SECURE WITH STEEL

New features in SAFIR

Damage-Plastic Multiaxial Model for Concrete

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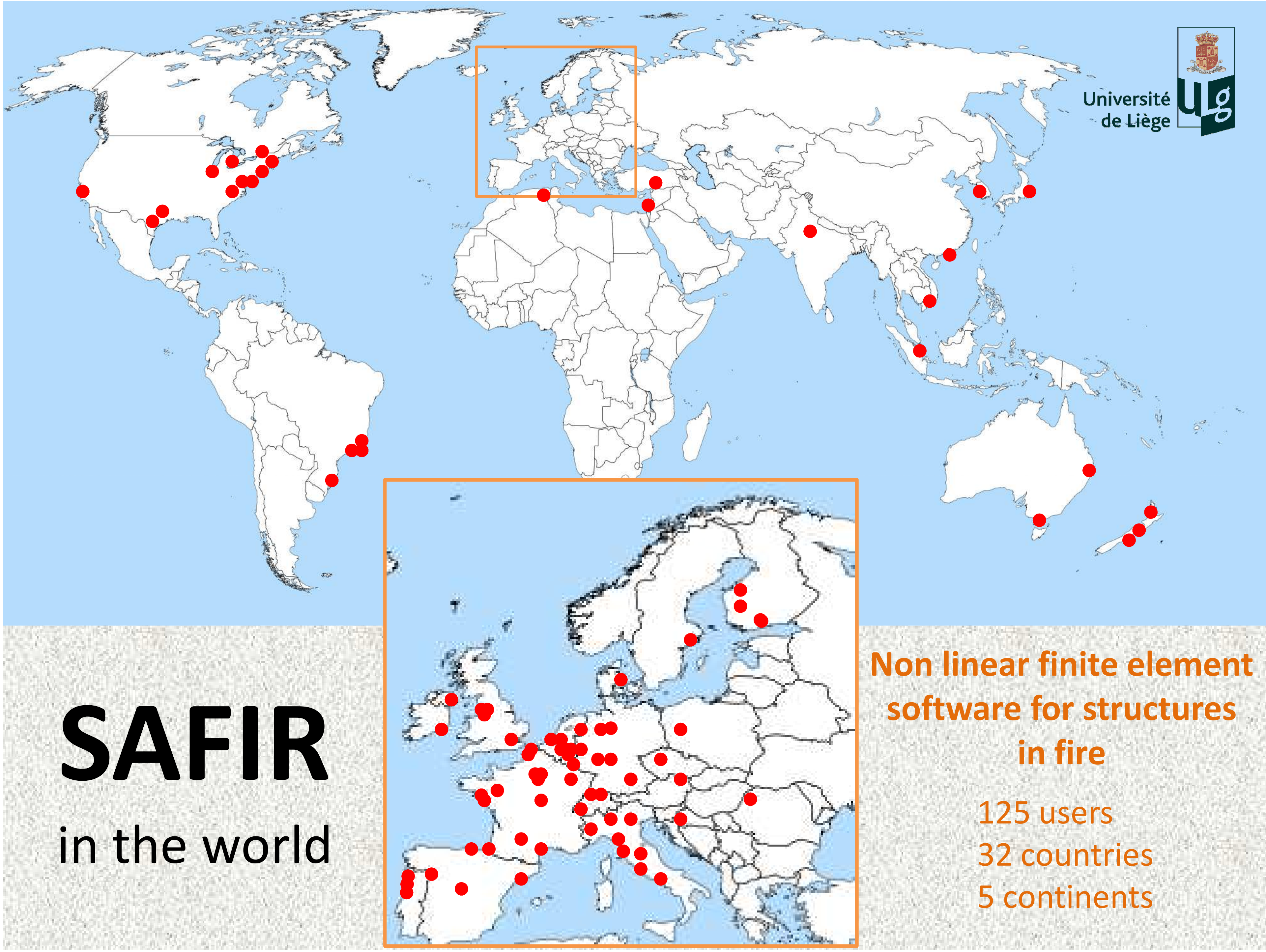


