Fire Behaviour of Steel and Composite Floor Systems

Numerical investigation of simple design method

Jan. 2011
Objectives of parametric study

Parametric study properties
- Grid size of the floor
- Load levels
- Link condition between floor and steel columns
- Fire rating: R30, R60, R90 and R120

Finite Element Analysis
- Numerical slab panel model
- Thermo-mechanical properties of materials used in FEA

Validation of the numerical model
- Thermal analyses
- Structural analyses

Effect of continuity at the panel boundary

Parametric study results
- Deflection of the floor
- Elongation capacity of reinforcing bars

Conclusion
Objectives of parametric study

- **Background**
  - FRACOF full scale *standard fire test*
    - Excellent fire performance of the composite floor systems (presence of tensile membrane action)
    - Max $\theta$ of steel $\approx 1000$ °C, fire duration $> 120$ min
    - French construction details
    - Deflection $\approx 450$ mm

- **Objective**
  - Verification of the Simple Design Method to its full application domain (using advanced calculation models)
    - Deflection limit of the floor
    - Elongation of reinforcing steel
Objectives

Parametric study properties

Finite Element Analysis

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Conclusion

**Grid size of the floor**

- Primary beams
- Protected secondary beams
- Unprotected intermediate beams

**Load levels**

According to EC0 load combination in fire situation for office buildings:

\[ G \ (\text{Dead Load}) + 0.5 \ Q \ (\text{Imposed Load}) \]

- \( G = \text{Self weight} + 1.25 \ \text{kN/m}^2 \)
- \( Q = 2.5 \ & \ 5 \ \text{kN/m}^2 \)
Objectives

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- **Link condition between floor and steel columns**

With mechanical link between slab and columns

Without mechanical link between slab and columns
Objectives

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- **Fire rating: R30, R60, R90 and R120**

  ![Graph showing heating of boundary beams (Max. 550 °C)]
**Finite Element Model**

- Hybrid model based on several types of Finite Element with computer code ANSYS

- **Objectives**
  - Parametric study properties

- **Finite Element Analysis**

- **Validation of the numerical model**

- **Effect of boundary conditions**

- **Parametric study results**

- **Conclusion**
Slab panel properties

- S235 beams
- COFRAPLUS60 trapezoidal steel decking (0.75 mm thick)
- Normal weight concrete C30/37
- S500 reinforcement mesh
- Average mesh position (from top surface) = 45 mm
Thermo-mechanical properties (1/2)

- **Steel thermo-mechanical properties:**
  - Thermal properties from EC4-1.2
  - Unit mass independent of the temperature ($\rho_a = 7850 \text{ kg/m}^3$)
  - Stress-strain relationships:

![Graph showing stress-strain curves at different temperatures]

- **Objectives**
- Parametric study properties
- Finite Element Analysis
- Validation of the numerical model
- Effect of boundary conditions
- Parametric study results
- Conclusion
Objectives

- Concrete thermo-mechanical properties:
  - Thermal properties from EC4-1.2
  - Unit mass as a function of temperature according to EC4-1.2
  - Drucker-Prager yield criterion
  - Compressive reduction factors from EC4-1.2:
Validation of the numerical model (1/2)

**Objectives**

- Parametric study
- Finite Element Analysis

**Validation of the numerical model**

- Comparison with fire test (heat transfer analysis)

**Effect of boundary conditions**

- Parametric study results

**Conclusion**
Validation of the numerical model (2/2)

Objectives

- Parametric study properties
- Finite Element Analysis
- Validation of the numerical model
- Effect of boundary conditions
- Parametric study results
- Conclusion

Comparison with fire test (deflection)

Time (min) vs Displacement (mm)

- Mid-span of unprotected central part of the floor
- Mid-span of protected edge secondary beams
- Mid-span of protected primary beams

Comparison of the deflection (slab and beams)

Simulated deformed shape of the floor after test
Effect of continuity at the panel boundary

Objectives

Parametric study properties

Finite Element Analysis

Validation of the numerical model

Effect of boundary conditions

Parametric study results

Conclusion

- More important predicted deflection in the corner grid with 2 continuous edges than in other 3 grids with 3 or 4 continuous edges.

Structure grid of a real building

Restraint conditions

ANSYS model
Comparison of the FEA deflection with the maximum allowable deflection according to SDM (Simple Design Method)

With mechanical link between slab and columns in advanced calculations
Parametric study results (2/4)

- Comparison of the FEA deflection with the maximum allowable deflection according to SDM (Simple Design Method)

Without mechanical link between slab and columns in advanced calculations
Parametric study results (3/4)

- Comparison of the time when the FEA deflection reaches span/30 with the fire resistance according to SDM (Simple Design Method)

![Graph showing comparison of t_{Span/30}/t_{Fire Resistance} for different dimensions and fire resistance ratings.]

- **Conclusion**
  
  - Span/30 criterion is not reached in FEA all through the fire resistance duration predicted by SDM
**Objectives**

Parametric study properties

Finite Element Analysis

Validation of the numerical model

Effect of boundary conditions

Parametric study results

Conclusion

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**Parametric study results (4/4)**

- **Elongation capacity of reinforcing bars**

![Graph showing elongation capacity of reinforcing bars for different dimensions and reinforcement grades.]

- **Conclusion**
  - Elongation of reinforcing steel $< 5\% = \text{Min. allowable elongation capacity according to EC4-1.2.}$
Conclusion

- SDM (Simple Design Method) is on the safe side in comparison with advanced calculation results.

- Concerning the elongation of reinforcing steel mesh, it remains generally below 5%.

- Mechanical links between slab and columns can reduce the deflection of a composite flooring system under a fire situation but they are not necessary as a constructional detail.

- SDM is capable of predicting in a safe way the structural behaviour of composite steel and concrete floor subjected to standard fire.