University
of Ljubljana
Faculty
of civil and
geodetic engineering

FIRE ANALYSIS OF STEEL-CONCRETE COMPOSITE BEAM WITH INTERLAYER SLIP

Tomaž Hozjan

Outline of the presentation

- Problem description
- Temperature – moisture analysis of a steel-concrete composite beam
- Mechanical analysis of a steel-concrete composite slab exposed to fire and mechanical loads
- Conclusions

Problem description

- Steel-concrete composite systems are widely used construction (floor system, beams,...).
- One of the most important design requirements: their fire resistance
- Fire resistance of steel-concrete composite structures (experiments, numerical methods)
- Fire experiments are expensive and of great pretension → the developed numerical methods represent an inexpensive alternative.

Mathematical modelling of fire analysis

- 1st phase:
  - Determination of fire scenario (fire curves, CFD,...)
  - On the basis of known fire scenario determinaton of temperature and moisture distribution in steel-concrete composite beam
- 2nd phase:
  - Mechanical response of steel-concrete composite slab exposed simultaneously to fire and mechanical loads
    - Geometrical nonlinear slab model is used to model mechanical behaviour of a composite slab.
    - Nonlinear temperature-dependent material properties of steel and concrete and connection are used.

Temperature and moisture analysis of a composite beam

- Mathematical model proposed by Davie et. al. is used.

- Basic assumptions of the used model:

  - There is thermal equilibrium between all phases within an infinitesimal volume.

  - Water vapour, air and their gaseous mixture behave as ideal gases.

  - There is no diffusion of bound water. It diffuses and evaporates only after it is released as free water.

  - Amount of free water is determined with the help of sorption curves.

System of differential equations

- Problem is described with 3 partial differential equations:

$$\frac{\partial(\varepsilon_G \tilde{\rho}_A)}{\partial t} = -\nabla \cdot \mathbf{J}_A,$$

$$\frac{\partial(\varepsilon_G \tilde{\rho}_V)}{\partial t} + \frac{\partial(\varepsilon_{FW} \rho_L)}{\partial t} + \frac{\partial(\varepsilon_D \rho_L)}{\partial t} = -\nabla \cdot (\mathbf{J}_L + \mathbf{J}_V),$$

$$(\underline{\rho c})\frac{\partial T}{\partial t} - \lambda_E \frac{\partial(\varepsilon_{FW} \rho_L)}{\partial t} + (\lambda_D + \lambda_E)\frac{\partial(\varepsilon_D \rho_L)}{\partial t} = \nabla \cdot (k \nabla T) + \lambda_E \nabla \cdot \mathbf{J}_L - (\underline{\rho c \mathbf{v}}) \cdot \nabla T.$$

- Primary unknowns: temperature T, pore pressure P_G, water vapour content $\rho_{V.}$
- Solution:
  - Finite element formulation
  - Finite difference scheme for the time discretisation (implicit)

Mechanical analysis of composite slab exposed to fire load

- Each layer of the composite slab is modelled by Reissner's geometrically exact beam theory.

- Shear strains are neglected.

- Stress-strain state is determined iteratively, where the whole time of the duration is divided into time intervals $[t^{i-1},t^{i}]$.

- The steel–concrete slab is subjected to a conservative, time independent load, and a time-dependent growth of temperature.

- Interlayer slip is allowed, while uplift between layers is not allowed.

Basic equations of a steel-concrete composite slab (a numerical model)

