SECURE WITH STEEL

New features in SAFIR

Transient Creep in Eurocode Concrete Model

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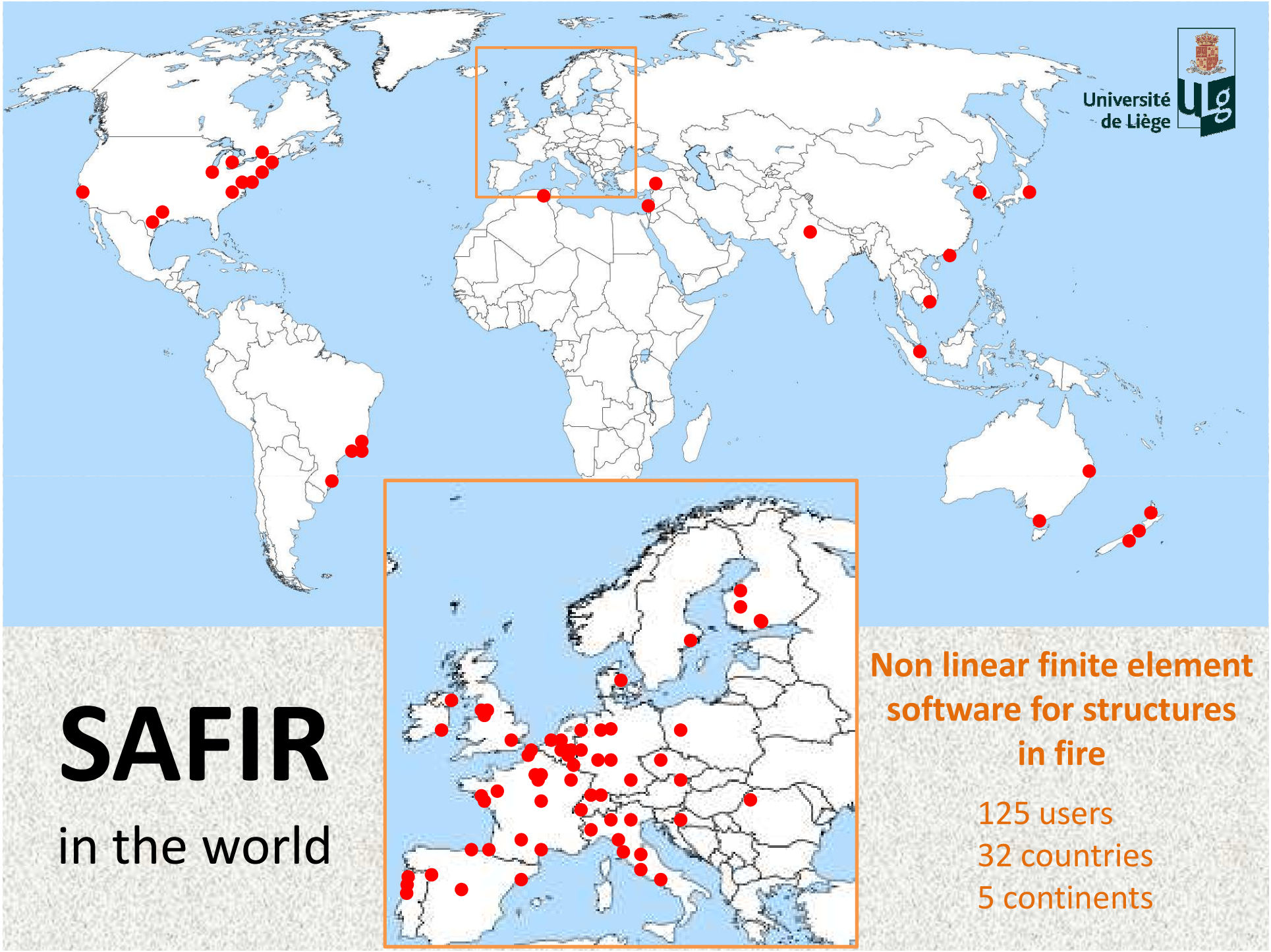


