ITA COSUF Workshop *Rome 22 June 2012*

Safety versus Economics, Cost-efficiency of tunnel safety measures

Fire Design of Tunnel Lining Segments

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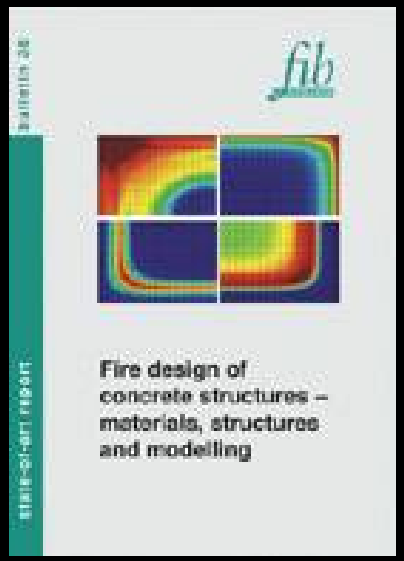
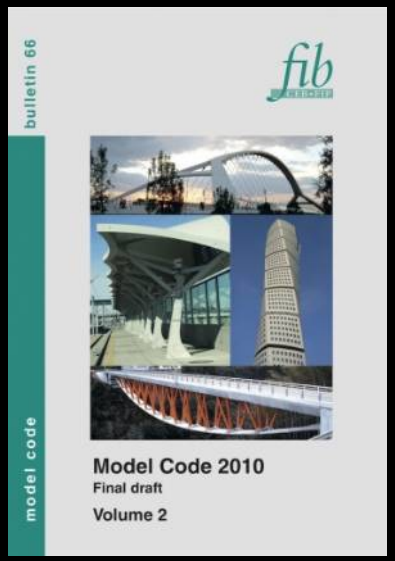
Introduction

- Fire design seen from a structural / concrete technology point of view
- In fib a working party WP4.3.5 ”Fire design of concrete tunnels” has been established in task group TG4.3
- The aim is to prepare a Bulletin on this topic – helping the designer adopting an efficient approach





fib CEB•FIP

Introduction

- The fib bulletin will cover:
- Conventional tunnels – with continuous lining
- Mechanical excavated tunnels – segmental lining
- Cut & cover tunnels / immersed tunnels
- Utilisation: road, rail and metro