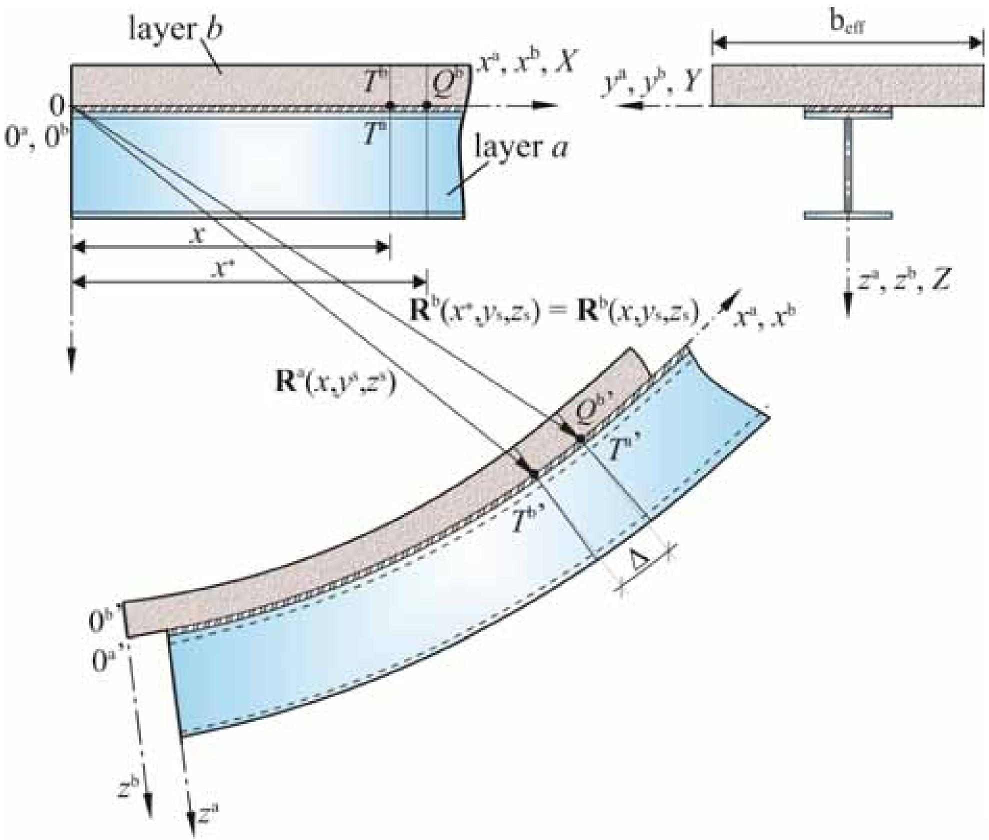
- constitutive eq.
- kinematic eq.
- equilibrium eq.

  + boundary conditions
- and constraining eq. (they assemble each layer into a multi-layered composite beam)

$$\mathbf{R}^a(x) = \mathbf{R}^b(x^*),$$

or in the componential form:

$$x + u^a(x) = x^* + u^b(x^*),$$
$$w^a(x) = w^b(x^*),$$



Basic equations

- Based on the given stress and strain state at the time t^{i-1} and temperature at t^i, we can determine the strains of each layer at the time t^i :