SAFIR

in the world

Non linear finite element software for structures in fire

125 users
32 countries
5 continents

New features in SAFIR

1) **Concrete - Transient Creep Strain in Eurocode model**

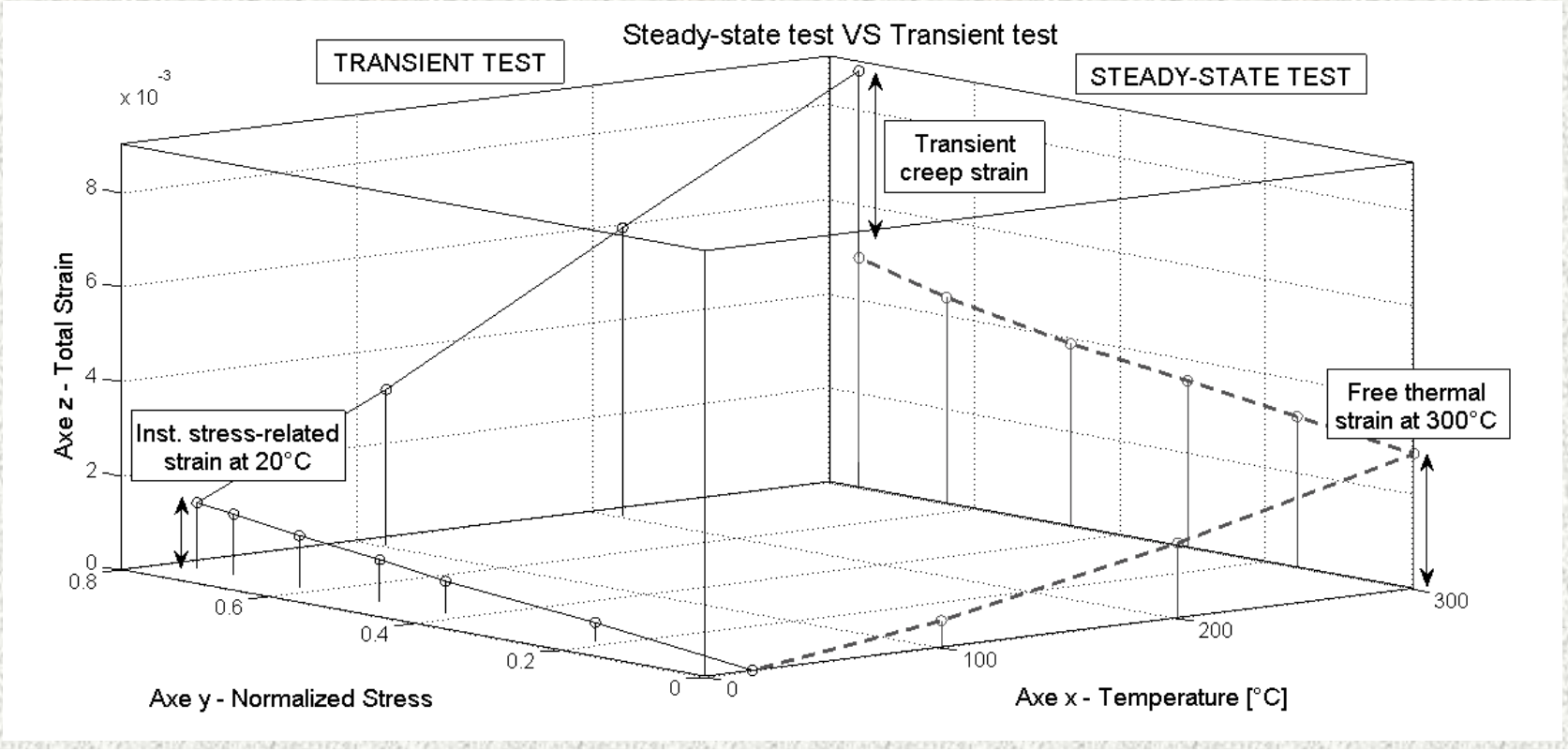
2) Damage-Plastic Multiaxial Model for Concrete

3) Plane Stress Application on a Shell Roof Structure

Transient creep

What is Transient Creep Strain?

TCS develops in **concrete** that is (first-time) **heated under stress**



What is Transient Creep Strain?

- Origins probably in the cement paste
- Depends on temperature and stress history
- Irrecoverable (permanent strain)
- First models by Anderberg [1976] and Schneider [1982]
- Has to be considered for any analysis of fire-exposed concrete structures
- Eurocode 1992-1-2 (EC2) → TCS implicitly in the mechanical strain

