



Numerical simulation of concrete under severe loading conditions

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Aitemin

autostrada del brennero s.p.a.



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Fracture-plastic constitutive model:

Model extension for fire analysis:

Examples and validation:

Fire tests AITEMIN, BRENNERO



autostrada del Brennero s.p.a.





Fundamentals

Strain decomposition:

Plastic strain

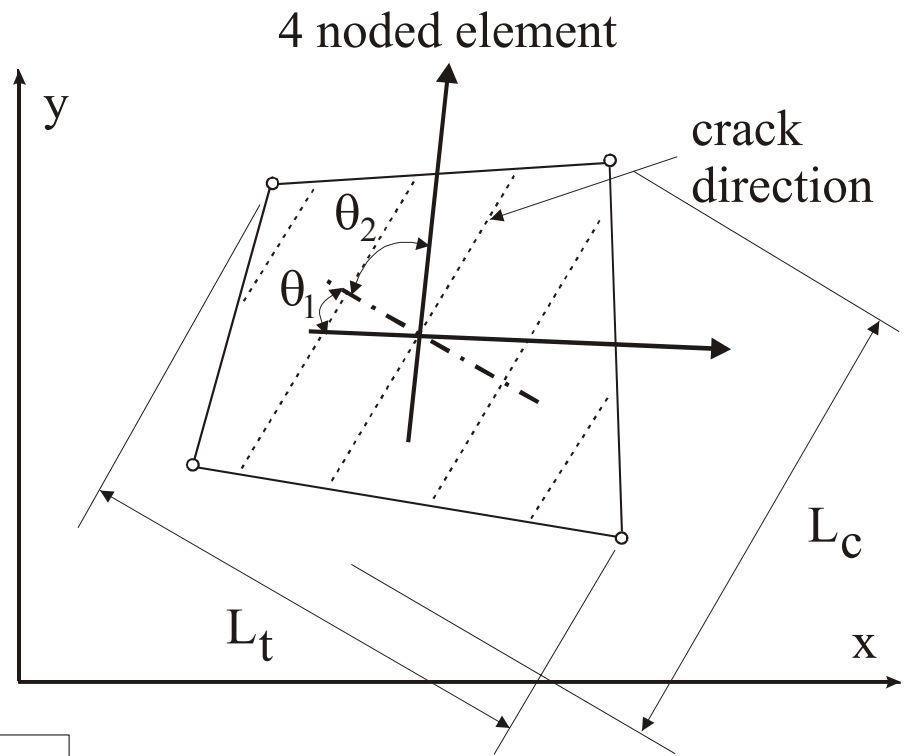
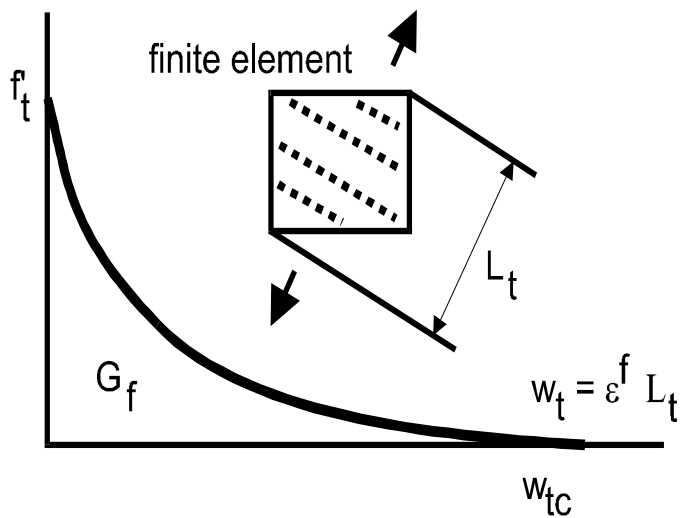
$$\varepsilon_{ij} = \varepsilon_{ij}^e + \varepsilon_{ij}^p + \varepsilon_{ij}^f \quad (1)$$

Fracturing strain

New stress state calculation

$$\sigma_{ij}^n = \sigma_{ij}^{n-1} + E_{ijkl} (\Delta \varepsilon_{kl} - \Delta \varepsilon_{kl}^p - \Delta \varepsilon_{kl}^f) \quad (2)$$

Rankine Softening Model in Tension



1.5

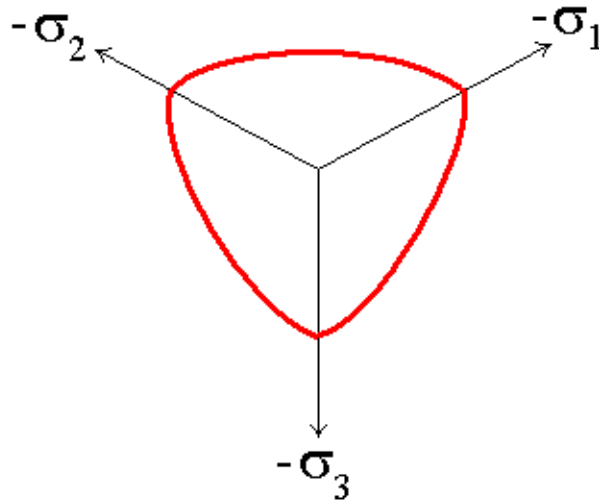
$$L_t' = \gamma L_t, L_c' = \gamma L_c \quad \gamma = 1 + (\gamma^{\max} - 1) \frac{\theta}{45} \quad \theta \in \langle 0; 45 \rangle$$

Plasticity Model for Crushing

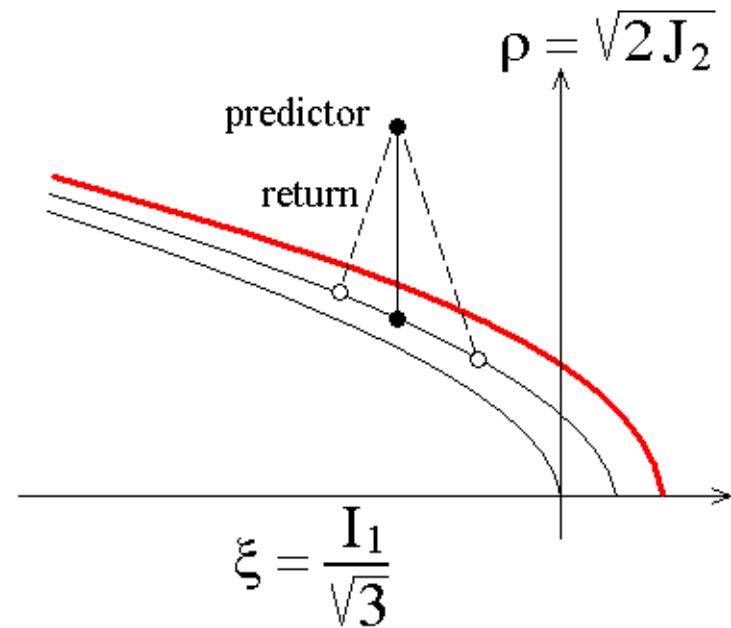


Plasticity:

MENETREY-WILLAM (1995)
Three Parameter Model (f_c , f_t , e)



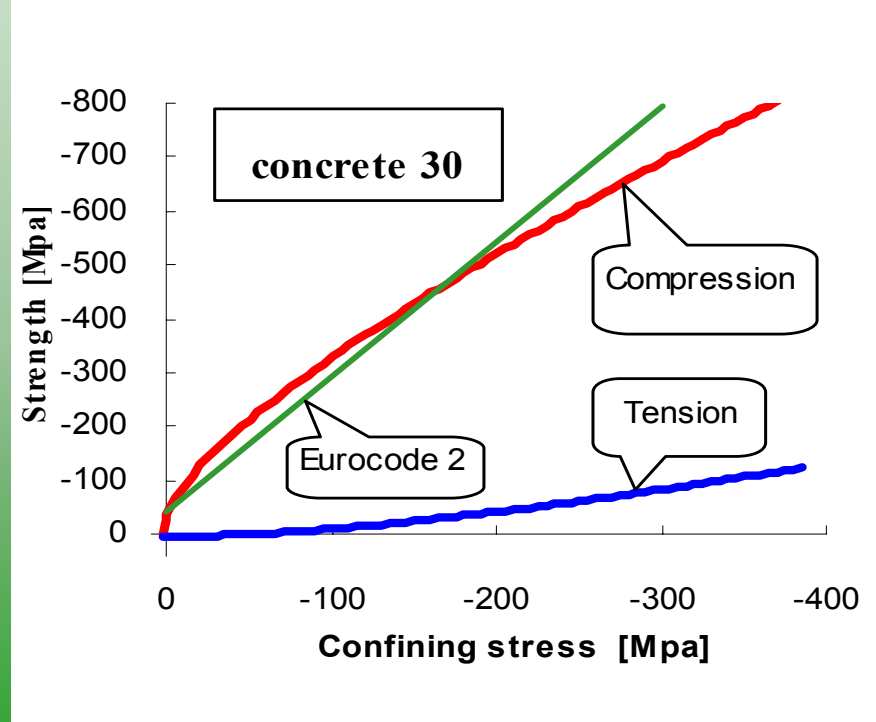
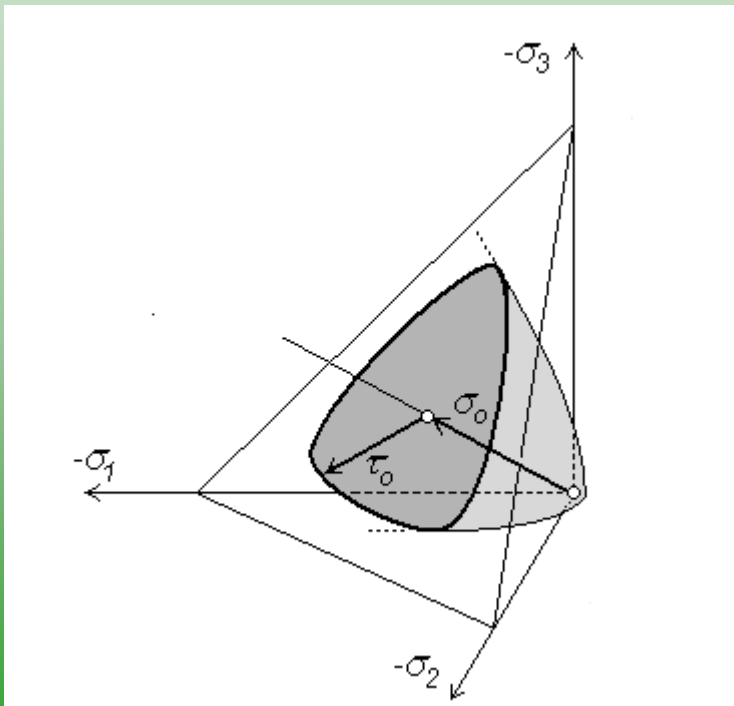
deviatoric section



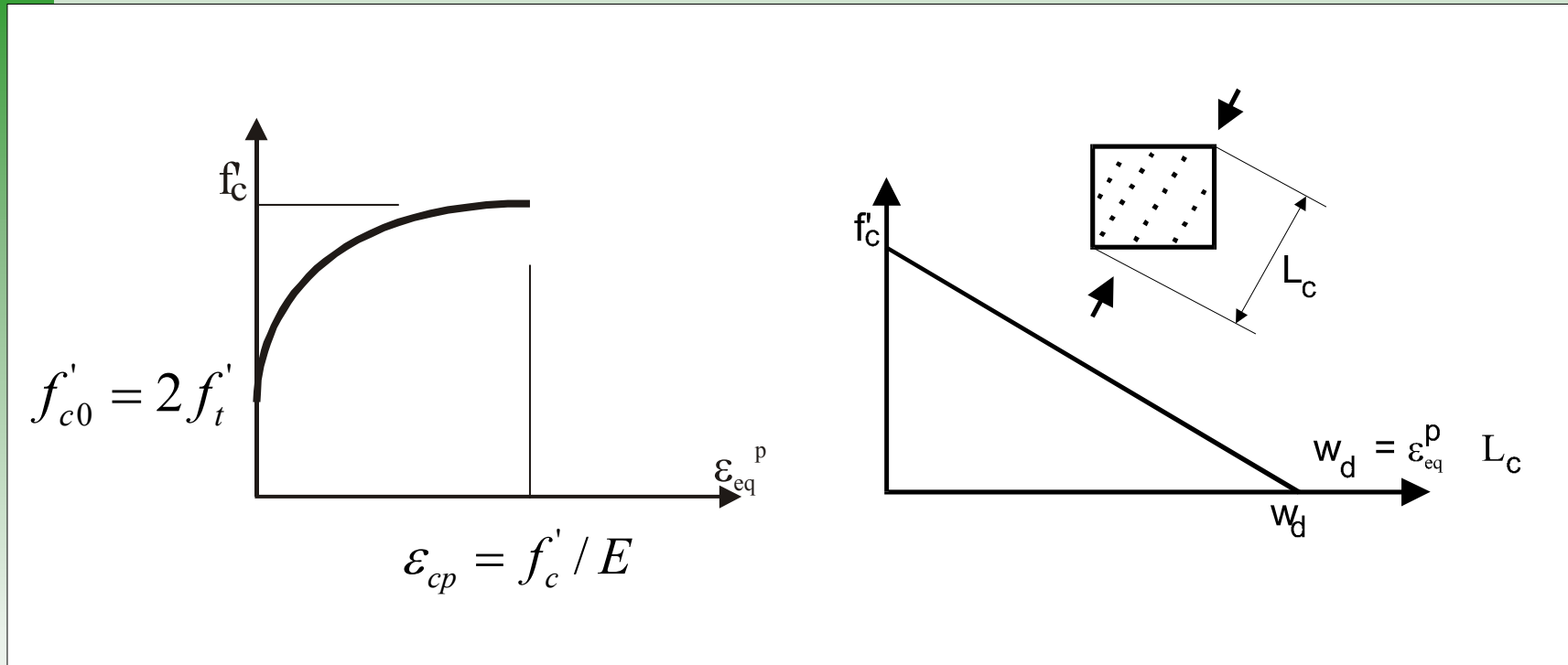
hydrostatic section



Confinement effect

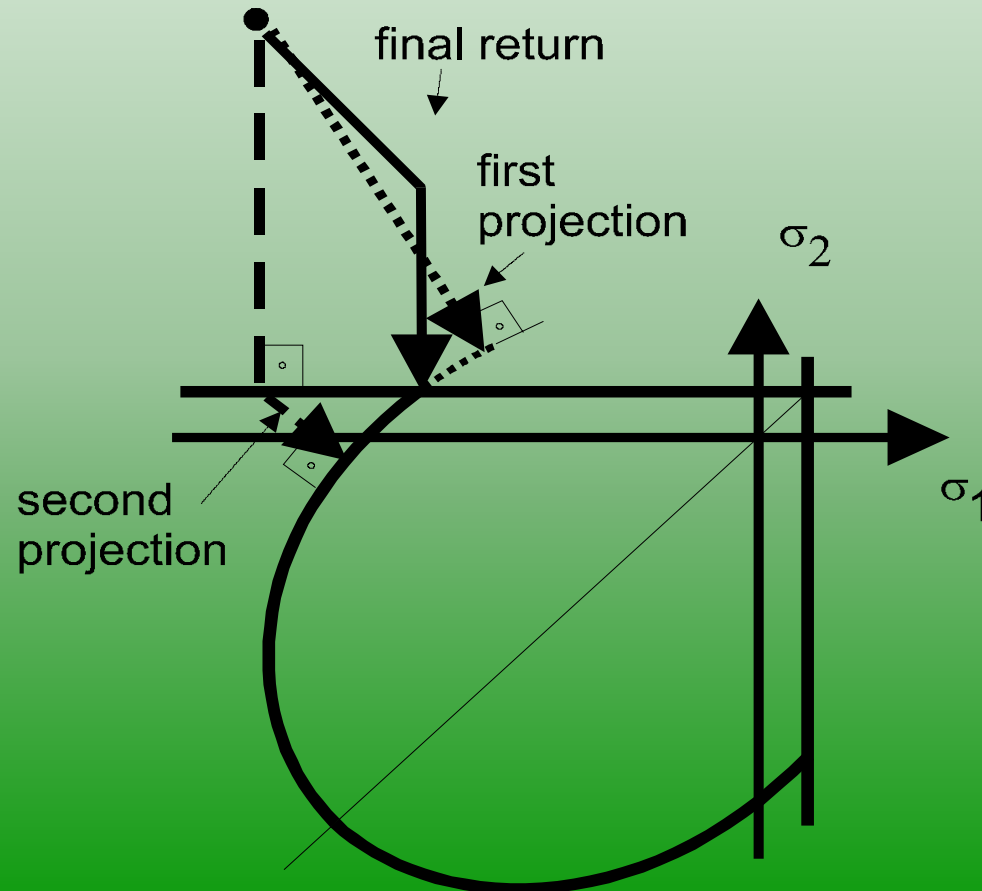


Hardening/softening in compression



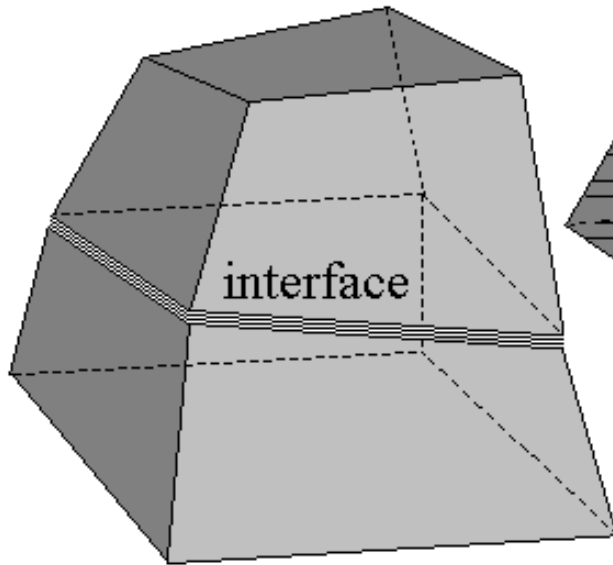
Schematic description of the iterative process for the combination of the 2 models

(for simplicity only in 2D)

