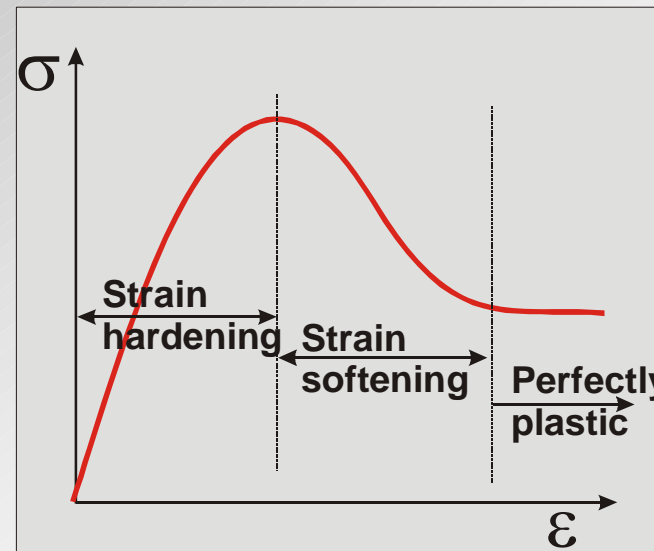
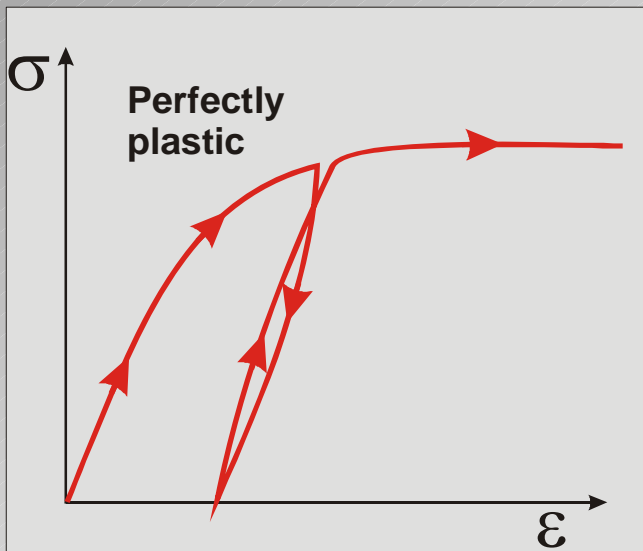
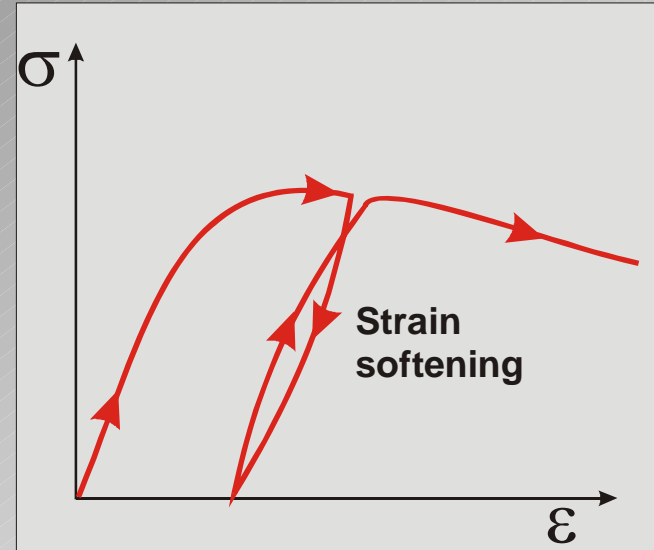
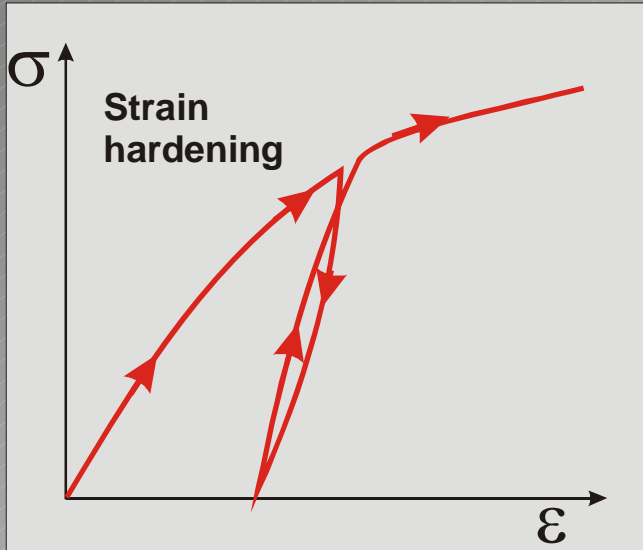
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1

2

Does rock change in mud in yielding zones ???

3

No !!!

4

Yielding zones only signal locations where the strength of the material, mostly calculated as shear strength, became lower than acting stresses.

5

All deformations calculated as yielding are always questionable and should be taken with caution. However, extensive existence of large yielding zones signal certainly problems in numerical Model, and might signal also problems in reality.