2 types of TCS models

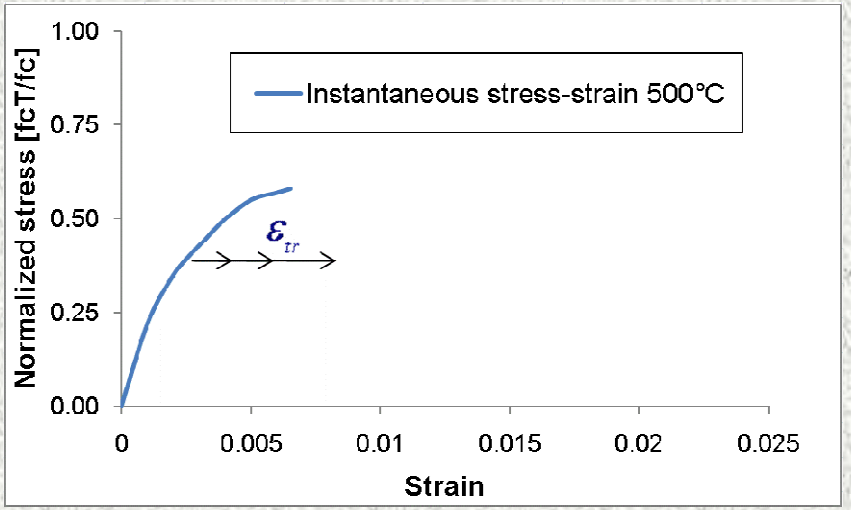
Explicit models

Strain partition: $\varepsilon_{tot} = \varepsilon_{th} + \varepsilon_{\sigma} + \varepsilon_{tr}$

Direct relationship: $\varepsilon_{\sigma} \leftrightarrow (\sigma; T)$

TCS: $\varepsilon_{tr} \leftrightarrow (\sigma; T; \tilde{\sigma}\text{-}\tilde{\mathrm{T}})$

depends on the “history”

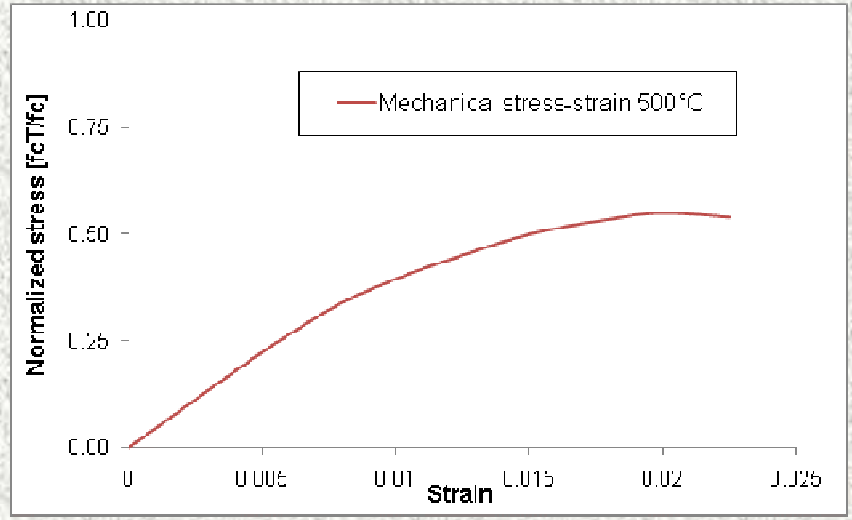


Implicit models

Strain partition: $\varepsilon_{tot} = \varepsilon_{th} + \varepsilon_{m}$

Direct, univocal relationship at given temperature $\varepsilon_{m} \leftrightarrow (\sigma; T)$