SAFIR

in the world

Non linear finite element software for structures in fire

125 users
32 countries
5 continents

New features in SAFIR

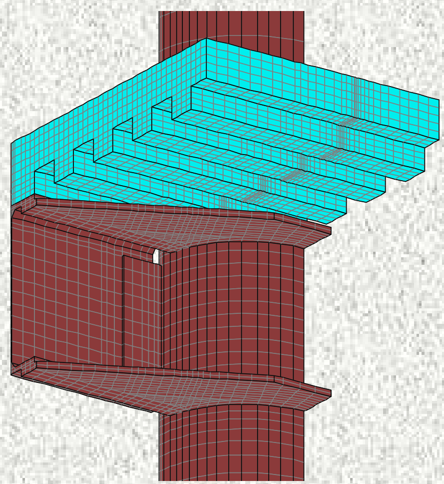
1) Concrete - Transient Creep Strain in Eurocode model

2) **Damage-Plastic Multiaxial Model for Concrete**

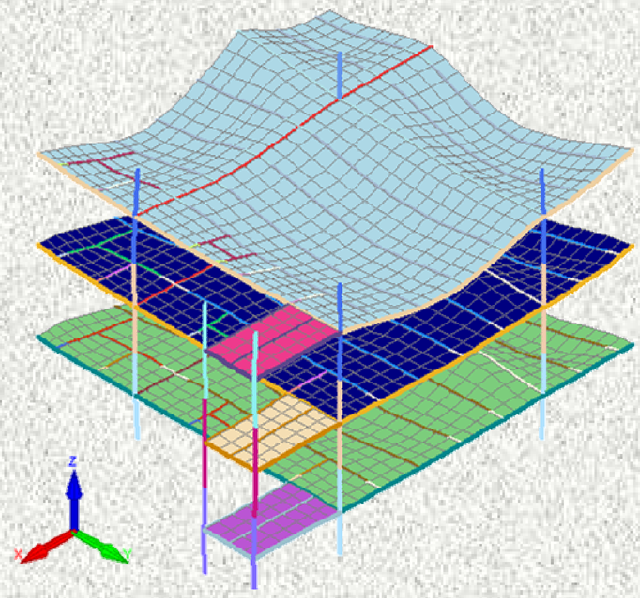
3) Plane Stress Application on a Shell Roof Structure

Multiaxial Model for Concrete

- •Applications: reinforced concrete structures in fire
- •Relationships for SOLID FE (ex: detailed joint model, strut and tie model)
- •Relationships for SHELL FE (ex: structural slab model)
- •Including transient creep



Numerical model by Alderighi
University of Pisa



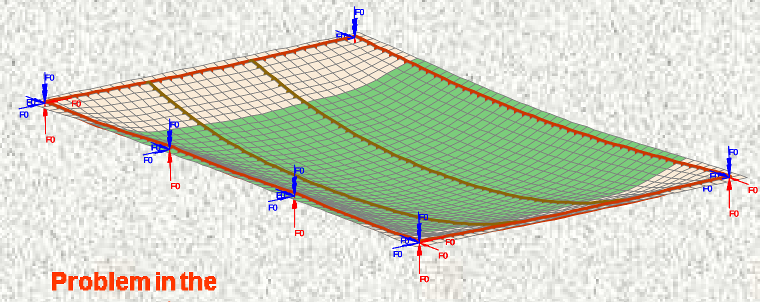
Numerical model by Fike and Kodur
Michigan State University

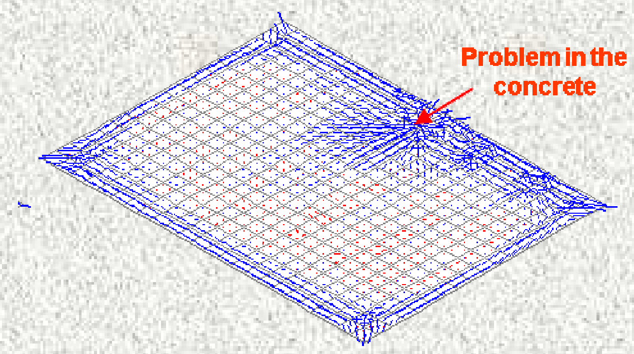
Limitations of the current SAFIR concrete model