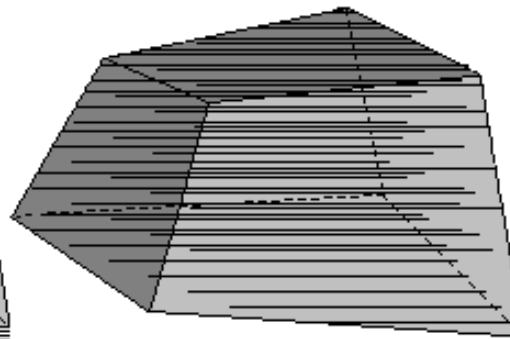


3D ELEMETS OF REINFORCED CONCRETE

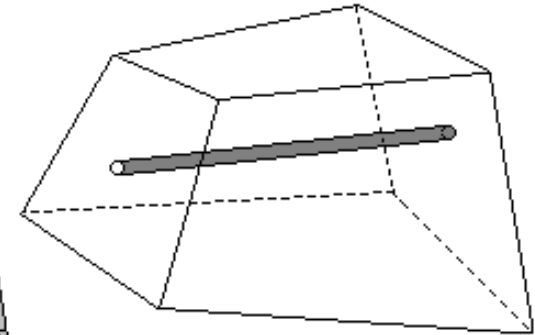
concrete



smearred reinforcement

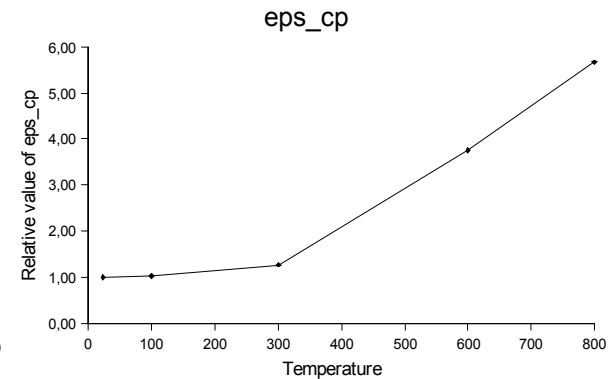
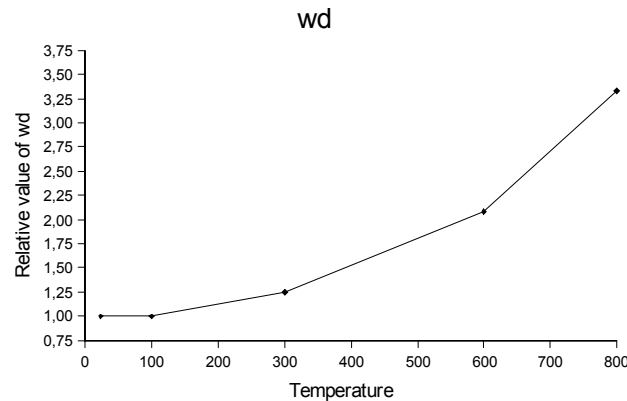
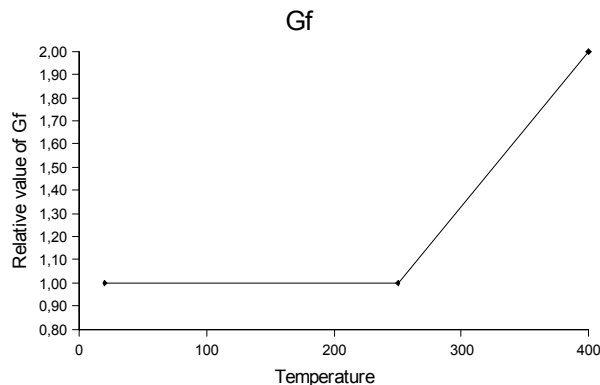
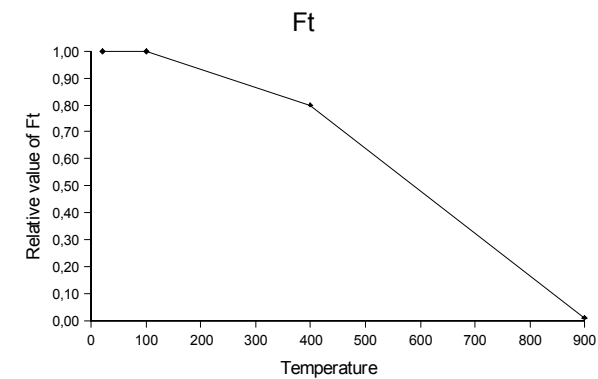
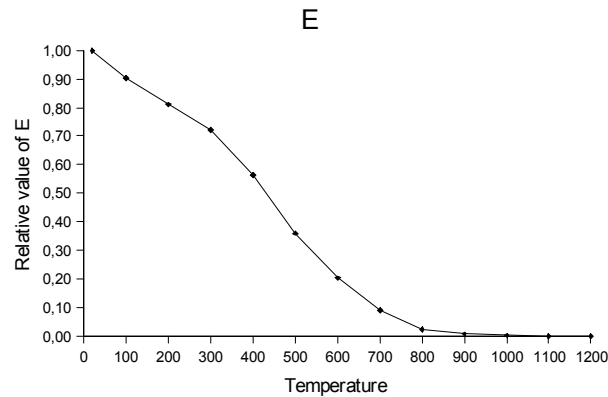
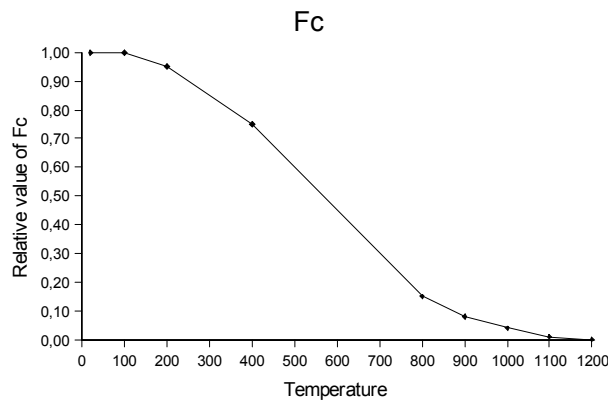


bar reinforcement

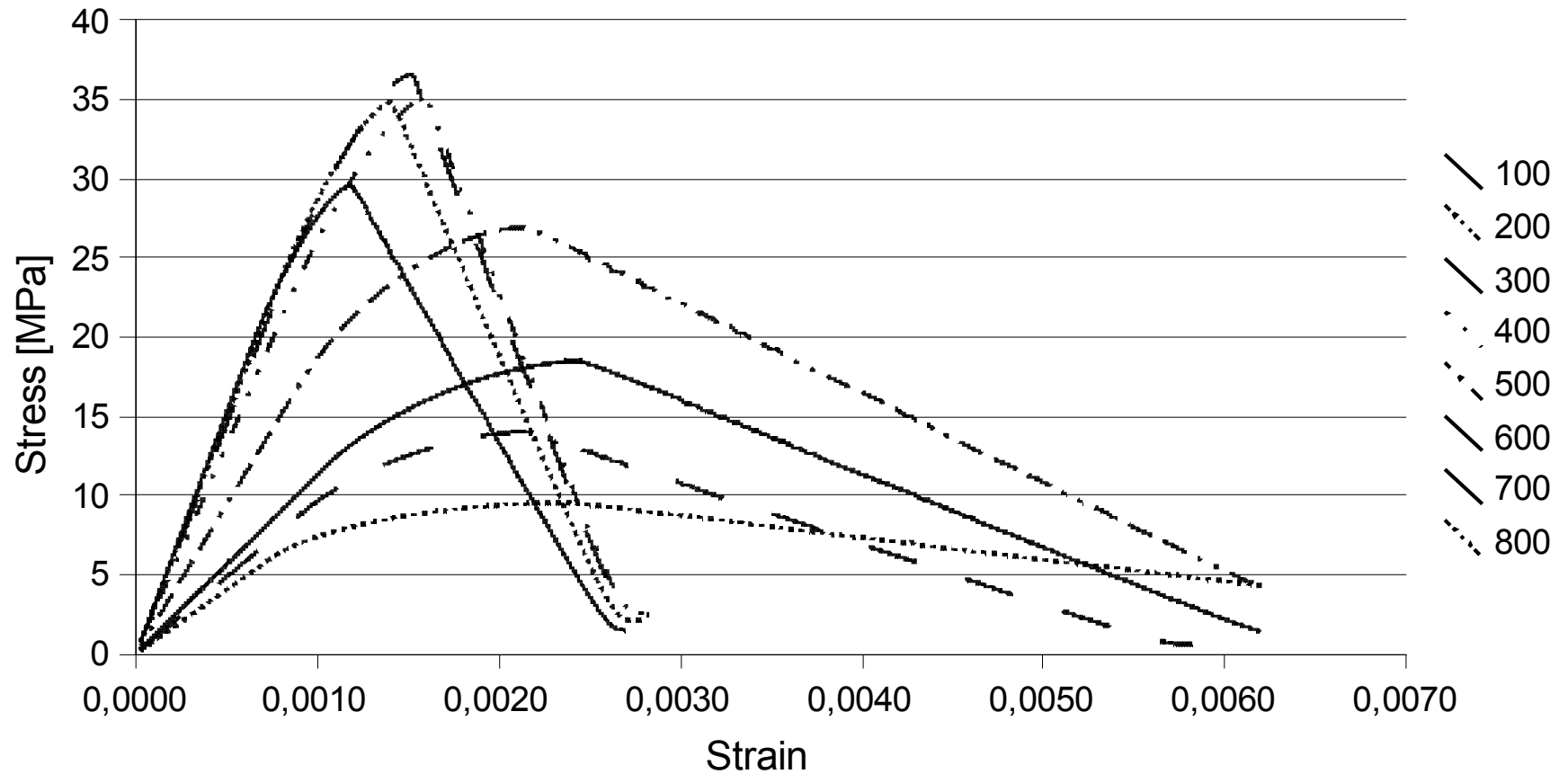


EXTENSION FOR FIRE MODELLING

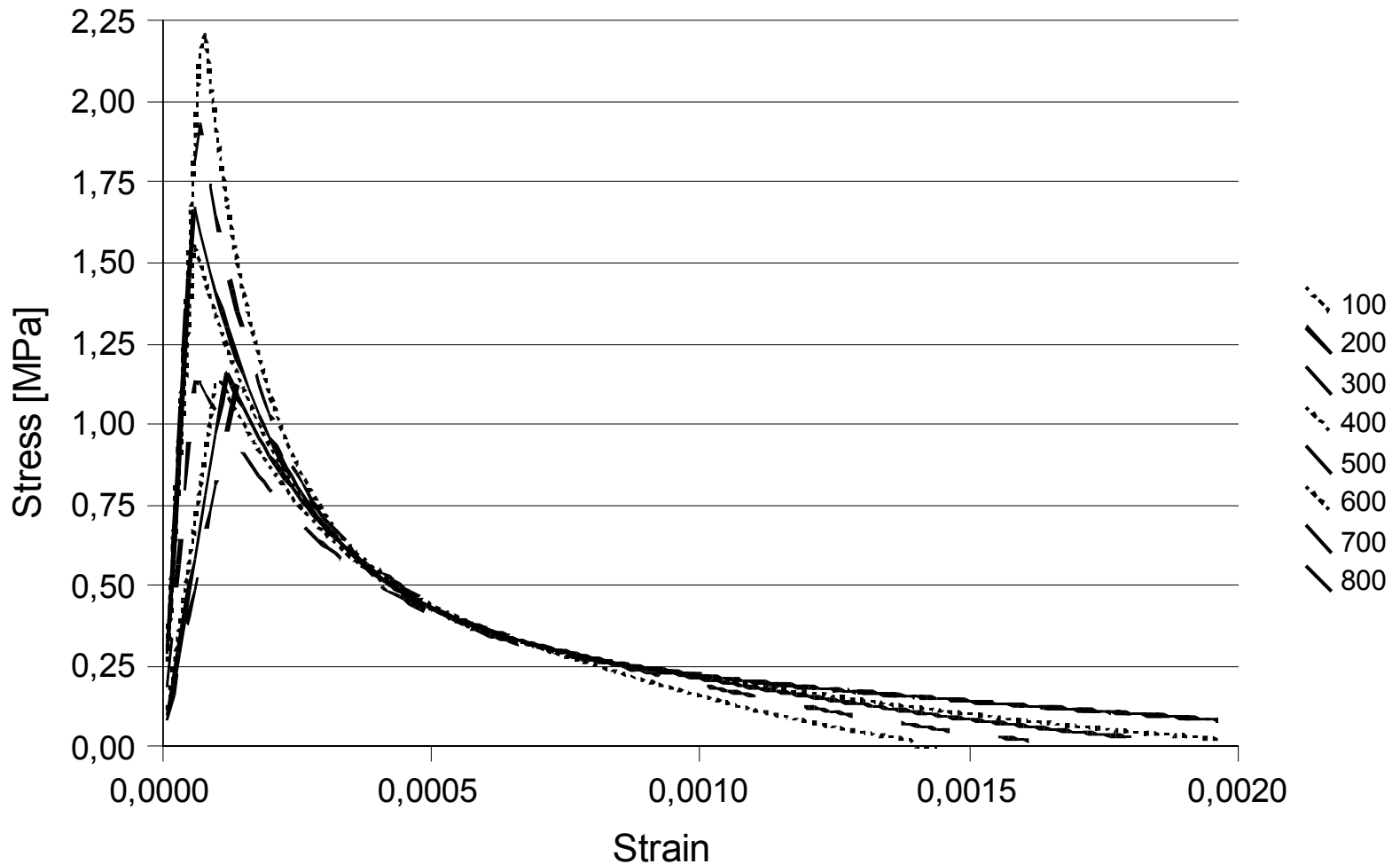
- uncoupled thermo-mechanical analysis
- fracture mechanics
- loading due to thermal strains
- material properties dependent on temperature – material degradation (Castilo, Durani, ACI, 1990)



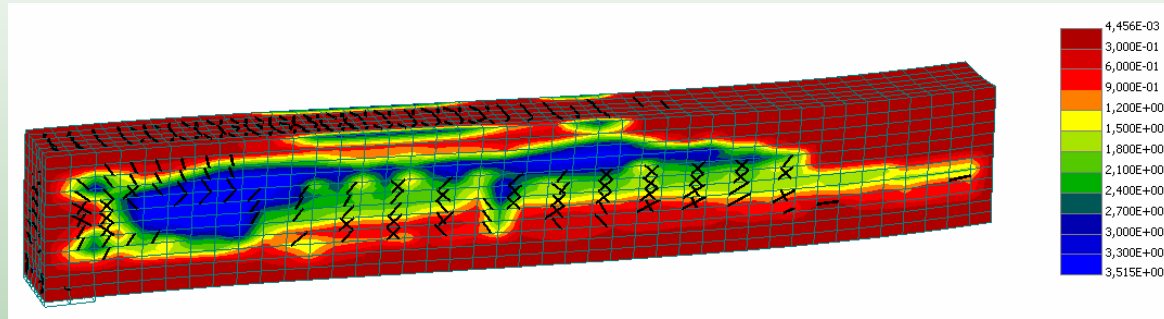
Uniaxial compression at various temperatures (Castillo, Durani, 1990)



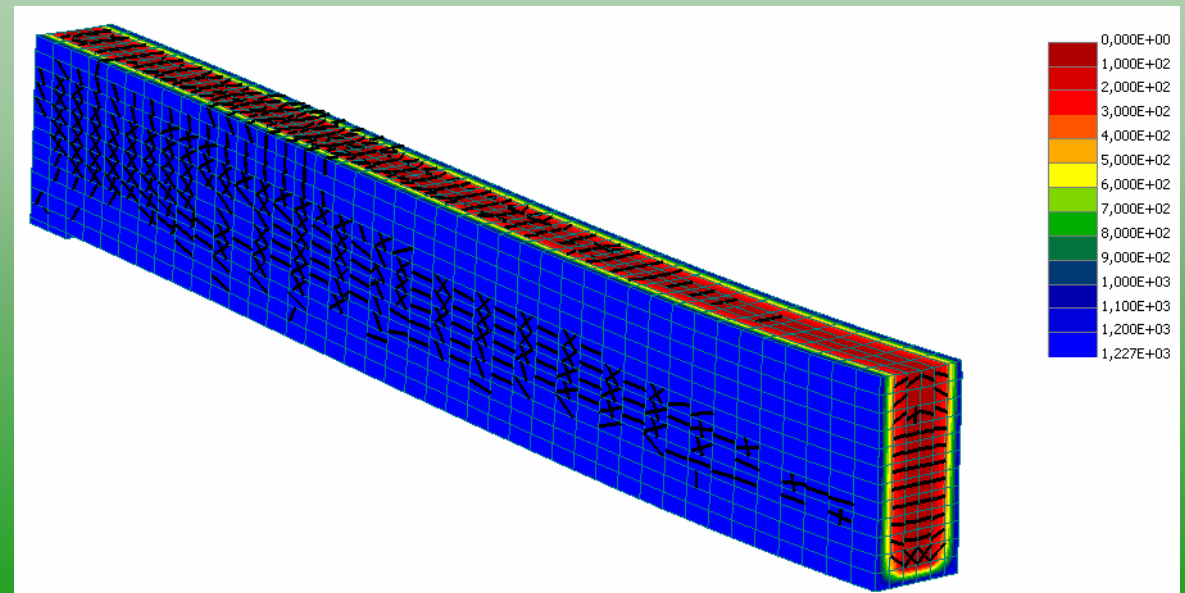
Uniaxial tension at various temperatures (Castillo, Durani, 1990)



Simply supported RC beam (3D) – part 2



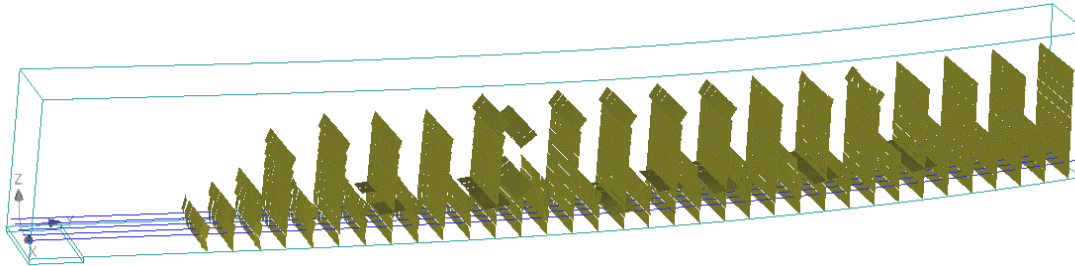
Residual tensile strength and cracks larger than 0.7 mm after 10 min



