SSCS 2012
Numerical Modeling
Strategies for Sustainable Concrete Structures

Aix en Provence – France
May 29 – June 1, 2012

AFGC

Analysis of cracking in a massive concrete structure at early age

A. Hilaire, F. Benboudjema, A. Darquennes, Y. Berthaud, G. Nahas

IRSN/LMT Cachan

LMT

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

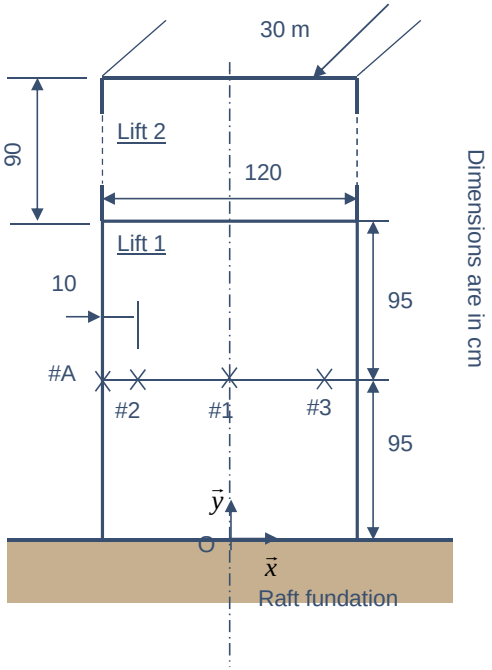
Context

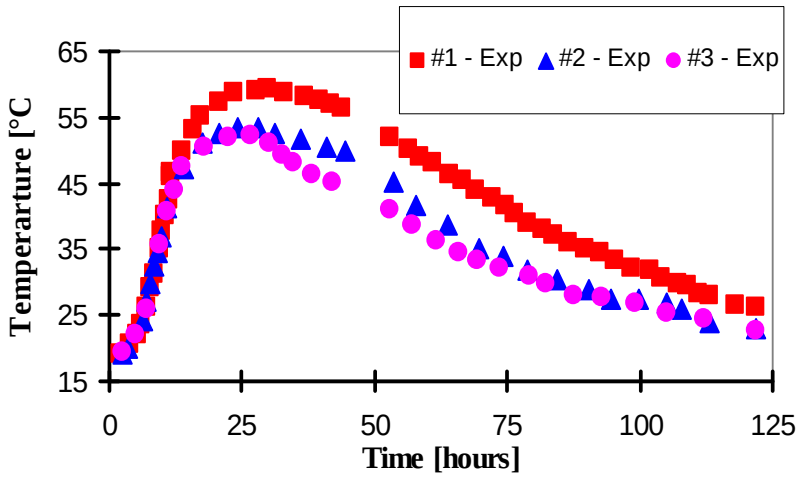
Cracking of massive structures (water treatment plant) :

Context

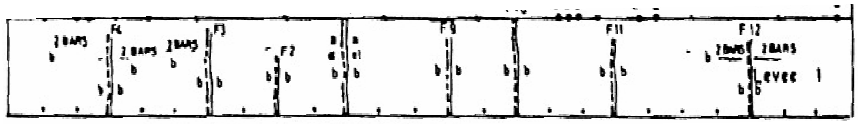
Cracking of massive structures (Civaux walls):

Concrete walls built to assess the risk of cracking at early age



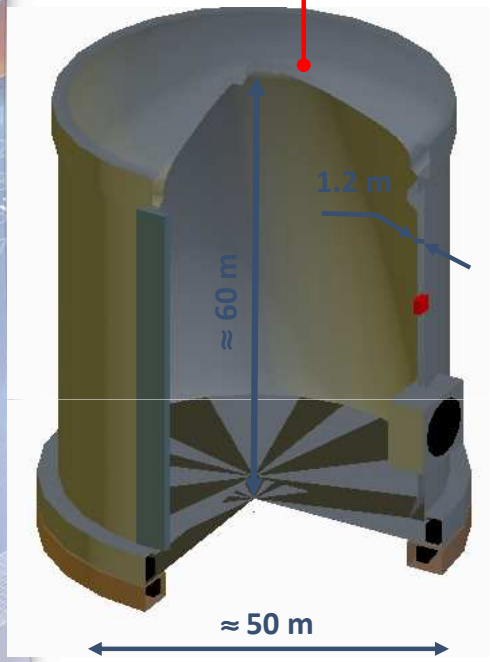


Itthuralde (1989)

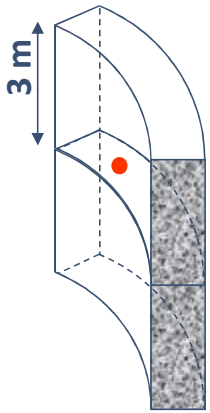


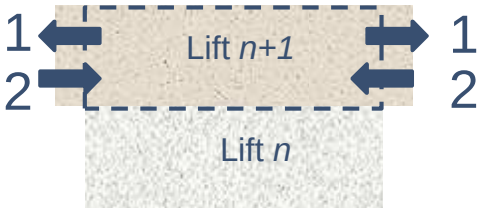
8 cracks, (1×40 µm) + (4×100 µm) + (2×200 µm) + (1×500 µm)