1

2

**Elastoplasticity
with
Mohr Coulomb**

**Elastoplasticity
with
Hoek and Brown**

Cam clay

3

E

E

M

4

μ

μ

Γ

ϕ

m

κ

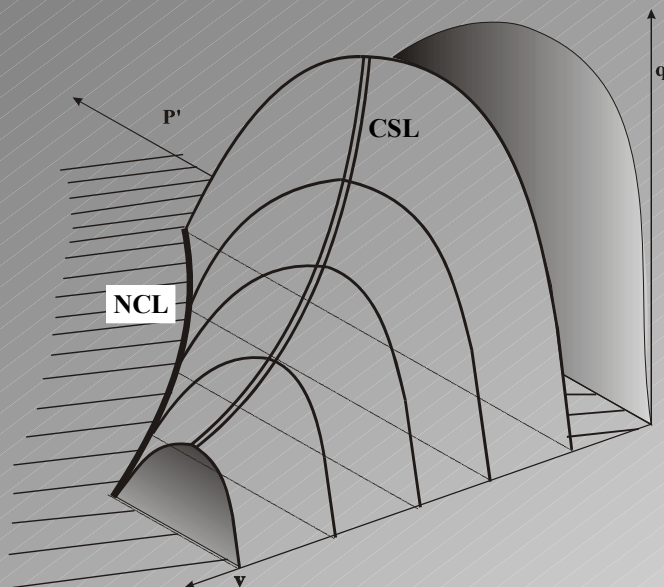
5

c

s

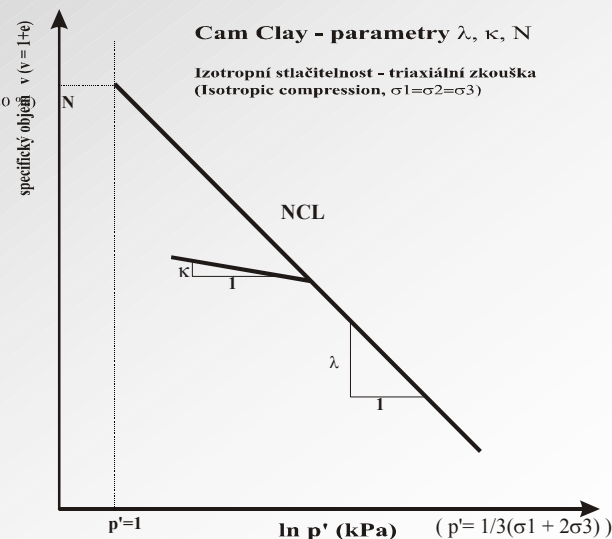
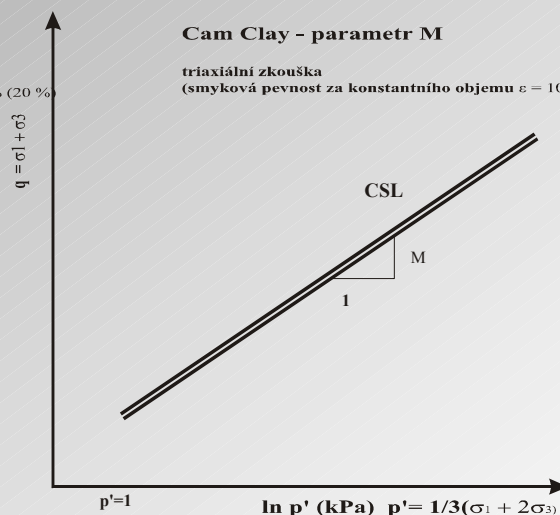
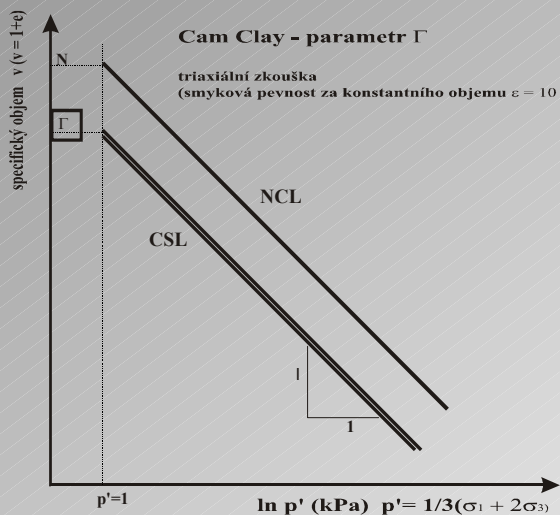
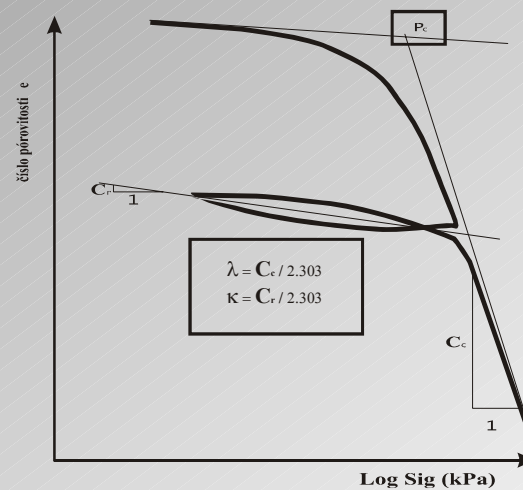
λ

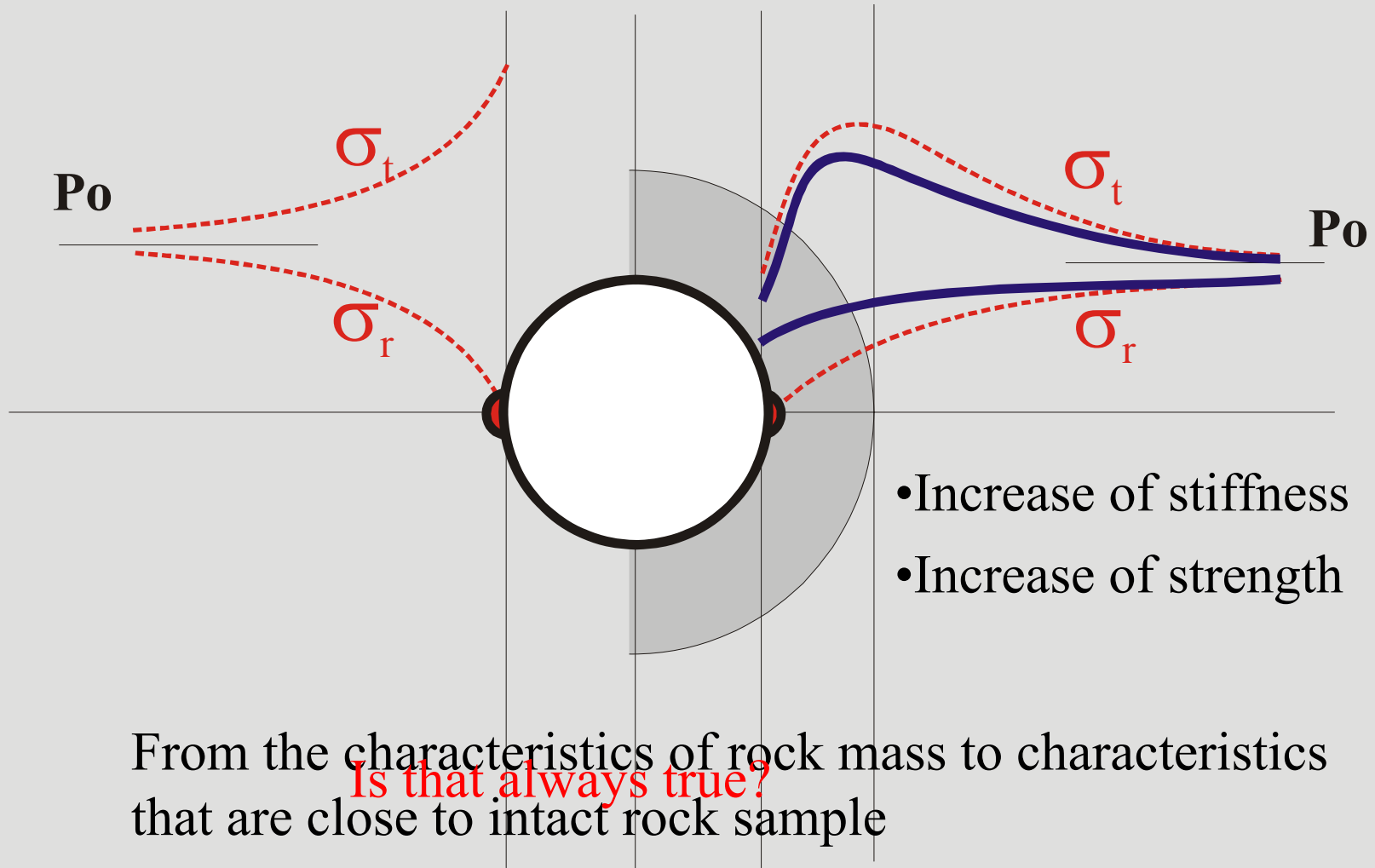




Cam Clay - parametry λ , κ , P_c

Zkouška stlačitelnosti - oedometrická zkouška
(One dimensional consolidation test)