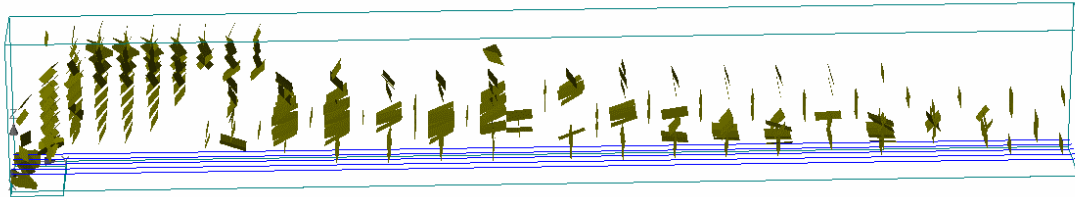
Temperature field and cracks larger than 0.5 mm after 26 min



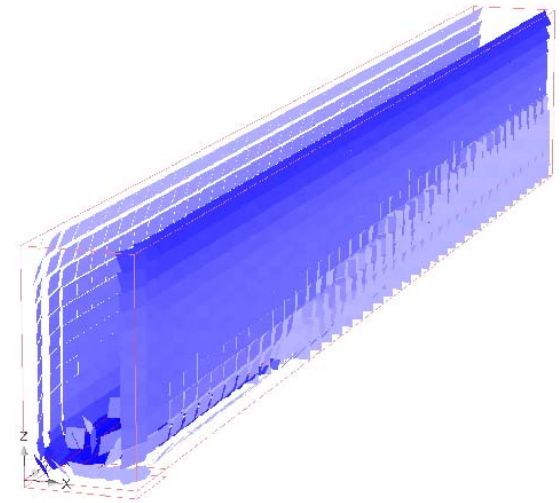
Simply supported RC beam (3D) – part 3



Cracks after applying the live load $t = 0$ min

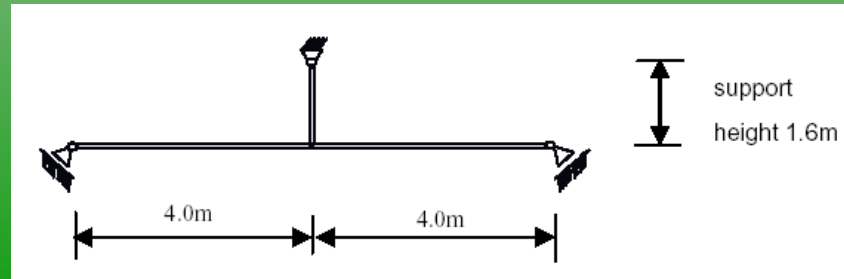
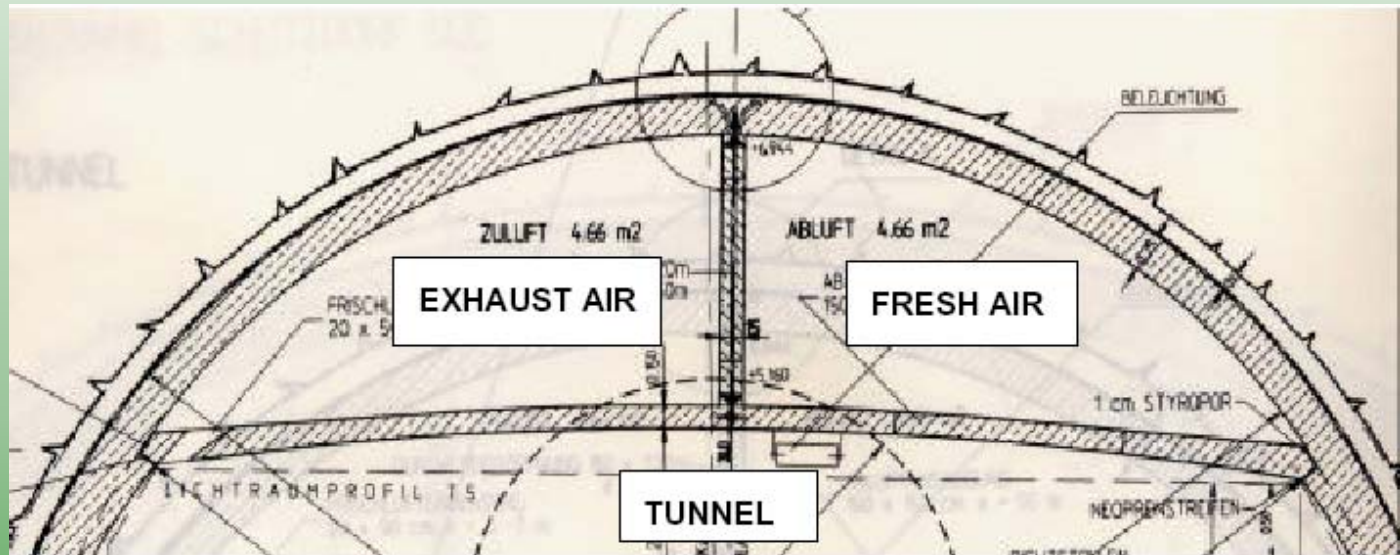


Cracks larger than 1.2 mm after 26 min

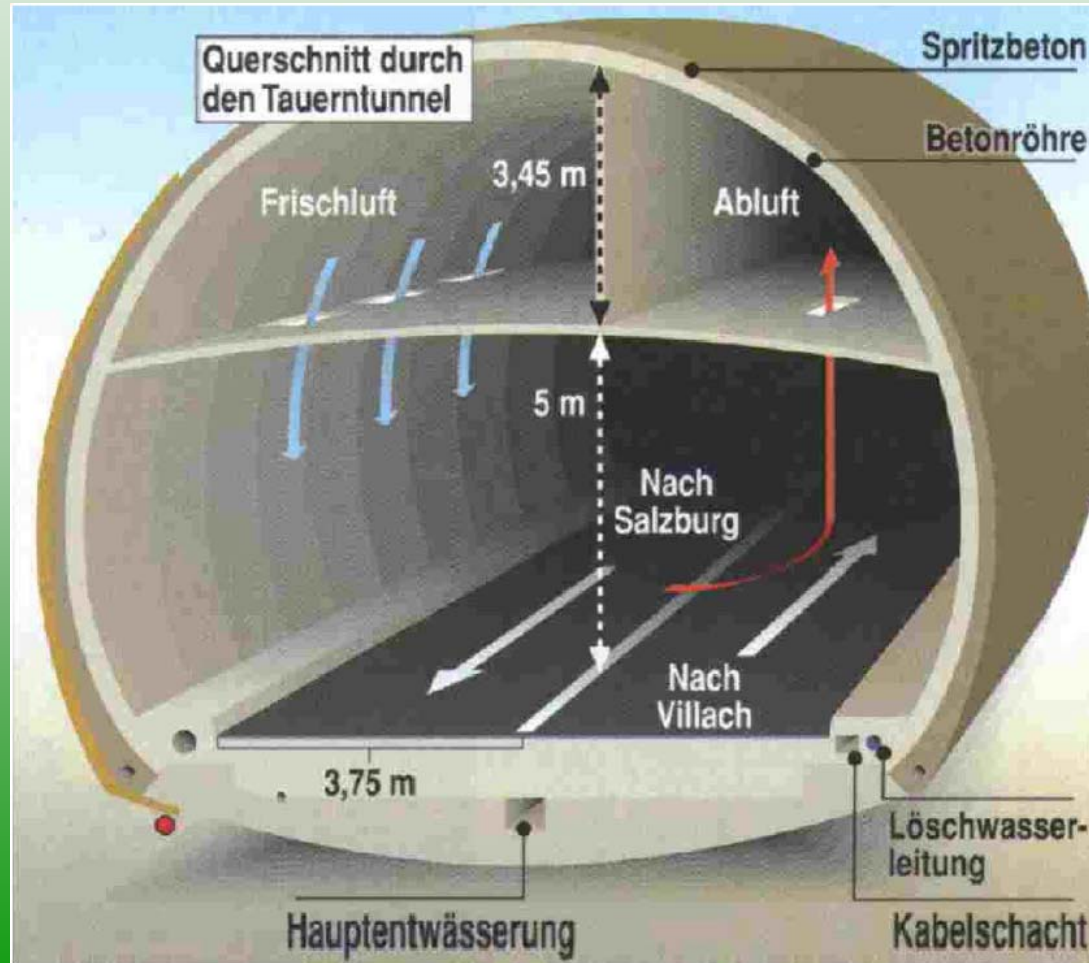


First cracks due to thermal load

Suspended tunnel ceiling simulation

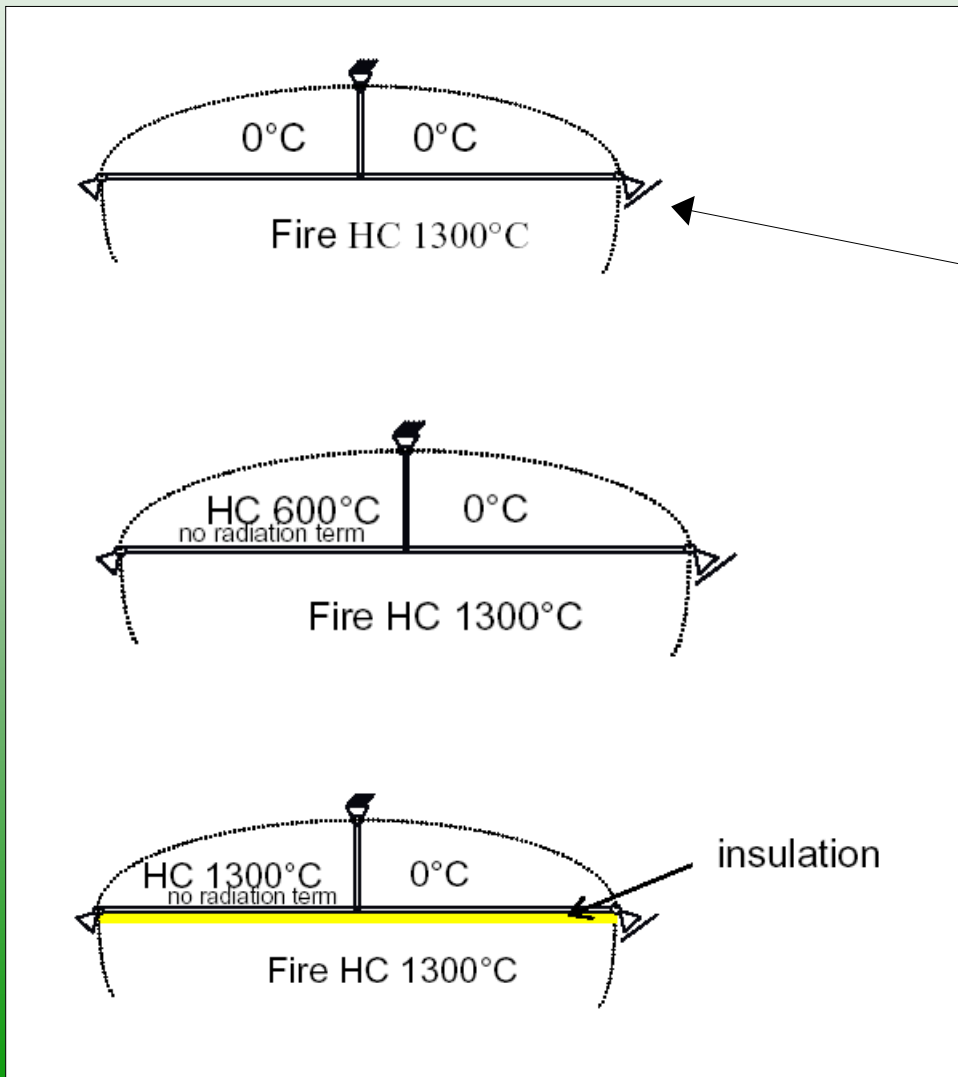


Typical tunnel design





Loading scenarios



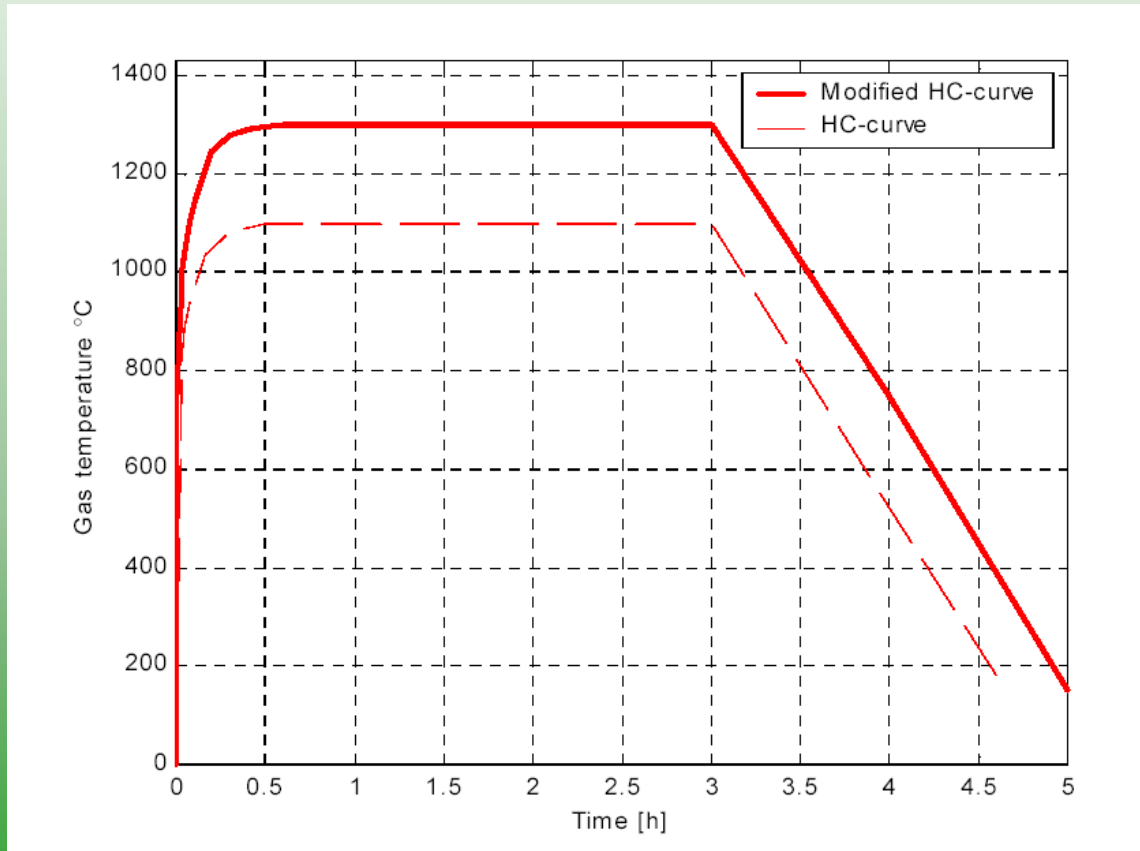
Load case 1

Fire test AITEMIN

Load case 2

Load case 3 (4)

Modified hydro-carbon fire



$$T(t) = T_1(1 - 0.325 e^{-0.167t} - 0.204 e^{-1.417t} - 0.471 e^{-15.833t})$$



UATUN
UPgrading of existing TUNnels

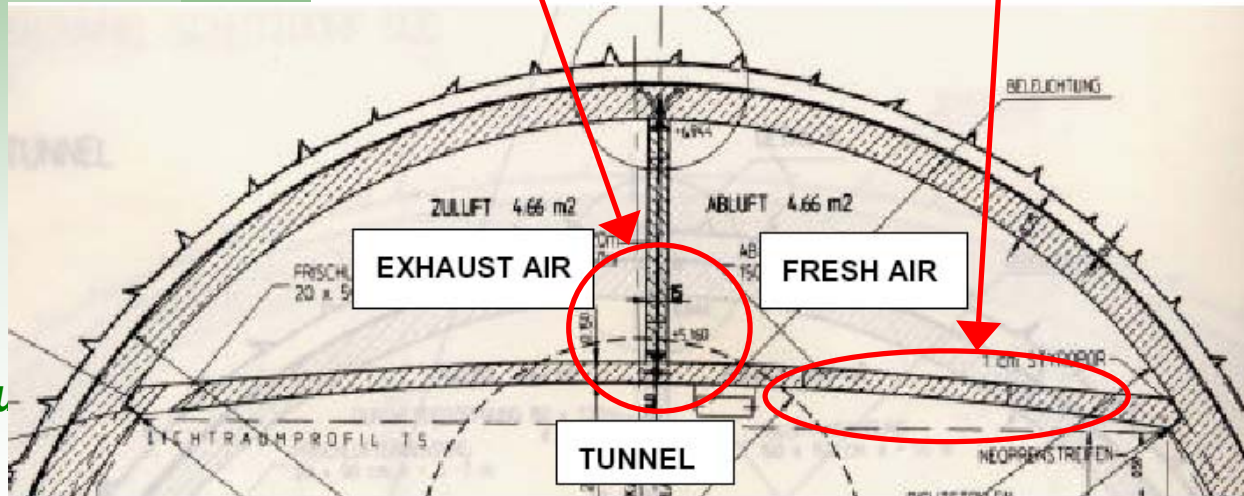
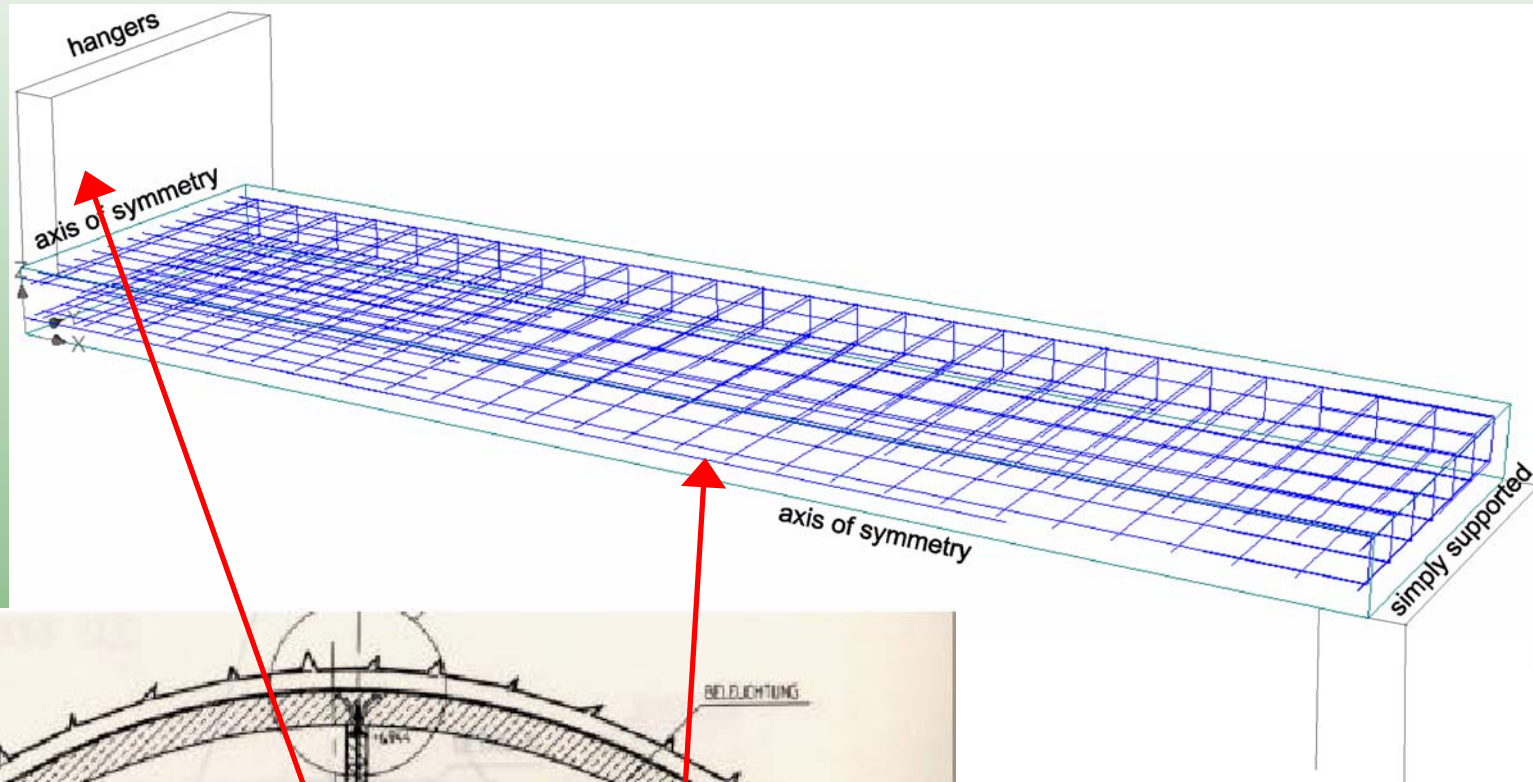


