Fire Behaviour of Steel and Composite Floor Systems

*Numerical parametric investigation of simple design method*
Content of presentation

- Objectives of parametric study
- Parametric study properties
- Finite Element Analysis
- Validation of the numerical model
- Effect of continuity at the panel boundary
- Parametric study results
- Conclusion
Objectives of parametric study

- **Background**
  - FRACOF (Test 1)- COSSFIRE (Test 2) full scale standard fire tests
    - Excellent fire performance of the composite floor systems (presence of tensile membrane action)
    - Max \( \theta \) of steel \( \approx 1000 ^\circ C \), fire duration \( > 120 \text{ min} \)
    - French construction details
    - Deflection \( \approx 450 \text{ mm} \)
  - FICEB (Test 3) full scale natural fire test with Cellular Beams

- **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

Validation of the numerical model

Effect of boundary conditions

Parametric study results

Conclusion

**Parametric study properties (1/3)**

- **Grid size of the floor**

  ![Diagram showing grid sizes and beam types](image)

  - 6 m x 6 m
  - 6 m x 9 m
  - 9 m x 9 m
  - 6 m x 12 m
  - 9 m x 12 m
  - 7.5 m x 15 m
  - 9 m x 15 m

- **Load levels**

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

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

  \[ G = \text{Self weight} + 1.25 \, \text{kN/m}^2 \]

  \[ Q = 2.5 \, \text{& 5 kN/m}^2 \]
Parametric study properties (2/3)

- Link condition between floor and steel columns

With mechanical link between slab and columns

Without mechanical link between slab and columns
• Fire rating: R30, R60, R90 and R120

Heating of boundary beams (Max. 550 °C)
Numerical parametric investigation of simple design method

Finite Element Model

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

Objectives
- Parametric study properties

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Conclusion
Objectives

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Conclusion

- Hybrid model based on several types of Finite Element with computer code SAFIR
Objectives
- Parametric study properties

**Finite Element Analysis**
- Validation of the numerical model
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- Parametric study results

**Conclusion**
- Numerical parametric investigation of simple design method

**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

![Diagram of slab panel properties]
Thermo-mechanical properties (1/2)

Objectives

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• 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 relationships at different temperatures]
• **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:

![Graph showing temperature and unit mass as a function of temperature](image)

**Objectives**
- Parametric study
- Properties

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

**Conclusion**
Validation of the ANSYS numerical model vs Test 1 (1/2)

Objectives

Parametric study properties

Finite Element Analysis

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Parametric study results

Conclusion

• Comparison with fire test (heat transfer analysis)

Unprotected steel beams

Protected secondary beams

Protected primary beams

Composite slab
Validation of the ANSYS numerical model vs Test 1 (2/2)

- Comparison with fire test (deflection)

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

**Validation of the numerical model**

**Effect of boundary conditions**

**Parametric study results**

**Conclusion**

**Comparison with fire test (deflection)**

Simulated deformed shape of the floor after test

Comparison of the deflection (slab and beams)

Mid-span of unprotected beams

Mid-span of protected primary beams

Mid-span of protected edge secondary beams

Central part of the floor

Test Simulation

Displacement (mm)

Time (min)
Validation of the SAFIR numerical model vs Test 1 (1/2)

Objectives

- Comparison with fire test (heat transfer analysis)

Validation of the numerical model

Effect of boundary conditions

Parametric study results

Conclusion

Unprotected secondary beam: Temperatures comparison

Unprotected steel beams

Structural Concrete

Thermal Concrete (material without mechanical resistance)

Composite slab

Parametric study properties

Finite Element Analysis

Parametric study results

Conclusion
Validation of the SAFIR numerical model vs Test 1 (2/2)

- Comparison with fire test (deflection)

Simulated stresses in the slab end of the test

Comparison of the deflection (slab and beams)
Validation of the SAFIR numerical model vs Test 2 (1/2)

Objectives

Parametric study properties

Finite Element Analysis

Validation of the numerical model

Effect of boundary conditions

Parametric study results

Conclusion

• Comparison with fire test (heat transfer analysis)
Validation of the SAFIR numerical model vs Test 2 (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)

Simulated stresses in the slab end of the test

Comparison of the deflection (slab and beams)
Validation of the SAFIR numerical model vs Test 3 (1/3)

Objectives

Parametric study properties

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Parametric study results

Conclusion

• Comparison with fire test (heat transfer analysis)

Unprotected secondary cellular beam: Temperatures comparison

Slab temperature comparison (zone A)
Validation of the SAFIR numerical model vs Test 3 (2/3)

- Hybrid Model to take into account the WPB with BEAM element

**Objectives**

- Parametric study properties
- Finite Element Analysis

**Validation of the numerical model**

- Effect of boundary conditions
- Parametric study results

**Conclusion**

Numerical parametric investigation of simple design method
Validation of the SAFIR numerical model vs Test 3 (3/3)

- Comparison with fire test (deflection)

Simulated stresses in the slab end of the test

Central vertical deflection of unprotected secondary beam

Comparison of the deflection
Effect of boundary conditions

Objectives

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Conclusion

Structure grid of a real building

Restraint conditions

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

![Graph showing comparison between FEA deflection and SDM limits.](image)

**Objectives**
- Parametric study properties
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**Parametric study results**

**Conclusion**

Without mechanical link between slab and columns in advanced calculations
• Comparison of the time when the FEA deflection reaches span/30 with the fire resistance according to SDM (Simple Design Method)

• Conclusion
  – Span/30 criterion is not reached in FEA all through the fire resistance duration predicted by SDM
• Elongation capacity of reinforcing bars

![Graph showing the max. mechanical strain of reinforcing steel for different dimensions and reinforcing categories (R 30, R 60, R 90, R 120).]

- Elongation of reinforcing steel < 5 % = Min. allowable elongation capacity according to EC4-1.2.

**Objectives**
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**Finite Element Analysis**
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**Effect of boundary conditions**
- Parametric study results

**Conclusion**
- Elongation of reinforcing steel < 5 % = 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.