1

Tunnel Dobrovského in Brno

2

3

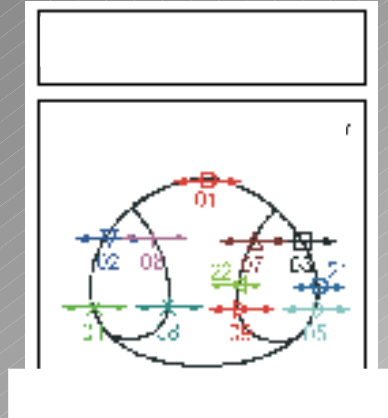
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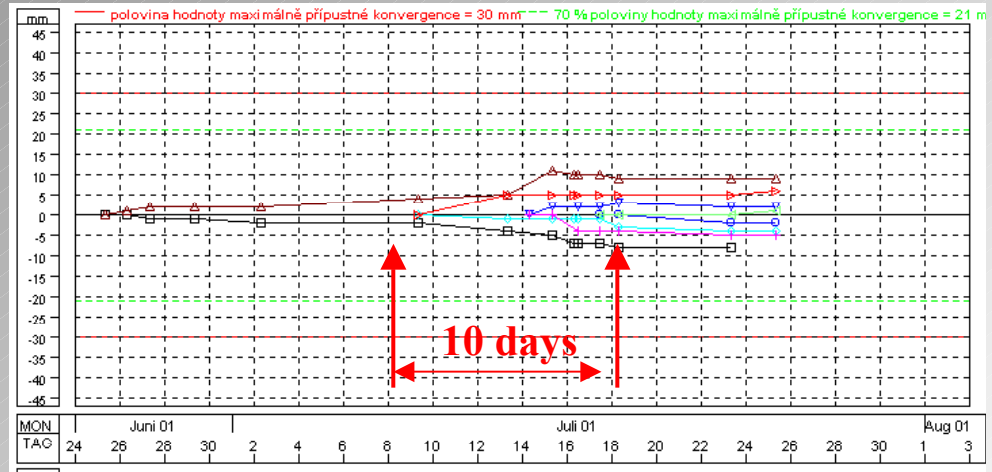


Deformation/time

E=80MPa



Mrázovka



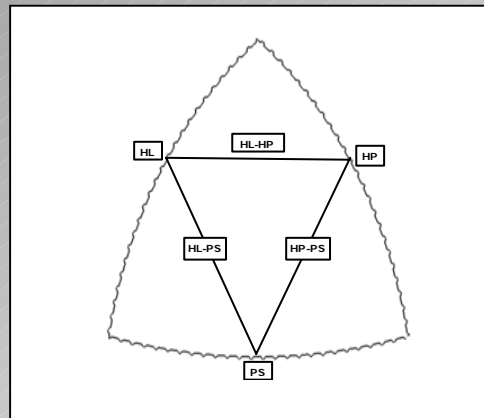
1

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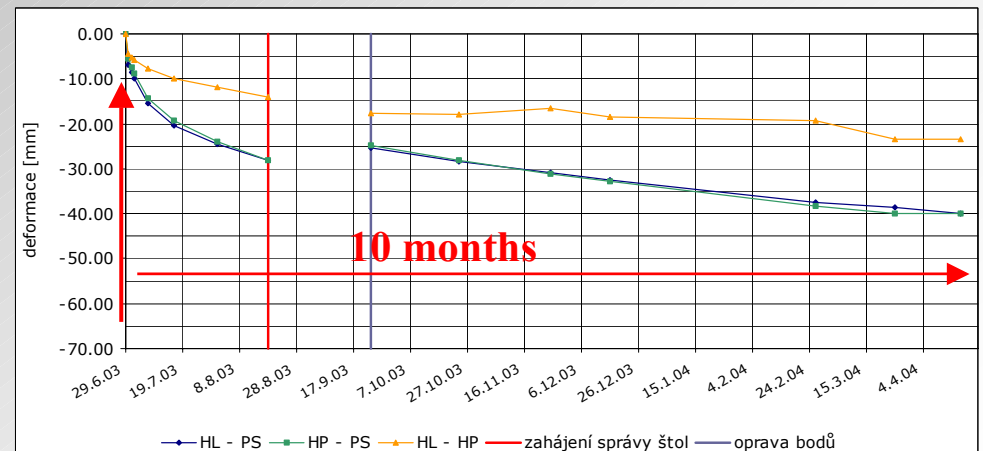
4

5



Dobrovského

E=20MPa



Numerical modelling in tunnels

1

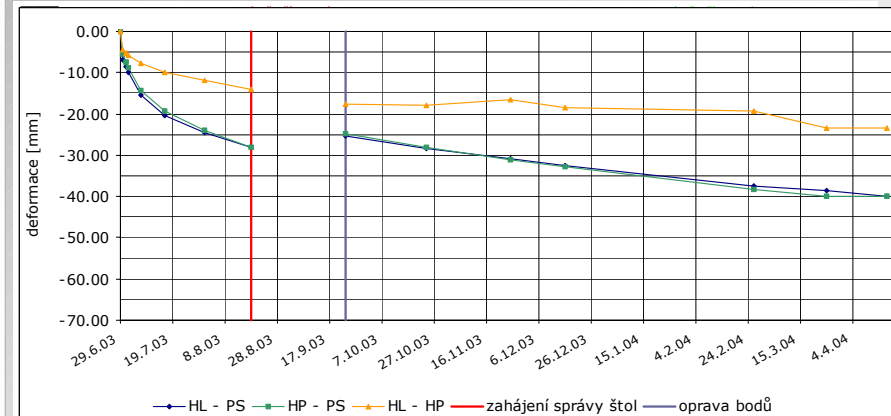
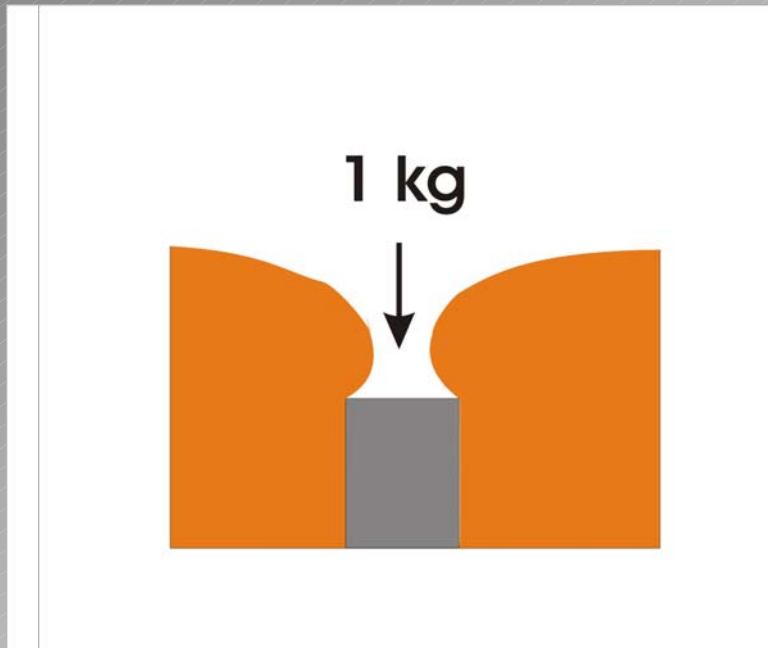
2