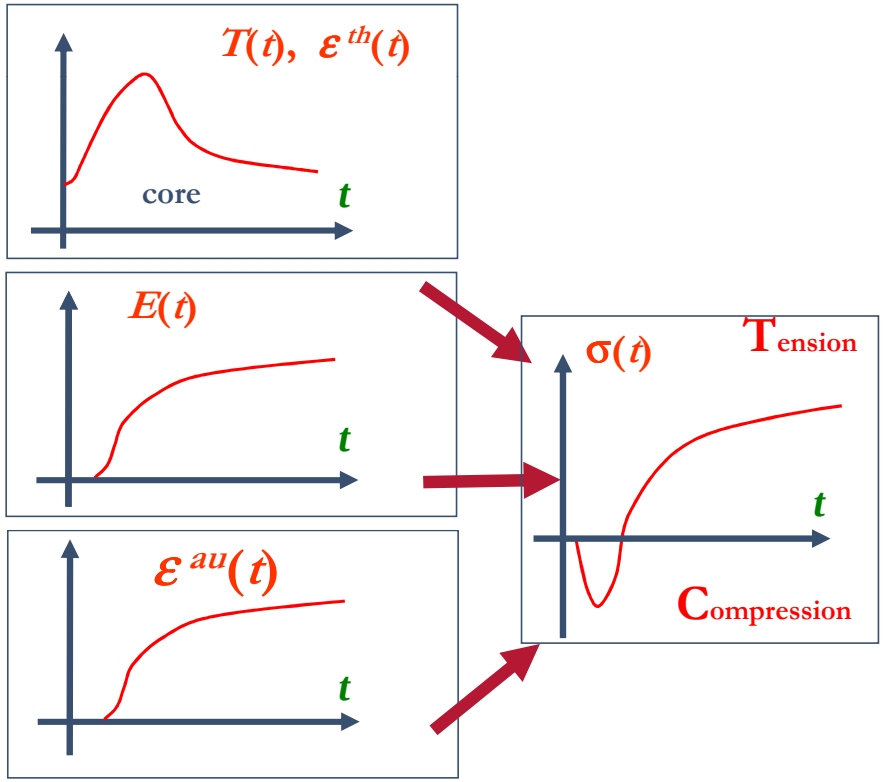
Context



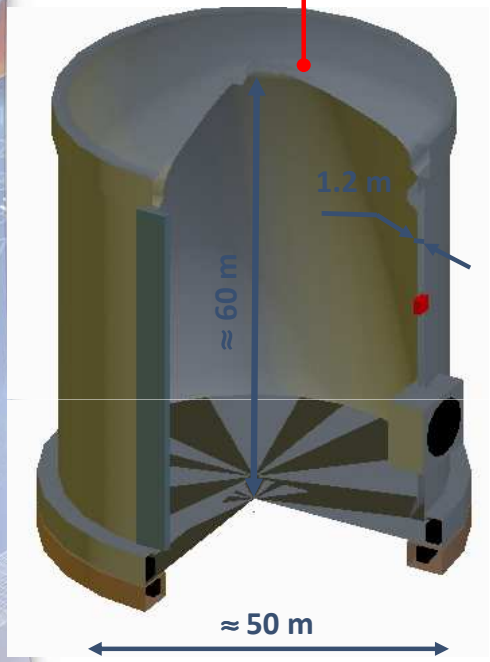
At early-age in a construction joint:



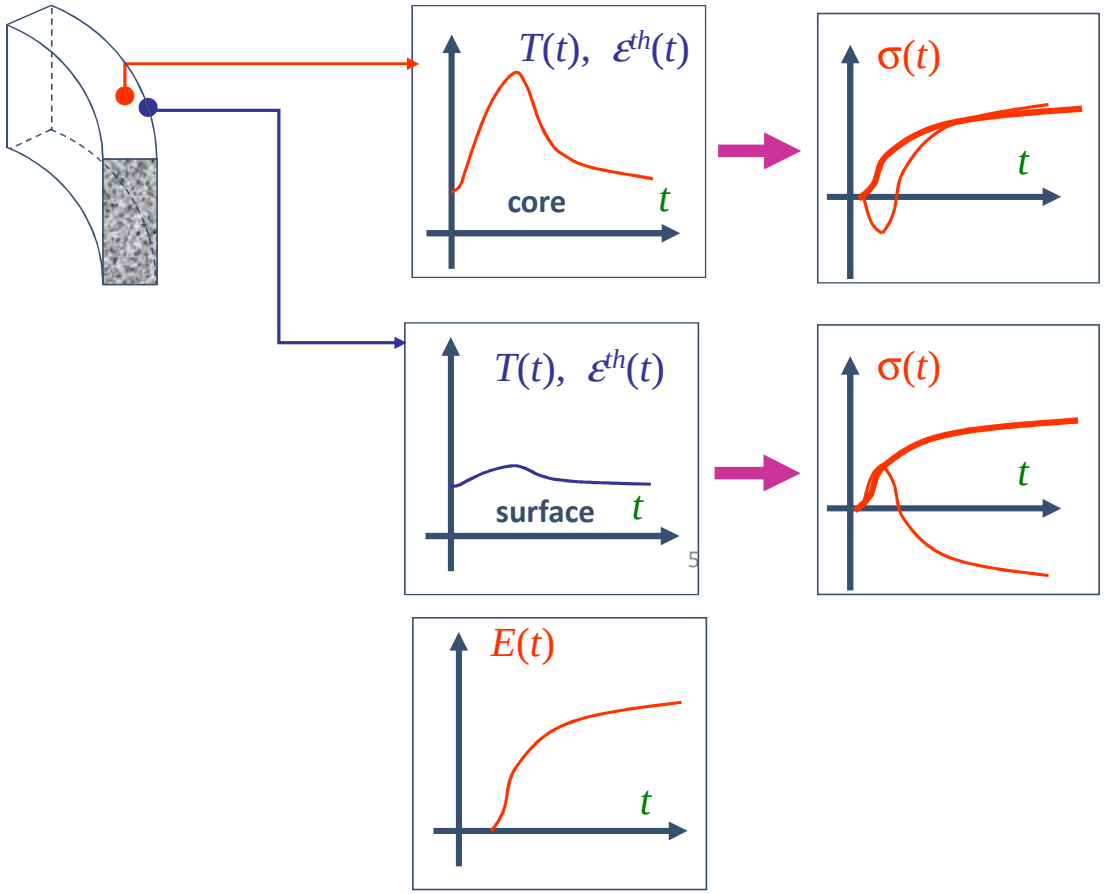




Context



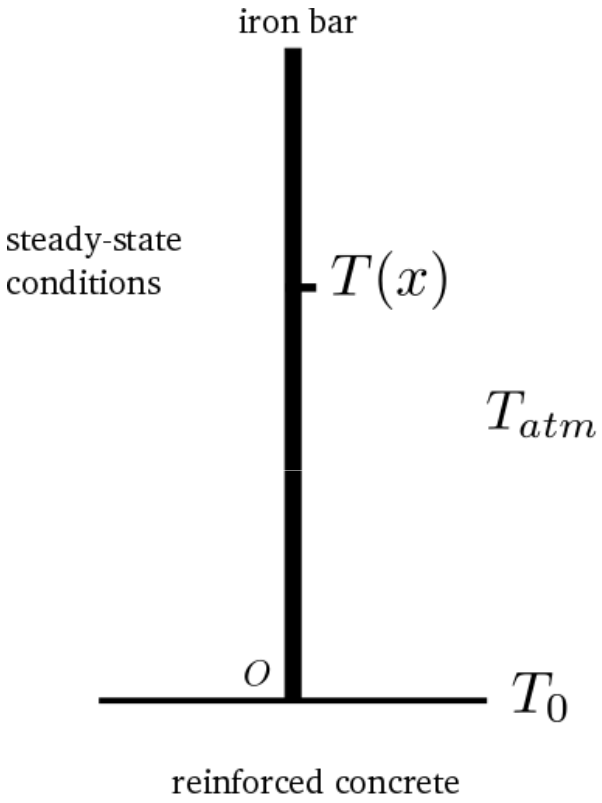
Self restrain at early-age:



Initial cracking strongly influenced by the temperature field

Thermal boundary conditions

Impact of starter bars (chimney effect)



Additional heat dissipation:

Temperature field in the bar:

$$T(x) - T_{atm} = (T_0 - T_{atm}) \times exp(-\sqrt{\frac{4h_e}{\lambda\phi}}x)$$

Heat dissipation of one bar:

$$q_{steel} = \iint h_e(T(x) - T_{atm})\pi\phi dx$$

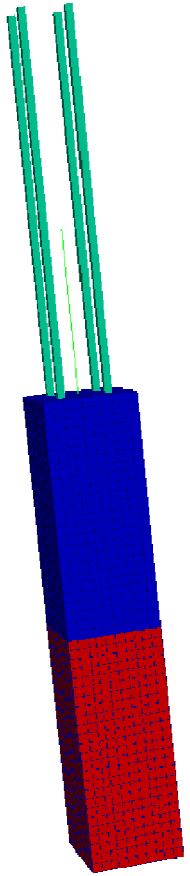
Convective heat transfer coefficient:

$$\begin{aligned} q_{tot} &= N q_{steel} + h_e S_{concrete}(T_0 - T_{atm}) \\ &= h_{hom} S_{tot}(T_0 - T_{atm}) \end{aligned}$$