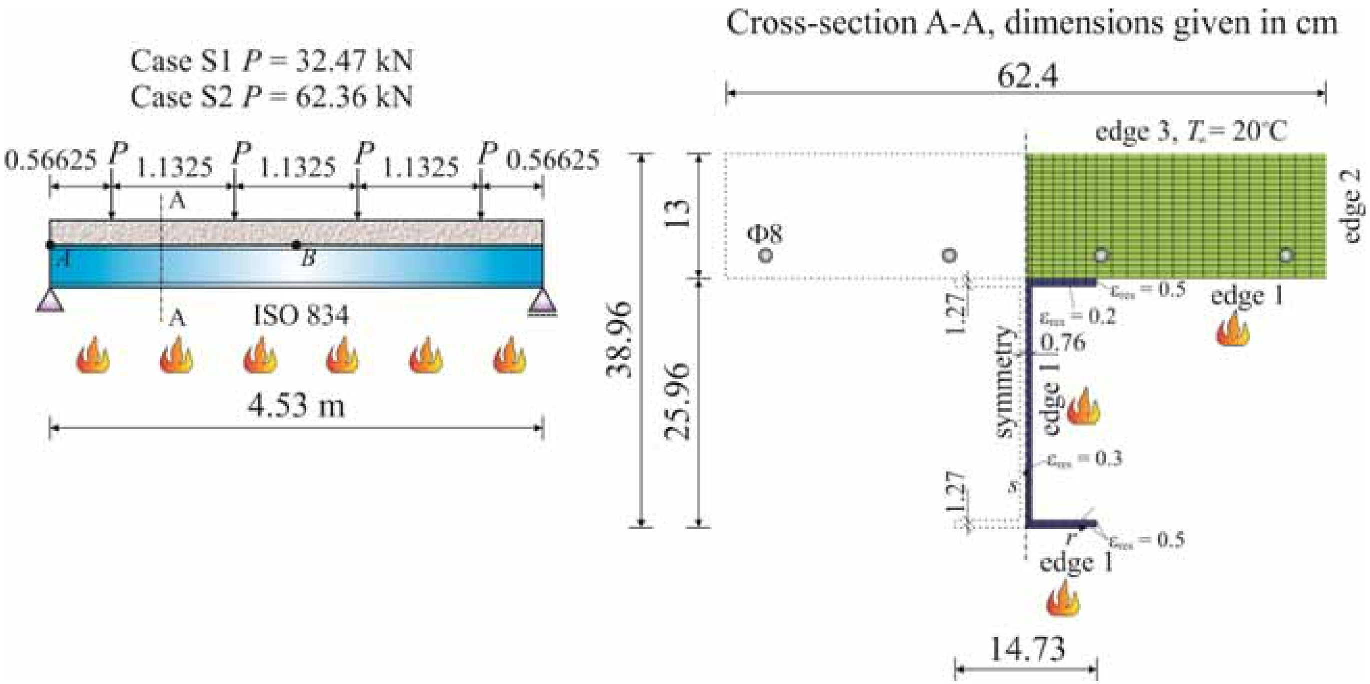
$$D^{a,i} = D^{a,i-1} + \Delta D^{a,i}$$
$$D^{b,i} = D^{b,i-1} + \Delta D^{b,i}$$

- Considering the principle of additivity of strains and the material models of concrete and steel at elevated temperatures, we propose that the strain increment is the sum of different strains:

$$\Delta D^{a,i} = \Delta D^{a,i}_{th} + \Delta D^{a,i}_{\sigma} + \Delta D^{a,i}_{cr}$$
$$\Delta D^{b,i} = \Delta D^{b,i}_{th} + \Delta D^{b,i}_{\sigma} + \Delta D^{b,i}_{cr} + \Delta D^{b,i}_{tr}$$

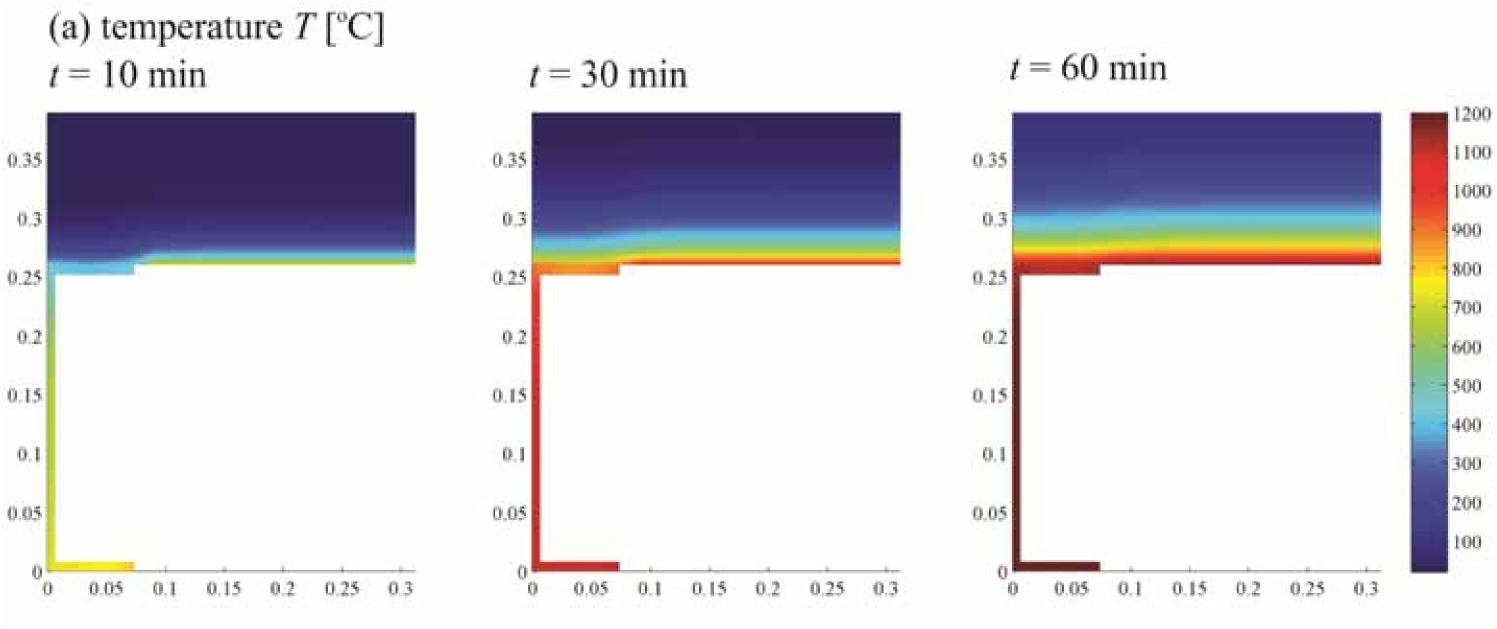
Numerical example (1st phase)