No calculation of TCS



Implications of the type of model

Explicit models

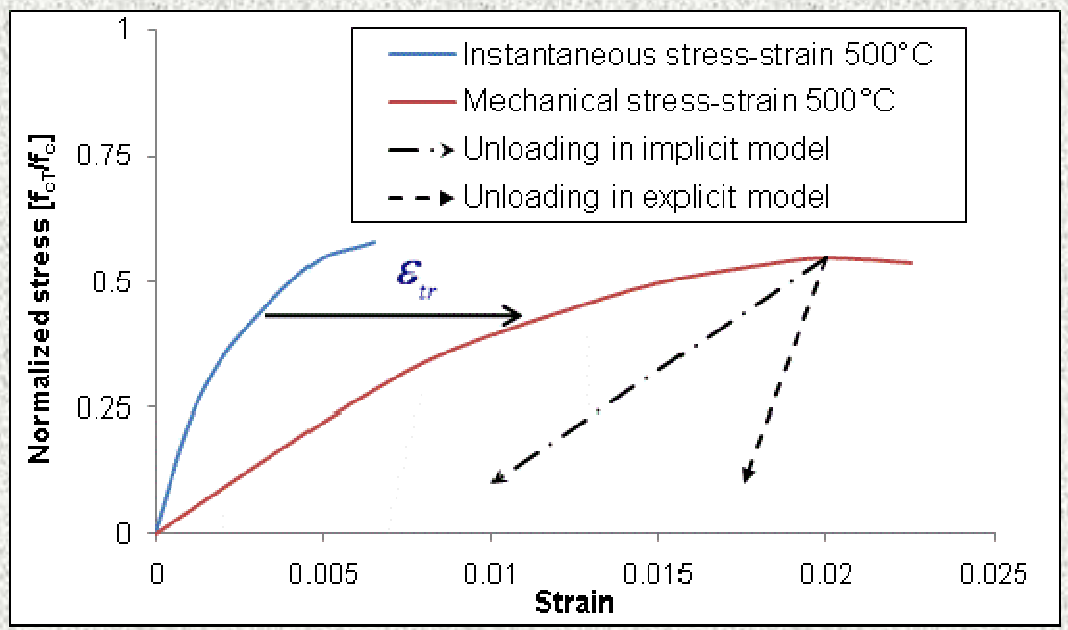
Stress-temperature history

TCS = permanent strain
→ Actual elastic modulus

Implicit models

Univocal at given temperature

TCS, not known, is recovered
→ Apparent elastic modulus
(mechanical strain curve)



Explicit Transient Creep Eurocode (ETC) Model

•Reformulating the EC2 model with explicit transient creep term

Mechanical strain is « splitted »: $\varepsilon_m^{\text{implicit}} \rightarrow \varepsilon_\sigma^{\text{explicit}} + \varepsilon_{tr}^{\text{explicit}}$

• Generic relationship (univocal at given temperature)

EC2 ETC

$$\frac{\sigma}{f_c(T)} = \frac{3\ \varepsilon_m^{\text{implicit}}}{\varepsilon_{c1}(T)\left[2+\left(\frac{\varepsilon_m^{\text{implicit}}}{\varepsilon_{c1}(T)}\right)^3\right]} \rightarrow \frac{\sigma}{f_c(T)} = \frac{2\ \varepsilon_\sigma^{\text{explicit}}}{\varepsilon_{c1,ETC}(T)\left[1+\left(\frac{\varepsilon_\sigma^{\text{explicit}}}{\varepsilon_{c1,ETC}(T)}\right)^2\right]}$$

•Generic TCS relationship (that depends on the « history »)

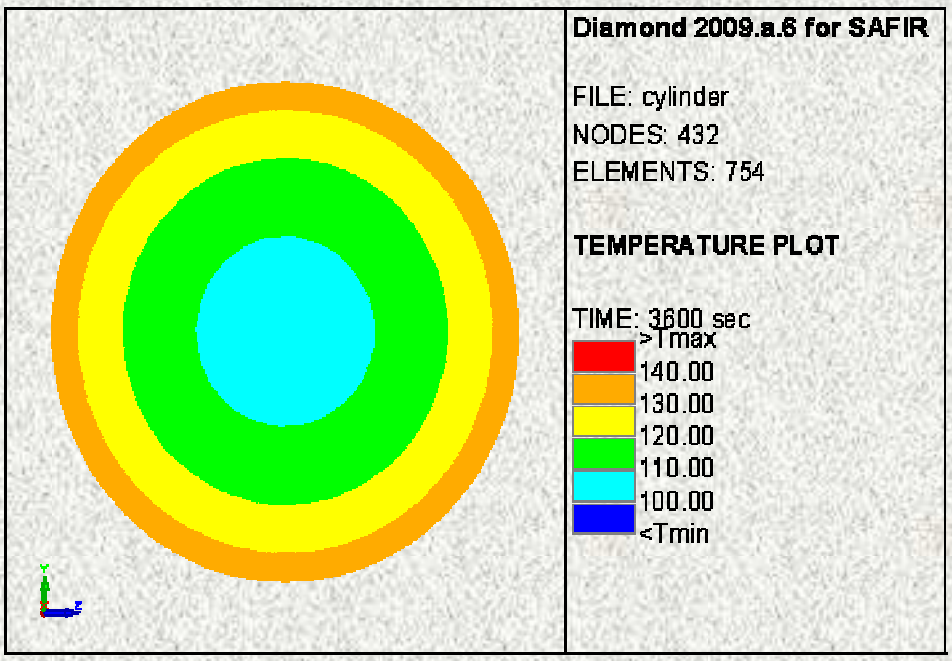
$$\varepsilon_{tr}^{\text{explicit}} = \phi(T) \times \frac{\sigma}{f_{ck}}$$

$\Rightarrow$**New in SAFIR: materials SILCON_ETC and CALCON_ETC**

Validation ETC model: material level

- Concrete specimens subjected to unsteady temperatures and loads [Schneider test, 2008]