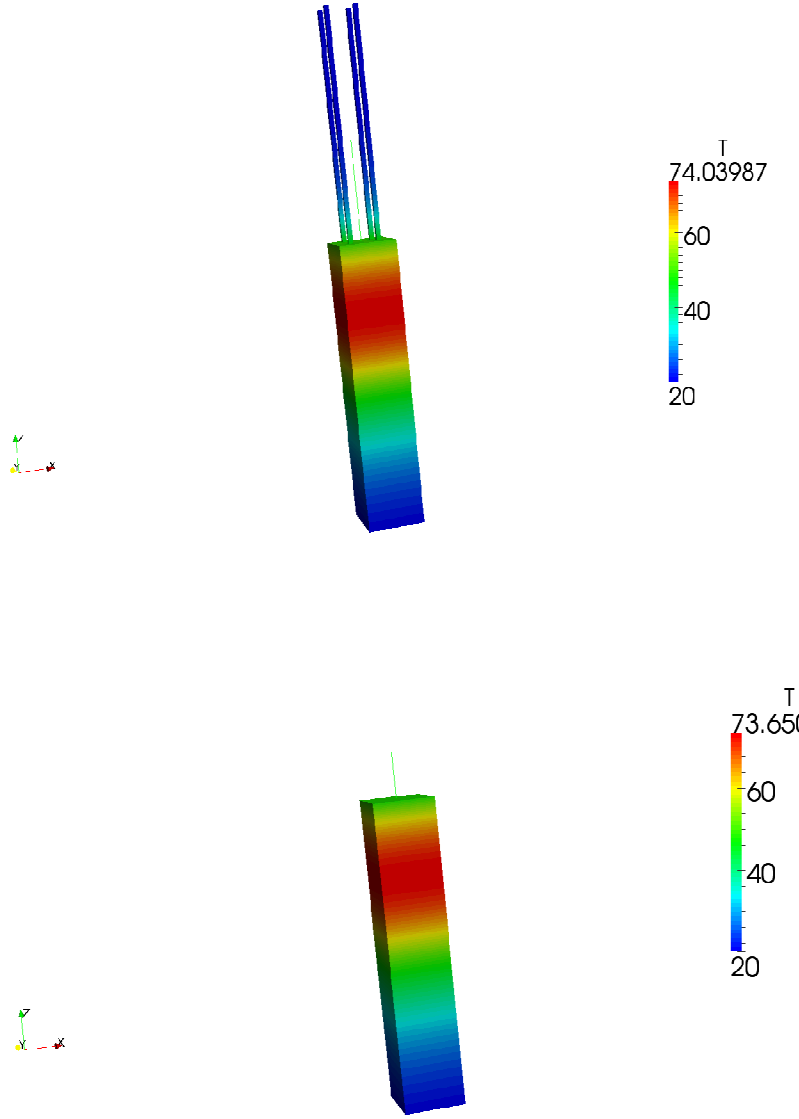
λ: thermal conductivity
Φ: iron bar diameter
N: number of bars
h: convective heat transfer coefficient