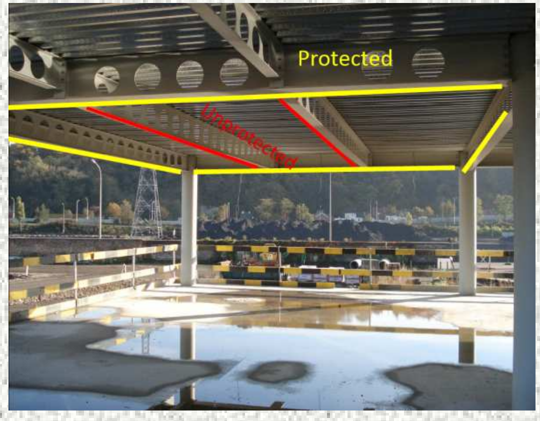
Phenomenology	Model limitations (SILCONC2D)
Unilateral effect (crack closure)	Plastic model only
Concrete dilatancy	Associated plasticity
Transient creep strain is irrecoverable (unloading stiffness)	Implicit transient creep model
Confinement effect (multiaxial compression)	Von Mises criterion in compression
Numerical robustness	Could be improved

Concrete modelling: a challenging issue

- Concrete models needed: challenging issue for structural fire engineering







Development of a multiaxial concrete model

•A new multiaxial concrete model has been developed (partly during a research stay at the French Atomic Energy Commission (CEA) in the team of Alain Millard)

Phenomenology	New Model
Unilateral effect	Plastic + Damage
Concrete dilatancy	Non-associated plasticity
Transient creep strain is irrecoverable (unloading stiffness)	Explicit transient creep model (based on ETC)
Confinement effect (multiaxial compression)	Drucker-Prager in compression
Numerical robustness	Special care to the numerical integration of the constitutive laws

•The new model is implemented in SAFIR for SOLID and for SHELL elements

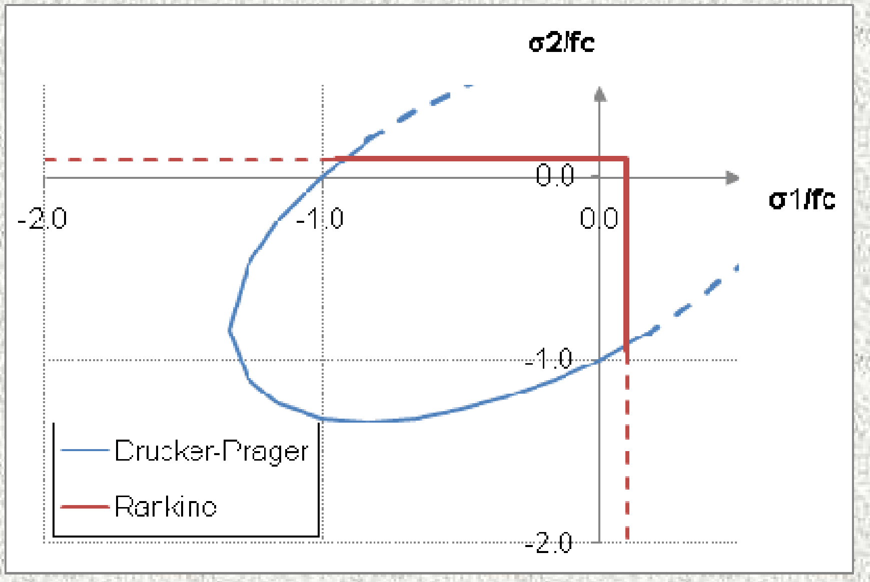
Development of a multiaxial concrete model

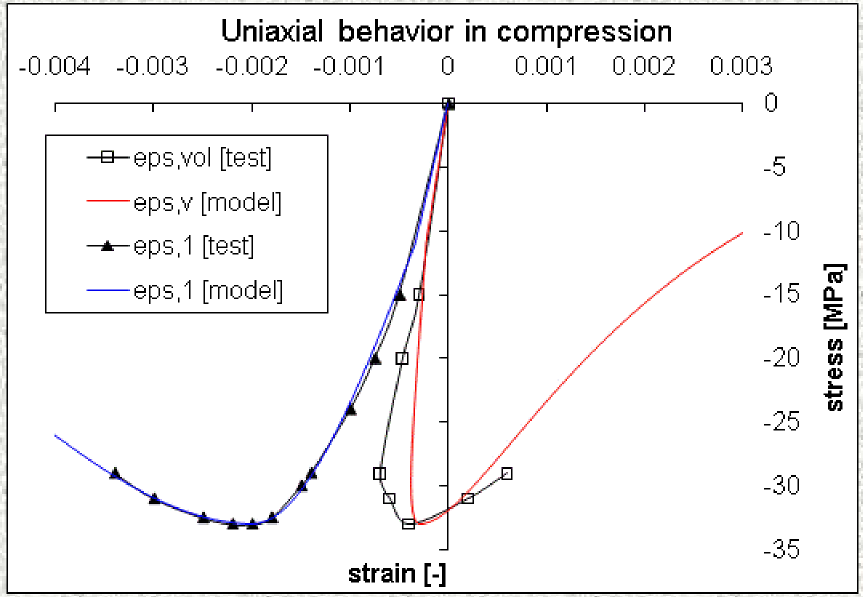
- Plastic-damage model
- Strain decomposition principle $\underline{\underline{\varepsilon}}_{tot} = \underline{\underline{\varepsilon}}_{th} + \underline{\underline{\varepsilon}}_{tr} + \underline{\underline{\varepsilon}}_{\sigma}$
- Permanent strain (plasticity) $\underline{\underline{\varepsilon}}_{\sigma} = \underline{\underline{\varepsilon}}_{el} + \underline{\underline{\varepsilon}}_{p}$
- Degradation of the elastic properties (damage) $\underline{\underline{\sigma}} = (1-d)\,\underline{\underline{\underline{\underline{C}}}}_0 : \left(\underline{\underline{\varepsilon}}_{\sigma} - \underline{\underline{\varepsilon}}_{p}\right)$