Thermal boundary conditions heat flux

$$q_n = h_c (T_g - T_b) + \varepsilon_r \sigma (T_g^4 - T_b^4)$$

- σ Stefan-Boltzmann constant [$5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$]
- T_g absolute temperature of radiation source [K]
- T_b boundary temperature [K]
- ε_r resulting emissivity factor of the radiation source and the heated surface [-]
- q_n heat flow at the boundary [W/m^2]
- h_c convection heat transfer coefficient [$\text{W/m}^2\text{K}$]

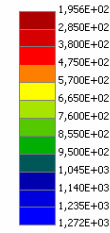
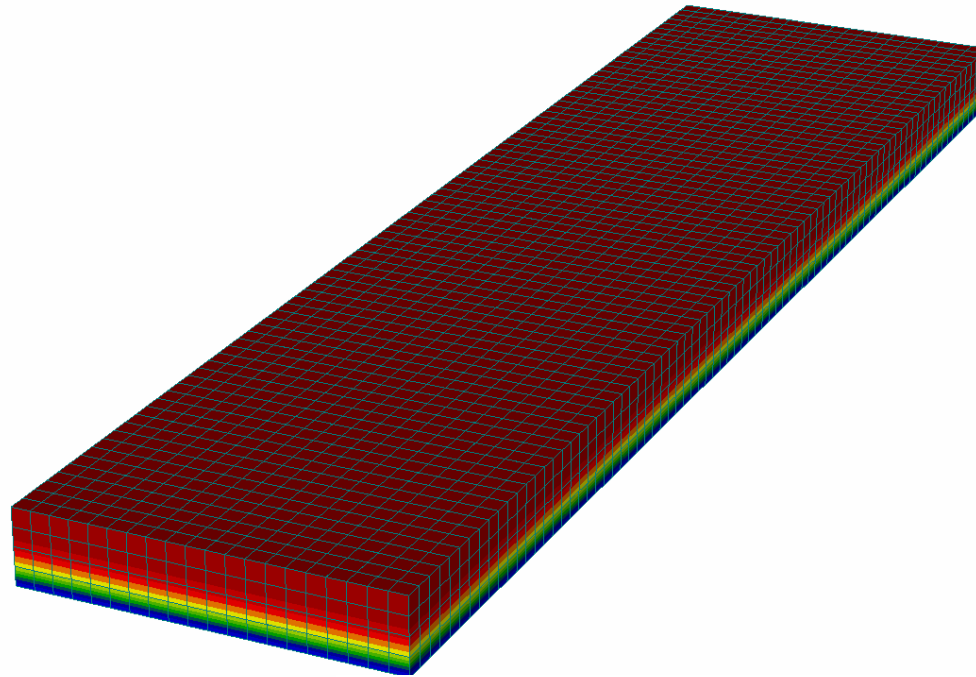
Load case 1, (3D)



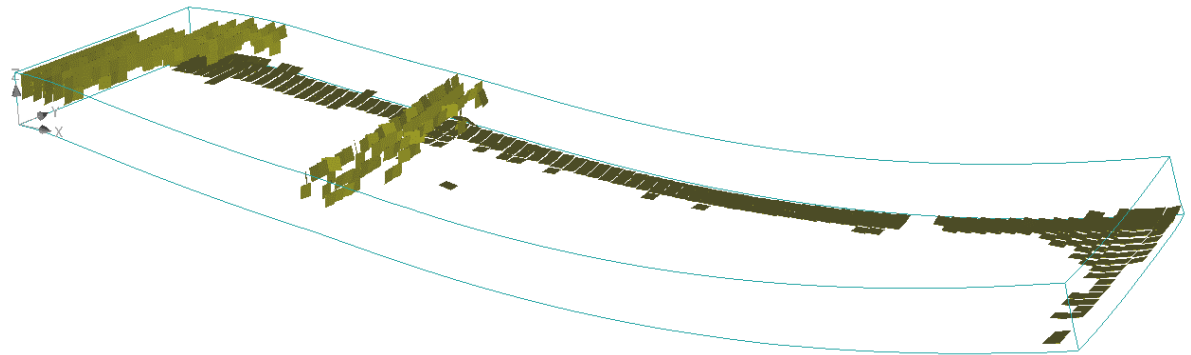
Eu



Scalars:iso-areas, in nodes, Elem Total Temperature, Totaltemp., G. <1,956E+02;1,272E+03> [°C]



Abs.min.
Abs.max.



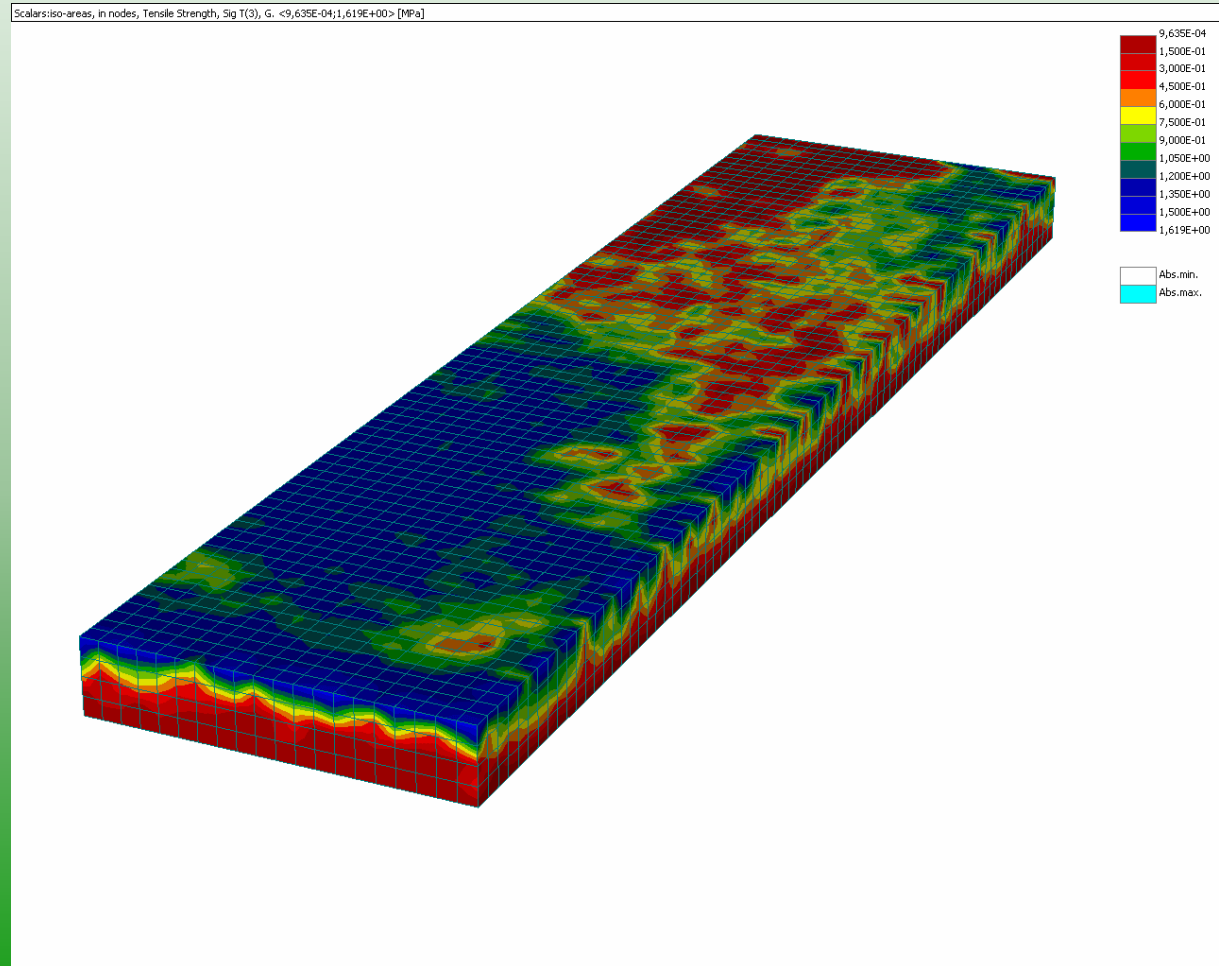
Suspended RC ceiling (3D) – deformed shape and crack pattern



Suspended RC ceiling (3D) – residual tensile strength

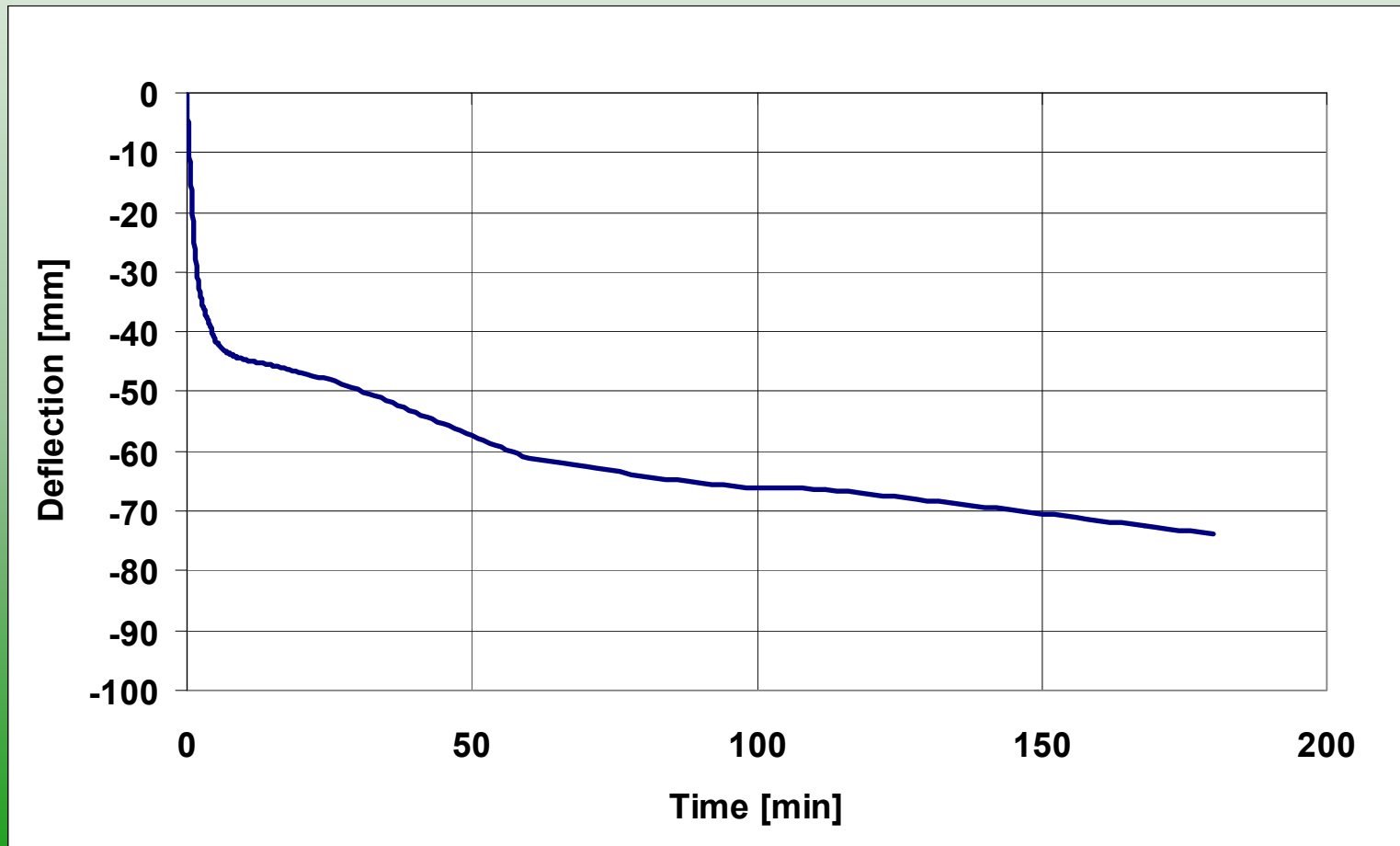


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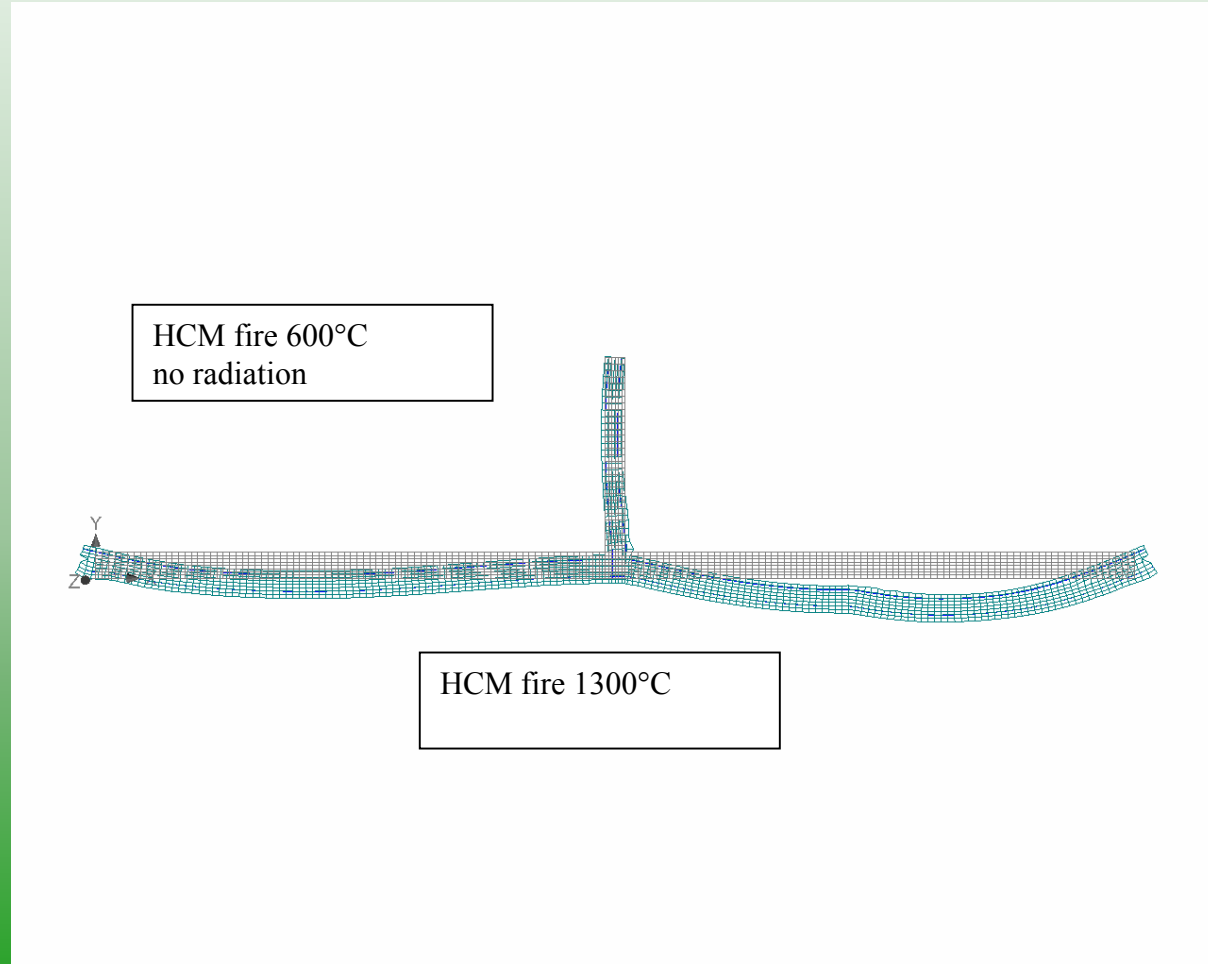