Thermal boundary conditions

Homogenization of reinforced concrete

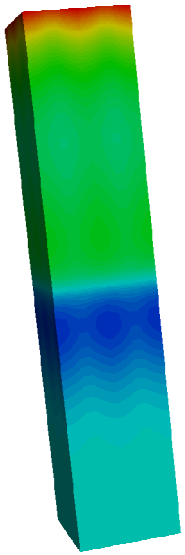


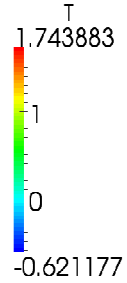
Results : T_{max}



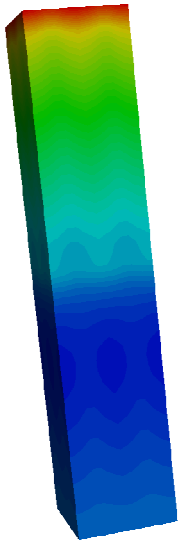
Thermal boundary conditions

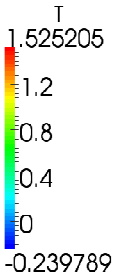
Results : $T_{steel} - T_{homo}$





$13\,h$

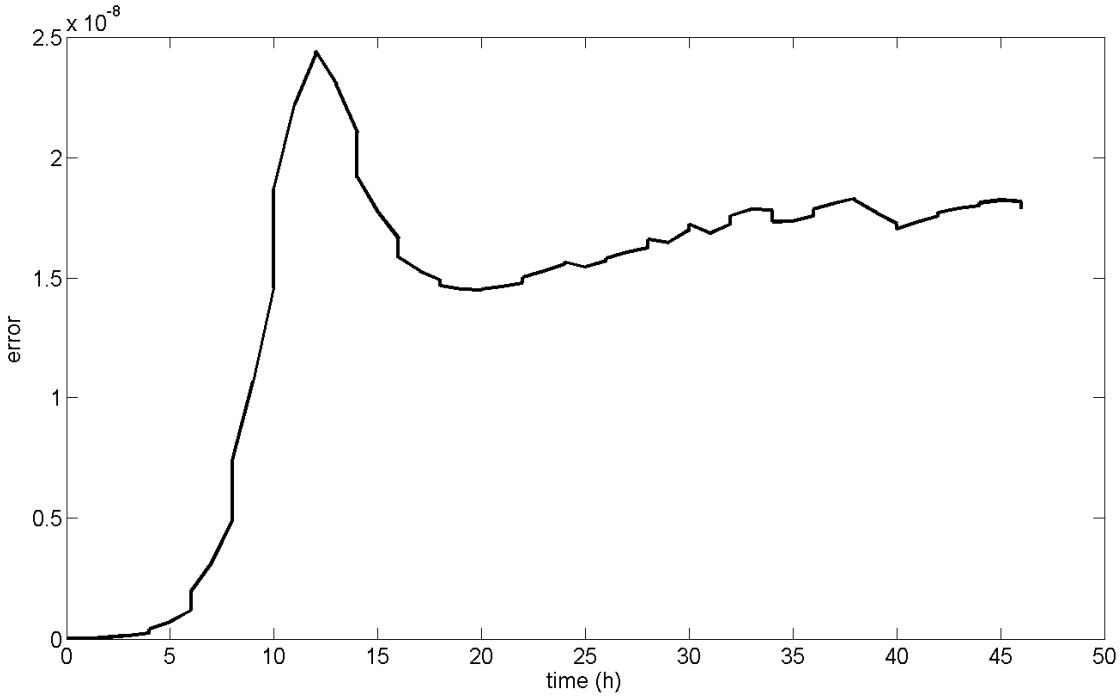




$40\,h$

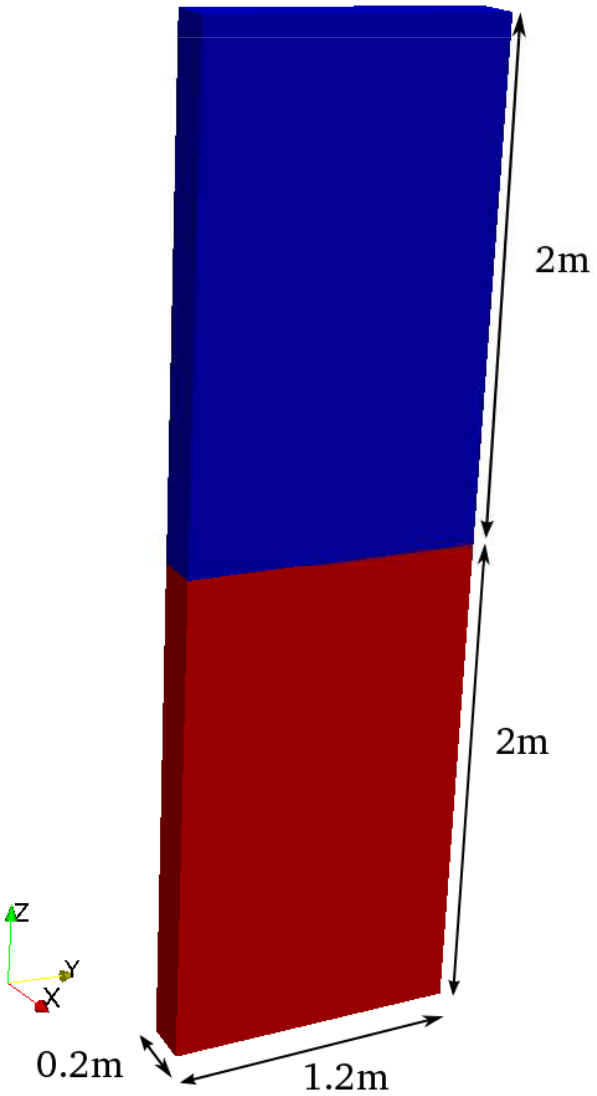
Error :

$$error = \frac{1}{n}\frac{\sum\left(T^{i}_{homo} - T^{i}_{steel}\right)^{2}}{\sum\left(T^{i}_{homo}\right)^{2}}$$



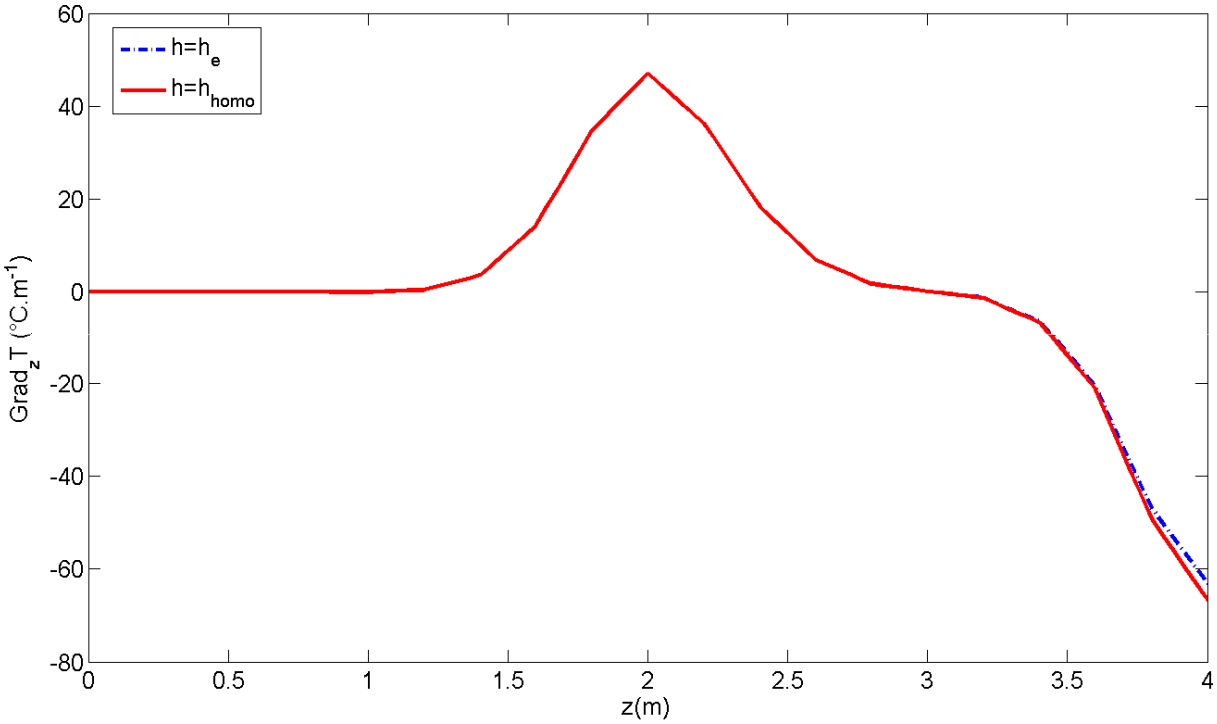
Thermal boundary conditions

Thermal simulation of a wall:



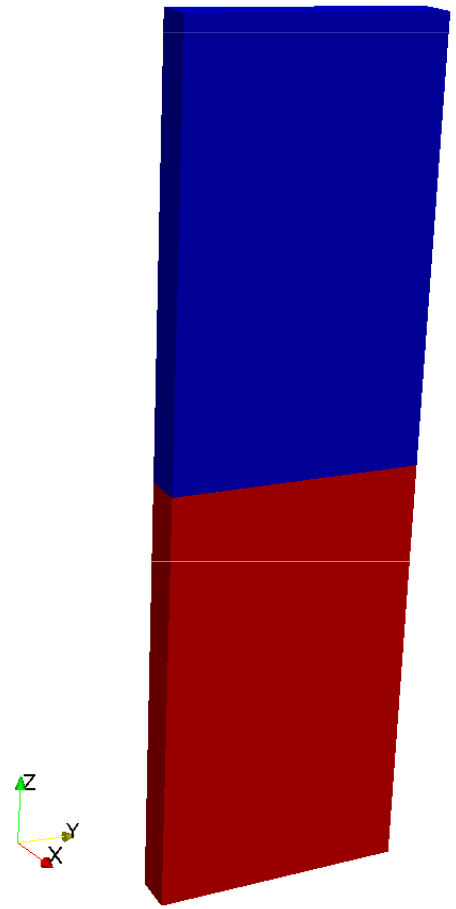
Gradient of temperature in the core of the structure