$\underline{\underline{\sigma}} = \underline{\underline{\underline{\underline{C}}}}_0 : \left(\underline{\underline{\varepsilon}} - \underline{\underline{\varepsilon}}_{p}\right)$ $\underline{\underline{\sigma}} = (1-d)\,\underline{\underline{\underline{\underline{C}}}}_0 : \underline{\underline{\varepsilon}}$ $\underline{\underline{\sigma}} = (1-d)\,\underline{\underline{\underline{\underline{C}}}}_0 : \left(\underline{\underline{\varepsilon}} - \underline{\underline{\varepsilon}}_{p}\right)$

Development of a multiaxial concrete model

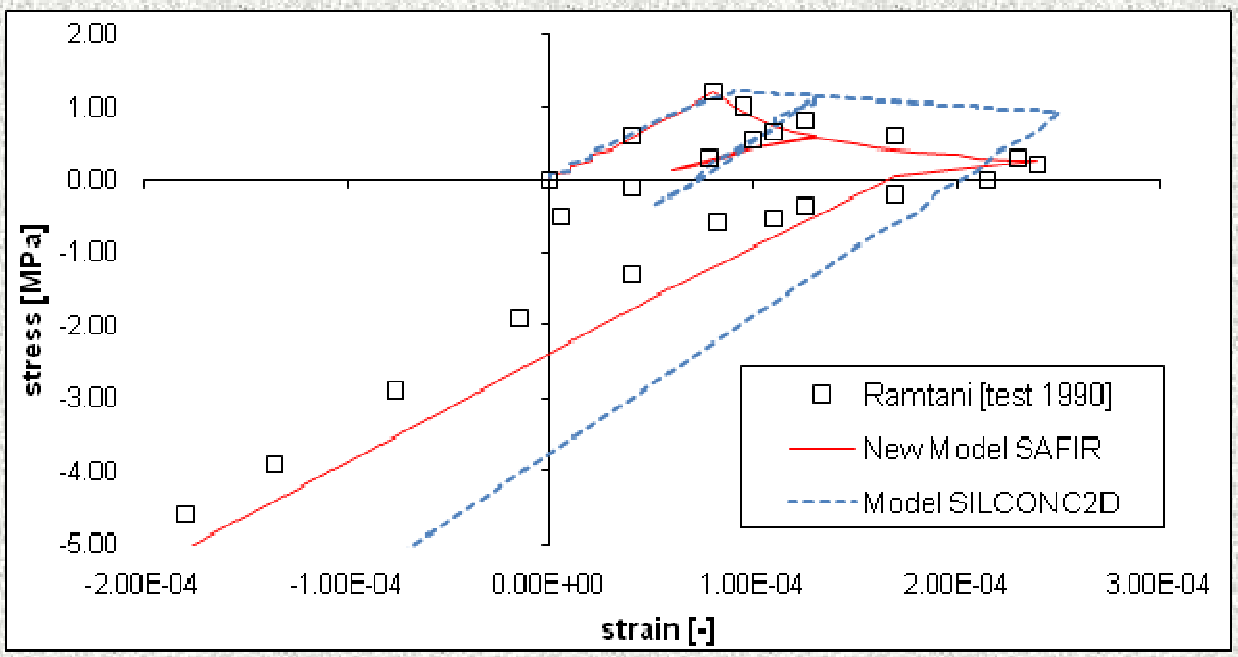
- Plasticity + Damage
- Yield surfaces: Drucker Prager – Rankine
- Dilatancy (non associated plasticity)