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Creep in clays

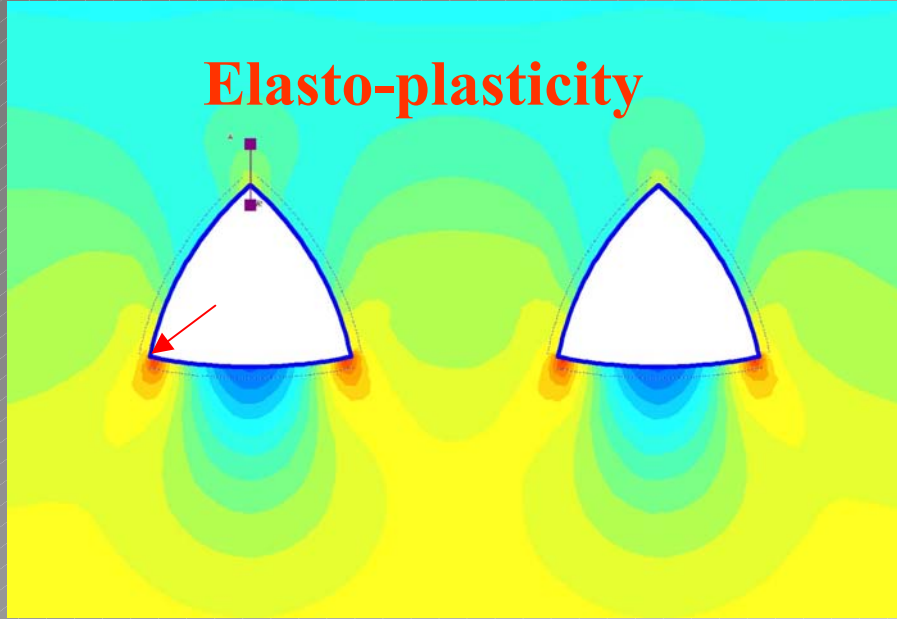


Clays, same dependent behavior

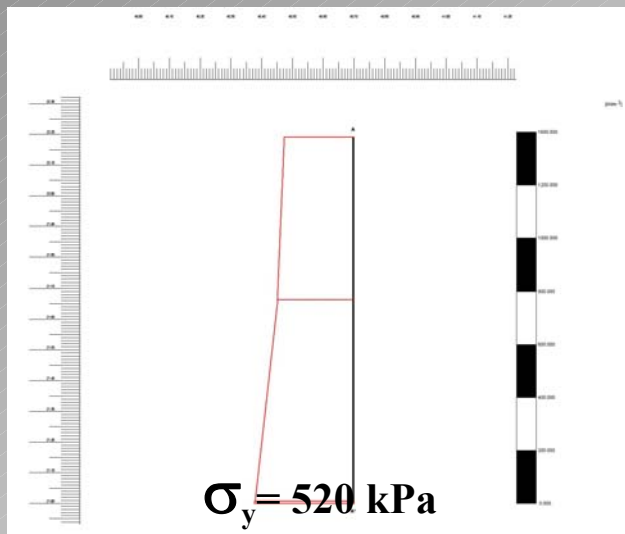
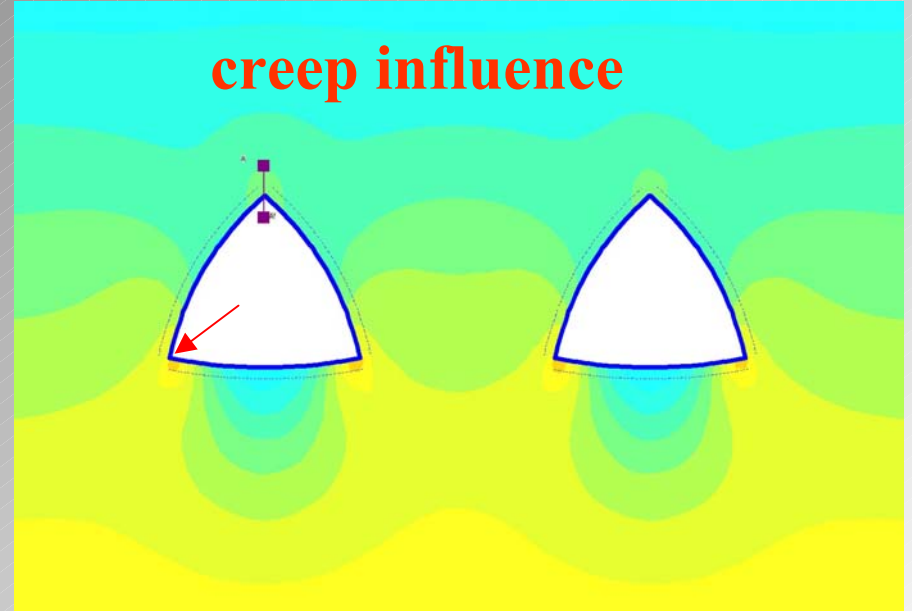
Result of creep