$\tau = 103 kg.m^{-3}$



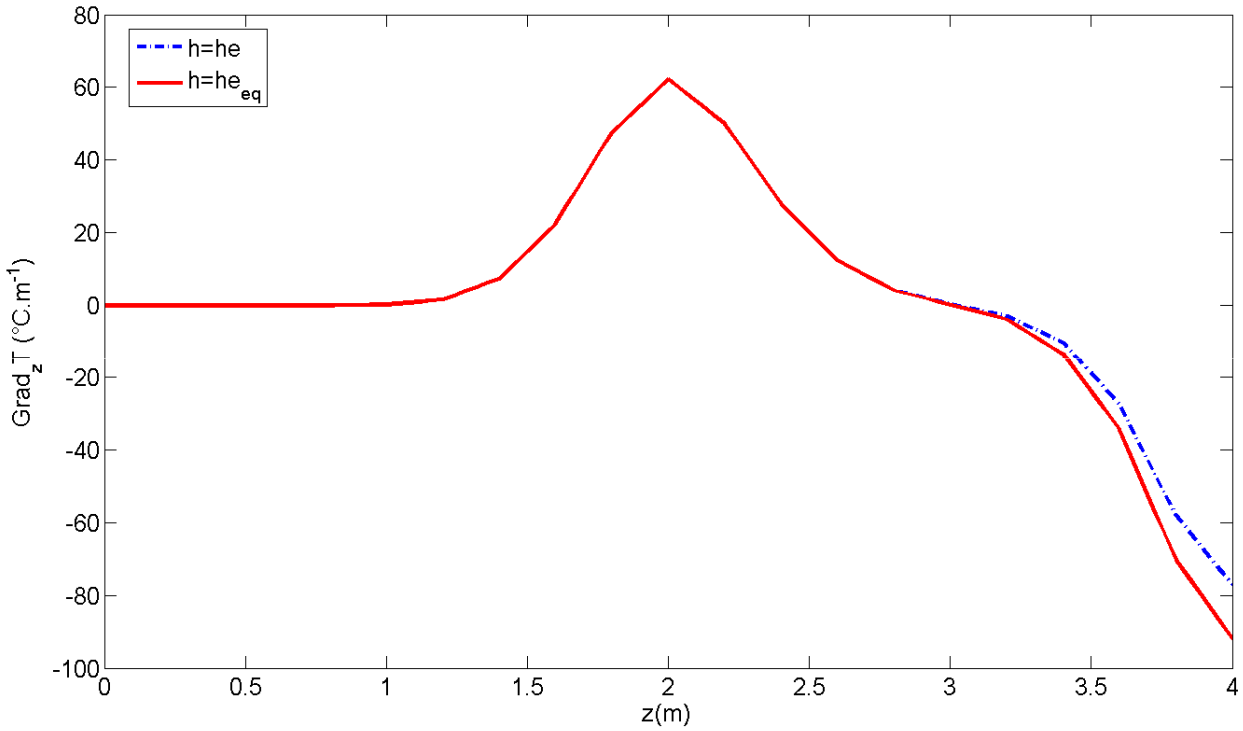
Thermal boundary conditions

Thermal simulation of a wall:

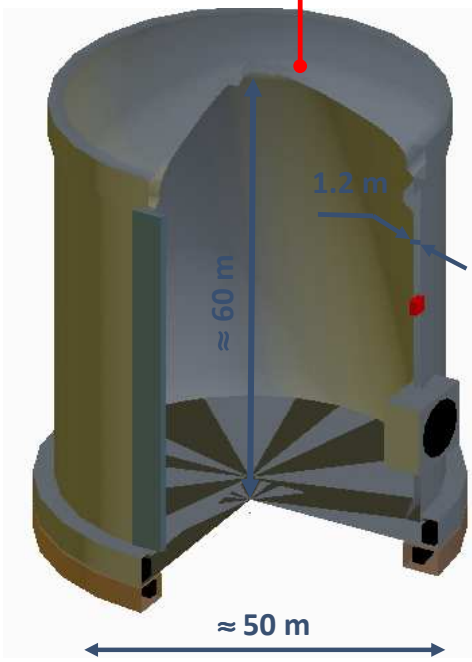


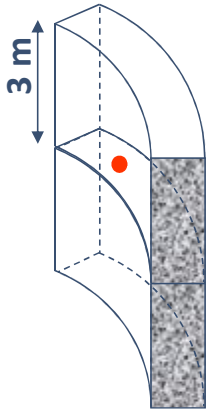
Gradient of temperature in the core of the structure

$\tau = 490 kg.m^{-3}$

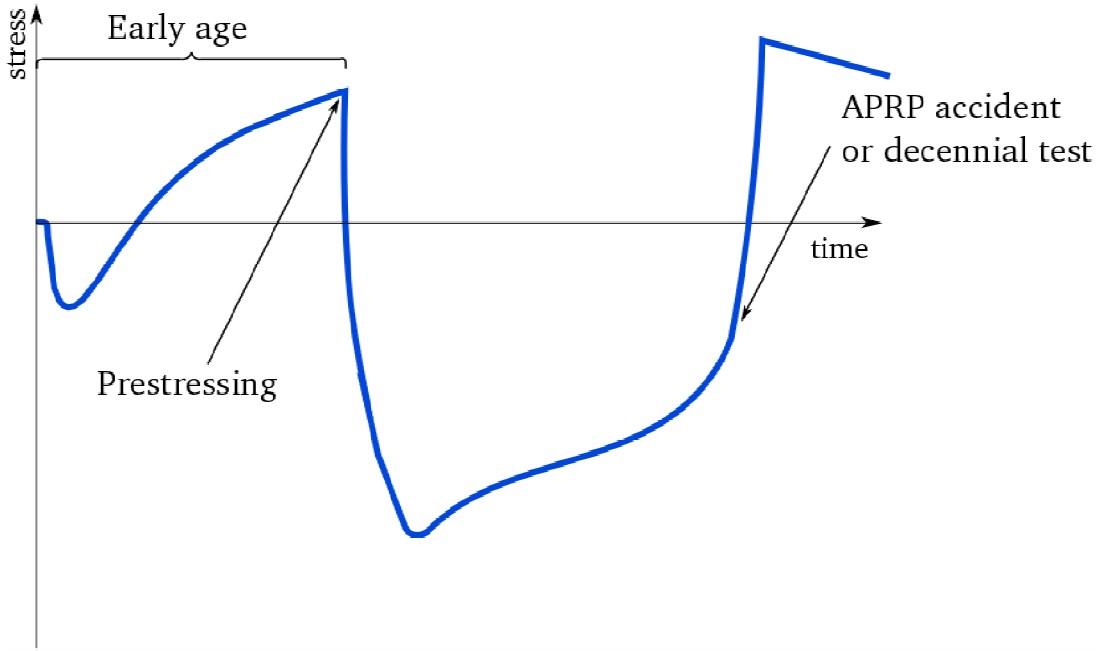


Context





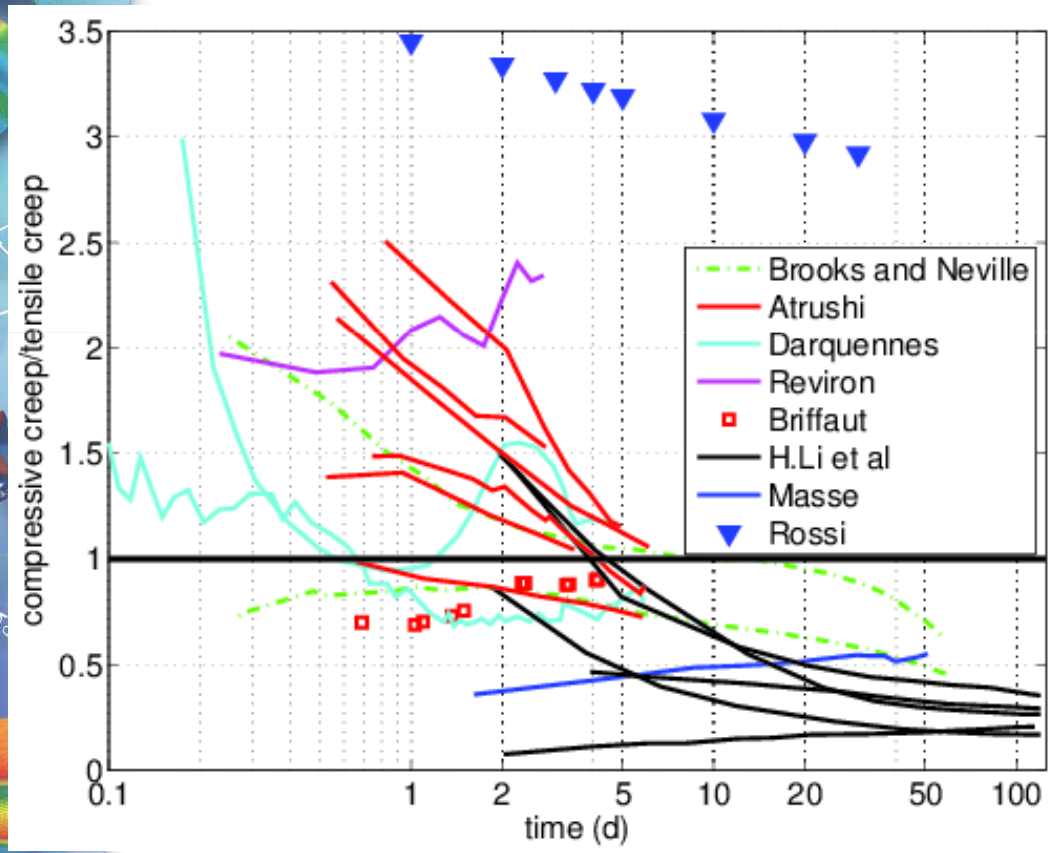
Stress state of concrete in the course of its operating life :