Development of a multiaxial concrete model

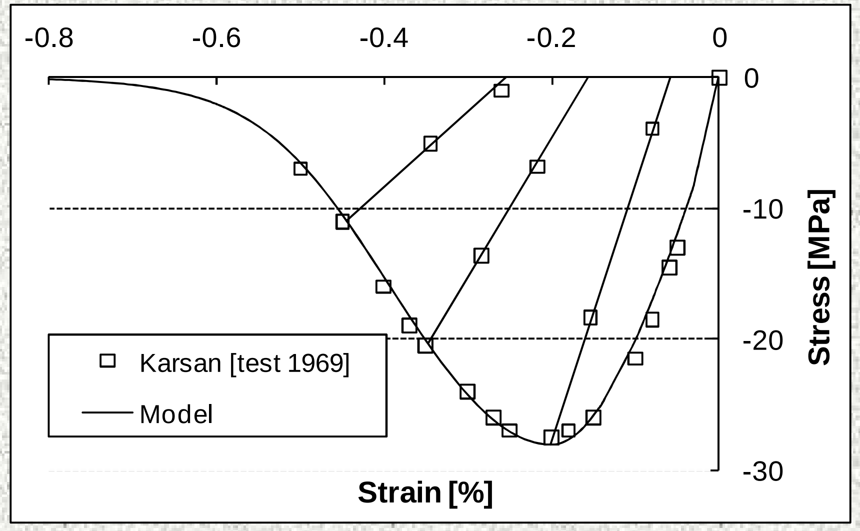
- Damage: degradation of the elastic properties + unilateral effect

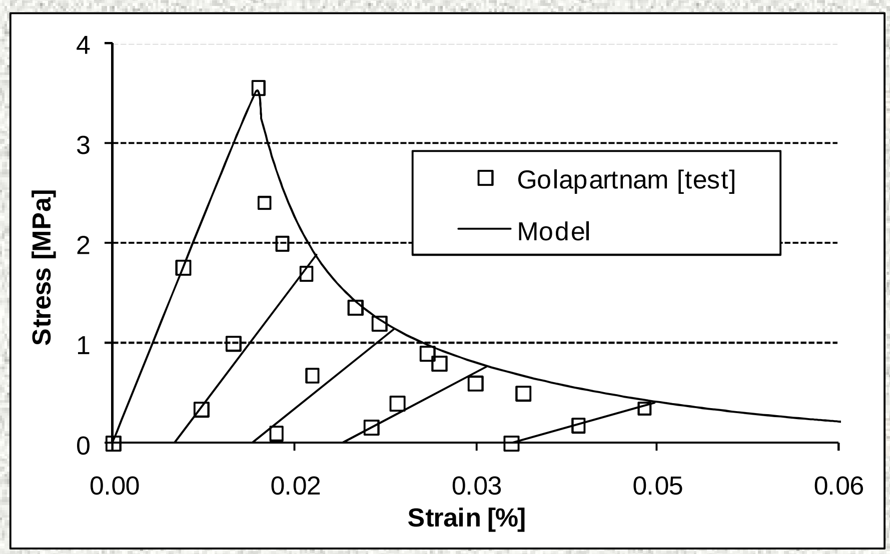


- 10 Material parameters obtained from 3 simple tests:
    - Uniaxial compression
    - Uniaxial tension
    - Biaxial compression

Validation of the new concrete model

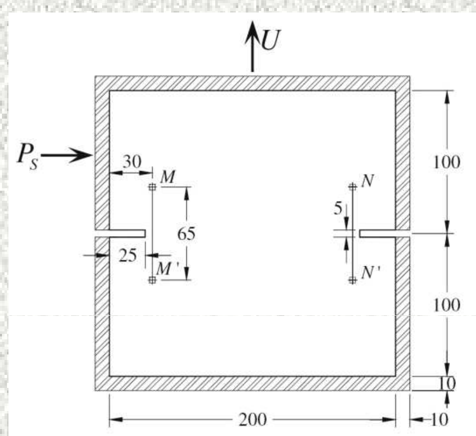
- Uniaxial compression and tension (loading + unloading)