Chapter 2

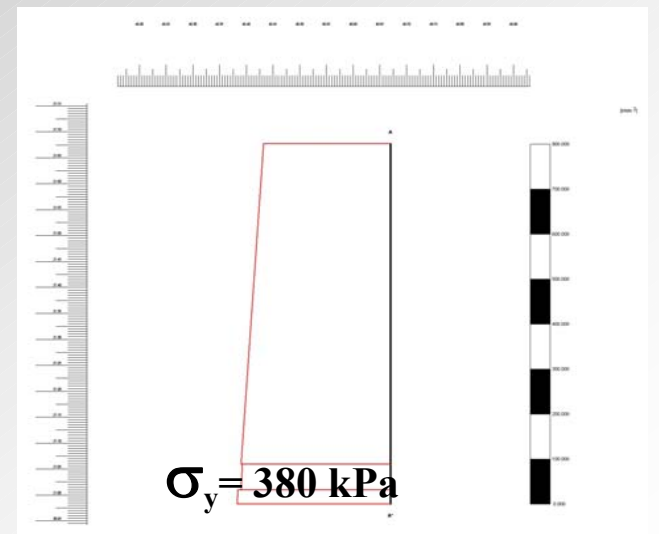
Elasto-plasticity



creep influence



$\sigma_y \text{ In Situ} = 360 \text{ kPa}$



Numerical modelling in tunnels

Settlement above shallow tunnels

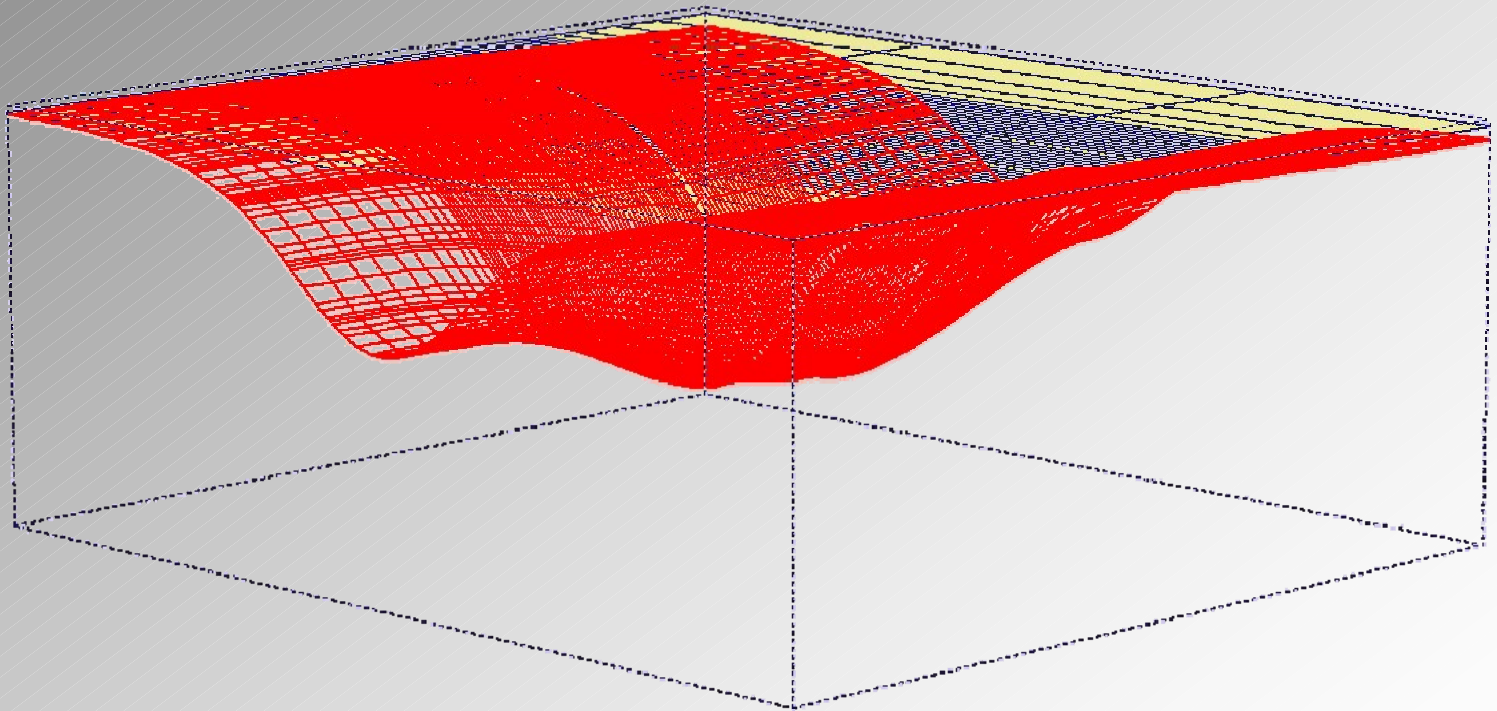
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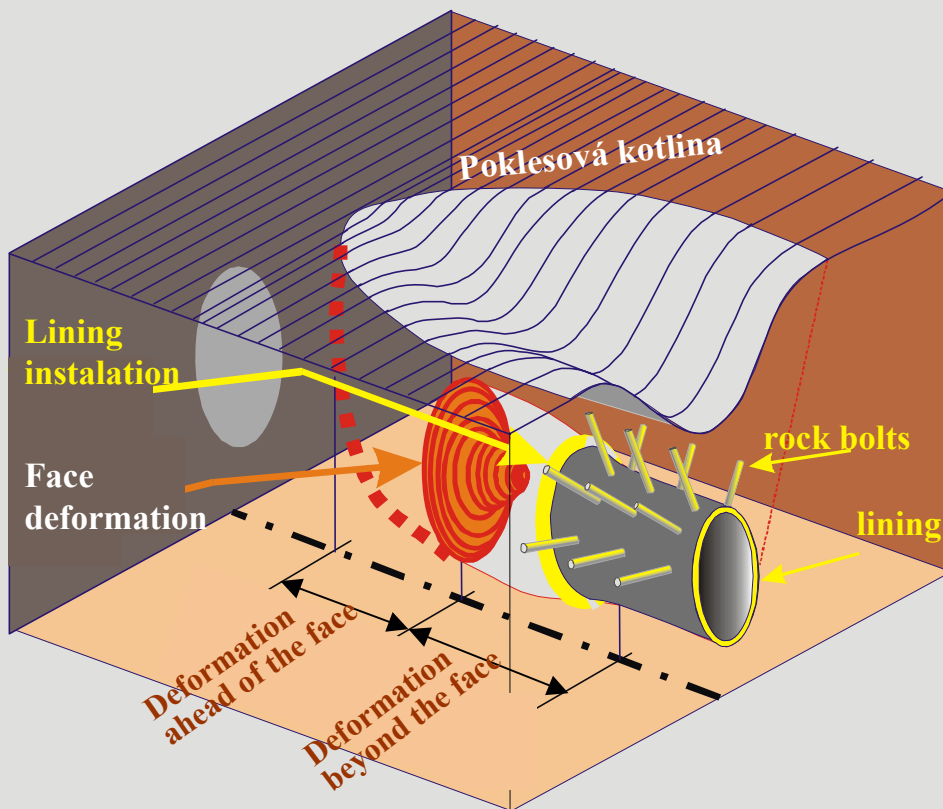
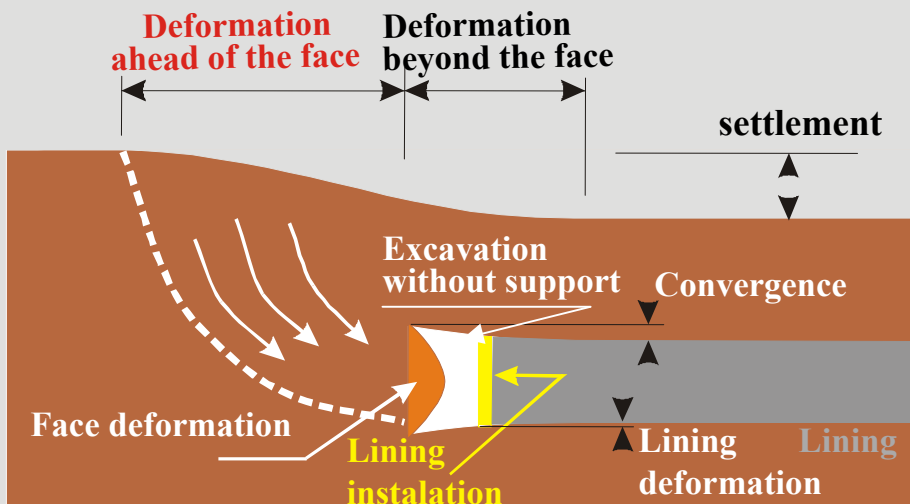
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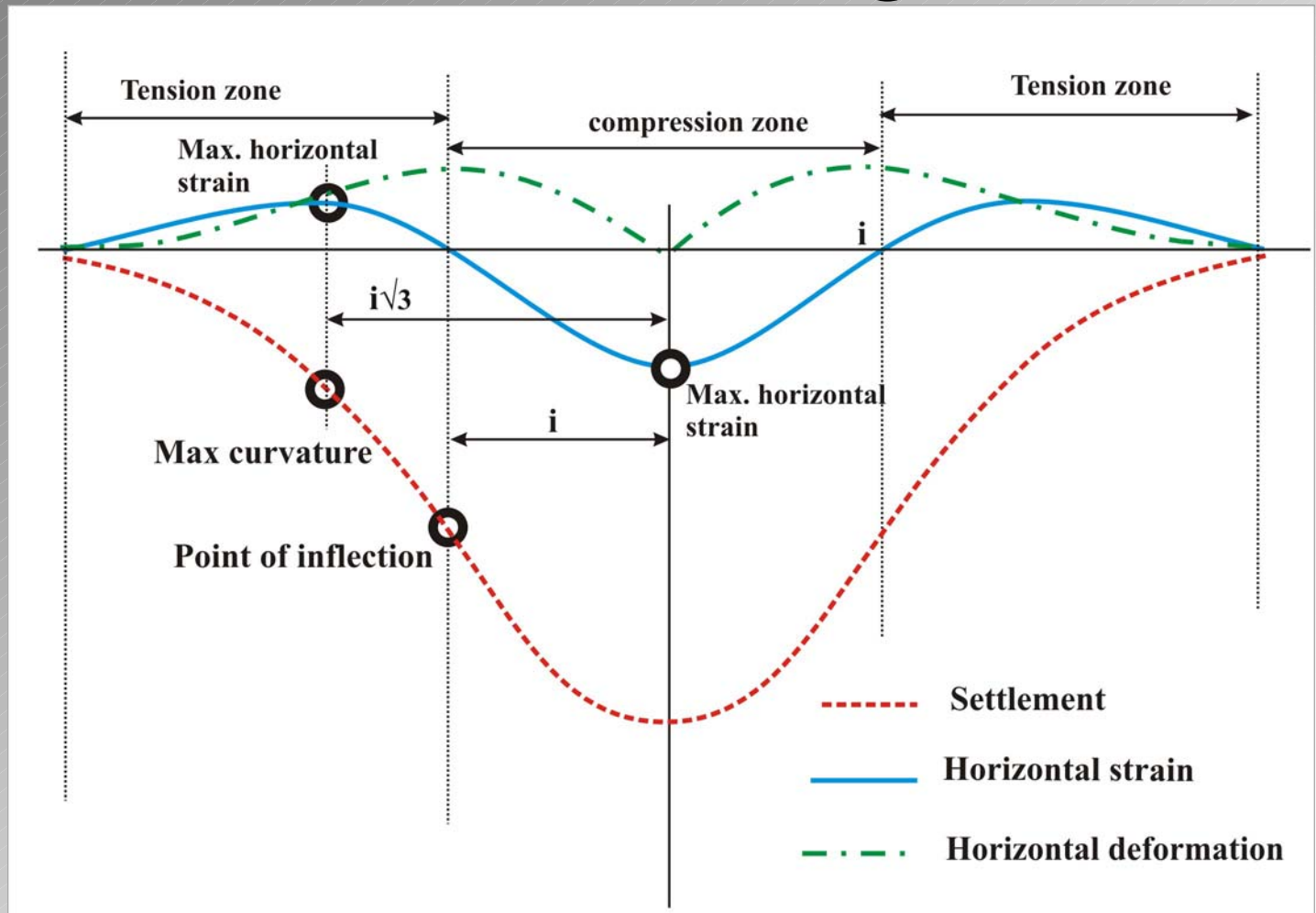
Deformation response to the excavation