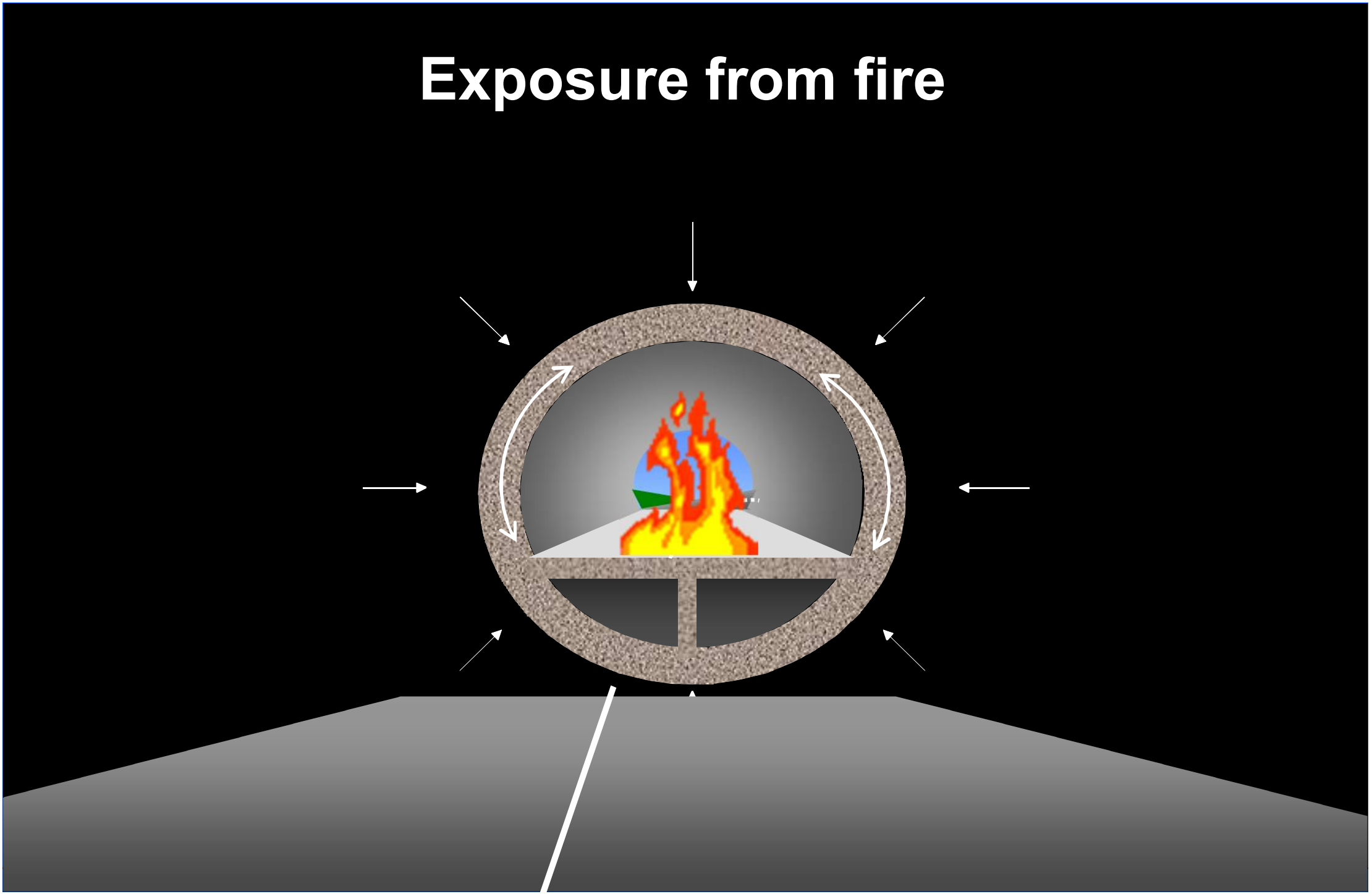
Lessons from real fires

- No collapse in the main structure
- No flooding
- Spalling is common

Tunnel fires / Channel tunnel

Channel Tunnel fire was close to being fatal

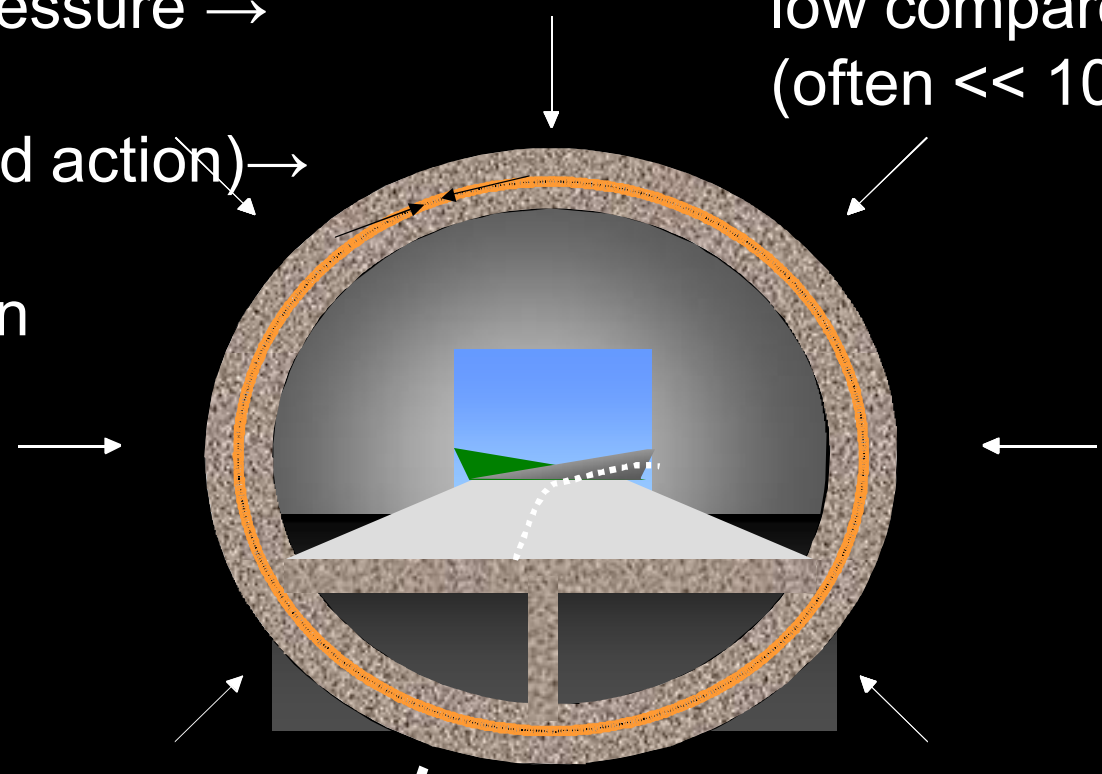
Exposure from fire



Mechanism

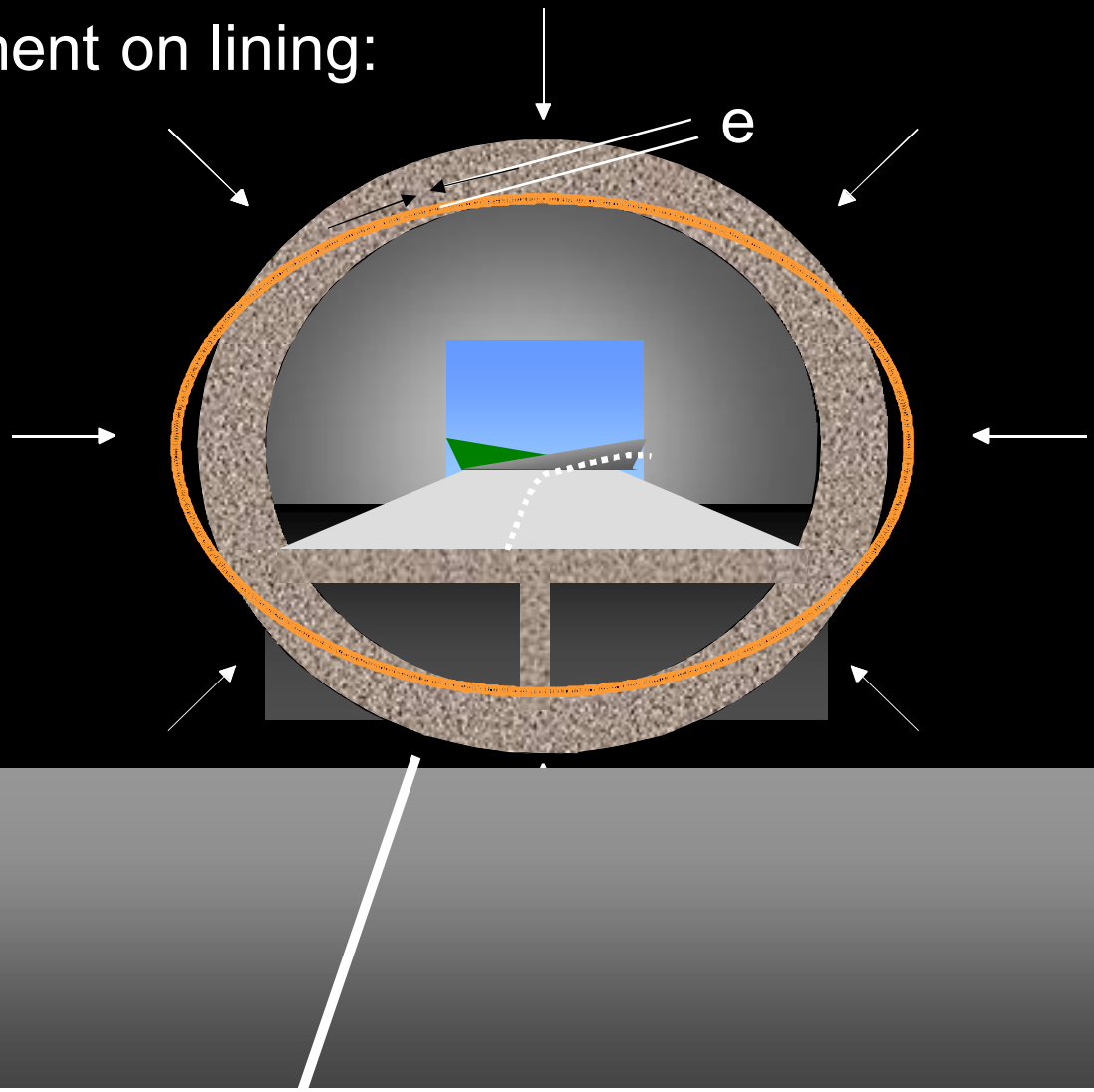
Ground and water load:
Ideal hydrostatic pressure →
Hoop load
(circular path of load action)→
(Circular) lining
in pure compression

The hoop load is typically very low compared to lining capacity (often << 10%)

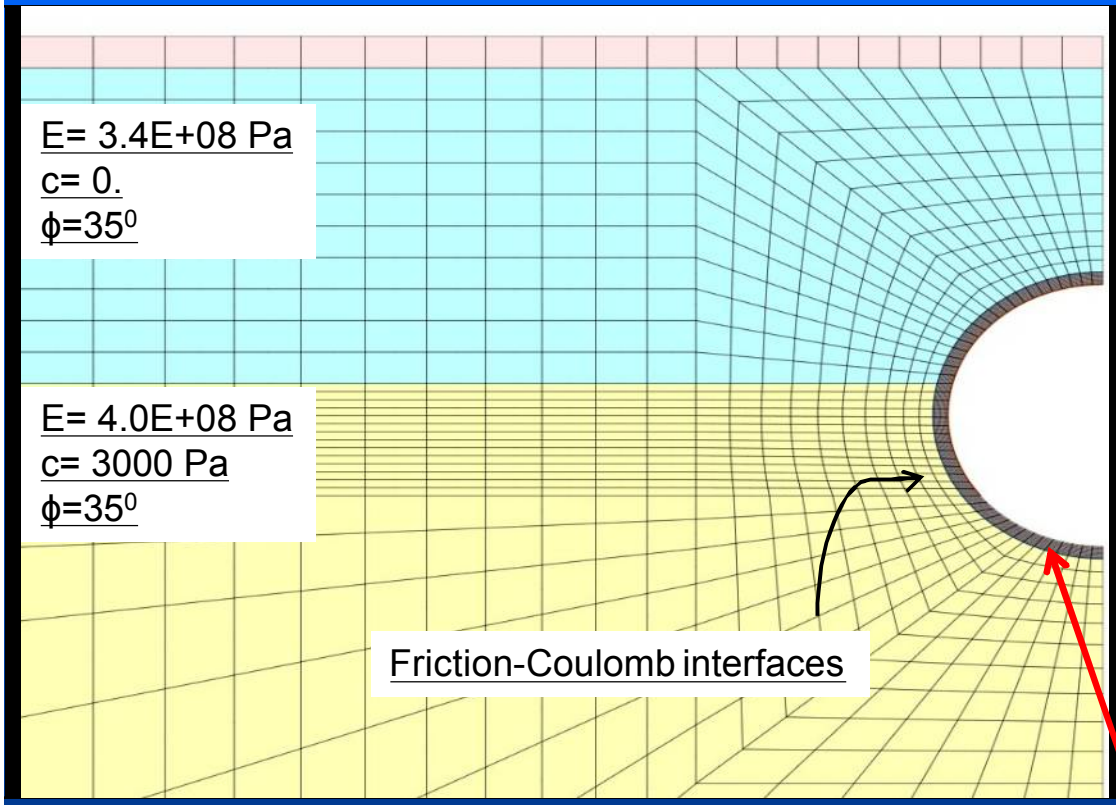


Mechanism

Ground pressure non-hydrostatic (shallow overburden) →
Non-circular path of load action→