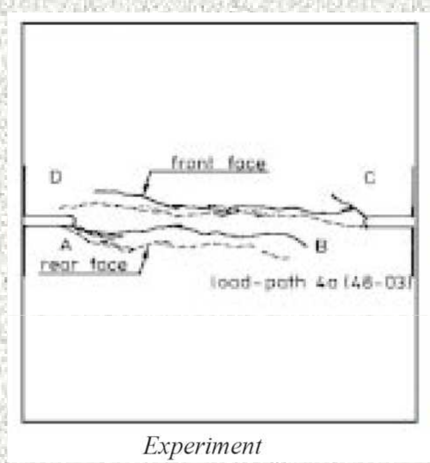


Validation of the new concrete model

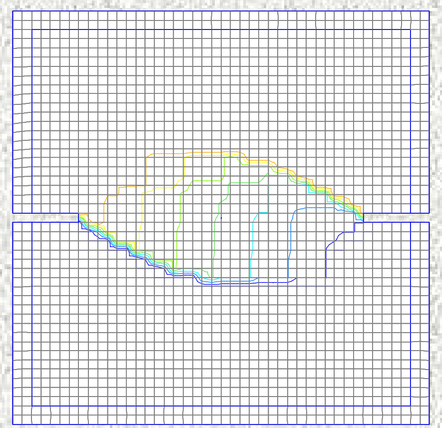
- Mixed-mode fracture of plain concrete: shear + tension [Nooru-Mohamed, 1992]



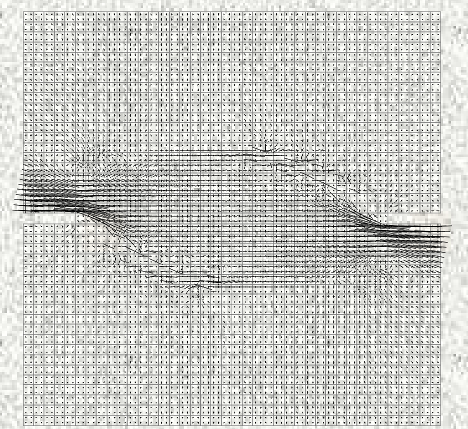
Application of shear force and then vertical displacement (tension)



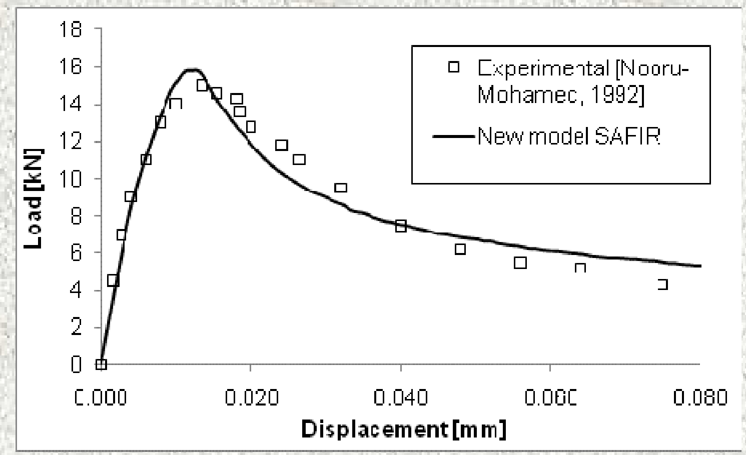
Cracked sample (end of test)