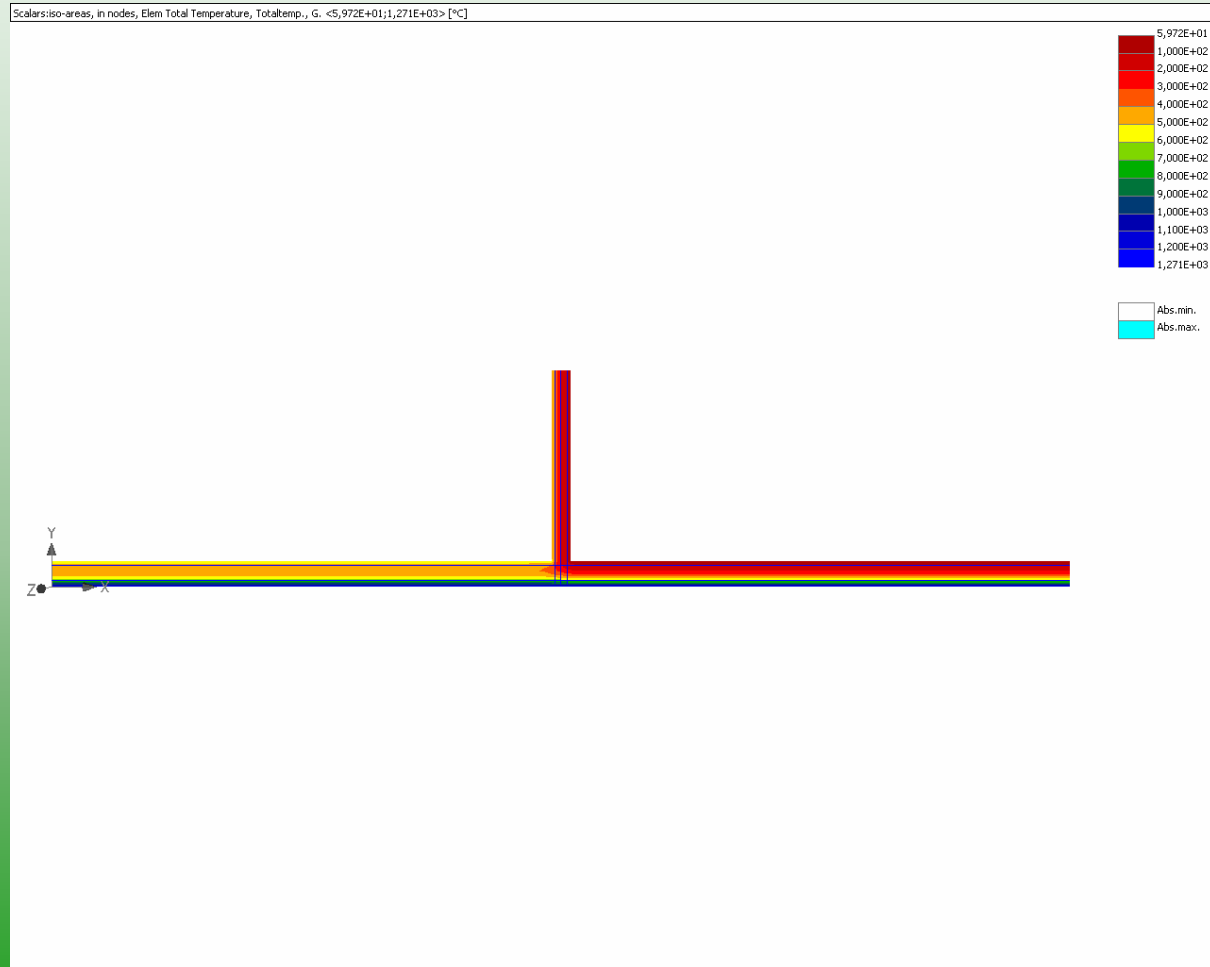
Mid-span deflection



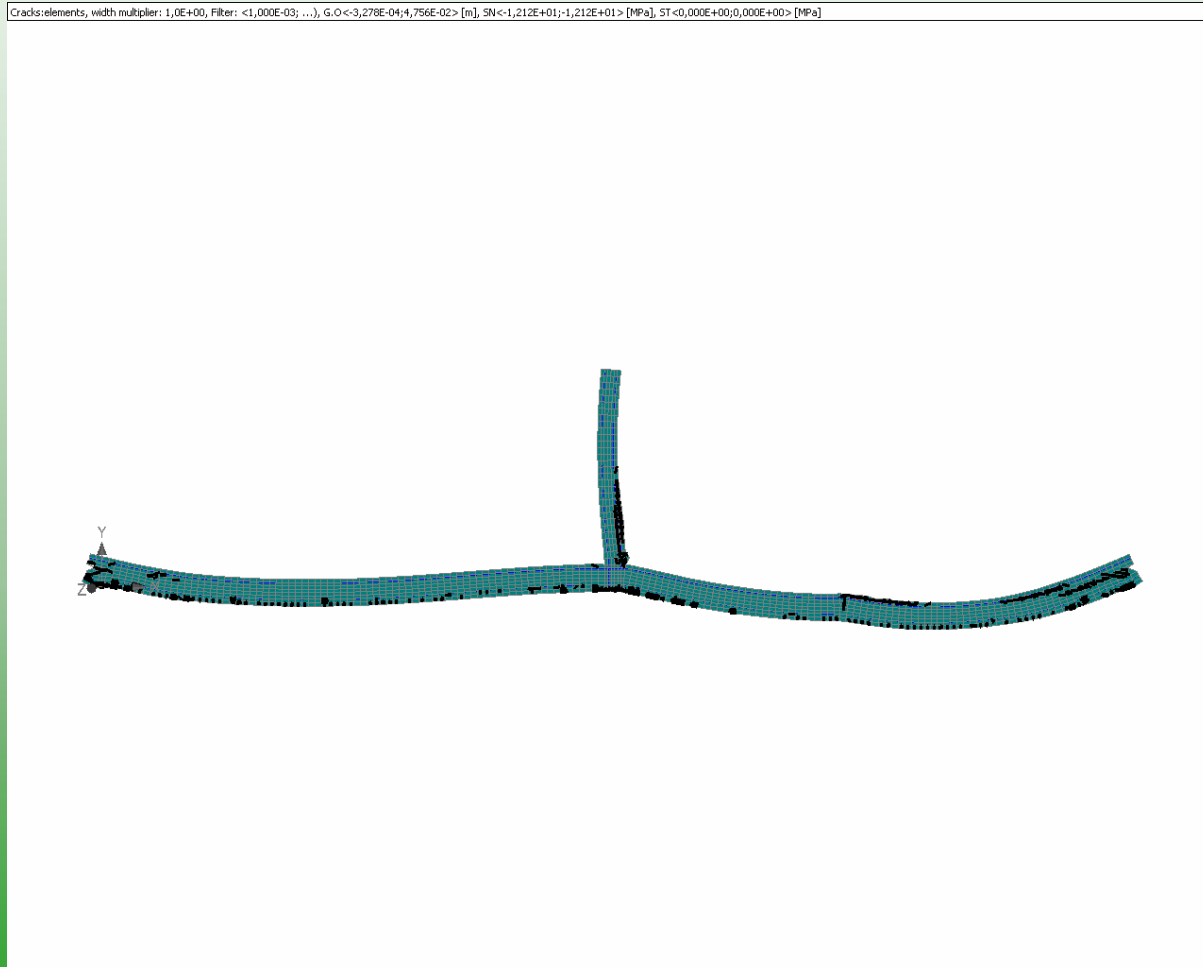
Suspended RC ceiling (2D) – load case 2 Deformed shape



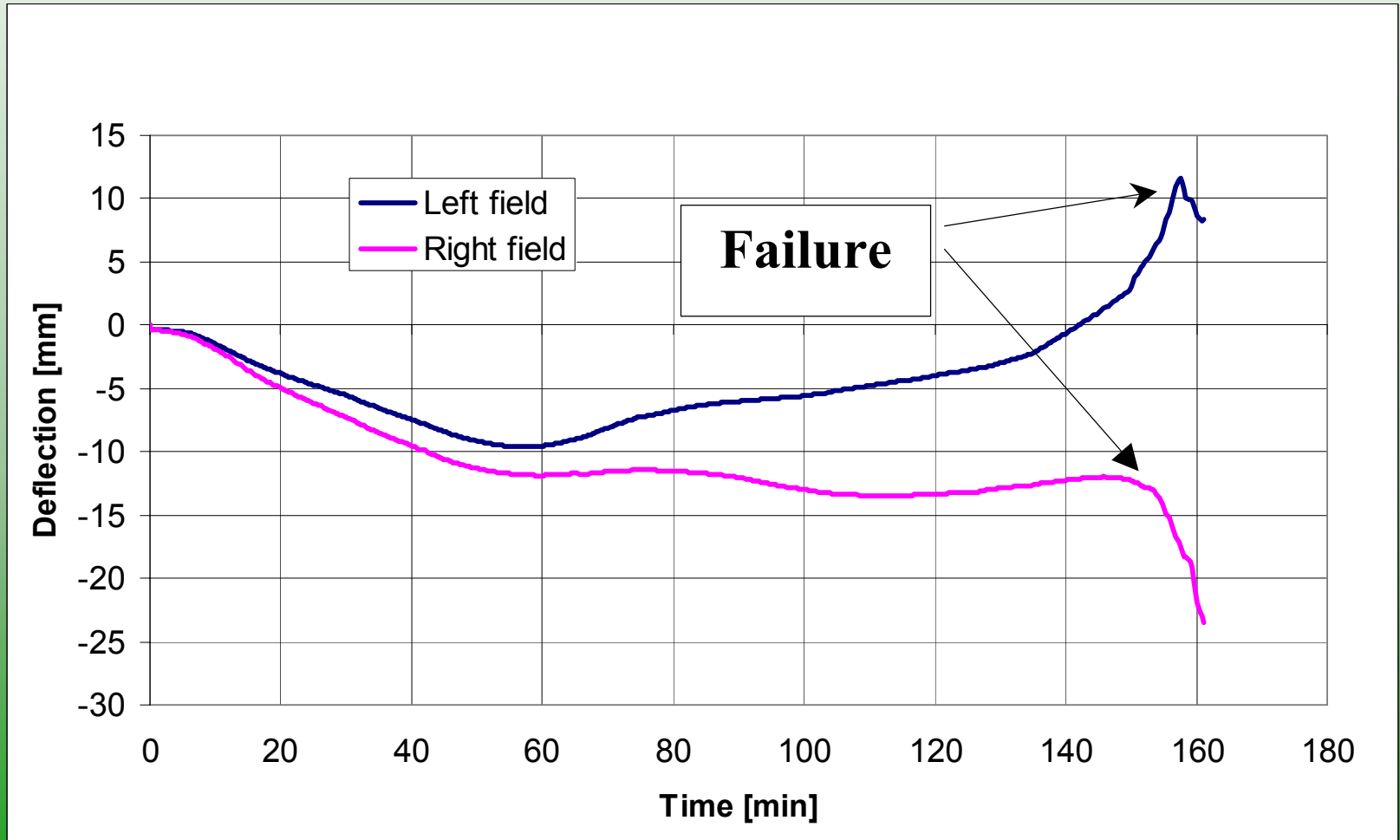
Temperature distribution after 3 hours of fire.



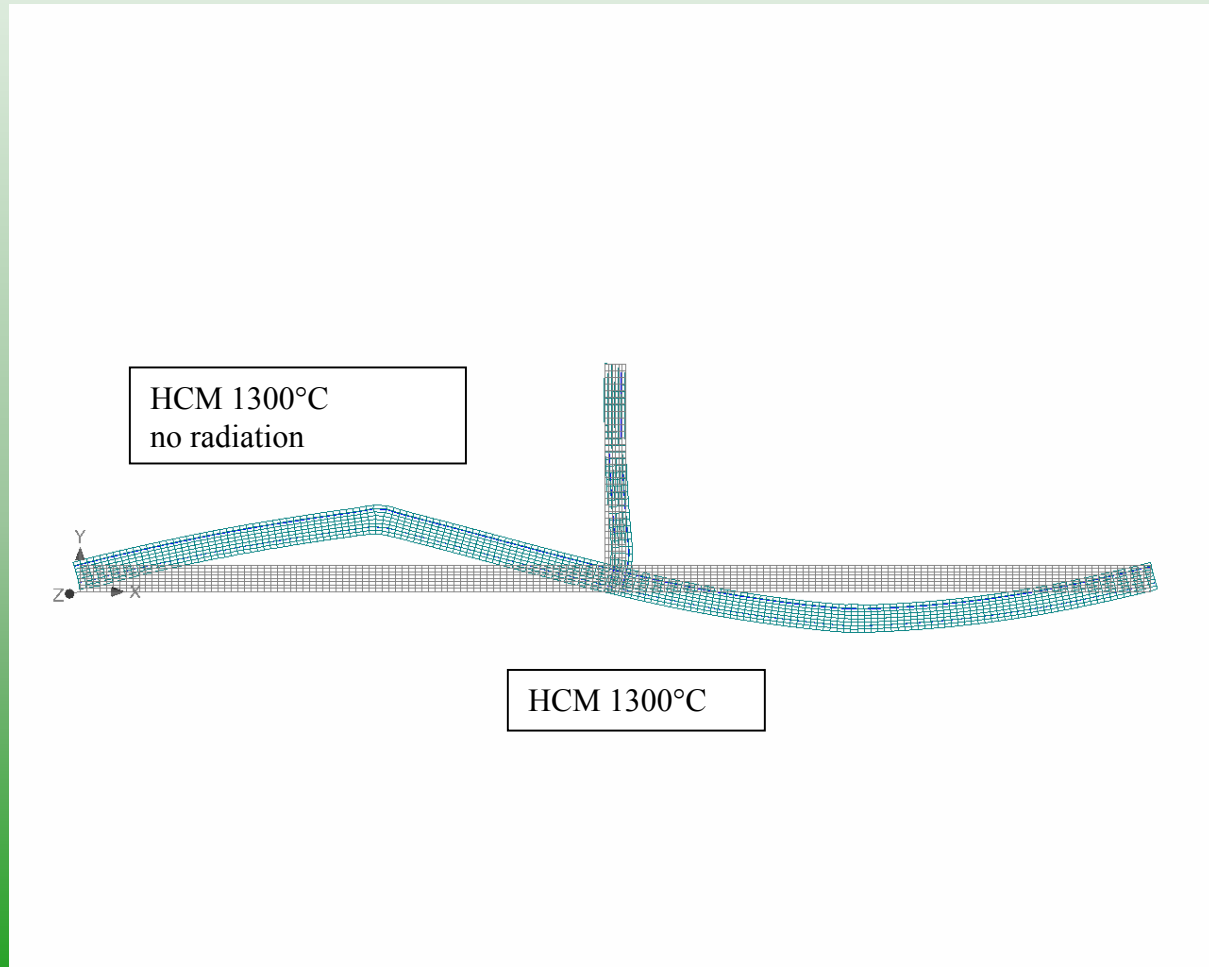
Crack pattern after 3 hours of fire.



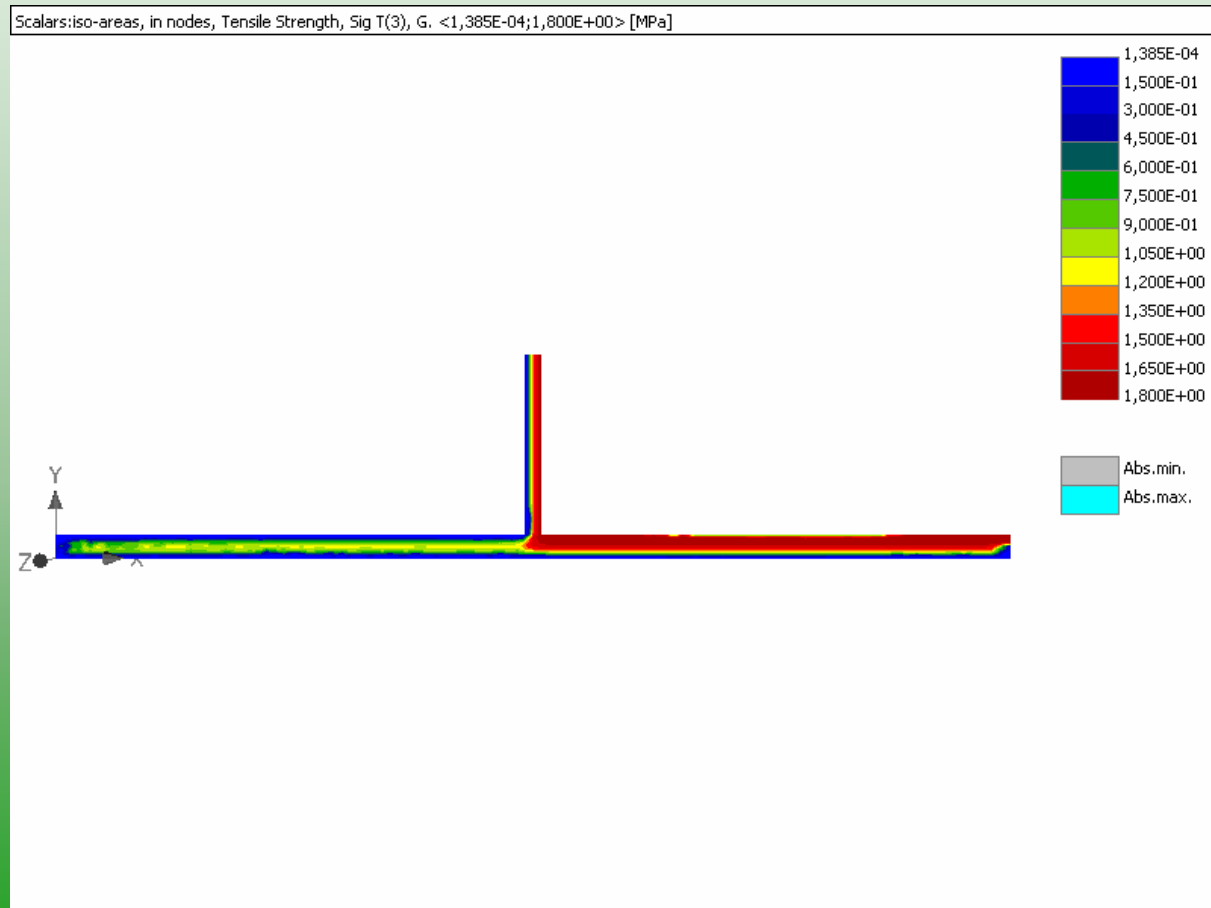
Deflection evolution in time.