Normal force + Moment on lining:
N; N·e



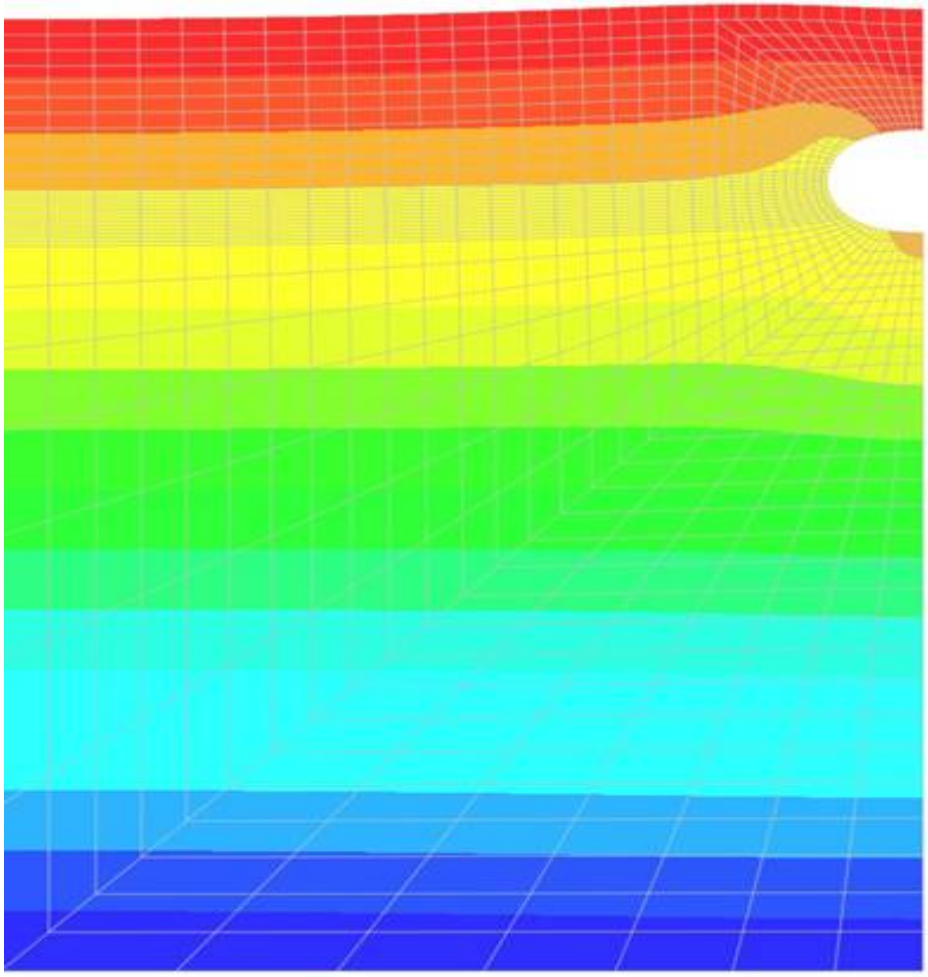
Analysis procedure



1. Stress initialization in the soil before excavation (K0 procedure)
2. Excavation and installation of the tunnel segment
3. Fire

Here: continuous lining is shown

Results- Initial stresses before the fire

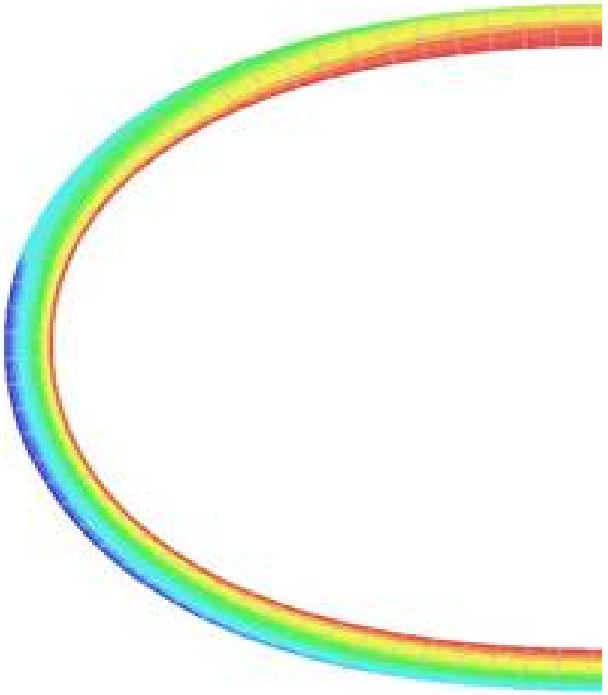


σ_{yy}

8.8%	+1.79942e+001
12.2%	-7.75657e+004
15.9%	-1.55149e+005
28.6%	-2.32733e+005
8.4%	-3.10317e+005
5.0%	-3.87901e+005
4.0%	-4.65484e+005
3.3%	-5.43068e+005
2.9%	-6.20652e+005
2.5%	-6.98236e+005
2.2%	-7.75819e+005
2.0%	-8.53403e+005
1.7%	-9.30987e+005
1.5%	-1.00857e+006
1.0%	-1.08615e+006
	-1.16374e+006