- Composite beam is exposed to standard fire ISO 834.
- 2 examples:
  - Case S1
  - Case S2



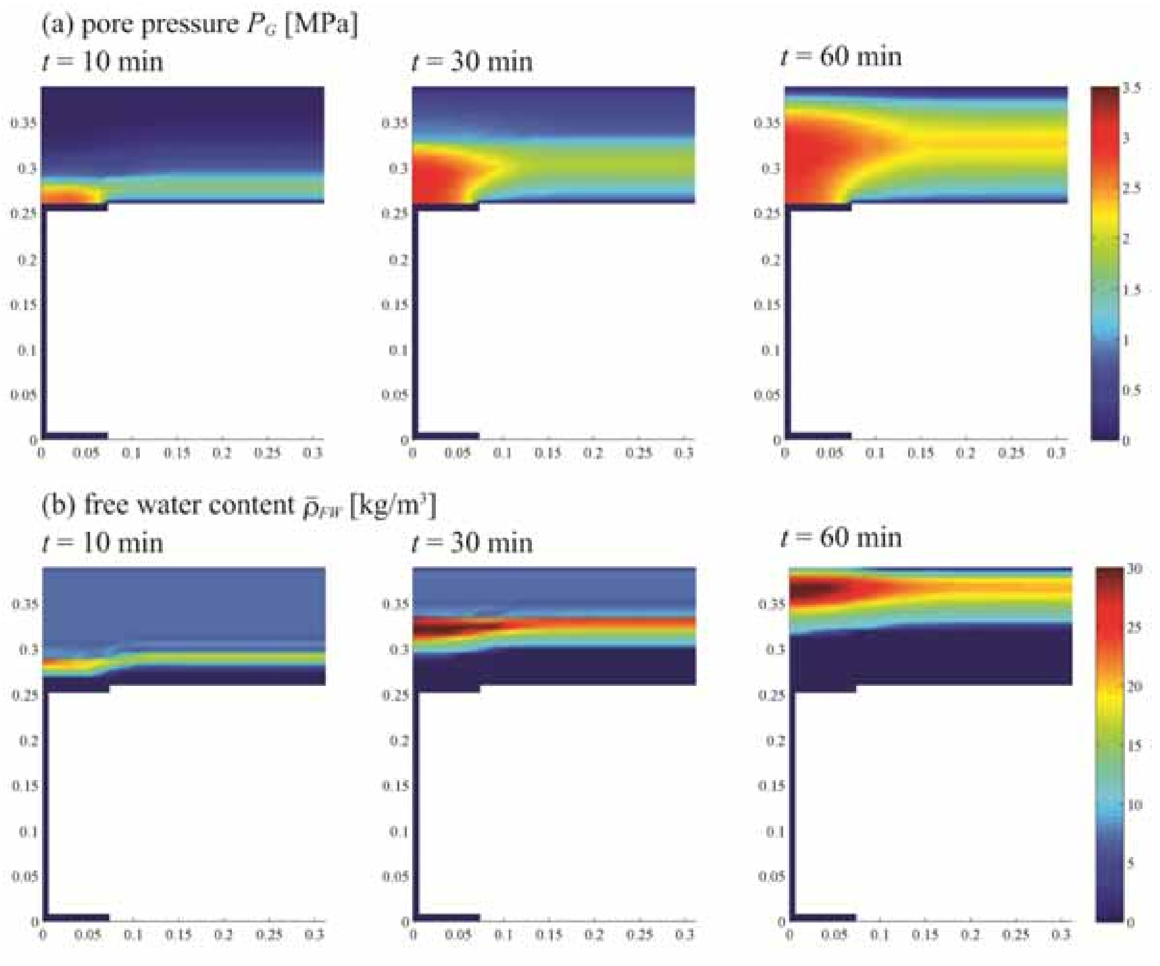
Results

- Distribution of temperature