Suspended RC ceiling (2D) – load case 3 (4) Deformed shape

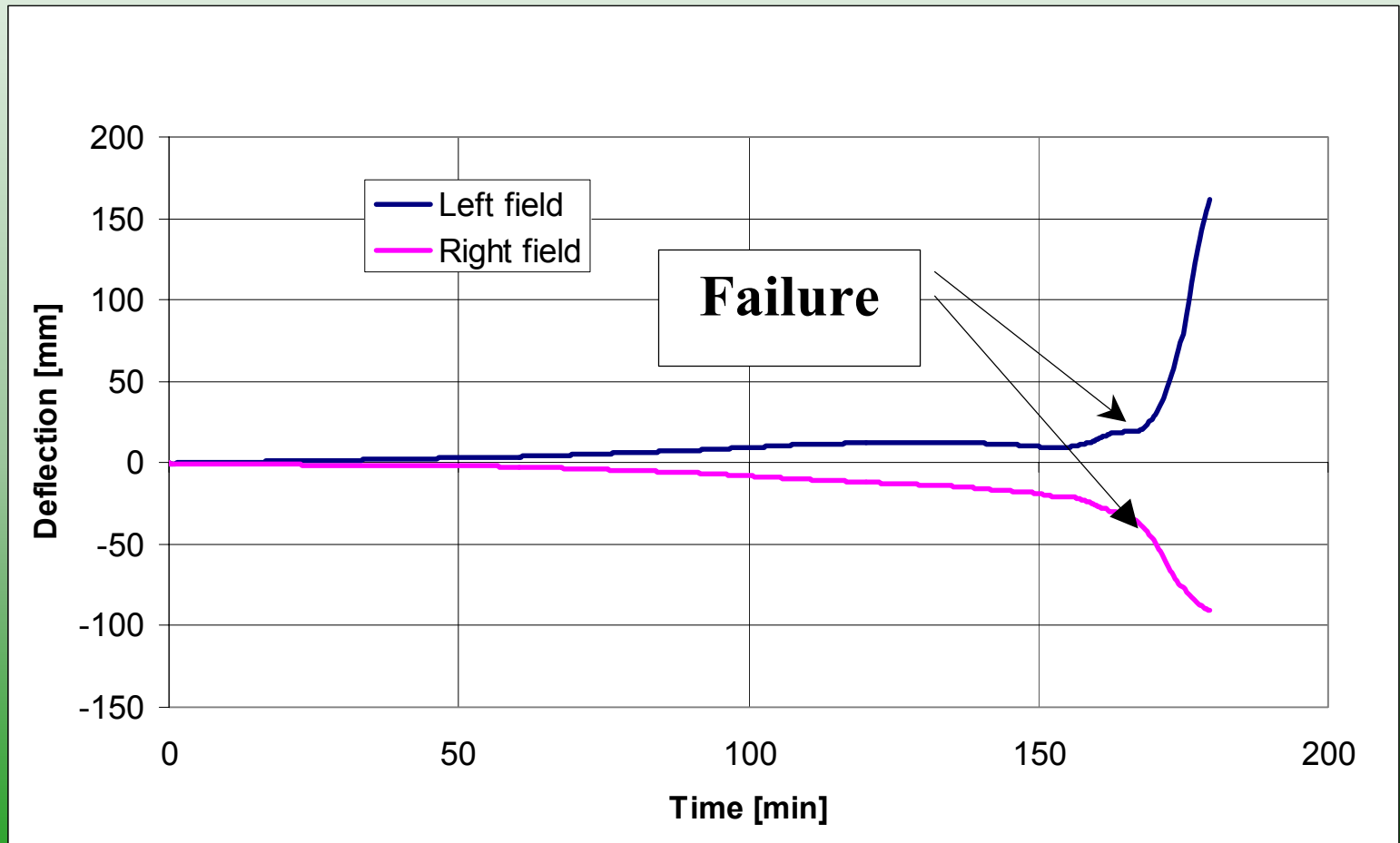


Material tensile strength degradation after 3 hours of fire.

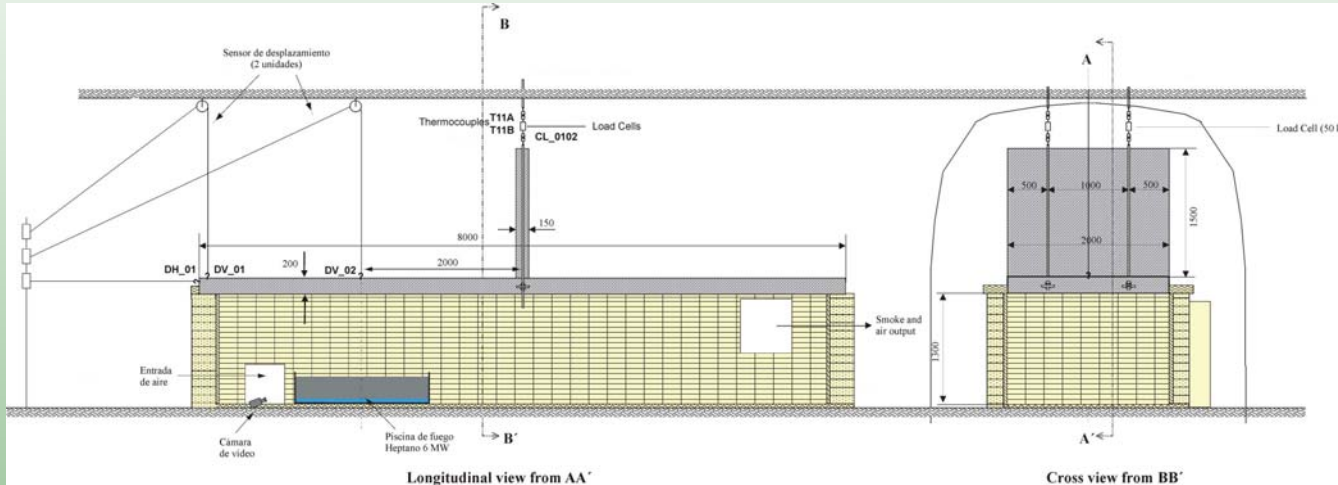




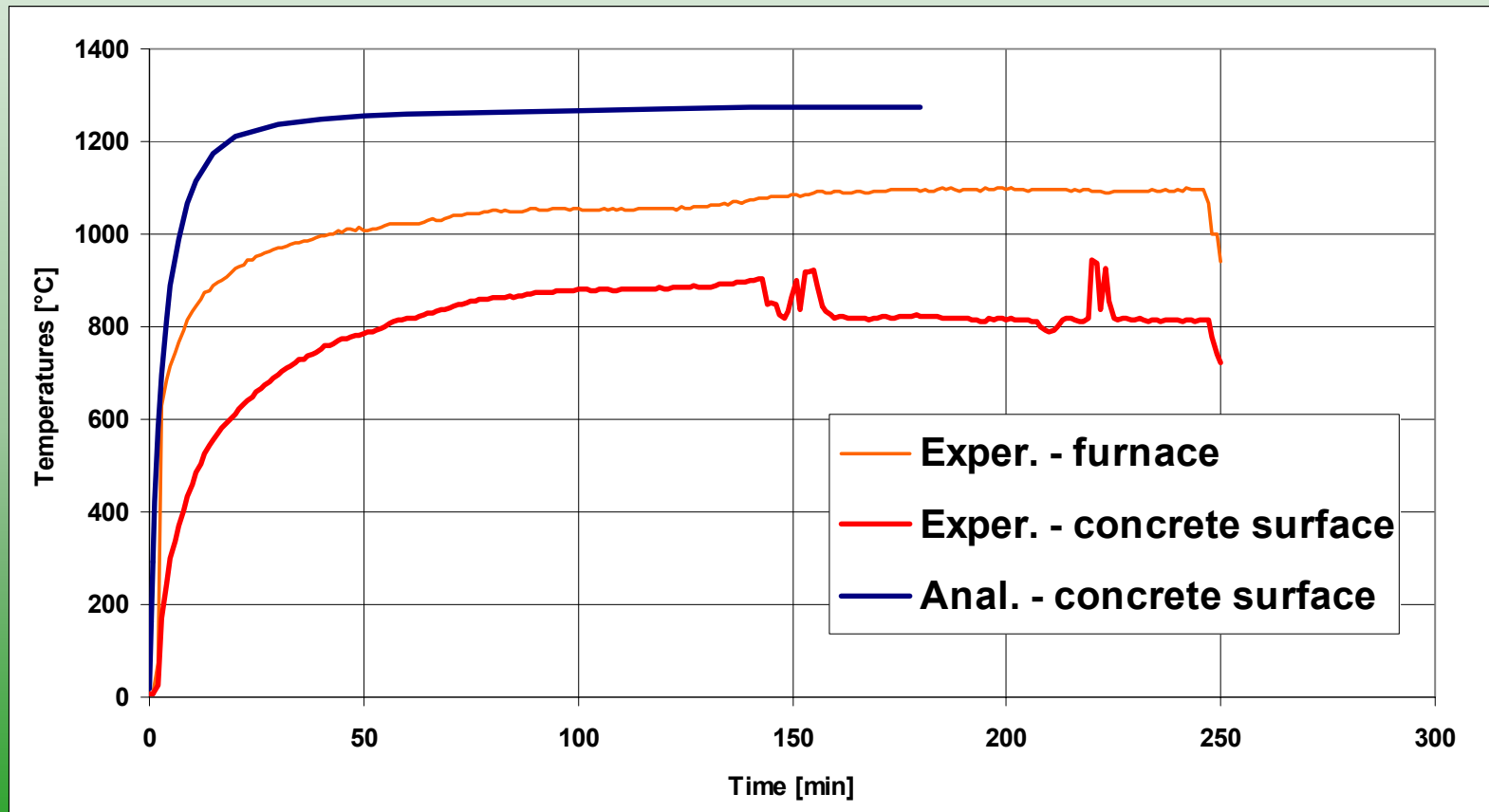
Deflection evolution in time.



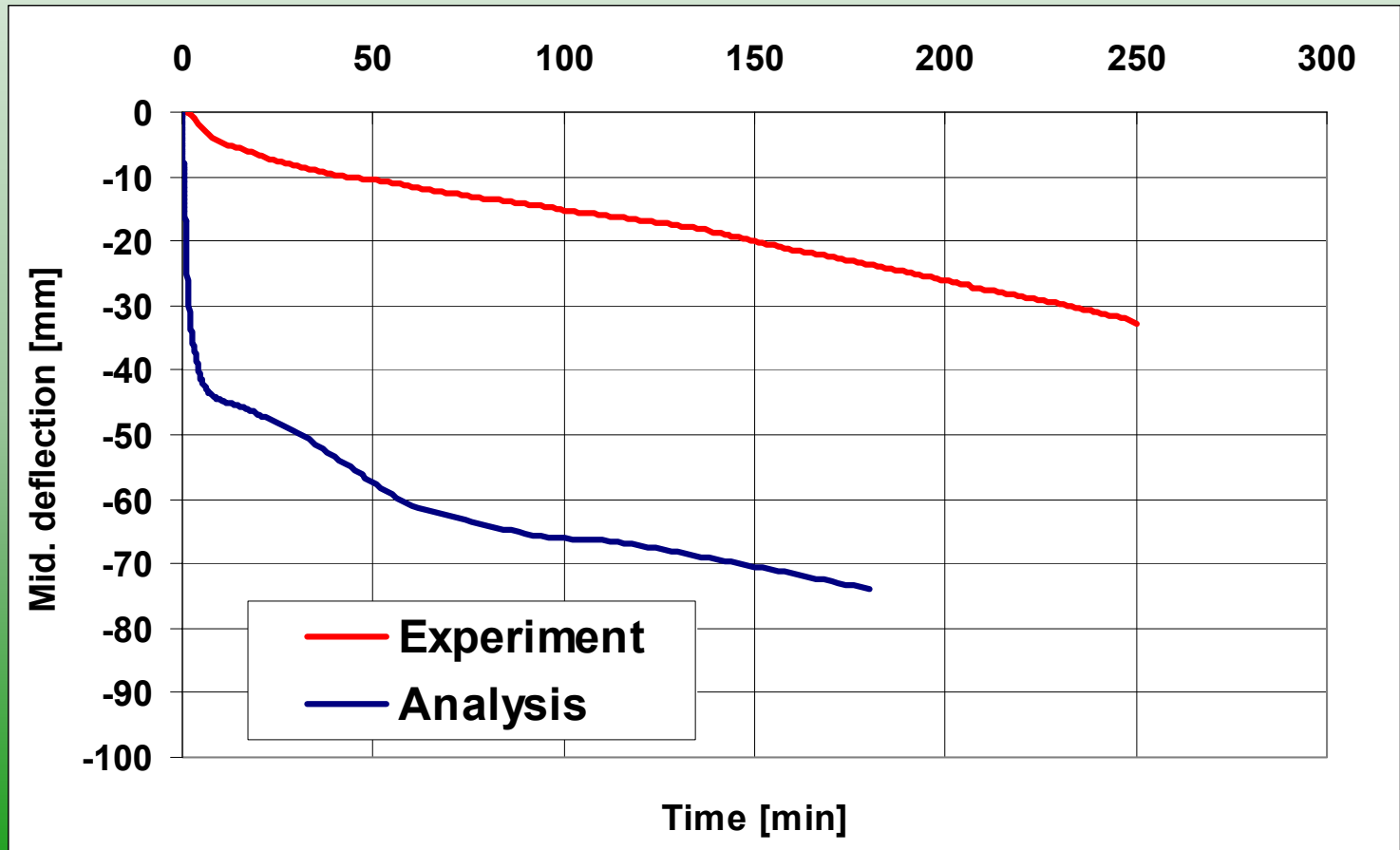
Test geometry – AITEMIN, SPAIN



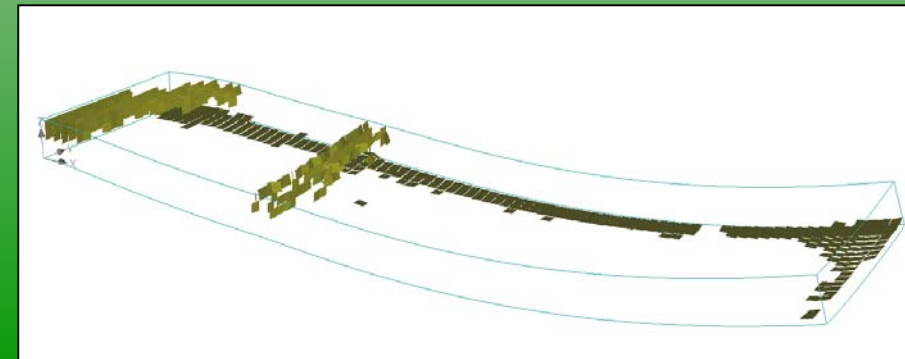
Concrete surface temperature comparison



Deflection comparison



Damage comparison





Virgolo Tunnel - fire test



**Full scale experimental proof
Demonstration**

Bolzano, 17.02-2005

**Euromech
2005**

autostrada del brennero s.p.a.