σ_1

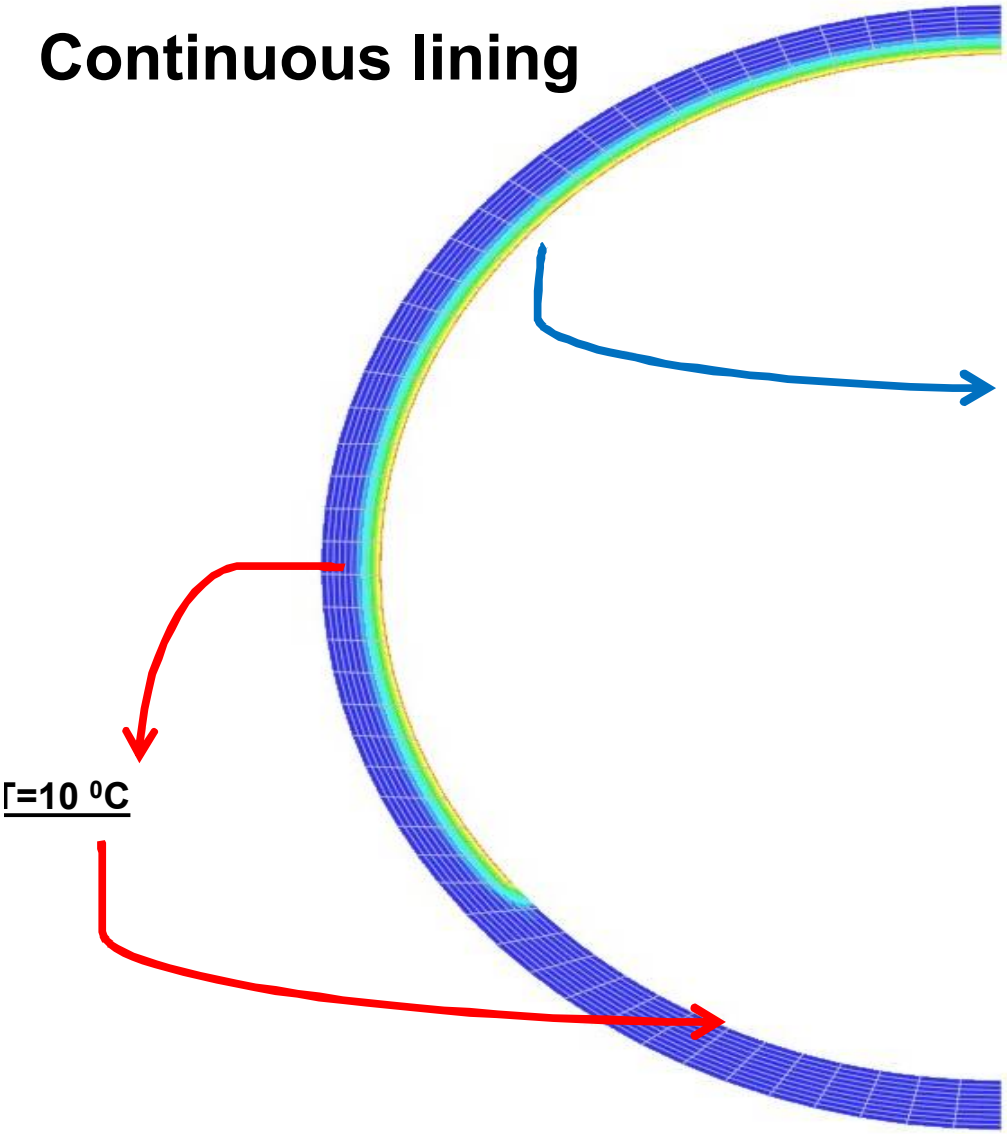
5.8%	+7.43048e+003
9.3%	-8.37320e+003
9.2%	-2.41769e+004
8.6%	-3.99806e+004
9.1%	-5.57842e+004
8.6%	-7.15879e+004
8.3%	-8.73916e+004
7.5%	-1.03195e+005
6.9%	-1.18999e+005
6.6%	-1.34803e+005
6.1%	-1.50606e+005
5.4%	-1.66410e+005
4.0%	-1.82214e+005
2.9%	-1.98017e+005
1.8%	-2.13821e+005
	-2.29625e+005

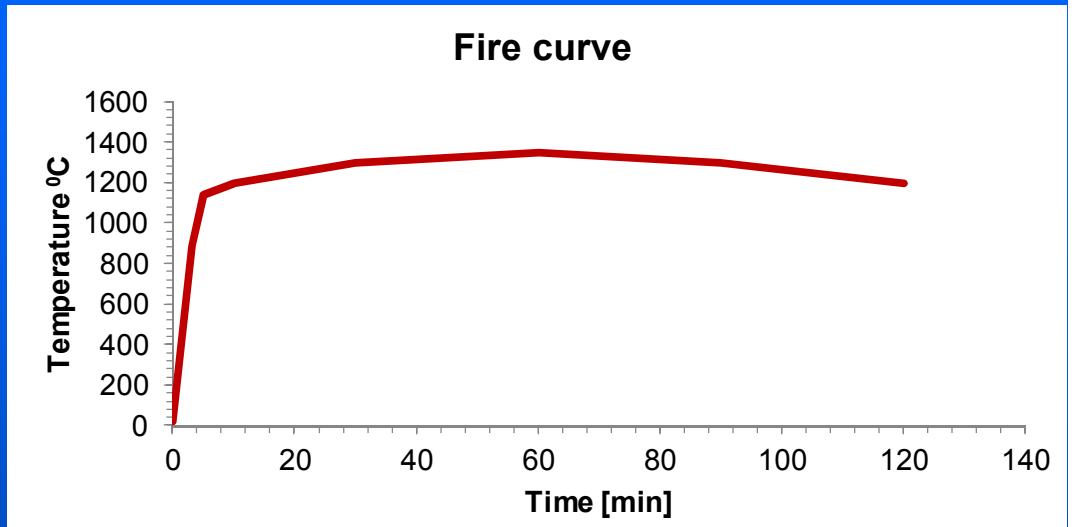


Continuous lining

Thermal analysis

Continuous lining

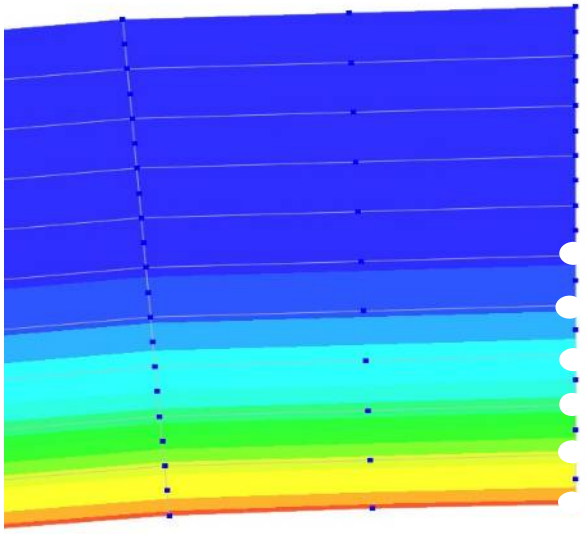




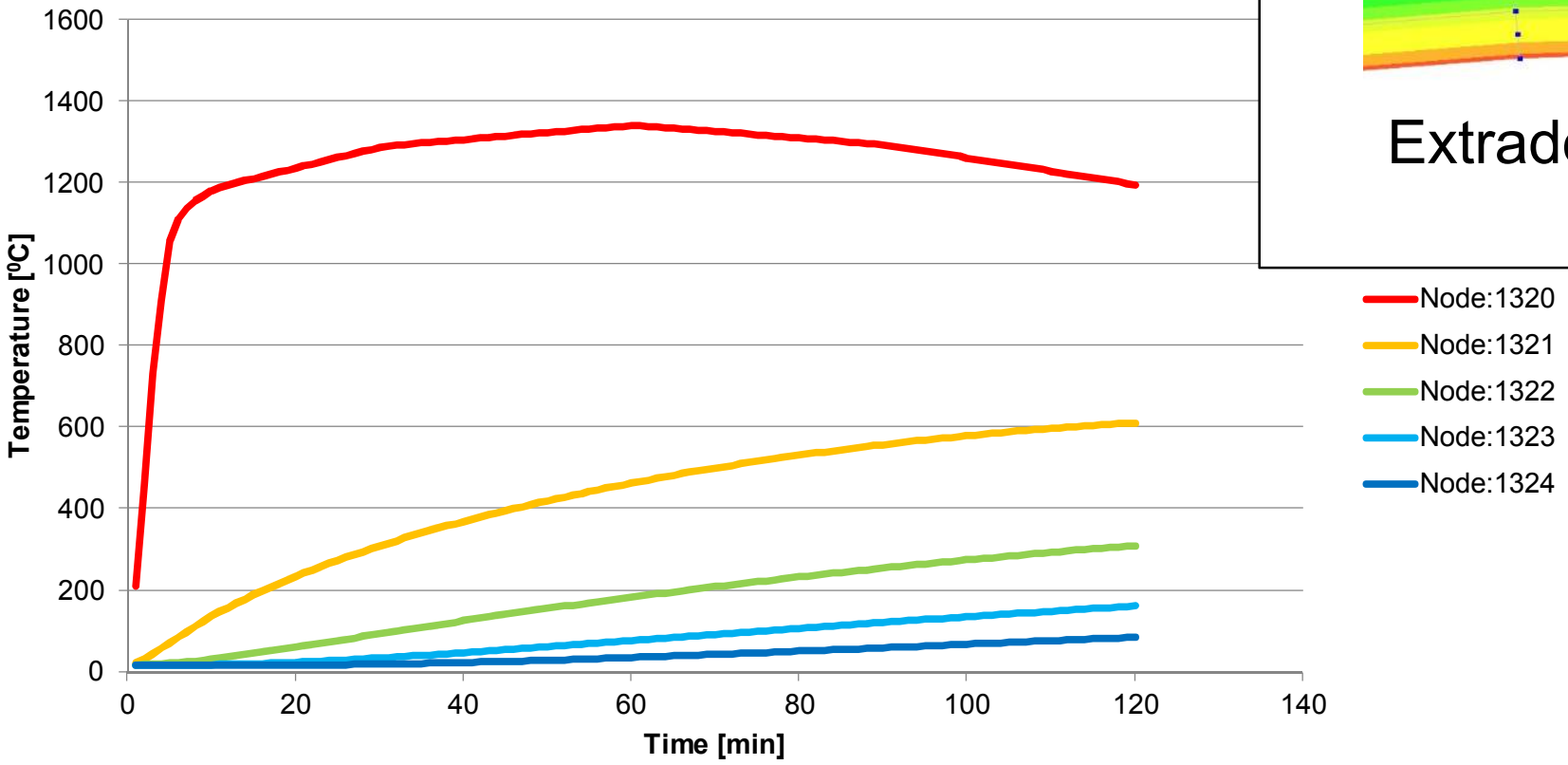
- Conduction, convection and radiation
- Thermal properties vary with temperature