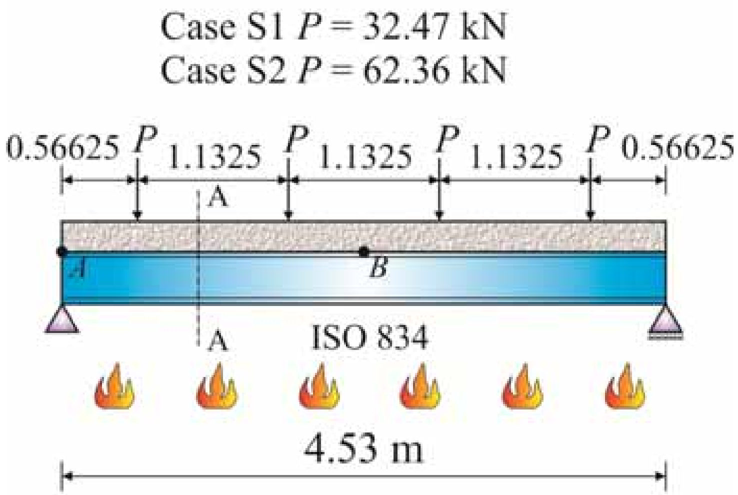
Results

- Distribution of pore pressure and free water content



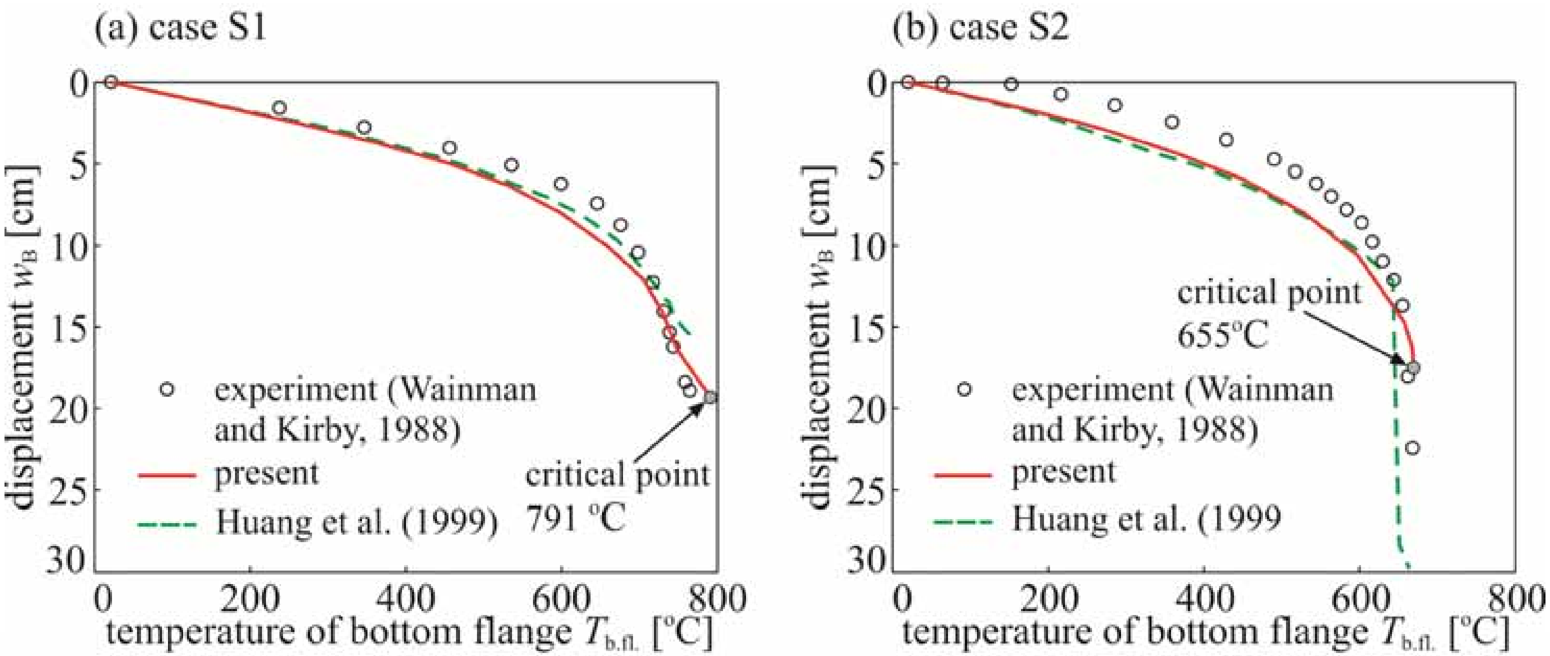
Numerical example (2nd phase)