1. Rock deformation in front of the face
2. Rock deformation between face and installed lining
3. Closing of discontinuities around opening due to radial movements
4. Rock lining interaction
5. Elastic part of deformation
6. Plastic part of deformation

↓
Settlement



Settlement trough



1

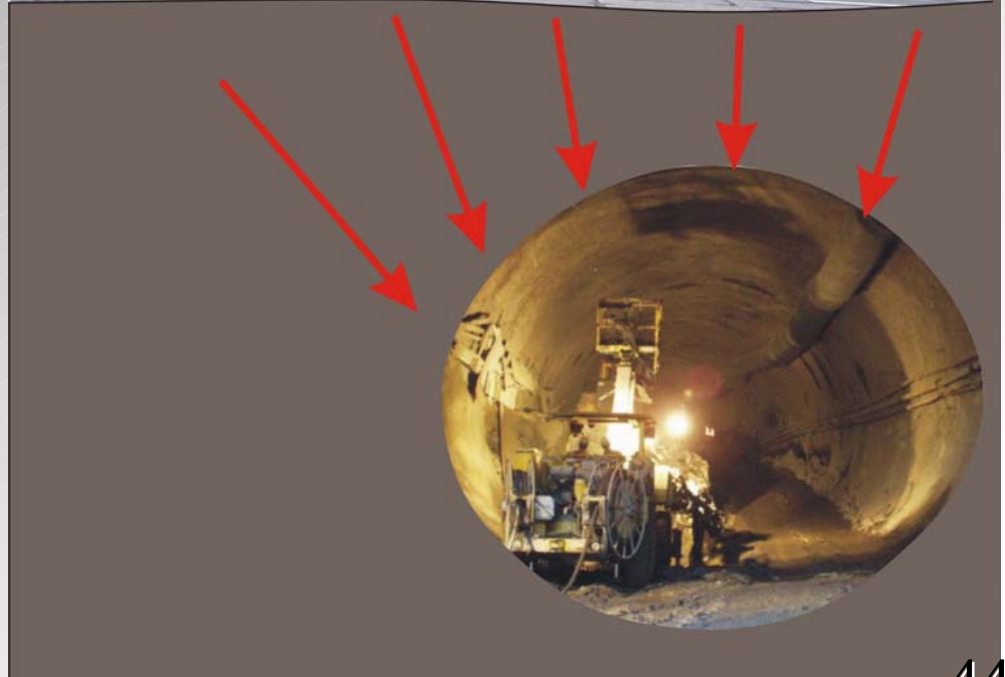
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Effect of tunnel excavation on surface structures