Thermal analysis

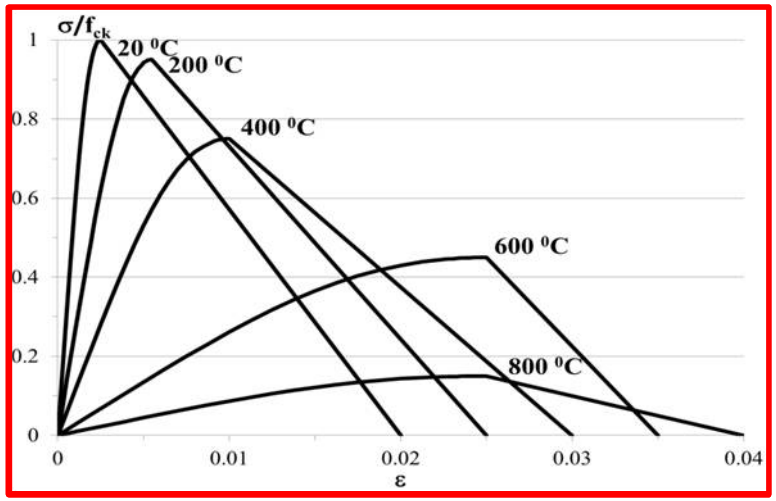
Intrados

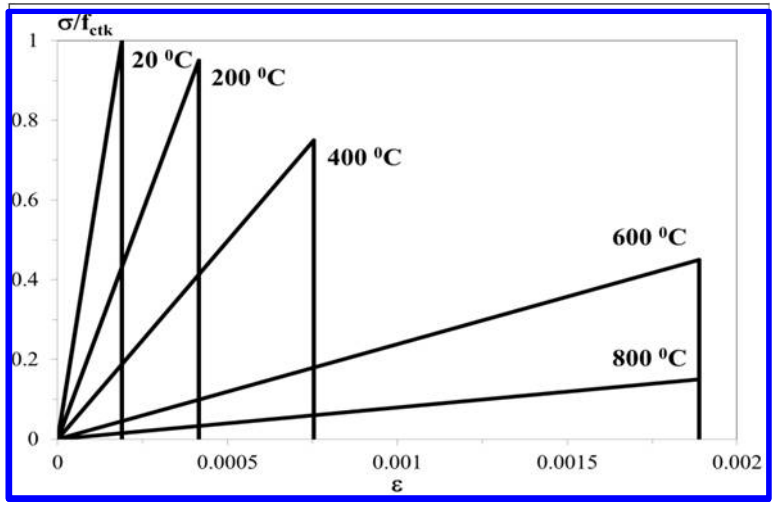


Extrados



Physical properties

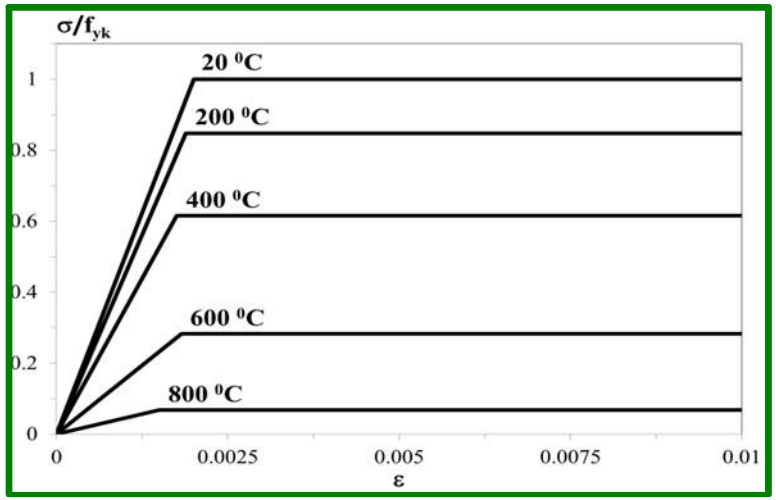




CONCRETE IN COMPRESSION

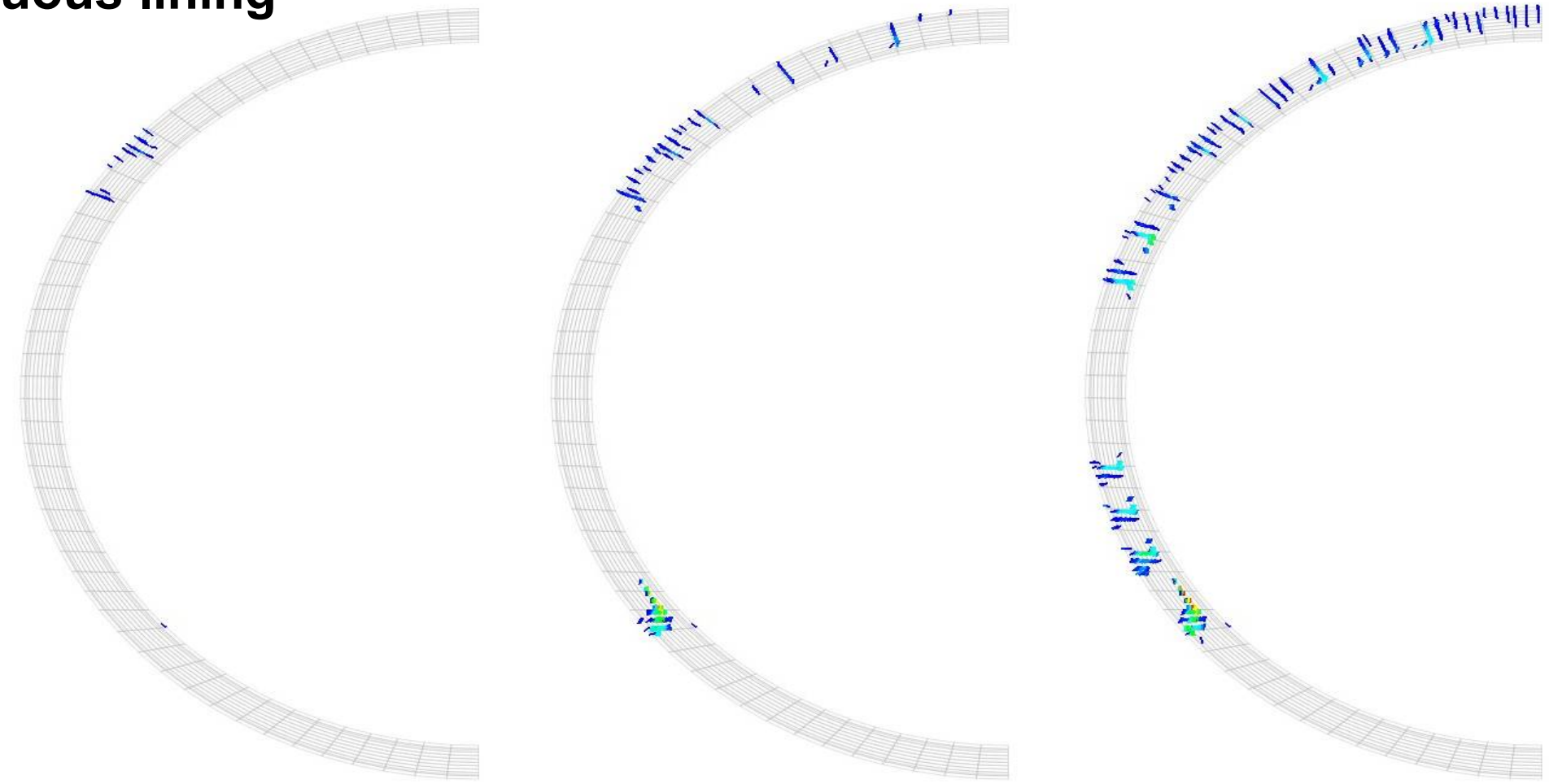
CONCRETE IN TENSION

REINFORCEMENT STEEL



Cracking from dilatation

Continuous lining



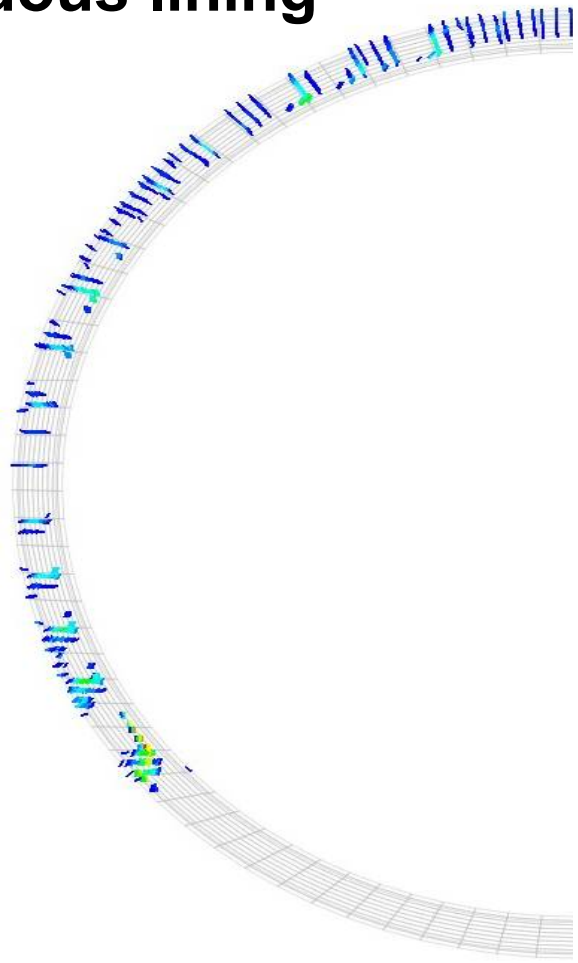
t=25 min

t=30 min

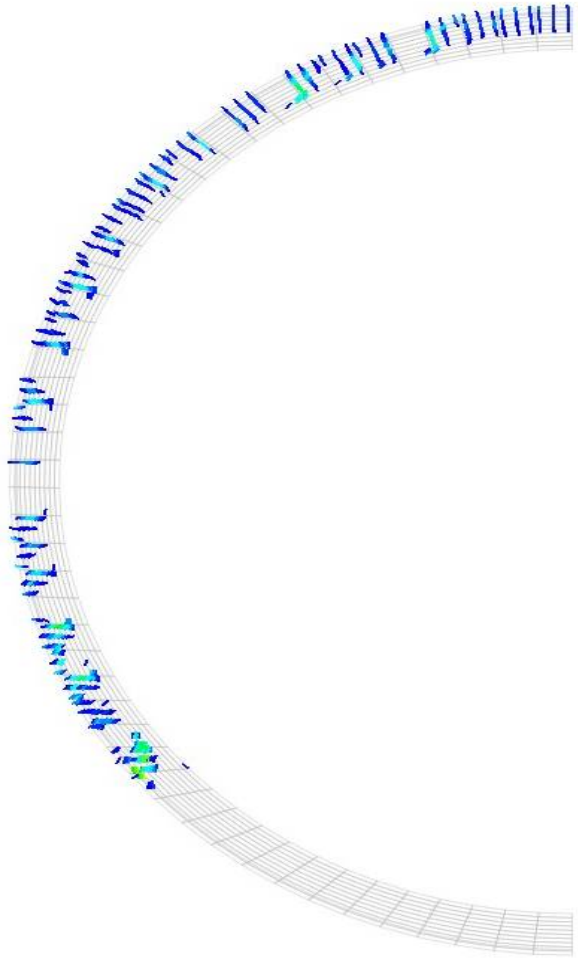
t=40 min

Cracking from dilatation

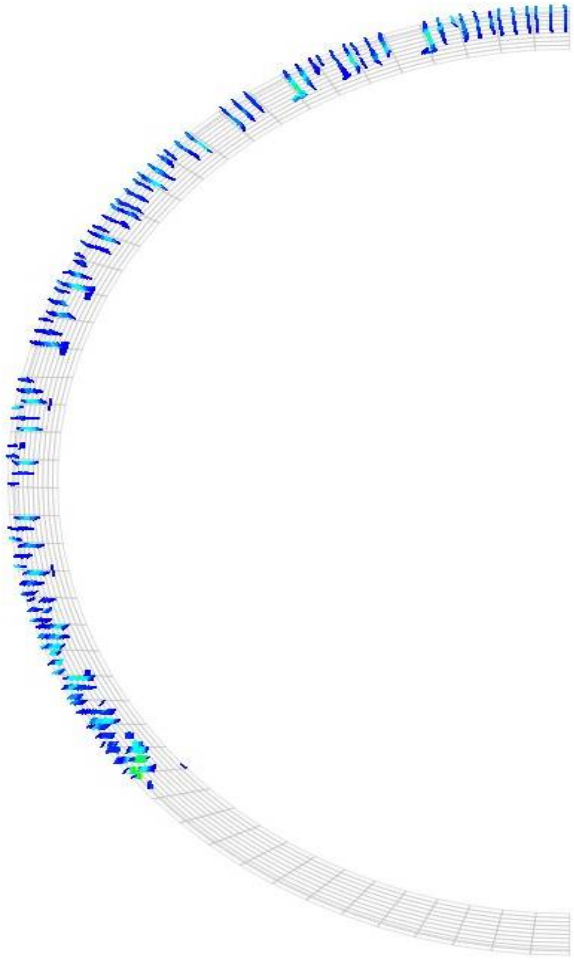
Continuous lining



t=60 min



t=90 min



t=120 min

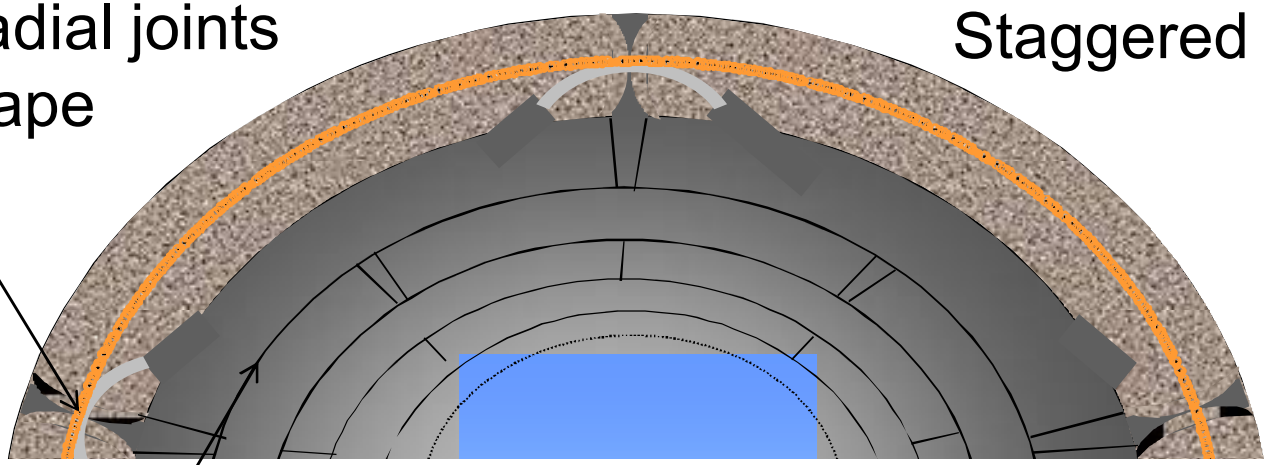
Remarks

- The most critical situation can occur in shallow tunnel in soft soil
- A correct analysis should consider the lining-soil interaction
- Safety of the structure under fire is guaranteed, against predictions from classical analysis
- The analysis shows a weak spot of the structure at the road level

Segmental lining

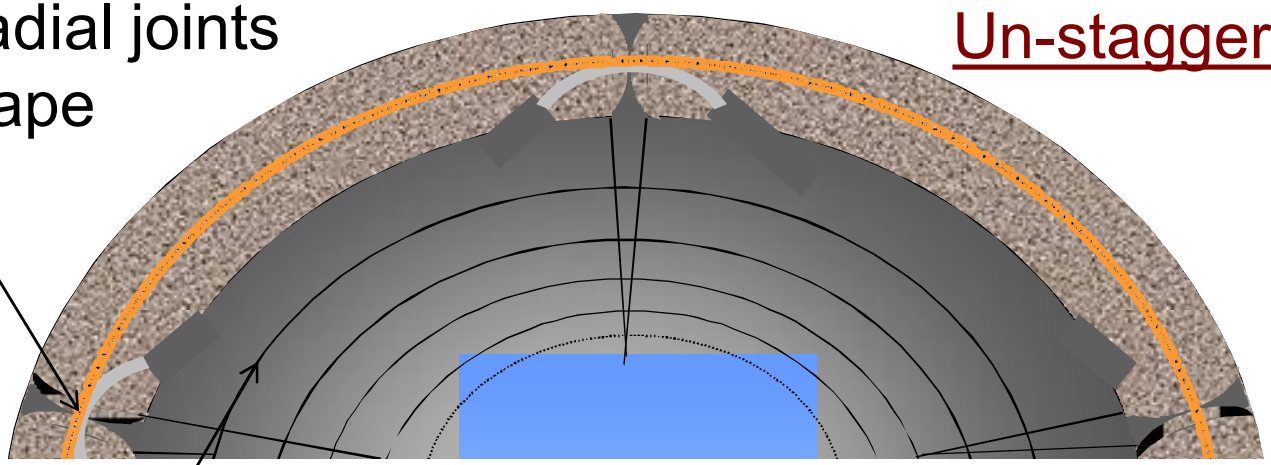
Zero-moment-radial joints
With circular shape