- Cylinders Φ 80 mm
- 300 mm height
- Axially unrestrained
- f_{ck} at 20°C = 38 MPa
- Temperature constantly increasing at 2°C/min

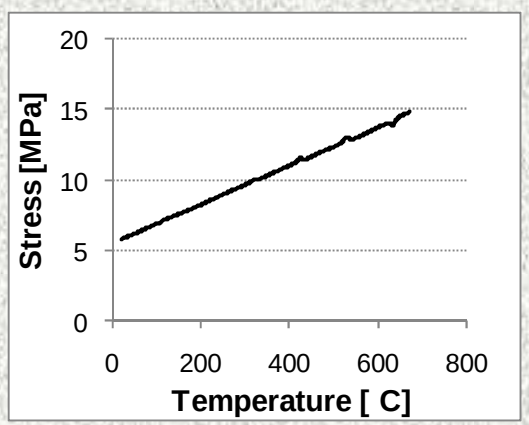


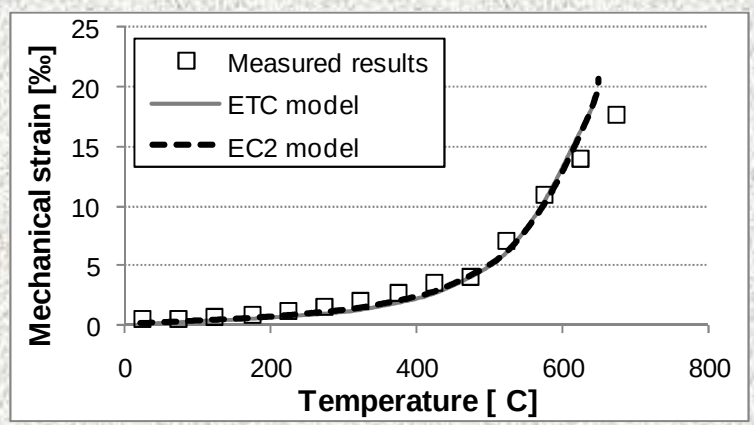
SAFIR analysis: EC2 model (SILCONC_EN) vs ETC model (SILCON_ETC)

Validation ETC model: material level

- 1st case: heating under compressive stress
  (compressive stress slowly increases)

- ETC model calibrated to yield the same mechanical strain as EC2 for the situation of heating under constant stress

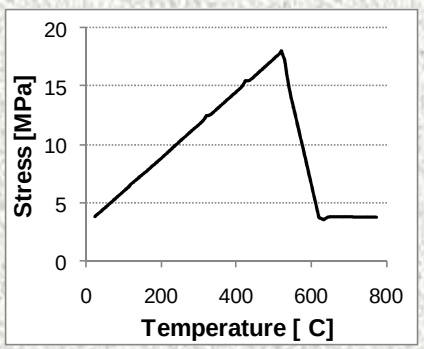


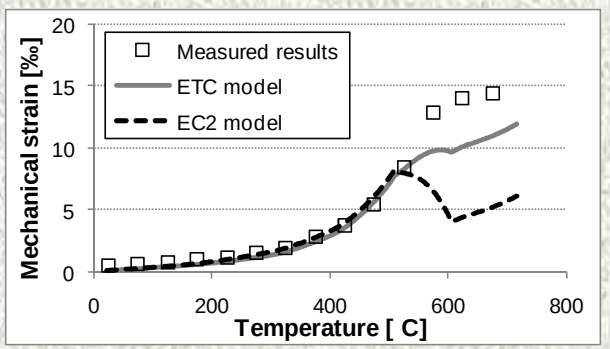


⇒ Where EC2 was good (prescriptive design), ETC model gives the same result

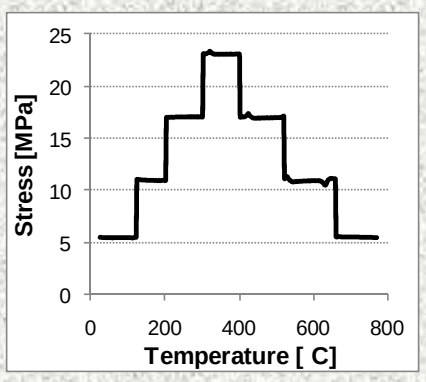
Validation ETC model: material level

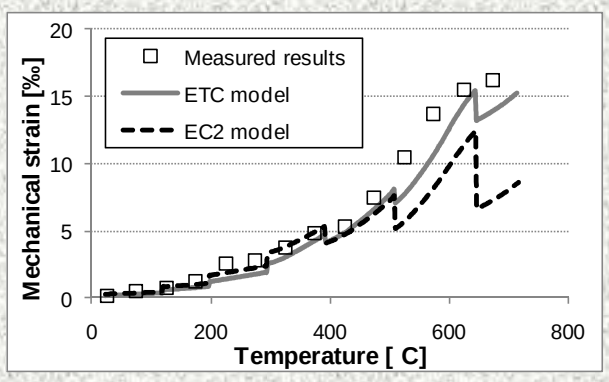
- 2nd and 3rd cases: loading and unloading
- Unloading stiffness different in explicit and implicit models