1

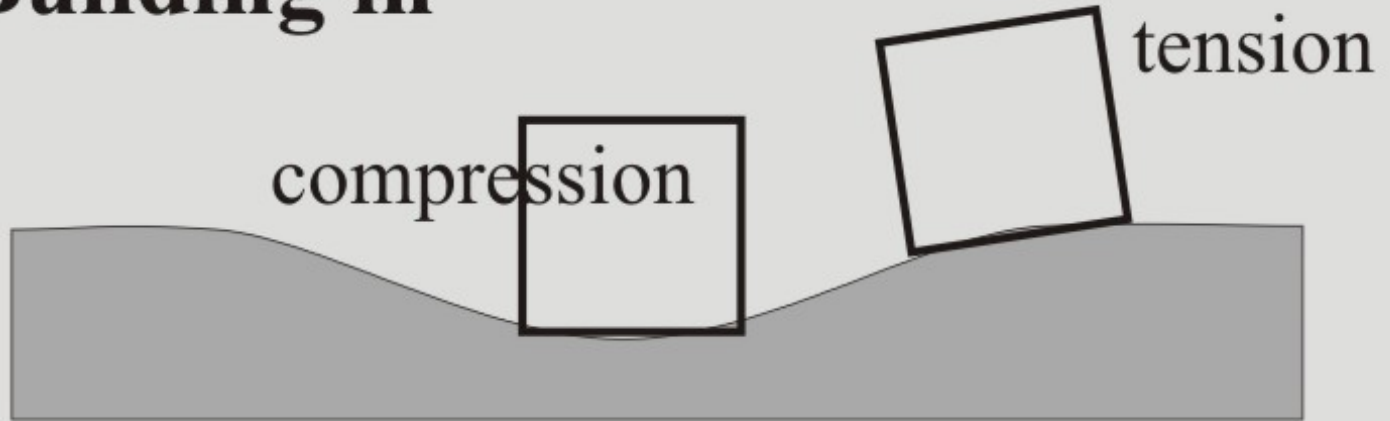
2

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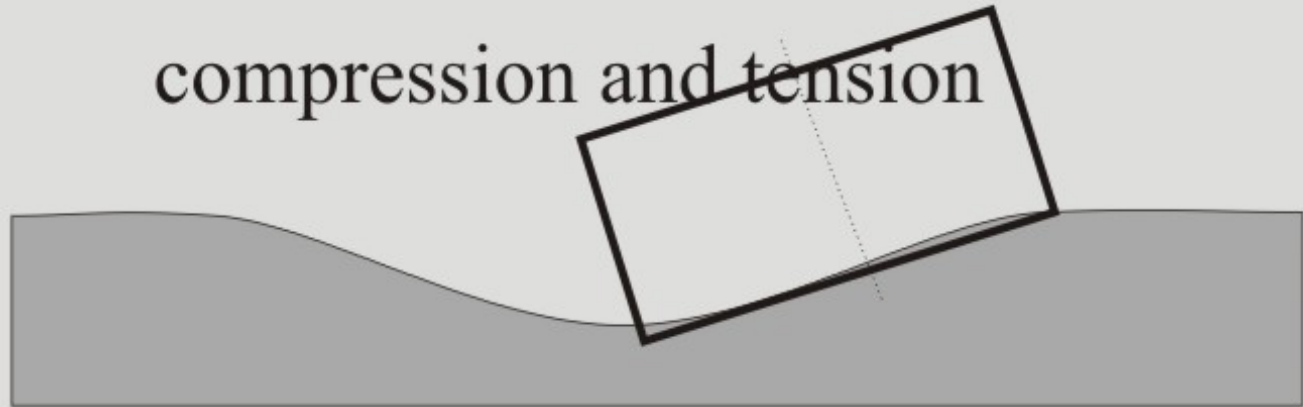
4

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Building in



compression and tension

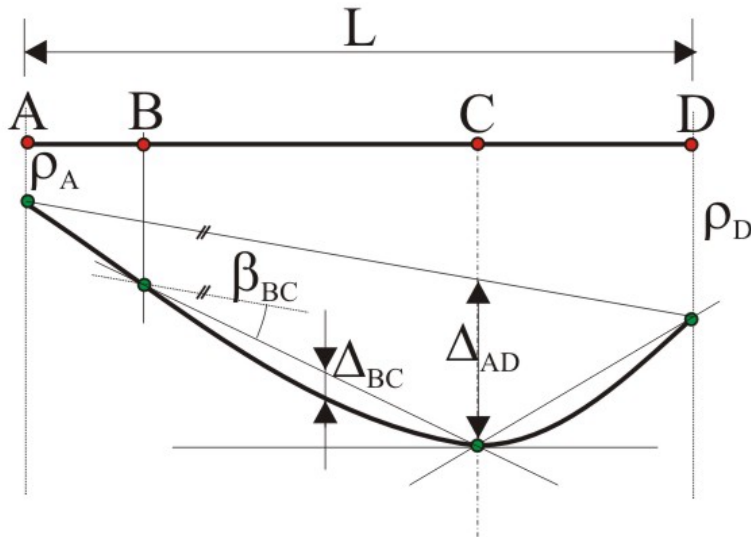


1

Terminology

2

Vertical movements



ρ_A settlement of A

ρ_D settlement of B

Δ_{AD} relative deflection between A a D

Δ_{BC} relative deflection between B a C

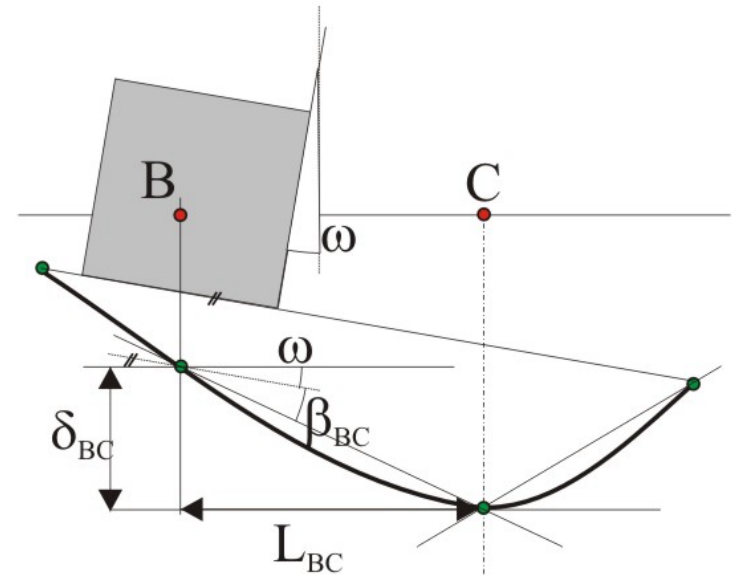
β_{BC} relative rotation BC

3

4

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Relative rotation



β_{BC} relative rotation BC

δ_{BC} differential settlement between B a C

If tilting $\omega = 0$,

then $\beta_{BC} = \text{gradient} = \delta_{BC} / L_{BC}$

Surface structures damage mechanisms

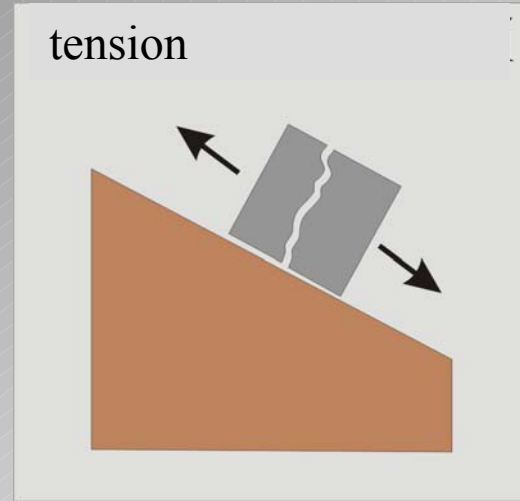
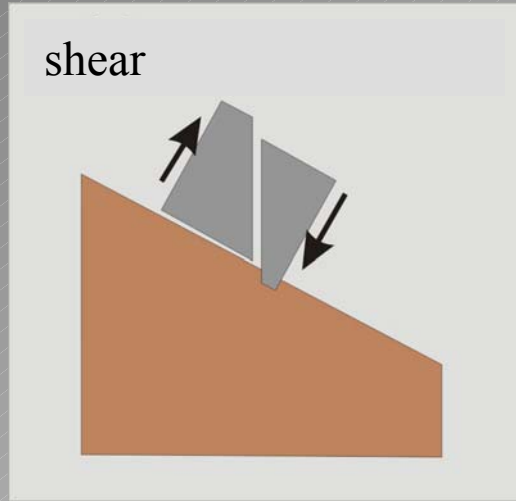
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1. shape of s.t.
2. extent of s.t.