Staggered segments



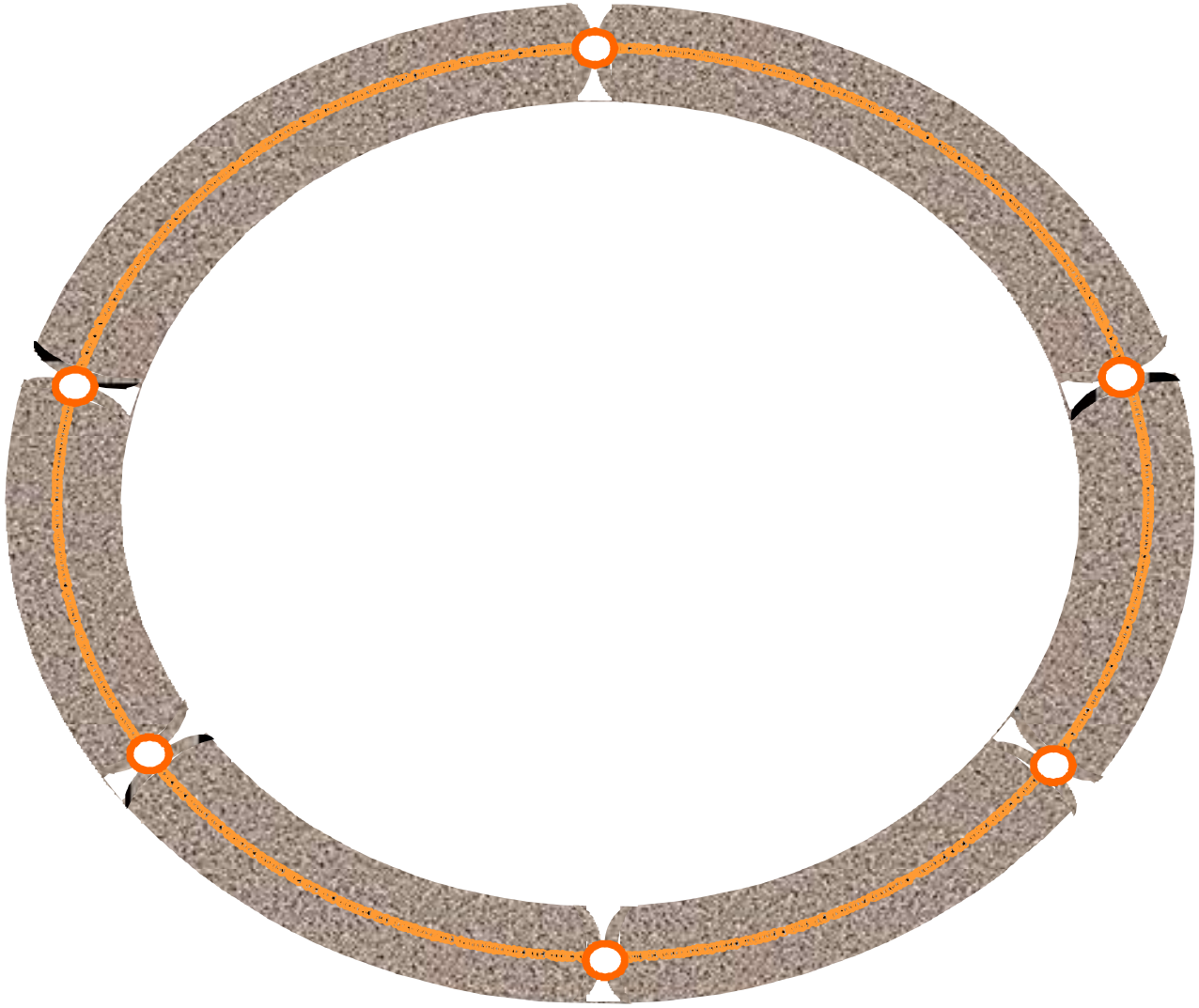
Circumferential joints
Transmission of forces by friction
(bitumenous filt packers etc: limit the friction)

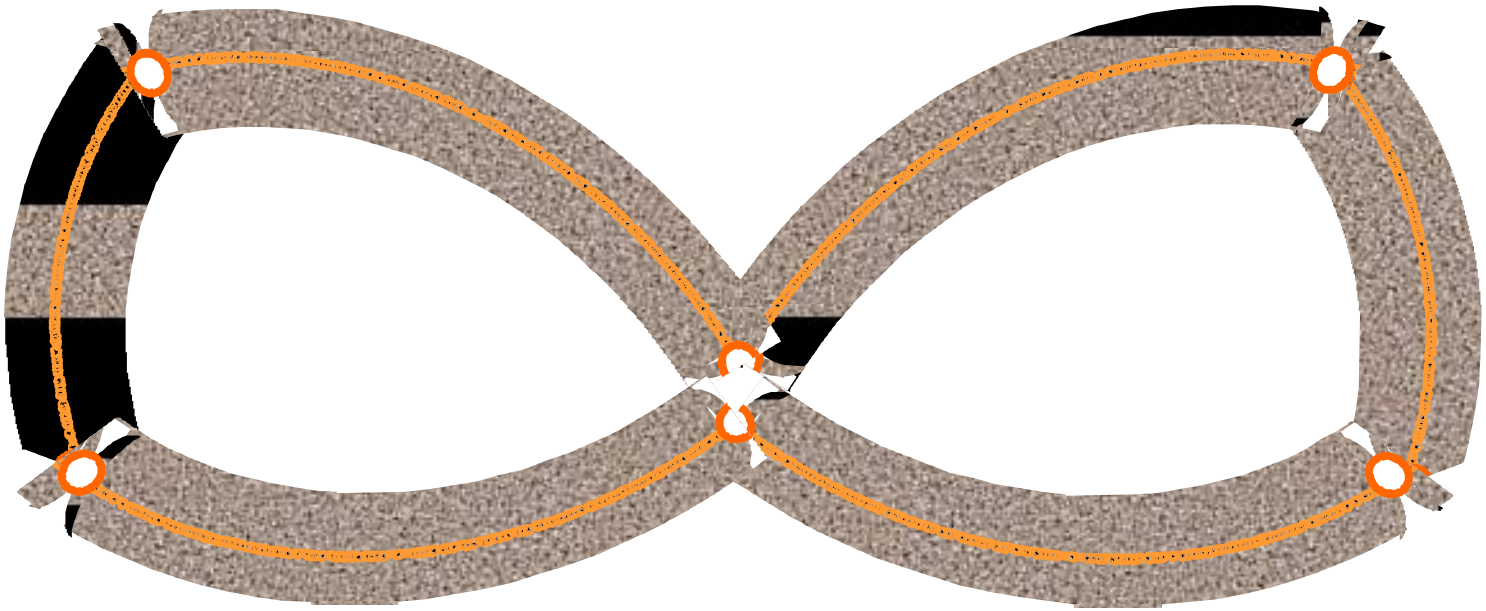
Zero-moment-radial joints
With circular shape



Un-staggered segments

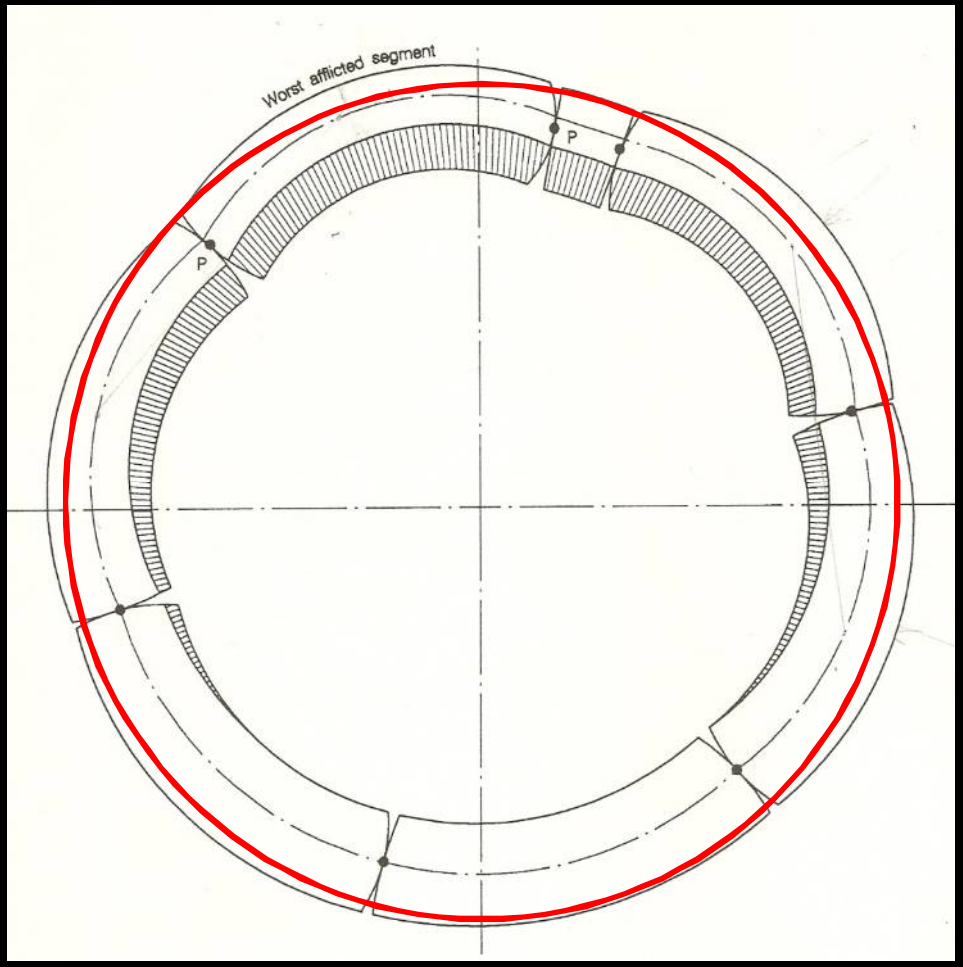
Circumferential joints
Transmission of forces by friction
(bitumenous filt packers etc: limit the friction)