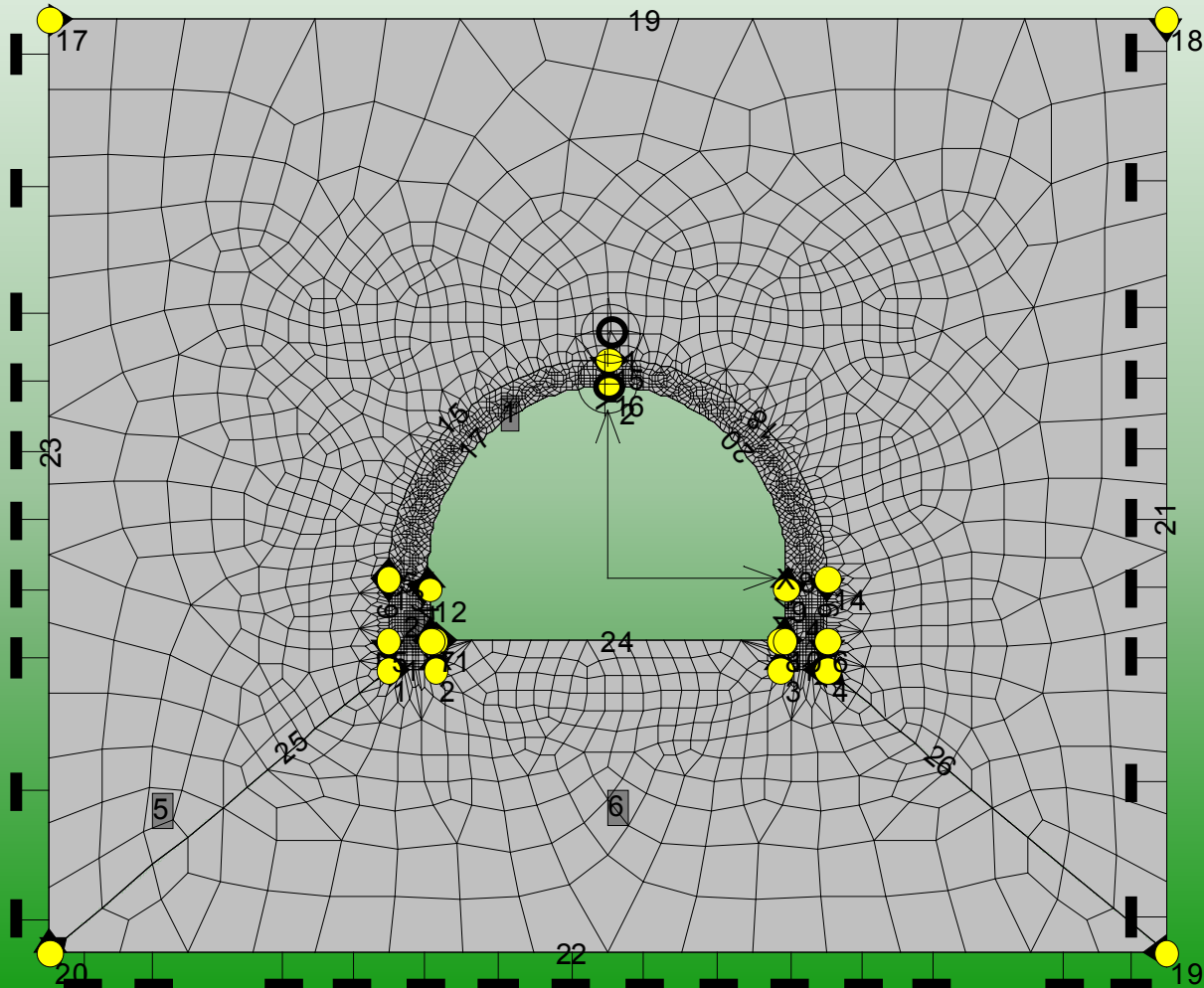




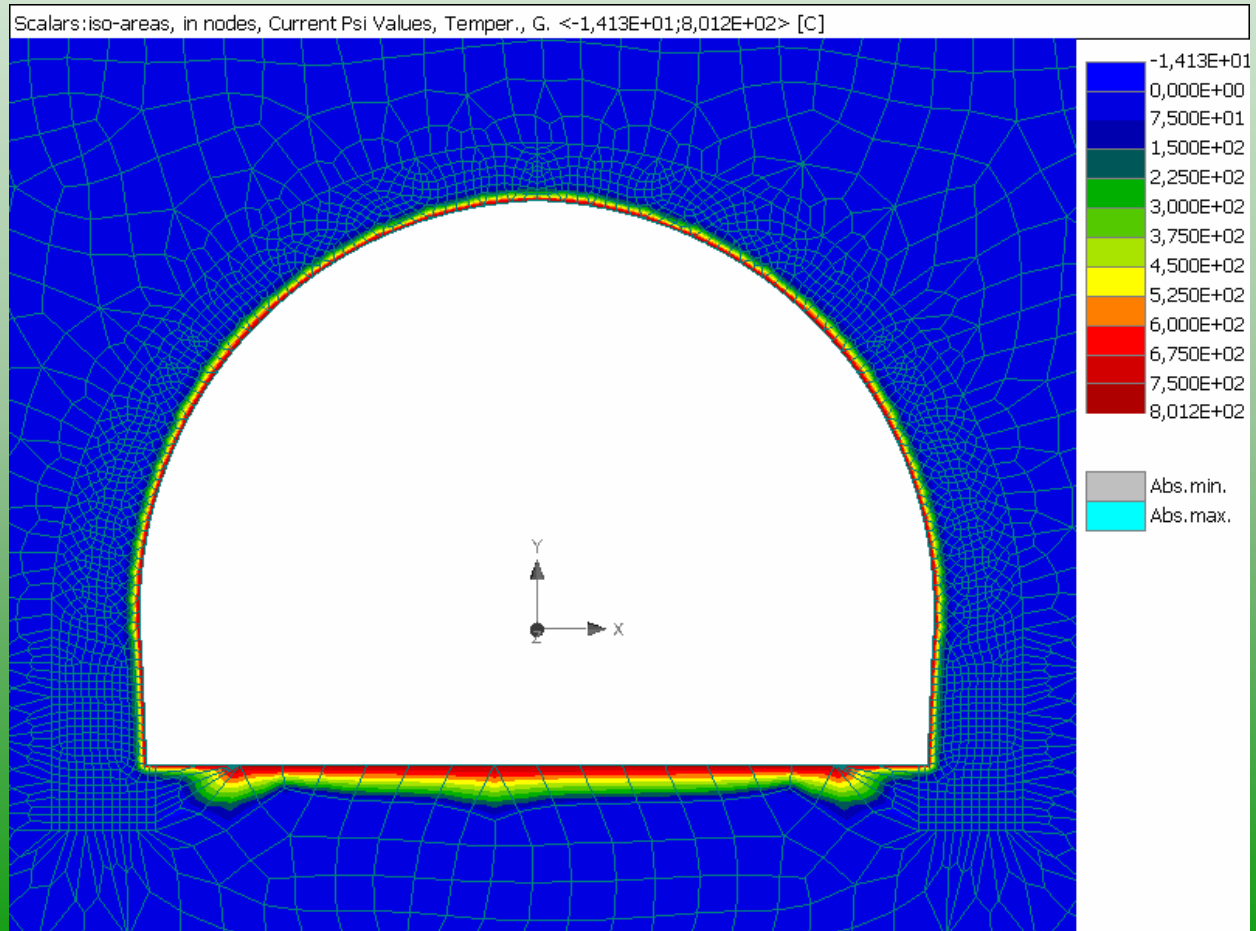
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ATENA 2D Model



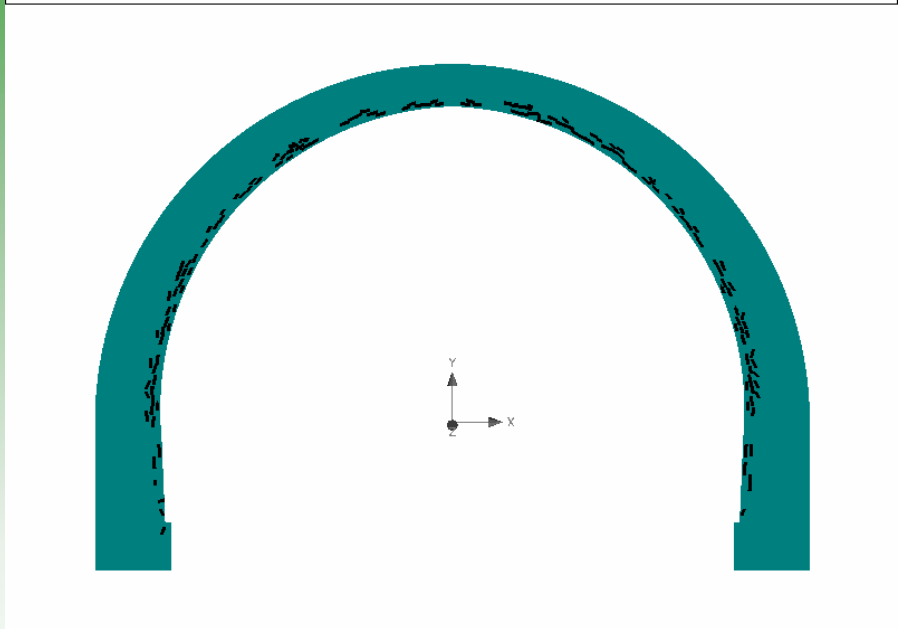
Thermal Analysis temperature distribution after 3 hours of 800°C HCM fire



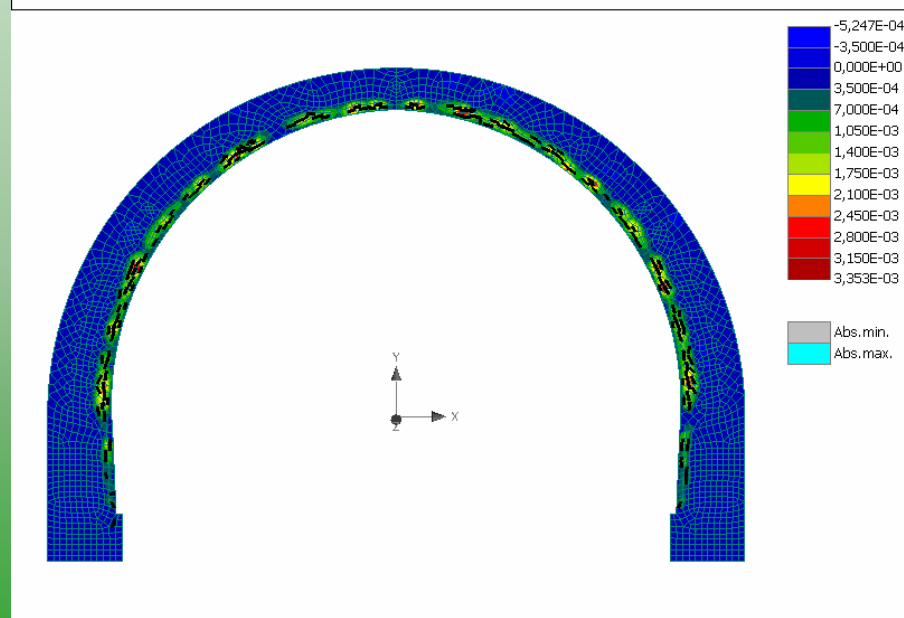
Cracking after 3 hours of fire



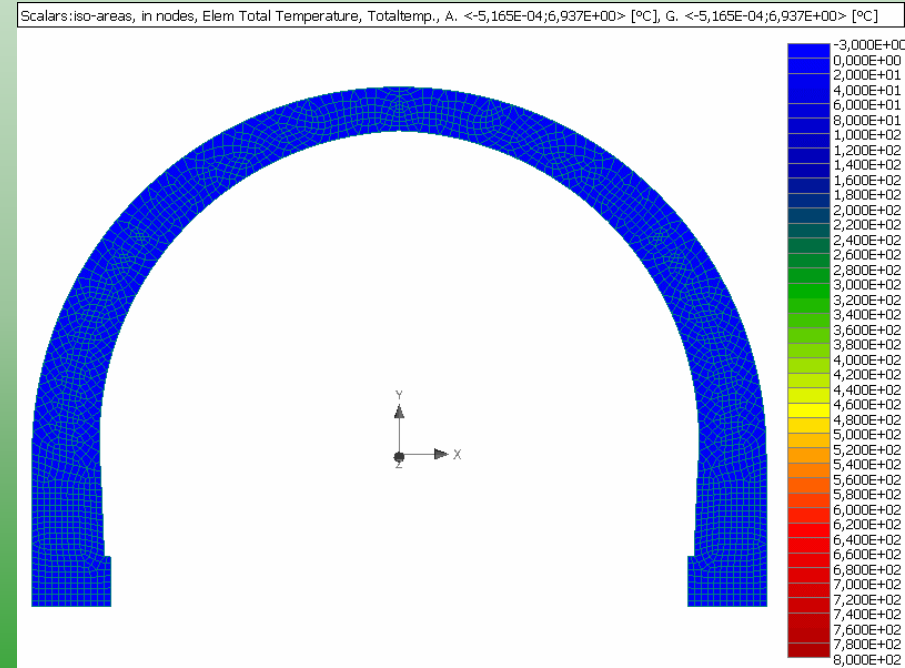
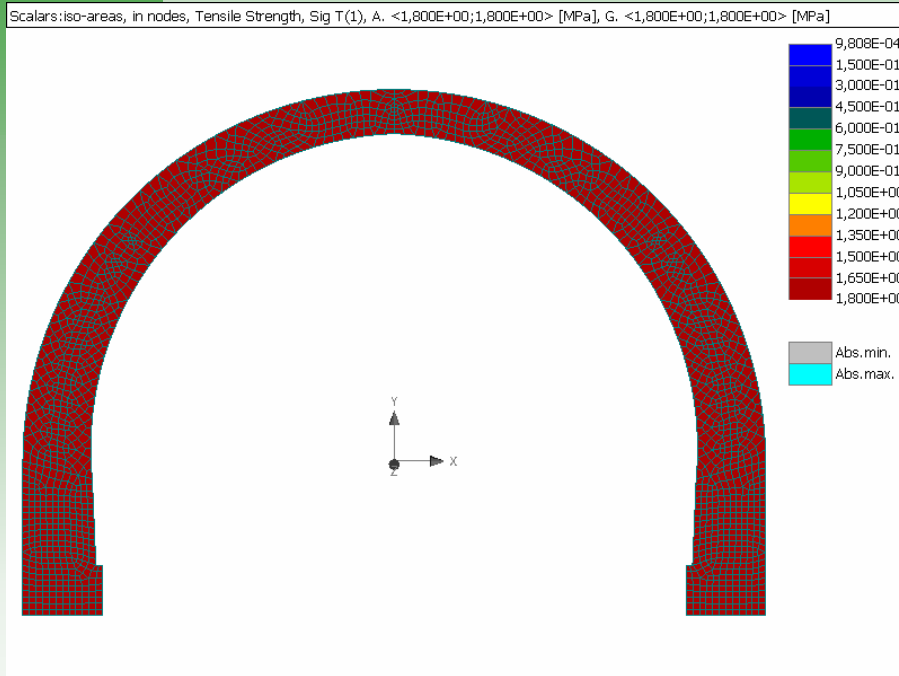
Cracks:elements, width multiplier: 1,0E+00, Filter: <1,000E-03; ...), A.O<-8,660E-04;6,449E-03> [m], SN<-5,103E+01;-5,103E+01> [MPa], G.O<-8,660E-04;6,449E-03> [m], SN<-5,103E+01;-5,103E+01> [MPa], ST<0,000E+00;0,000E+00> [MPa]



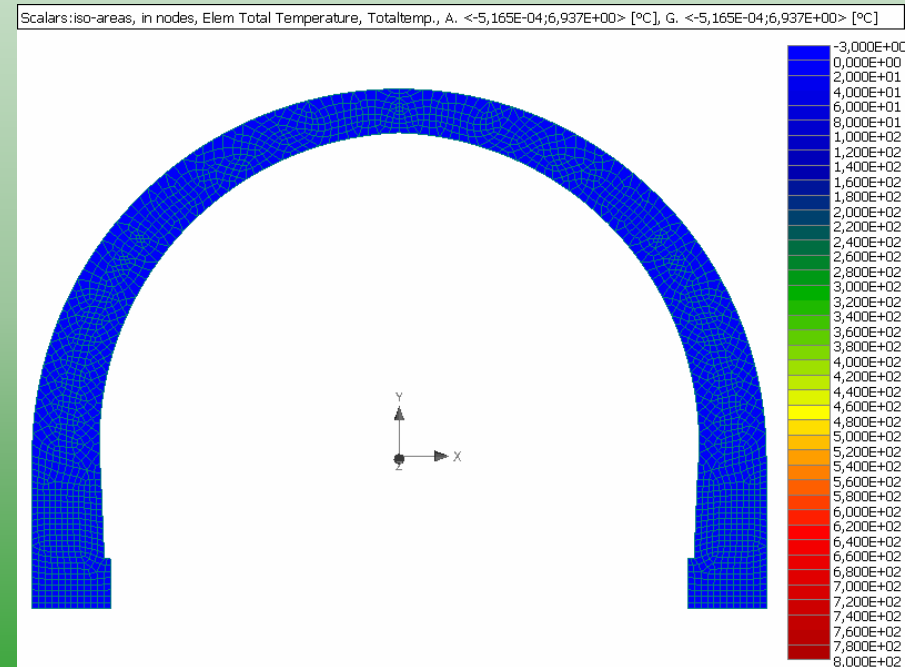
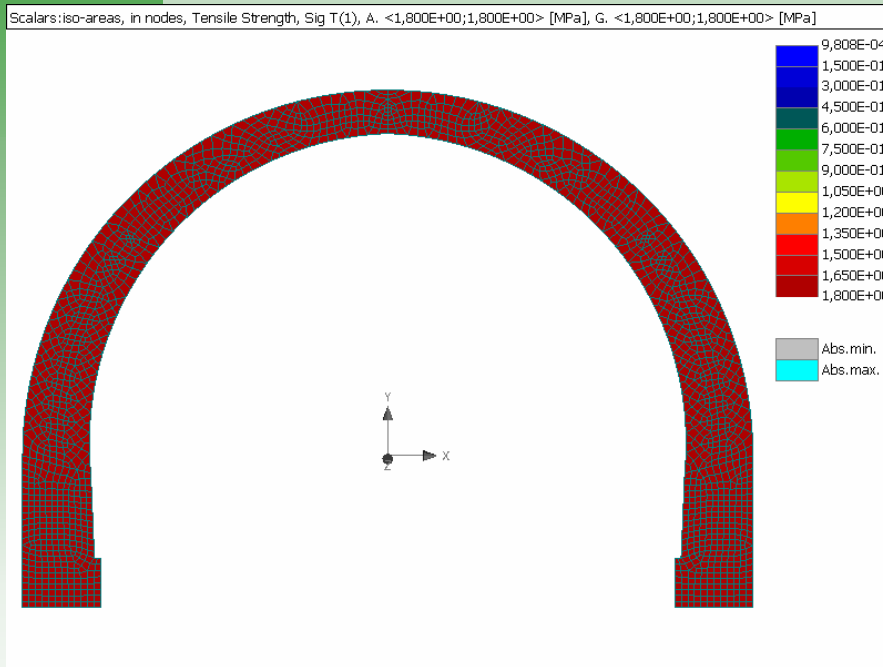
Scalars:iso-areas, in nodes, Crack Width, Cod1, A. <-5,247E-04;3,353E-03> [m], G. <-5,247E-04;3,353E-03> [m]
Cracks:elements, width multiplier: 1,0E+00, Filter: <1,000E-03; ...), A.O<-8,660E-04;6,449E-03> [m], SN<-5,103E+01;-5,103E+01> [MPa], G.O<-8,660E-04;6,449E-03> [m], SN<-5,103E+01;-5,103E+01> [MPa], ST<0,000E+00;0,000E+00> [MPa]