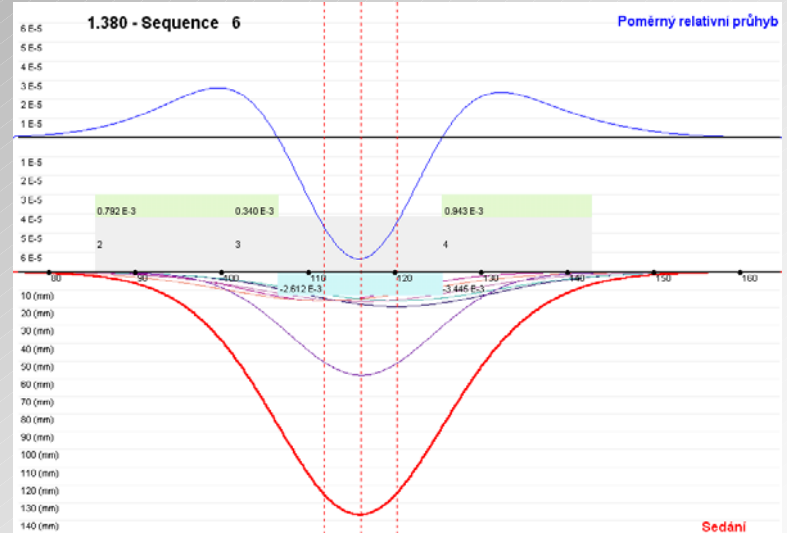
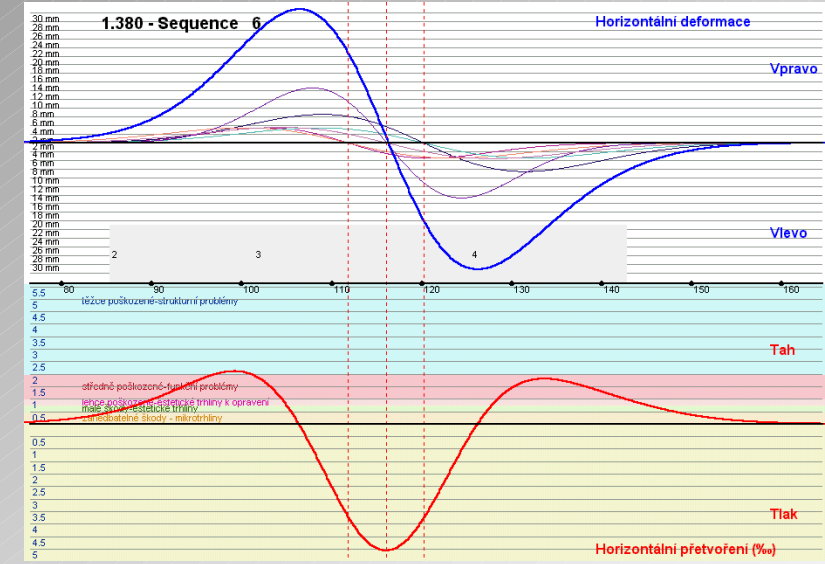
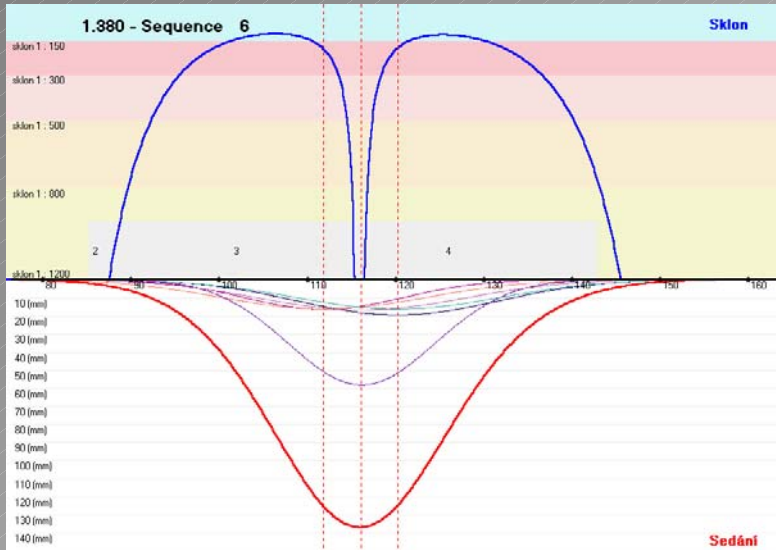
1 Criteria for analyzing damage

2

3

4

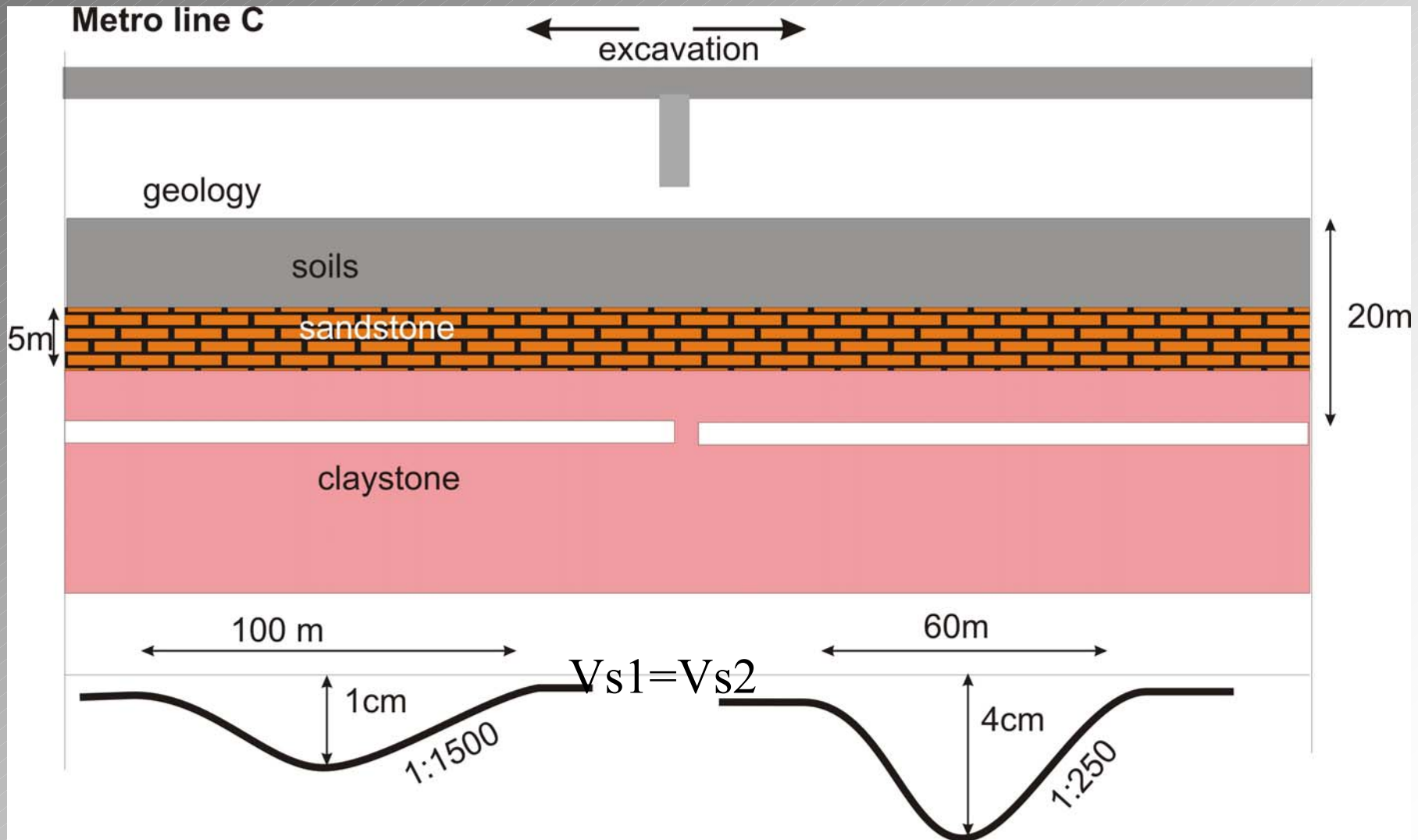
5



Numerical modelling in tunnels



Prague metro line C



Numerical modelling in tunnels

1

2

What is the value of a numerical model ?

3

Technical value of a numerical model is directly proportional to the

4

- professional skills of the engineer working with the model,
- his ability to use the software, and
- his understanding of all aspects of the technical problem under consideration.

5