- Composite exposed to a uniform load and standard fire ISO 834.
- Material models for steel and concrete at elevated temperatures according to EC2 and EC3
- Modified shear traction-slip material model proposed by Huang *et al.*



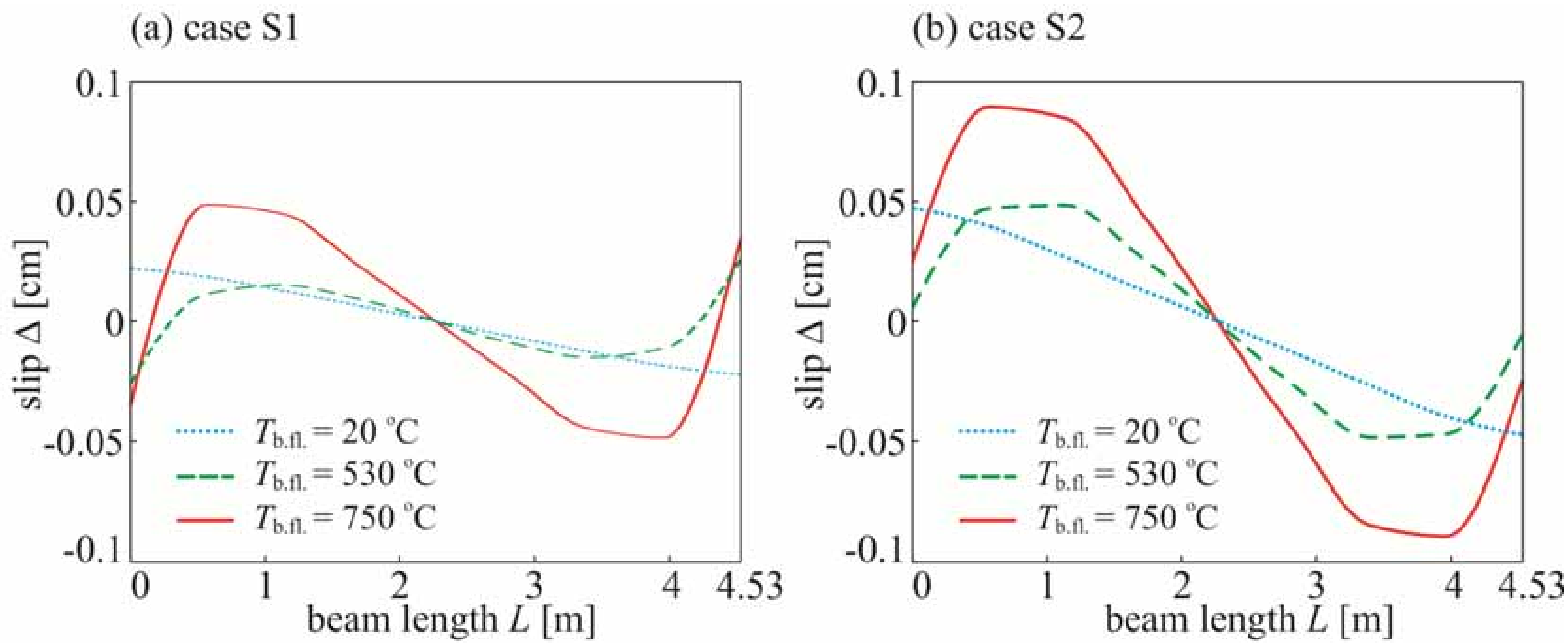
Results

- Variation of the mid-span deflection of the composite beam vs. bottom flange temperature:



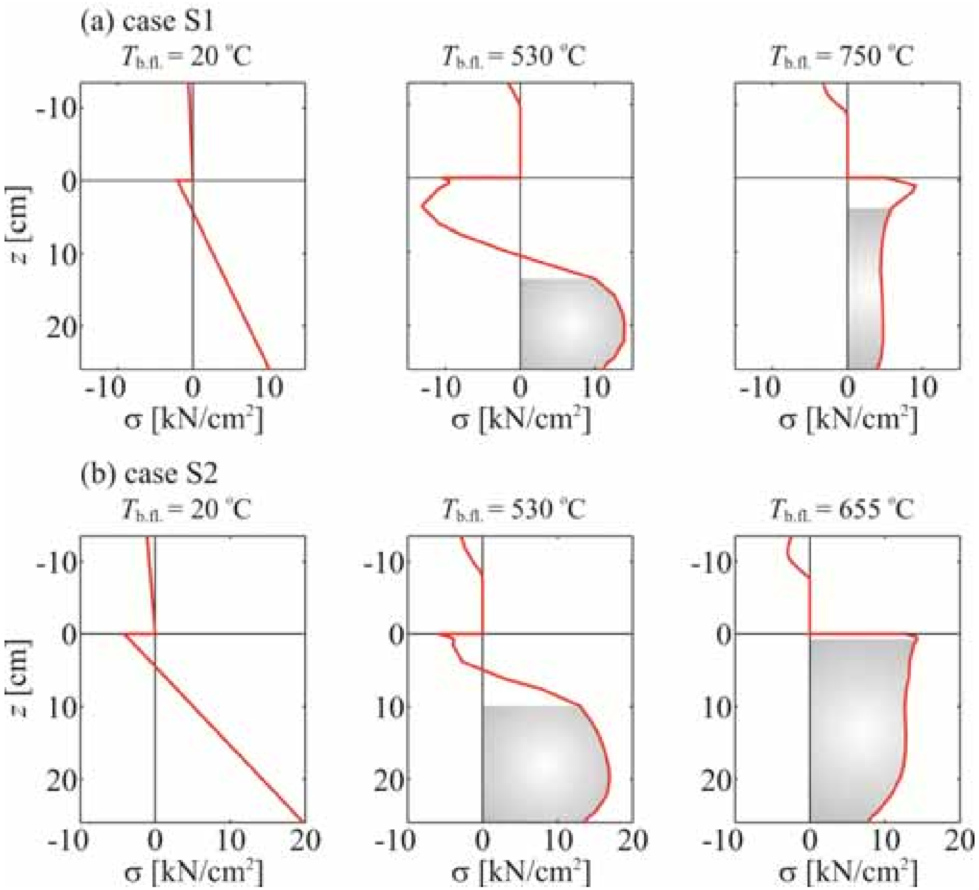
Results

- The variation of slip along the contact



Results

- The distribution of stresses and spread of the plastic zone over the cross section in the midpoint of the beam:



Conclusions

- Presented fire analysis divided into two phases:
  - Thermal (heat+mass transport)
  - Mechanical
- The presented strain-based finite-element beam formulation proves to be an appropriate tool for the thermo-mechanical analysis of frame-like structures, as it is robust, reliable and accurate.

Thank you for your attention