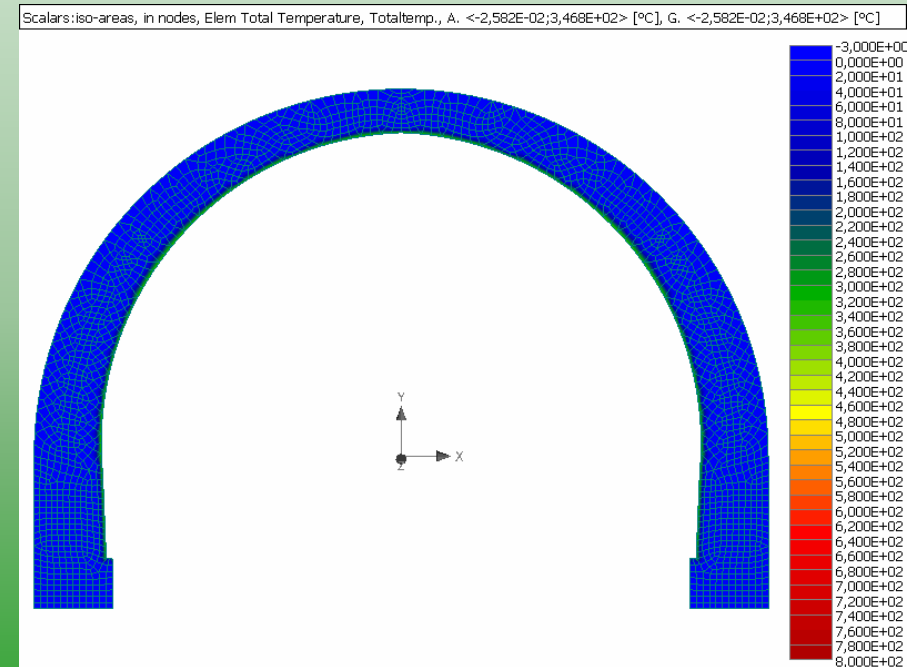
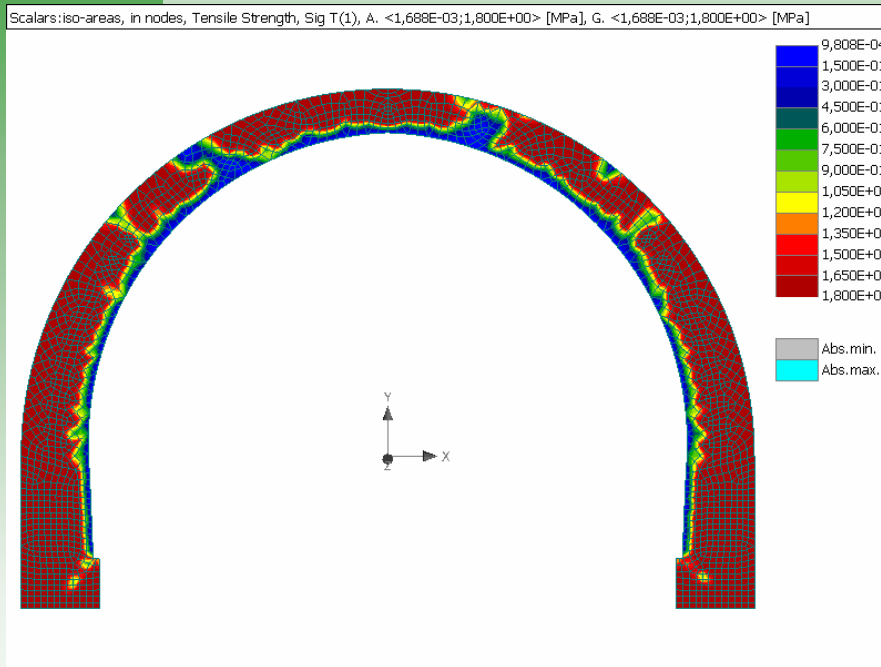
Damage, Temperature development 0 seconds, 0 °C



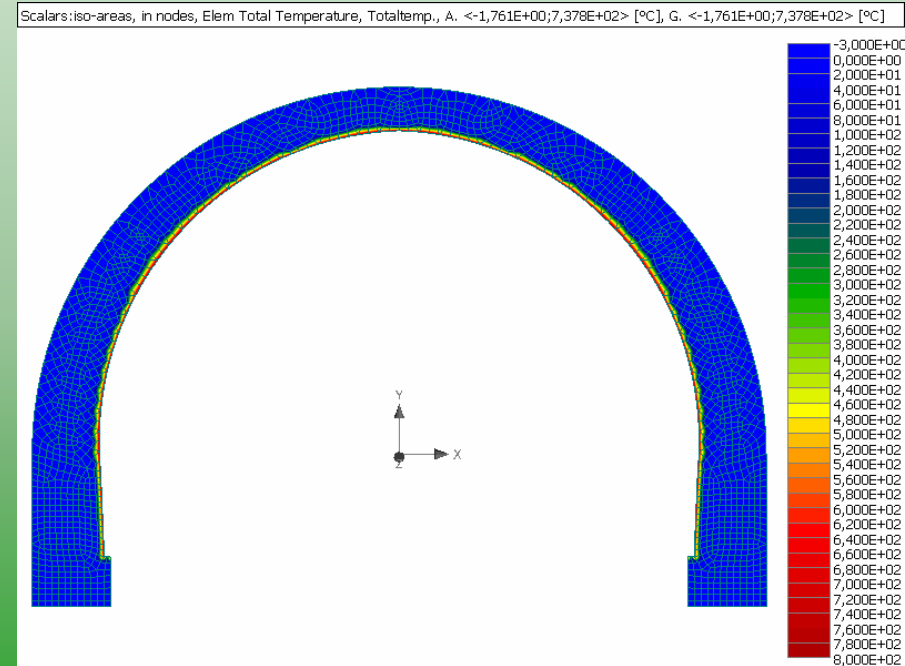
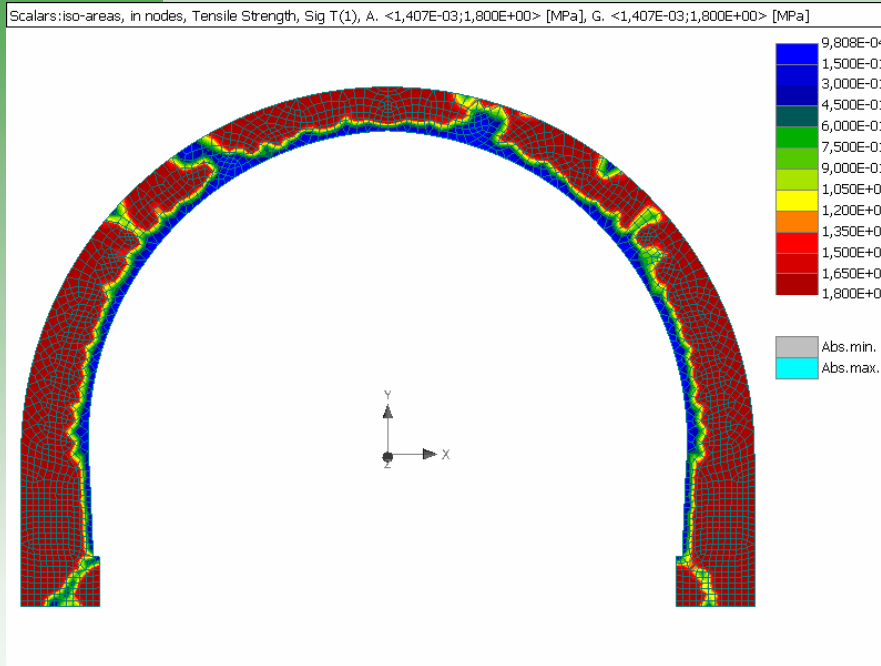
3 seconds, 200 °C



10 seconds, 350 °C



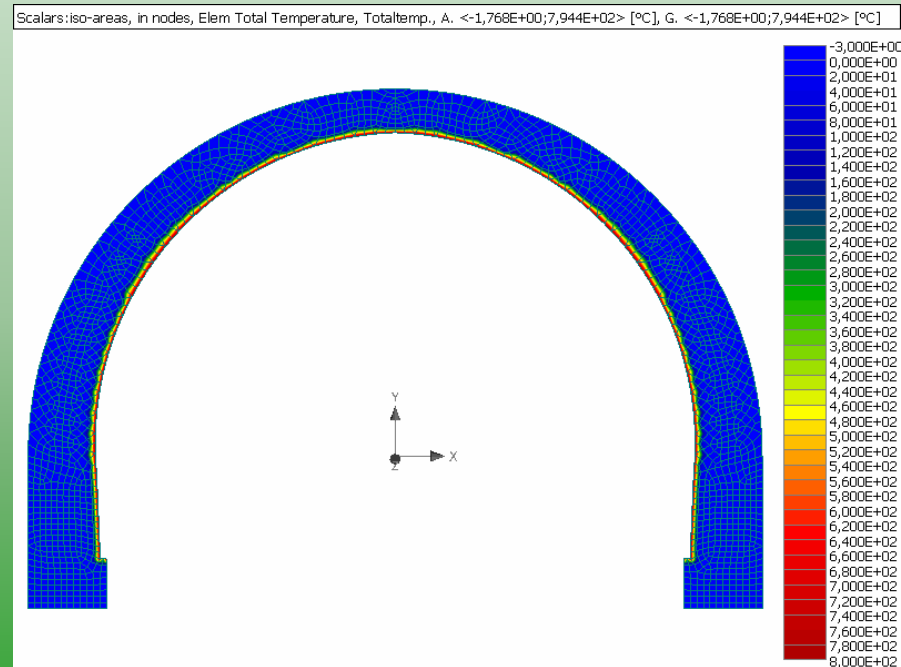
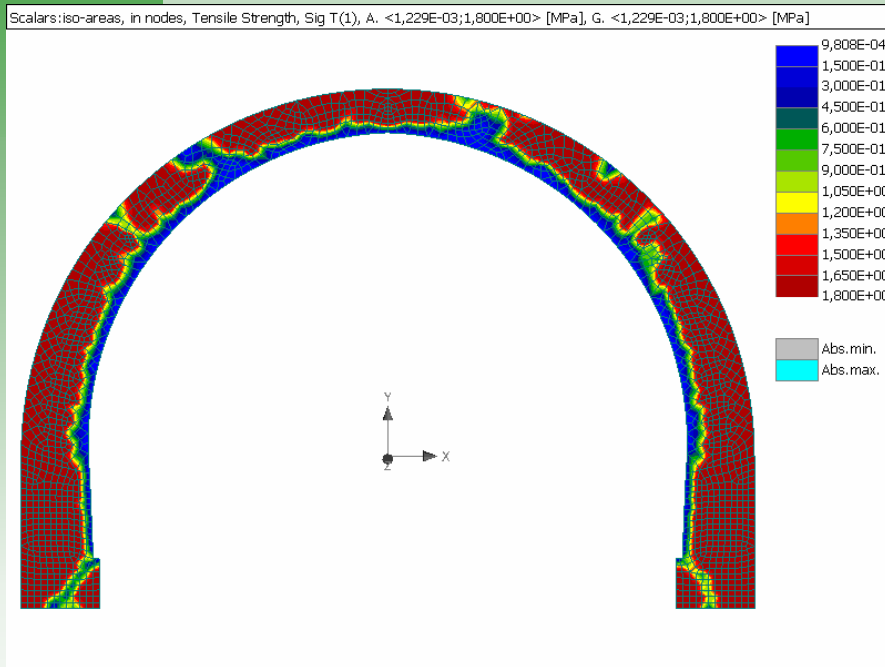
10 min, 750 °C



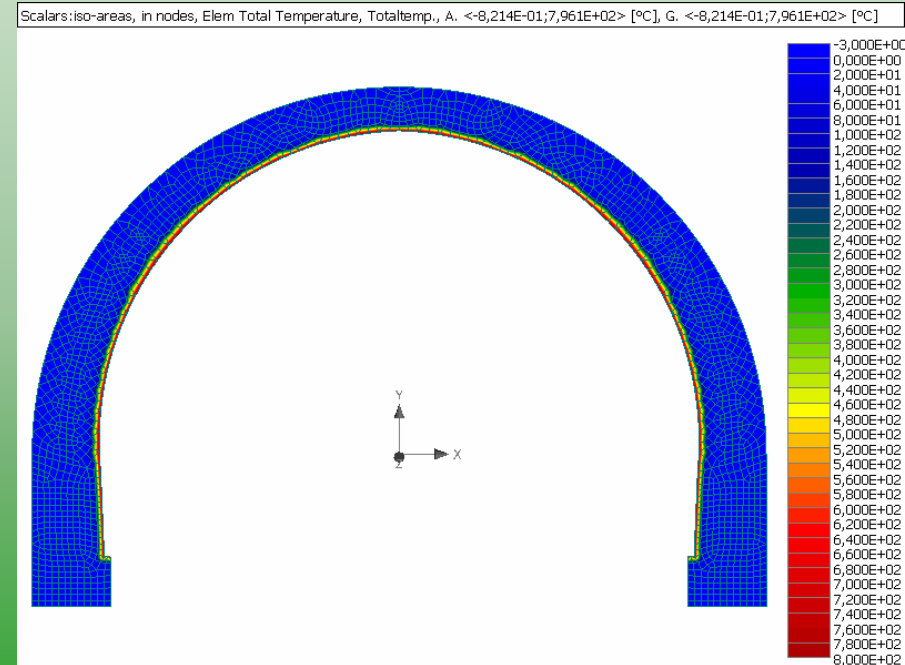
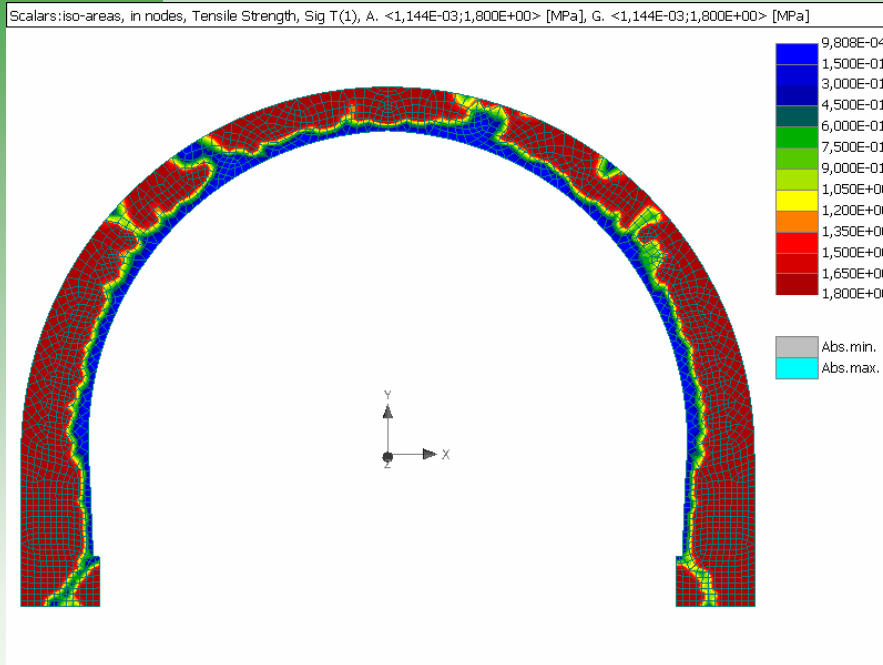
30 min, 800 °C



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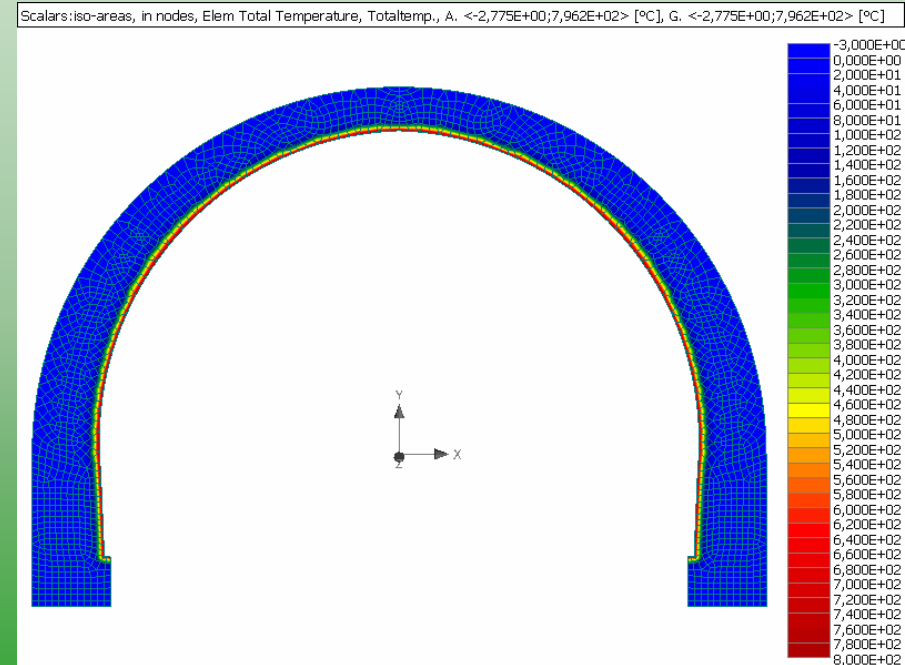
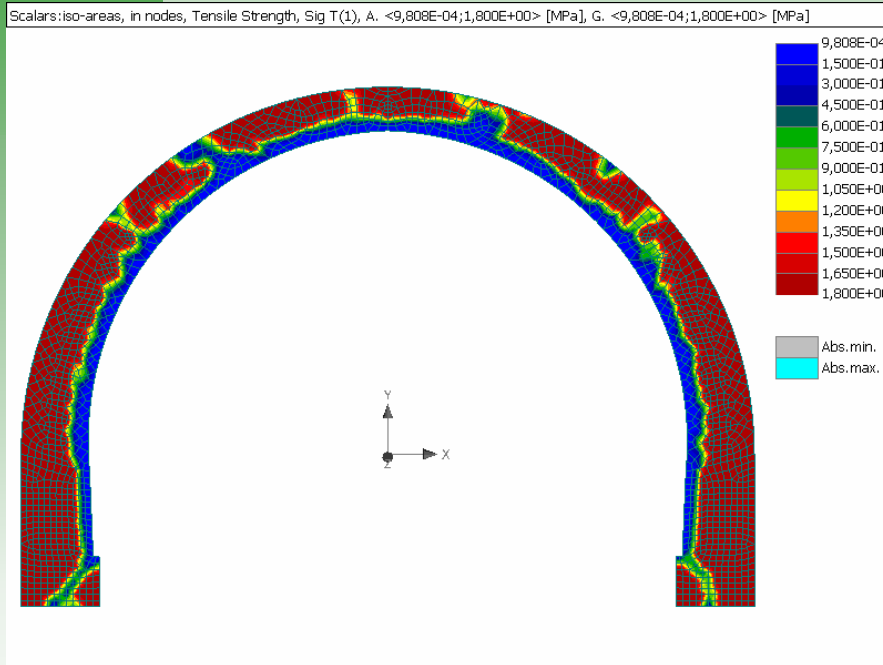
1 hour, 800 °C



3 hours, 800 °C



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CONCLUSIONS:

Fracture-plastic material model was extended for fire analyses including temperature dependent material properties.

The model was successfully applied to practical engineering problems