SAFIR model: displacements



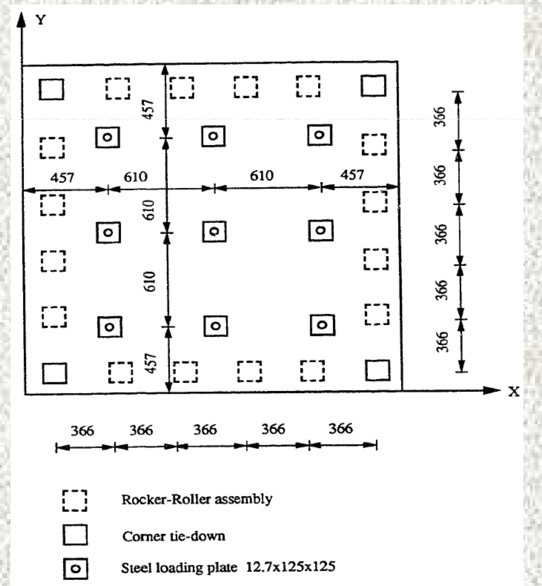
SAFIR model: membrane forces

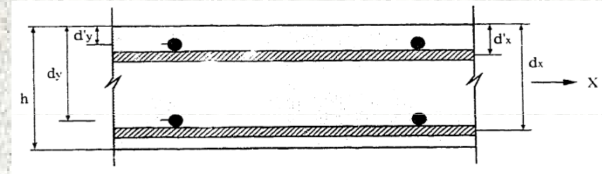


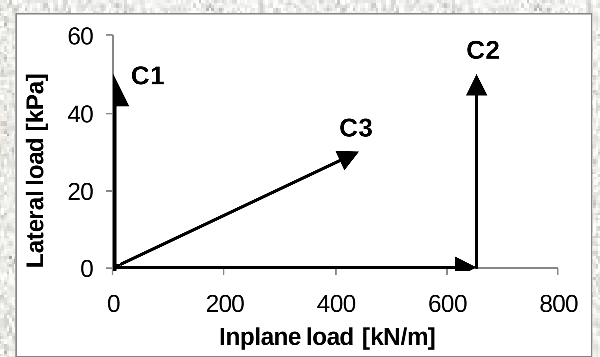
Validation of the new concrete model

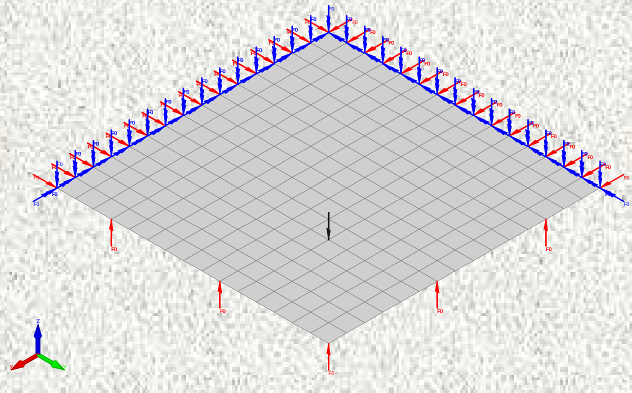
•Reinforced concrete slabs subjected to inplane loads (compression) + transversal loads [M.G. Ghoneim and J.G. MacGregor, Univ. of Alberta, 1992]

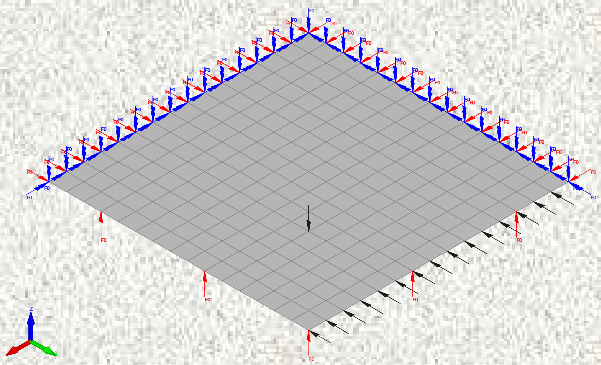
Tests C1, C2, C3 differ by the loading path