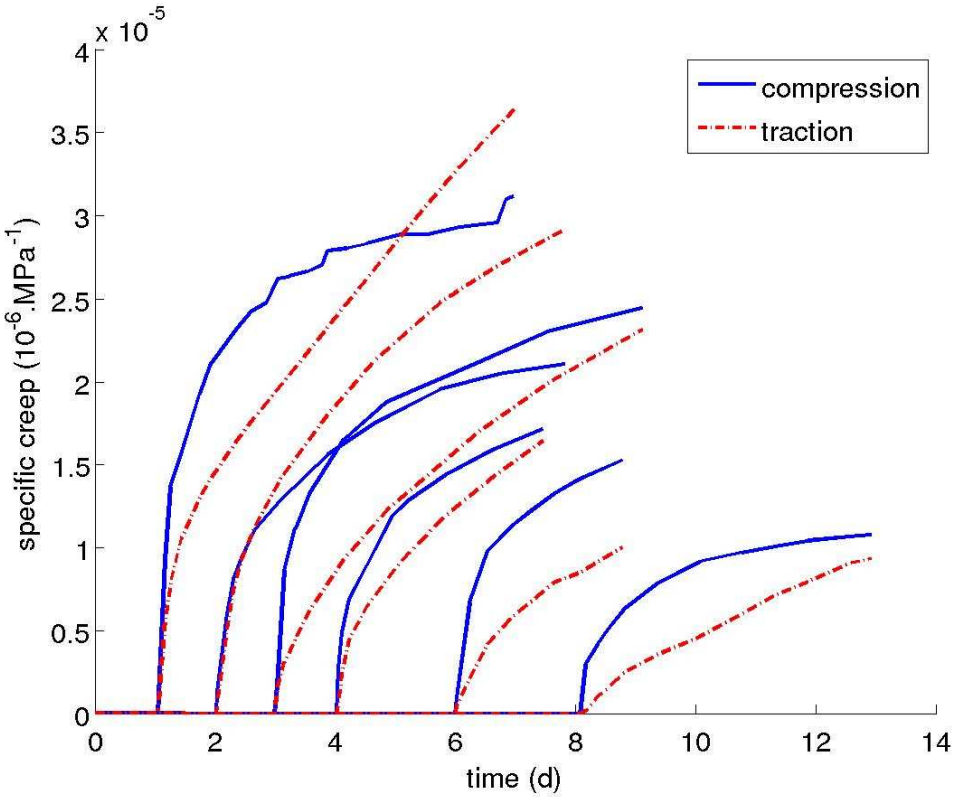


Extension of expected lifespan of the nuclear power plants requires a correct prediction of:
Initial cracking + Stress state in the core of the concrete

Importance of the creep modeling

Bibliography

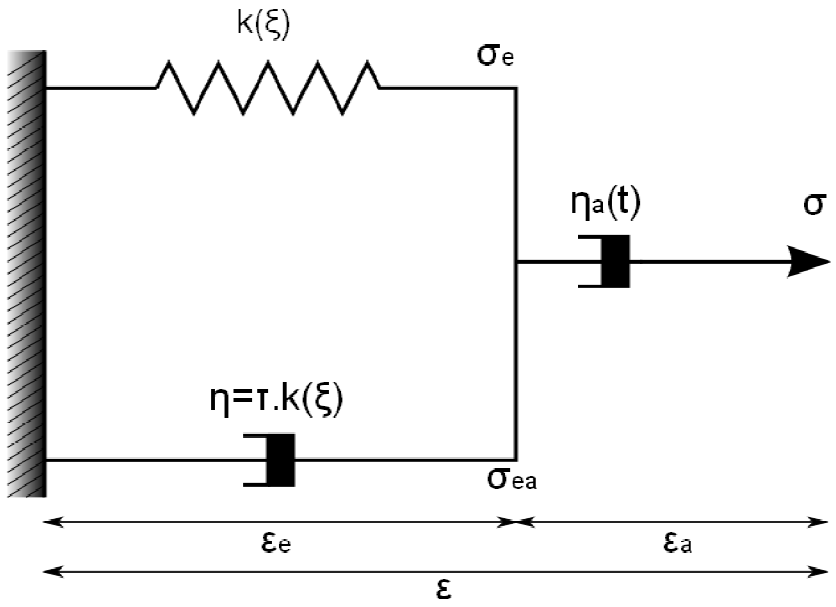




There is not any consensus about:

- The asymmetry of the behavior between tension and compression
- Physical mechanisms of basic creep

Modeling



Governing equations :

$$k(\xi) = k_\infty \frac{0.473}{2.081 - 1.608\bar{\xi}} \bar{\xi}^{0.62}$$

[De Schutter, 1999]

$$\frac{\dot{\sigma}}{k} = \tau \ddot{\epsilon}_e + \left(1 + \frac{\dot{k}}{k}\tau\right)\dot{\epsilon}_e$$

$$\eta_a . t . \dot{\epsilon}_a = \alpha < \sigma >_+ + < \sigma >_-$$

4 parameters:

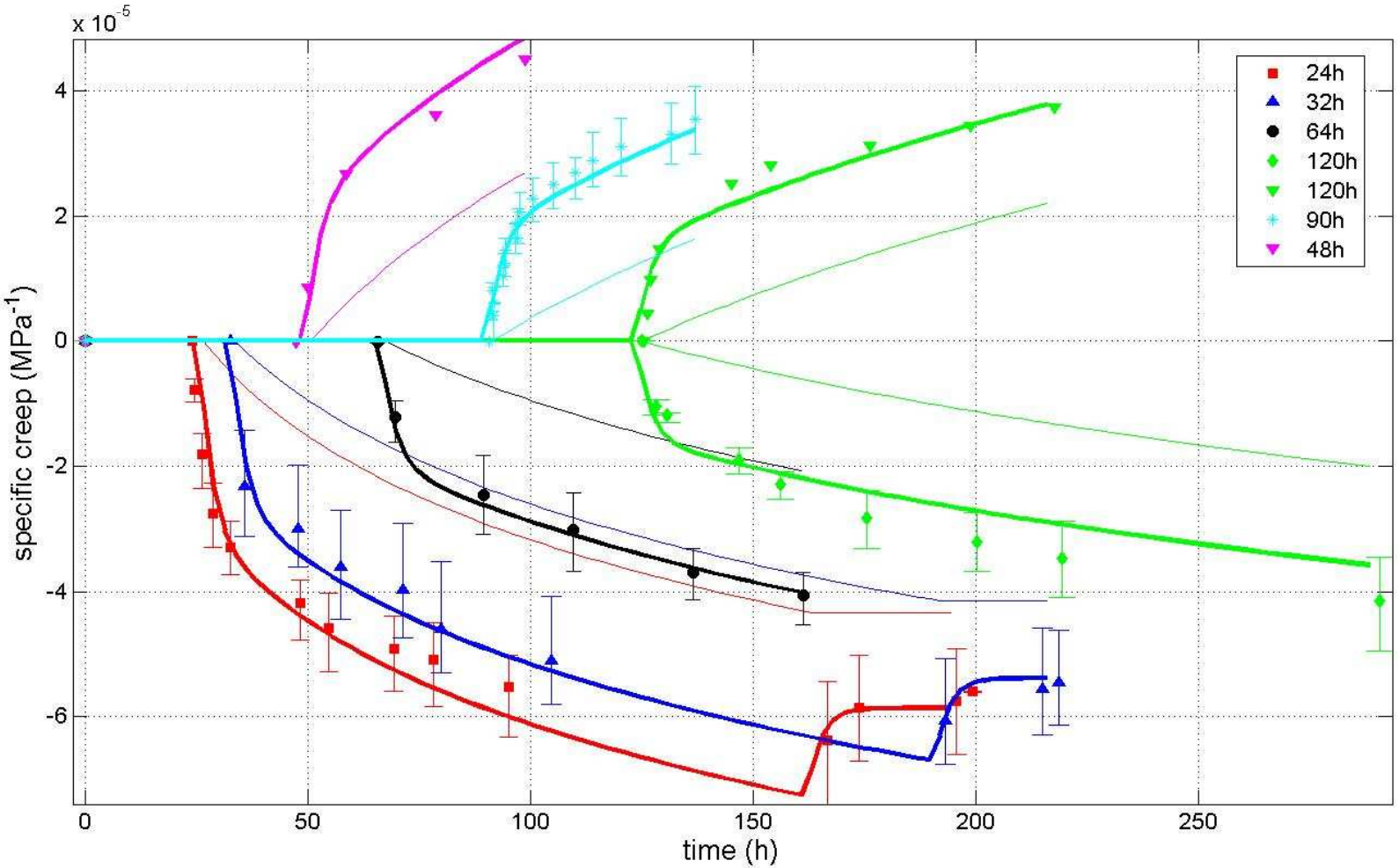
- α : difference between tensile creep and compressive creep
- $\mathbf{k}, \boldsymbol{\eta}$: hydration dependence
- η_a : time dependence

Validation

Rheological parameters:

k_∞	τ	η_a	α
160 GPa	3 h	42 GPa	1.69

[Briffaut, 2011]

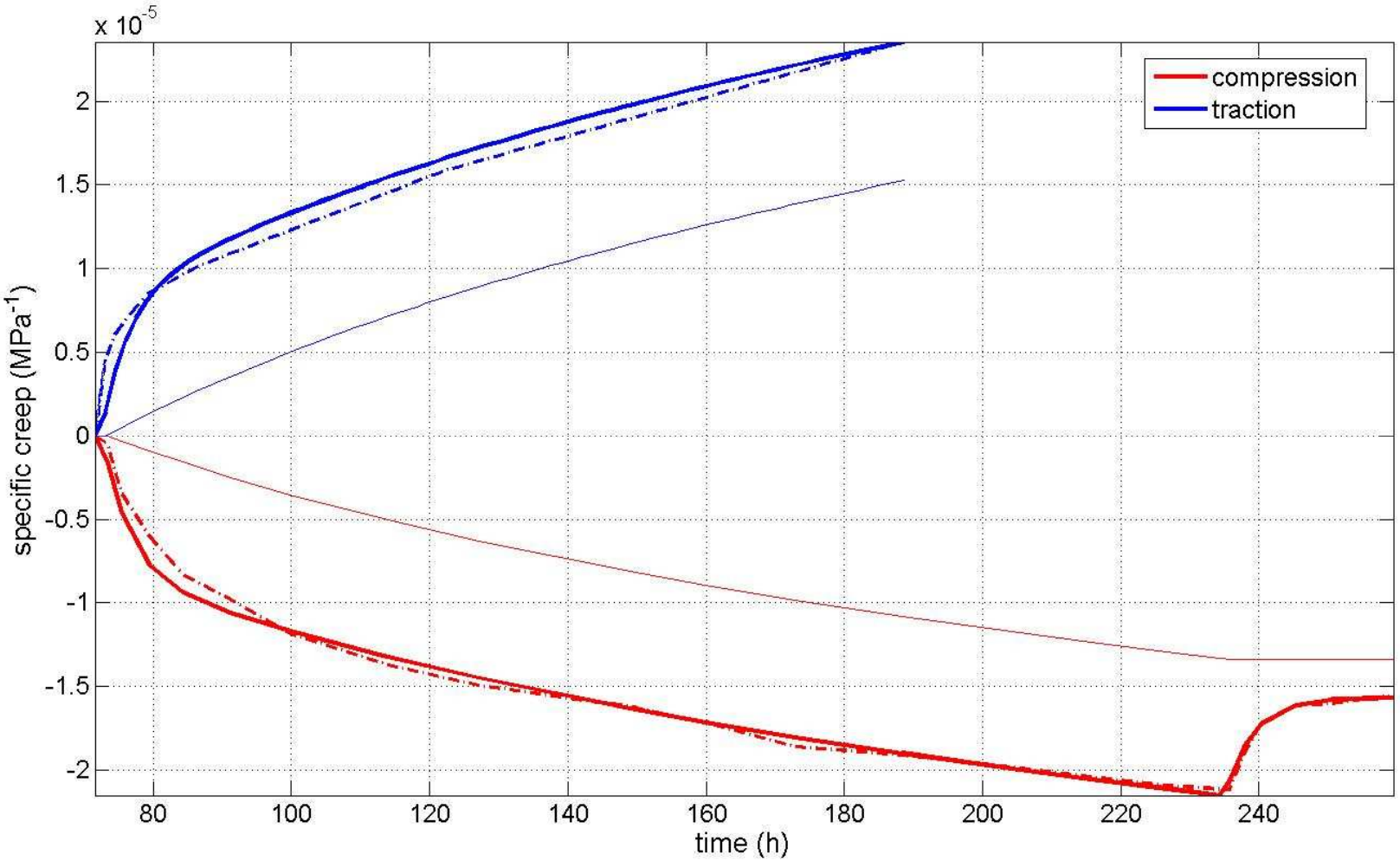


Validation

Rheological parameters:

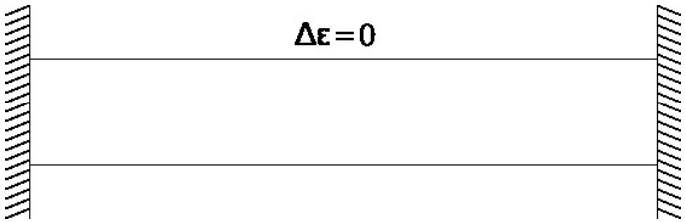
k_∞	τ	η_a	α
300 GPa	4 h	87 GPa	1.4

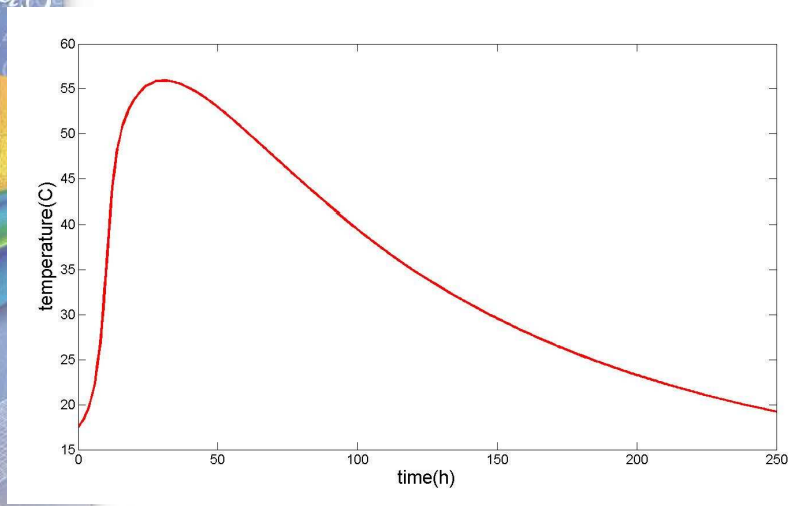
[Atrushi, 2003]



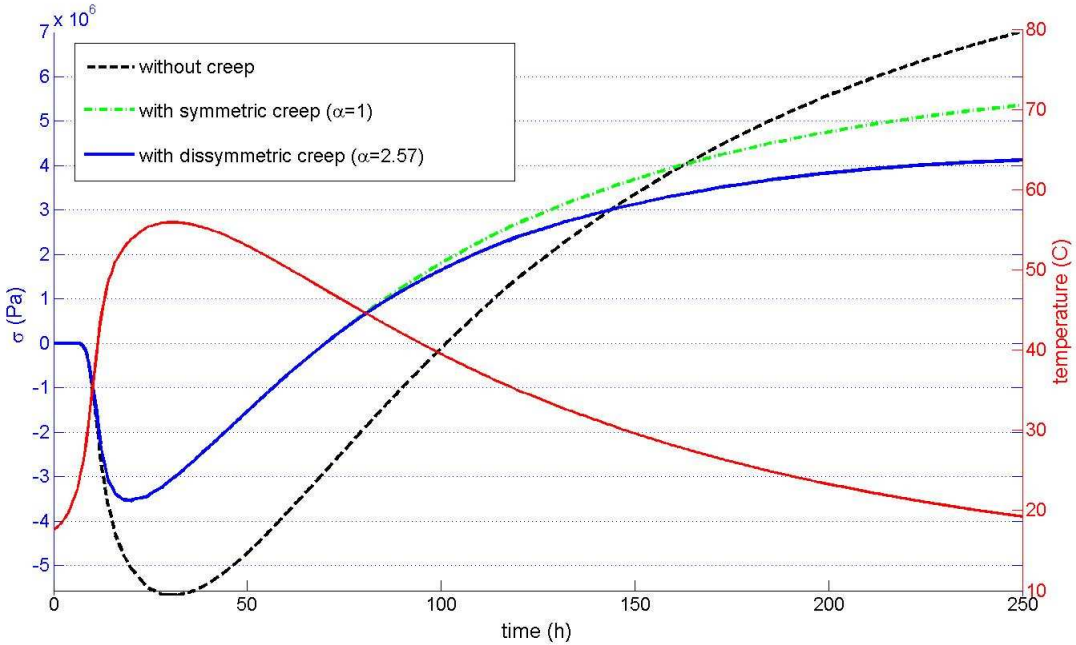
Influence of the dissymmetry

A simple case:





Results:



Conclusions and perspectives

Conclusions

Chimney effect is very small on both maximal temperature and temperature gradient.

Reinforcement bars have a significant effect on maximal temperature as expected.

A modeling with several advantages :

- Only 4 parameters have to be identified
- Enable to calculate creep at early-age and at long-term
- Dissymmetry of tensile/compressive creep is considered

The influence of the creep dissymmetry on the initial cracking is demonstrated.

Perspectives

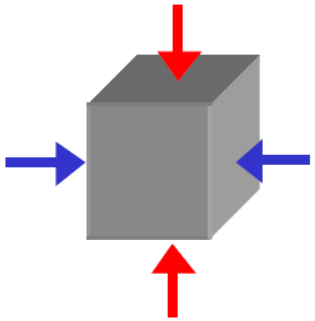
The identification of the creep parameters has to be improved.

Extension of the 1D rheological chain to a 3D modeling

Biaxial creep test

Context

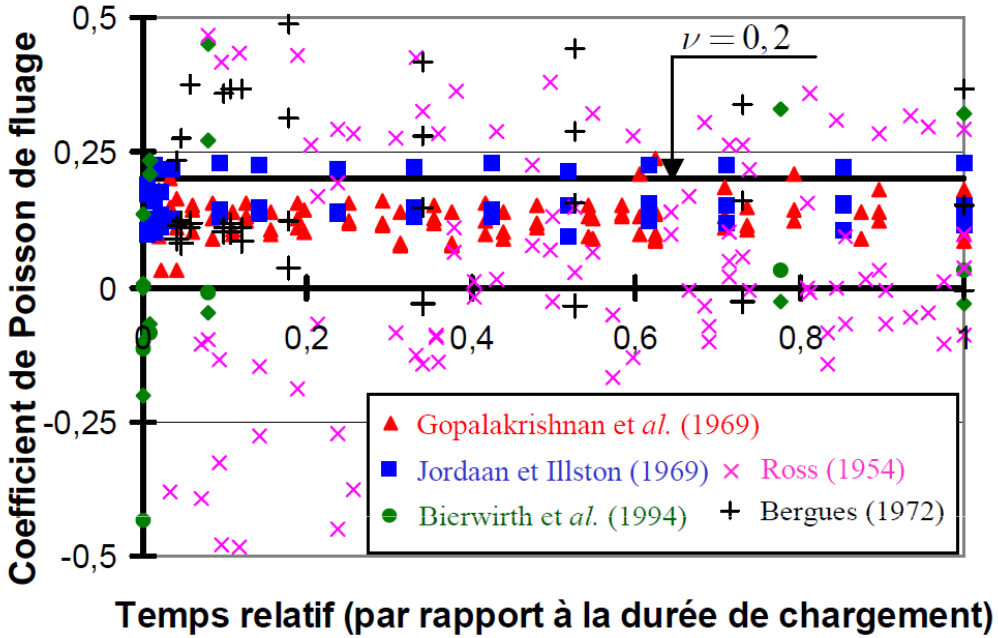
$\sigma_{zz} = 8,5$ MPa



$\sigma_{\theta\theta} = 12$ MPa

$$\varepsilon_{ii}^{flu} = J_u \left(\sigma_{ii} - \nu_f \left(\sigma_{jj} + \sigma_{kk} \right) \right)$$

Poisson creep coefficient



Development of experimental tests to assess Poisson creep coefficient and the dissymmetry between tension and compression.

Thank you for your attention