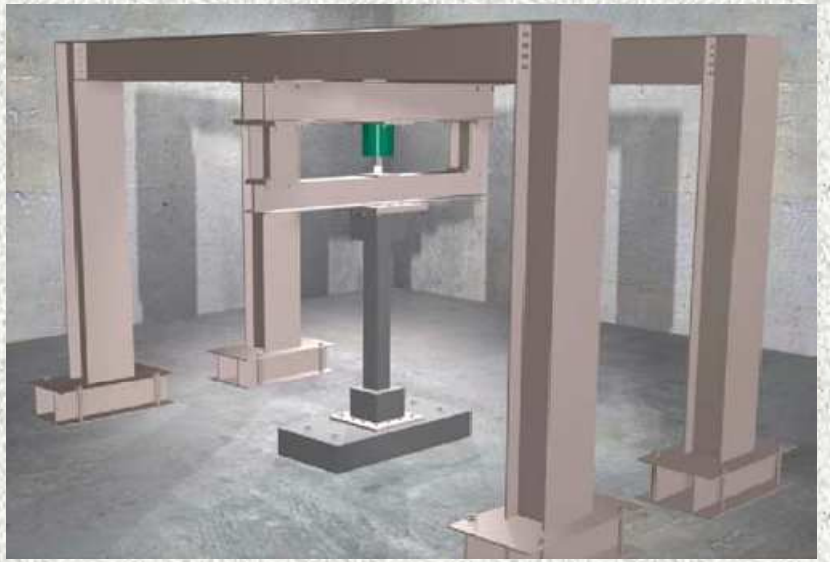
- In EC2 model, TCS is recovered → explicit model needed!



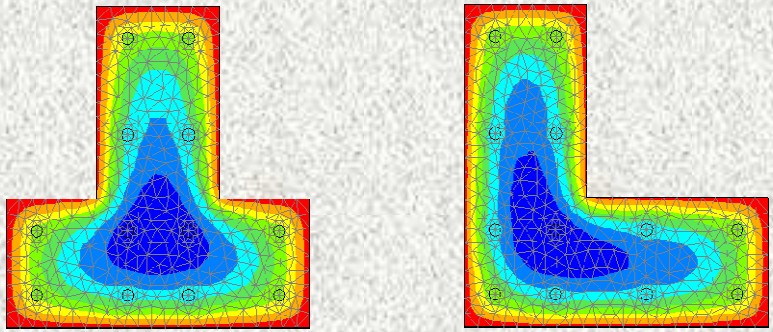


Validation ETC model: structural element

- Axially restrained reinforced concrete columns subjected to heating and cooling [tests by Wu & al., 2010]