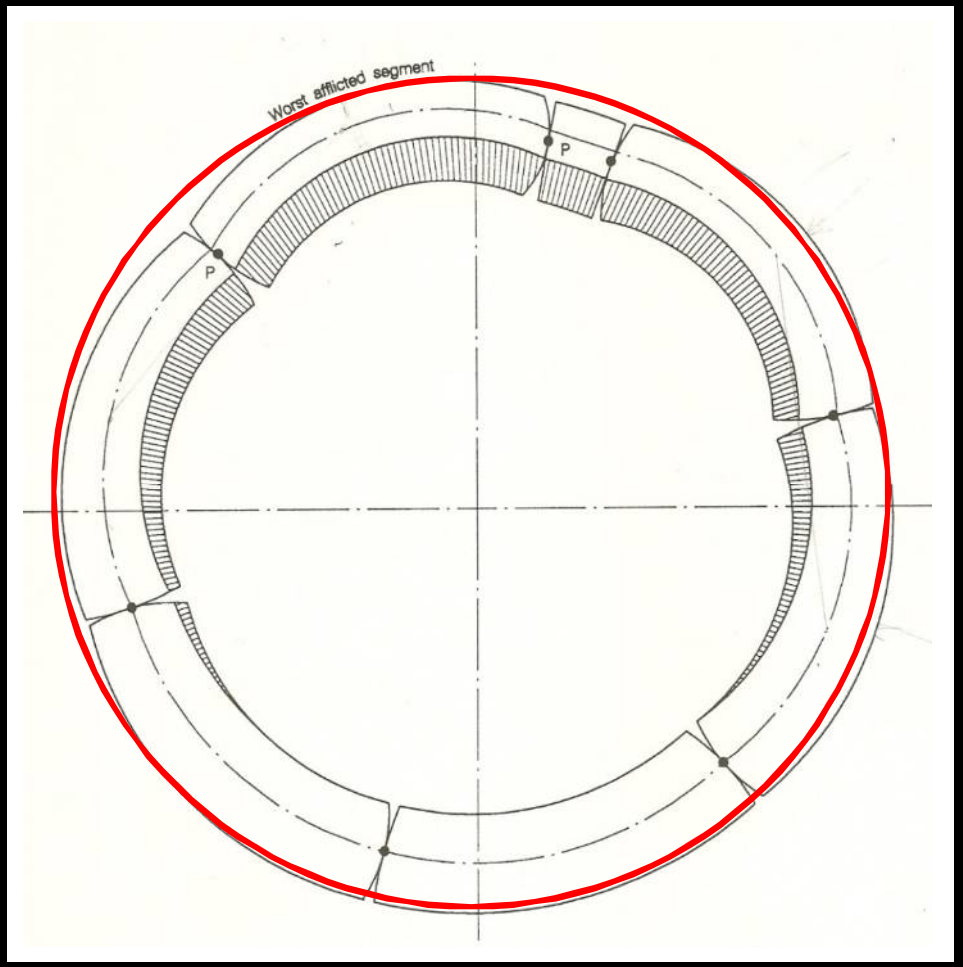


Ground – tunnel interaction

Soft ground



Hard ground / rock

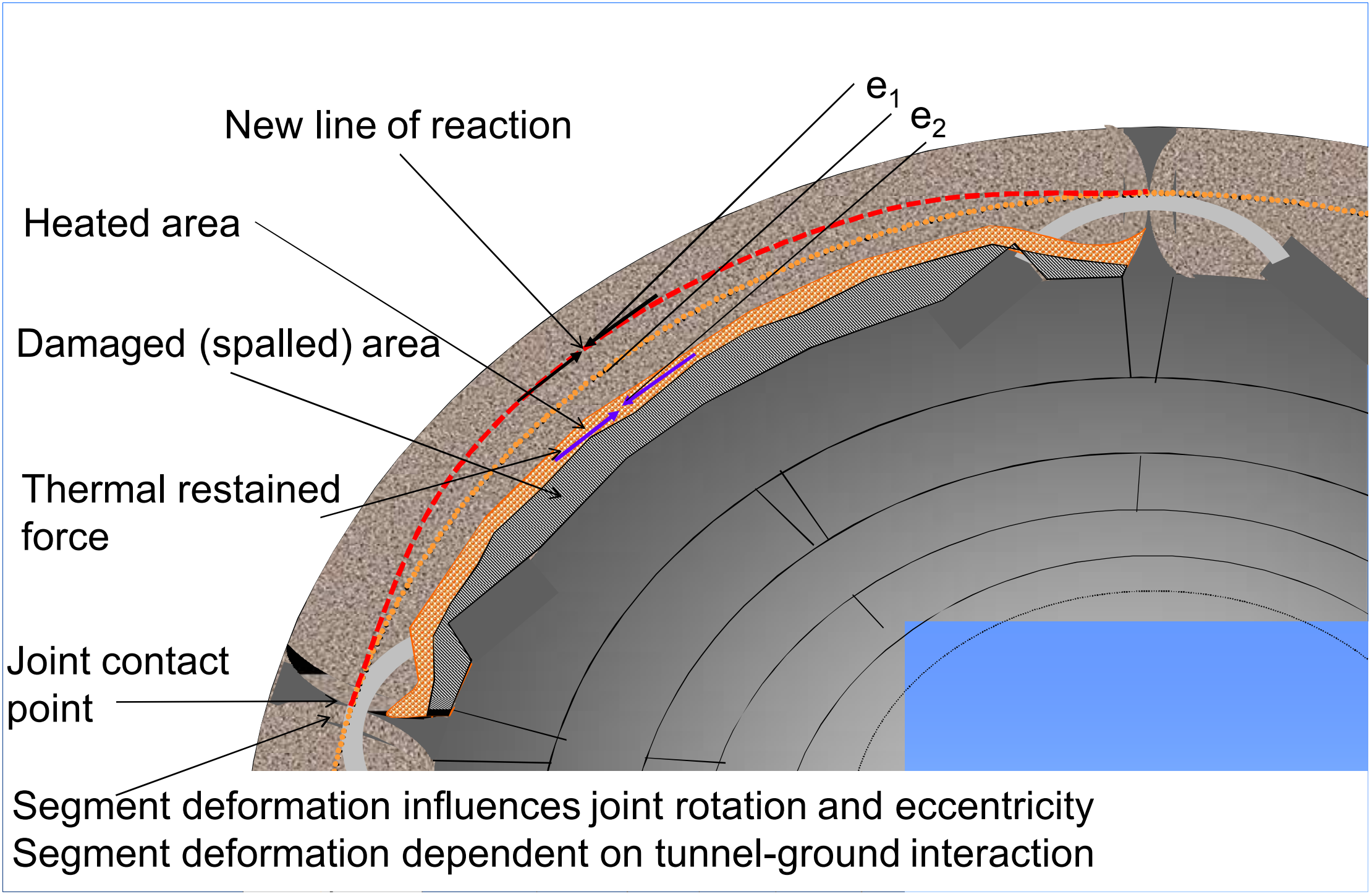


Here shown: moment action from eccentricity of the normal force

Concrete behaviour due to fire

Heating:

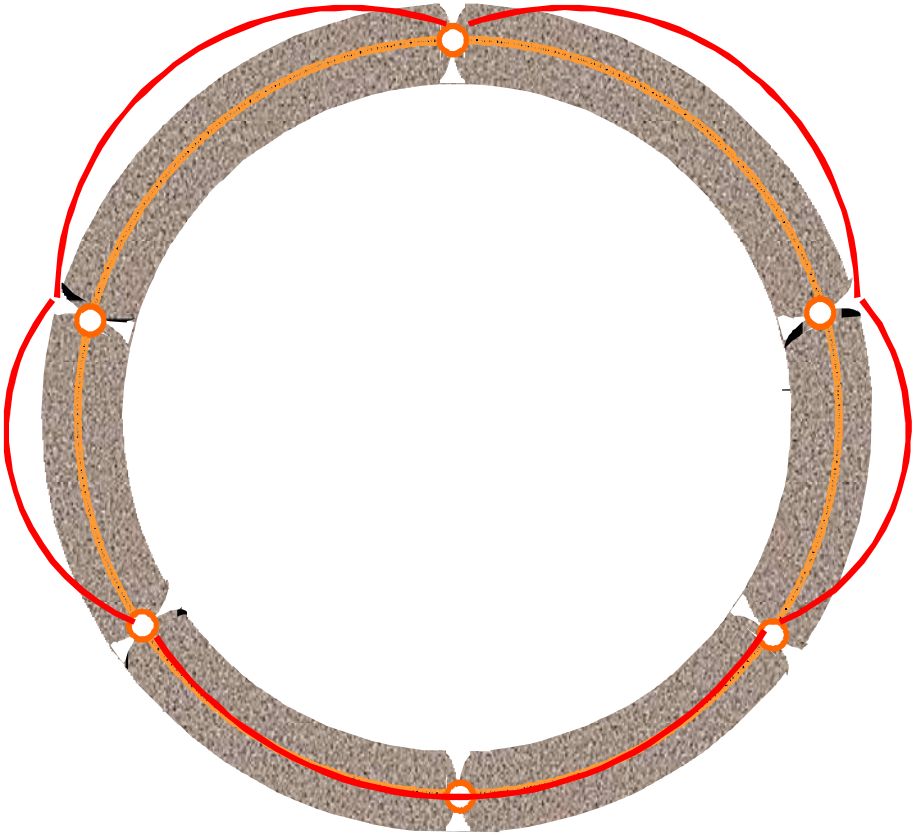
- **Loss of section**
- **Loss of stiffness**
- **Loss of strength**
- **Expansion**


New line of reaction
e_1
e_2
Heated area
Damaged (spalled) area
Thermal restained force
Joint contact point
Segment deformation influences joint rotation and eccentricity
Segment deformation dependent on tunnel-ground interaction