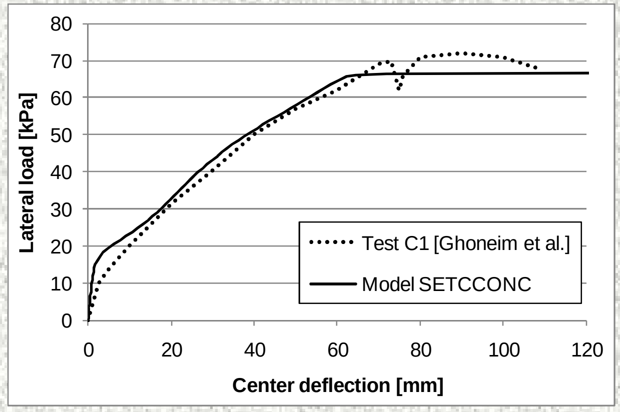


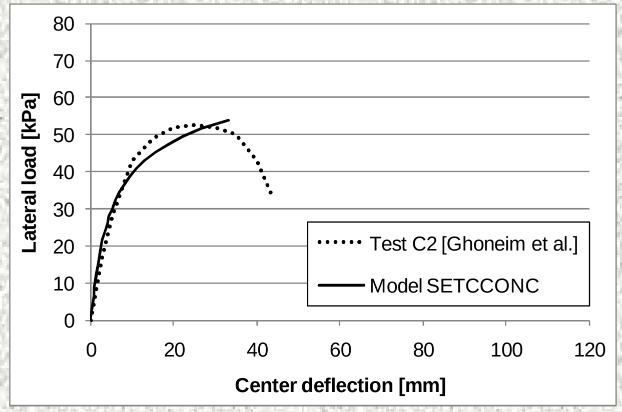


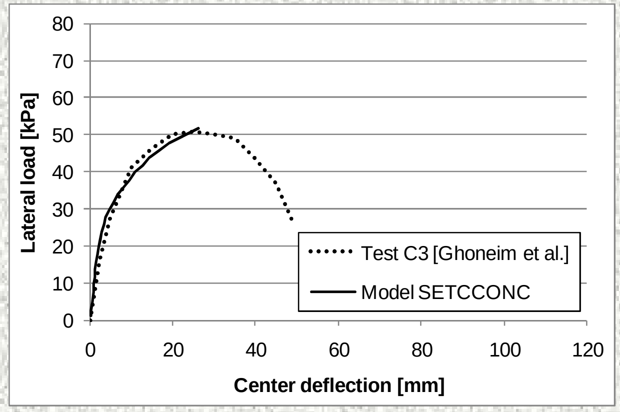


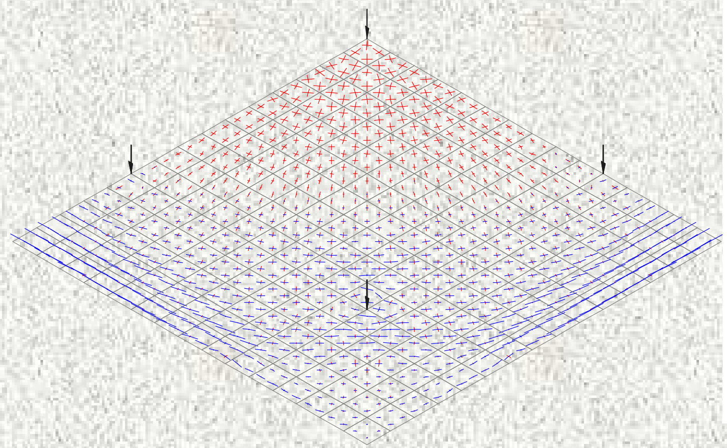
Validation of the new concrete model

- Reinforced concrete slabs subjected to inplane + transversal loads
  [M.G. Ghoneim and J.G. MacGregor, University of Alberta, 1992]









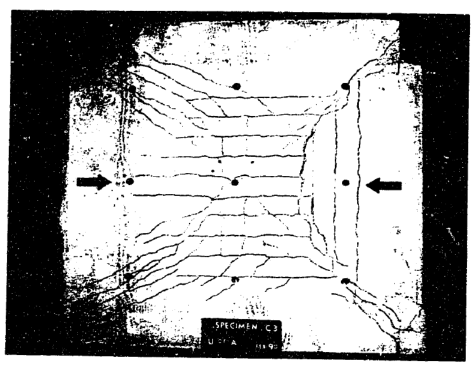
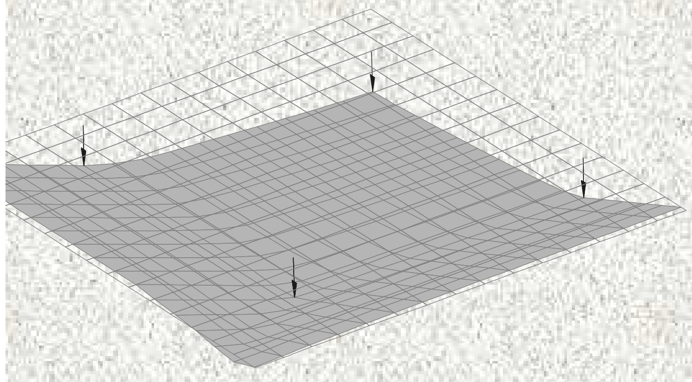


Figure 3.7 Tension Face of Specimen C3 after Failure



Conclusion

- Multiaxial constitutive relationships for concrete needed in structural fire engineering → challenging, up-to-date issue

- Development of a model coupling **plasticity** and **damage**, to capture the complex behavior of concrete (permanent strains + degradation of elastic properties)

- Implementation in SAFIR for SOLID elements (full 3D) and SHELL elements (plane stress)

- Validation at ambient temperature

- Validation at elevated temperature: in progress
  A practical application → fire analysis of a shell roof structure