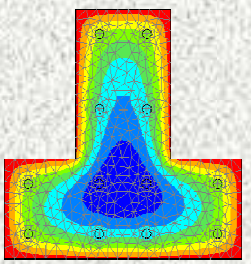


- 2 different sections were tested

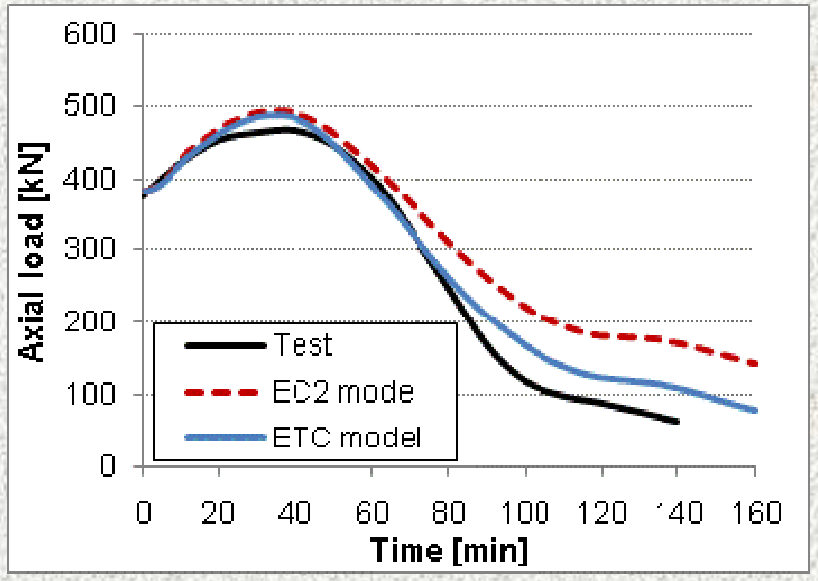


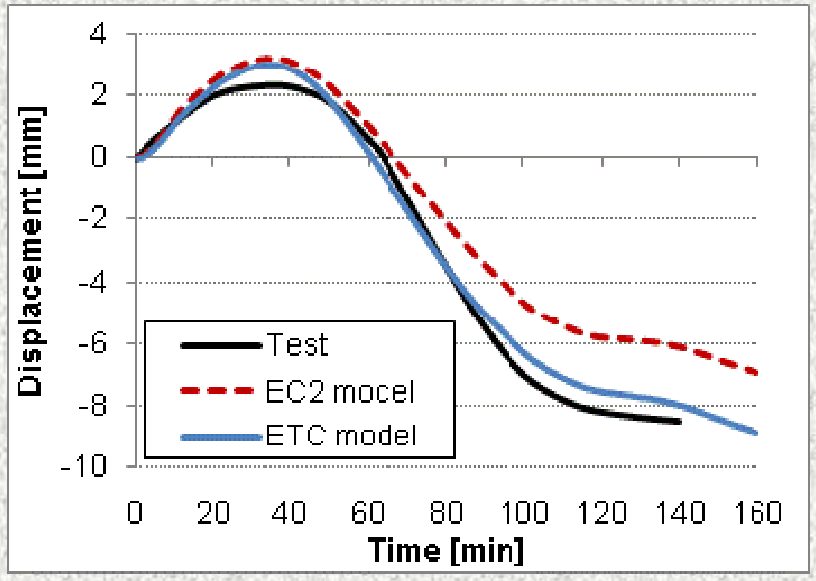
- 2 different load levels and 2 different axial restraints
- Numerical simulations performed with the software SAFIR

Validation ETC model: structural element



- Load = 375 kN (ratio 0.34)
- Axial restraint = 34.5 MN/m (ratio 0.0578)
- Heating during about 90 min



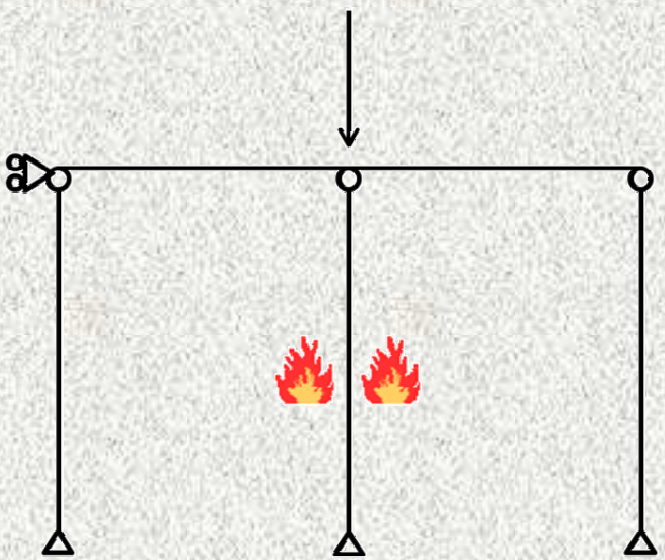


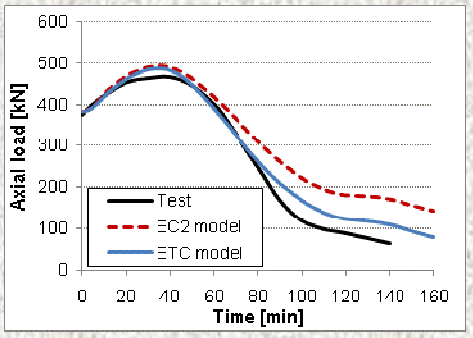
⇒ EC2 and ETC models give slightly different results during the contracting phase (= unloading) because of TCS

Validation ETC model: structural element

Practical application:

- Performance-based analysis
- Natural fire (including cooling phase)
- Robustness of the structure: forces redistributed to other columns by horizontal elements