Tendency of deformation of segments

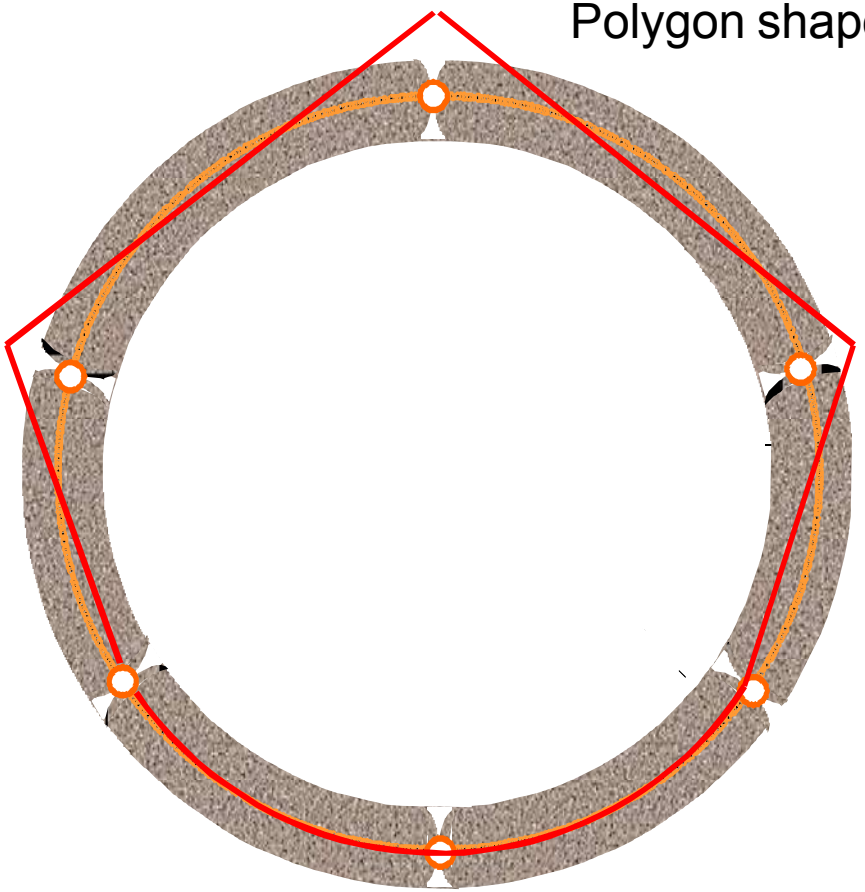
Moment dominated by e_1

Flower shape



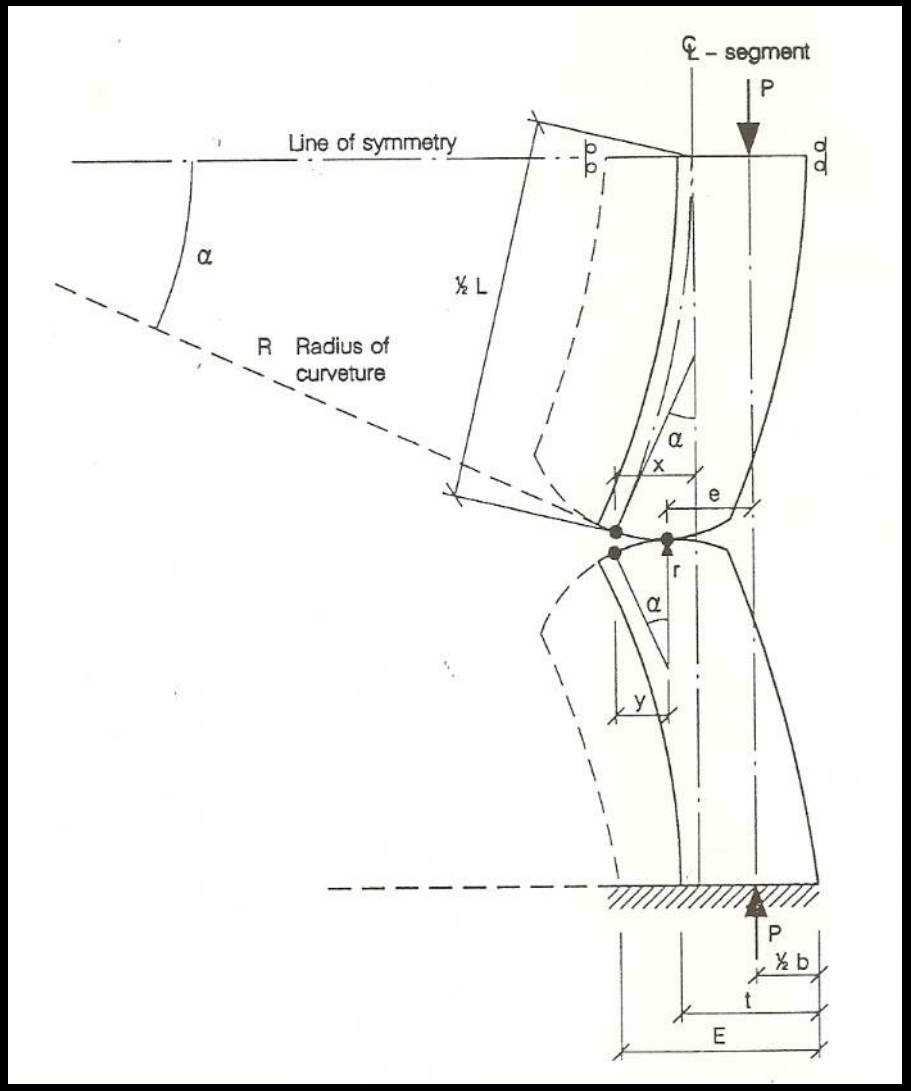
Moment dominated by e_2

Polygon shape



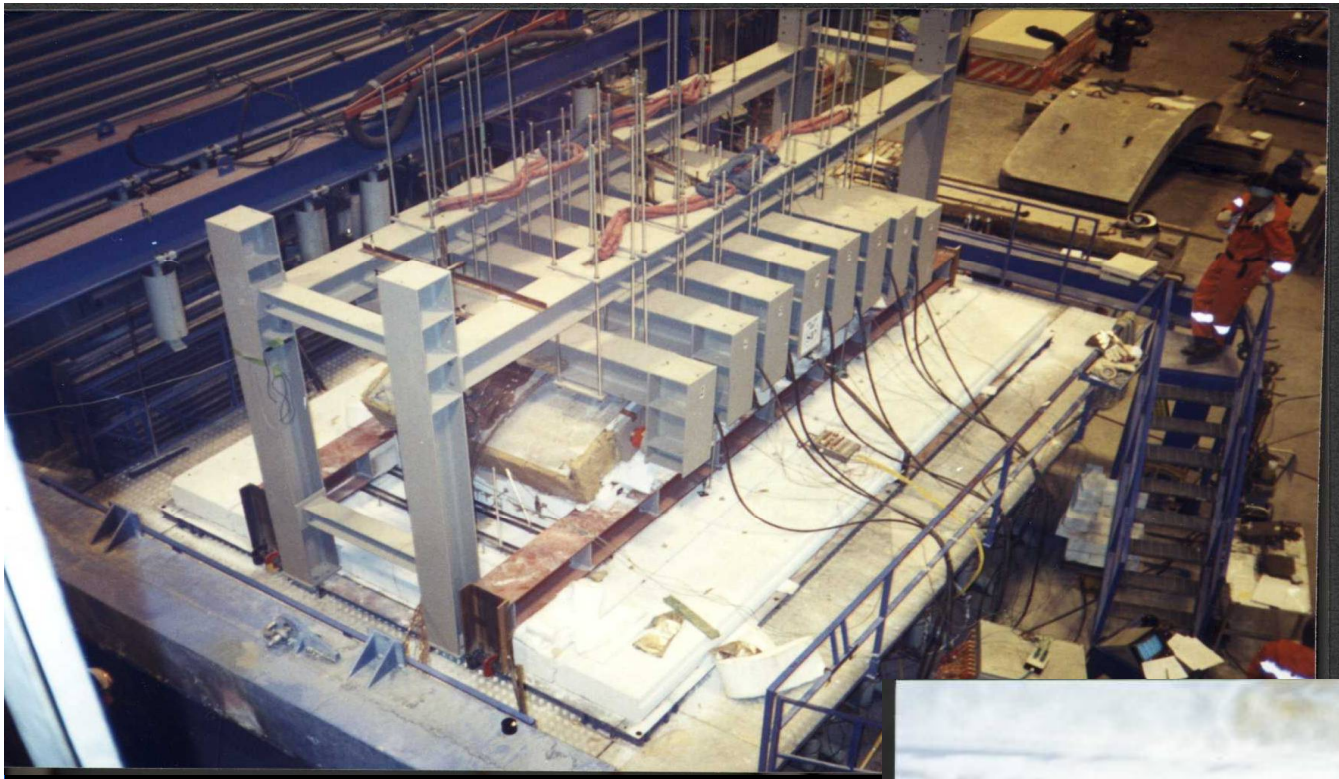
Here shown: soft ground

Rotation of joint



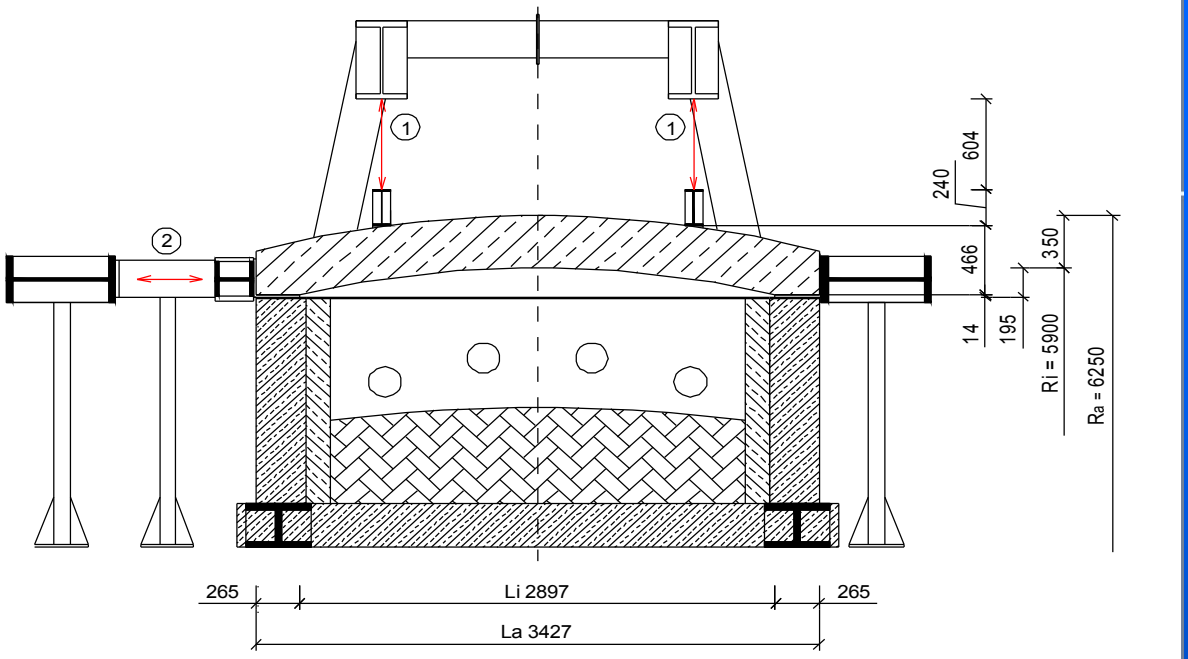
Spalling

- Spalling is a sudden dislocation of concrete – explosive spalling is caused by vapour pressure in the concrete
- No quantitative models exist
- pp-fibers significantly reduce the risk of spalling
- Tests may be necessary in order to investigate the spalling behaviour (both with and without pp fibres)



Fire effects

- Tests to update physical models
- (Lab-) Tests for the structural behaviour of a tunnel is difficult



30 jacks,
from 5 T to 300 T

MPFA Leipzig Germany

CERIB France


Thank you for your attention
Niels Peter Høj, HOJ Consulting
Alberto Meda, University of Rome Tor Vergata
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