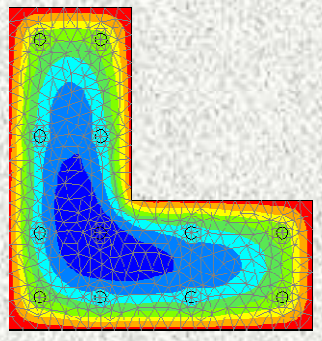




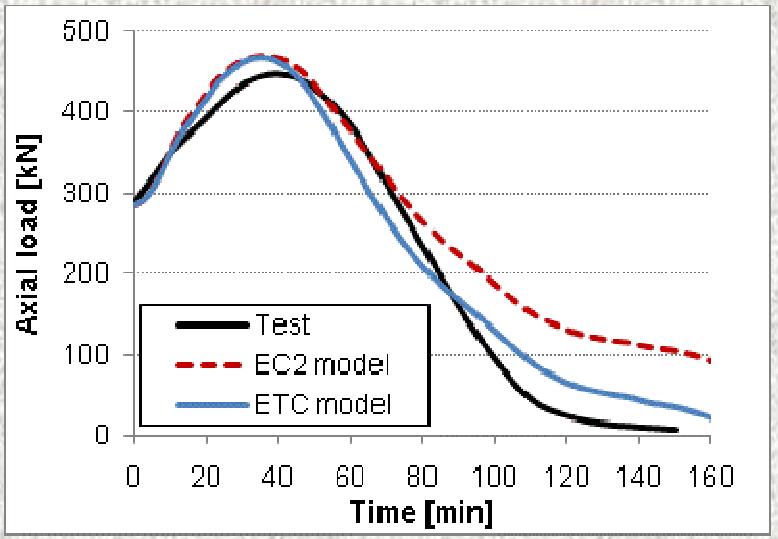
axial load decreases by 100 kN

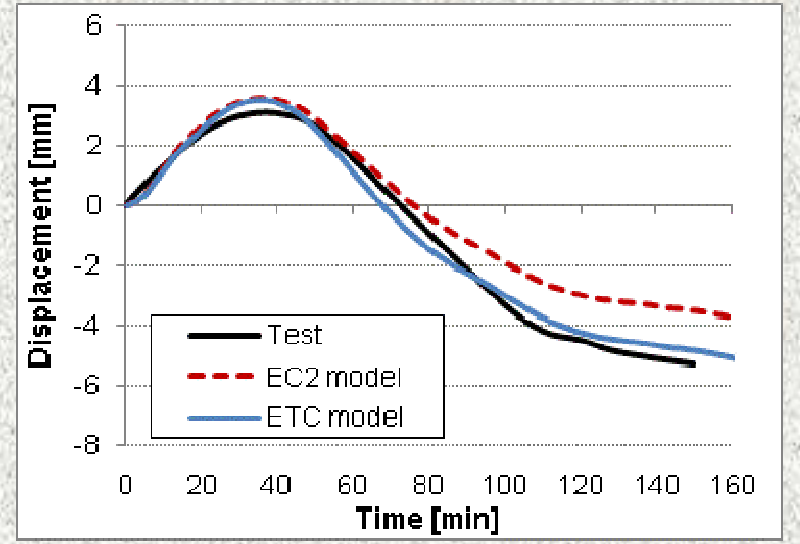
→ 50 kN to add in other columns

Validation ETC model: structural element



- Load = 285 kN (ratio 0.24)
- Axial restraint = 51.9 MN/m (ratio 0.0870)
- Heating during about 100 min





Conclusion

- Transient creep strain develops in concrete heated under stress

- TCS can be included implicitly or explicitly in concrete models

- Implicit models (such as EC2) have limitations:
  - No influence of the stress-temperature path
  - Actual unloading stiffness not known (TCS is recovered)

- The Explicit Transient Creep (ETC) model is a new formulation of the generic EC2 concrete model that contains an explicit term for transient creep strain

- ETC model calibrated on EC2 model for « simple » situations (prescriptive); the improvement may be significant for « complex » situations (unloading / natural fire /performance-based)

- ETC model in SAFIR 2011b0 → **SILCON_ETC** and **CALCON_ETC**

References

•T. Gernay, Effect of Transient Creep Strain Model on the Behavior of Concrete Columns Subjected to Heating and Cooling, Fire Technology, accepted for publication.
http://www.springerlink.com/content/3362rp1hv5355462/fulltext.pdf

•T. Gernay, J-M Franssen, A Comparison Between Explicit and Implicit Modelling of Transient Creep Strain in Concrete Uniaxial Constitutive Relationships, Proceedings of the Fire and Materials Conference (2011), San Francisco, pp. 405-416.
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