Fire Behaviour of Steel and Composite Floor Systems

New Experimental Evidences

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26th of May 2011

Content of presentation

- Objectives of new fire tests
- Full scale fire tests within the projects of
  - FRACOF
  - COSSFIRE
- Test set-up
- Experimental results
  - Temperature
  - Displacement
- Observation and analysis
- Comparison with simple design methods
- Conclusion
**Why more fire tests**

- **Background**
  - Cardington fire tests
    - Excellent fire performance under natural fire condition
    - Max θ of steel ≈ 1150 °C, fire duration ≈ 60 min (> 800°C)
    - UK construction details

- **Objectives**
  - To confirm same good performance under long fire duration (at least 90 minutes of ISO fire)
  - To investigate the impact of different construction details, such as reinforcing steel mesh and fire protection of edge beams
  - To validate different fire safety engineering tools

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**Design of test specimens**

- **FRACOF test**

  - Structure grid of a real building
  - Adopted steel frames for FRACOF fire test

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Design of test specimens

- COSSFIRE test

Structure grid of a real building

Adopted steel frames for COSSFIRE fire test

Design of test specimens

- Final composite floor systems

FRACOF

COSSFIRE
Design of structural members

Objectives

- Steel frame
  - Steel and concrete composite beams
    - According to Eurocode 4 part 1-1 (EN1994-1-1)
  - Short steel columns

- Composite slab
  - Total depth
    - According to Eurocode 4 part 1-2 (EN1994-1-2)
  - Reinforcing steel mesh
    - Based on simple design rules

- Steel joints
  - Commonly used joints: double angle and end plate
    - According to Eurocode 3 part 1.8 (EN1993-1-8)

Test setup

- Arrangement of headed studs over steel beams

  - TRW Nelson KB 3/4” – 125 (Φ = 19mm; h = 125 mm; \( f_y = 350 \text{ N/mm}^2 \); \( f_u = 450 \text{ N/mm}^2 \))
Steel joints

<table>
<thead>
<tr>
<th>Beam to column</th>
<th>Beam to beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary beam</td>
<td>Primary beam</td>
</tr>
<tr>
<td>Double angle web cleats</td>
<td>Flexible end plate</td>
</tr>
<tr>
<td>Flexible end plate</td>
<td>Double angle web cleats</td>
</tr>
</tbody>
</table>

Grade of steel bolts: 8.8
Diameter of steel bolt: 20 mm

Sizes of structural members

Composite slab

Reinforcing steel mesh

Mesh size: 150x150
Diameter: 7 mm
Steel grade: S500
Axis distance from top of the slab:
- 50 mm FRACOF
- 35 mm COSSFIRE

Steel deck: COFRAPLUS60 – 0.75 mm
Concrete quality: C30/37
**Mechanical loading condition**

- **15 sand bags of 1512 kg**
  - Equivalent uniform load: 390 kg/m²

- **20 sand bags of 1098 kg**
  - Equivalent uniform load: 393 kg/m²

**Preparation of FRACOF fire test**

1. [Image of preparation setup]
2. [Image of equipment arrangement]
3. [Image of initial setup]
4. [Image of final setup]

**Objectives**

- Test set-up
- Experimental results & Observation
- Comparison with simple design methods
- Conclusion

**FRACOF**

**COSSFIRE**
Behaviour of the floor during fire

Before the test

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

After the test

Unprotected secondary beams

Composite slab

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Experimental results

- Fire temperature
- Heating of unprotected steel beams
- Heating of protected steel members
- Heating of composite slab
- Deflection of the floor
- Observations over the behaviour of composite floor systems
  - Concrete cracking and concrete crushing
  - Failure of reinforcing steel mesh during the test
  - Collapse of edge beams

Objectives
Test set-up
Experimental results & Observation
Comparison with simple design methods
Conclusion
• Heating of unprotected steel beams

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time (min)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>300</td>
<td>90</td>
</tr>
<tr>
<td>400</td>
<td>120</td>
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<tr>
<td>500</td>
<td>150</td>
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<tr>
<td>600</td>
<td>180</td>
</tr>
<tr>
<td>700</td>
<td>210</td>
</tr>
<tr>
<td>800</td>
<td>240</td>
</tr>
</tbody>
</table>

- Much hotter beams in COSSFIRE test = 550 °C and one edge secondary beam heated up to > 600 °C
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Experimental results

• Heating of composite slab

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time (min)</th>
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<tbody>
<tr>
<td>0</td>
<td>30</td>
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<tr>
<td>100</td>
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<td>200</td>
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</tbody>
</table>

D and E: reinforcing steel

FRACOF  COSSFIRE

Displacement transducers for deflection

<table>
<thead>
<tr>
<th>Displacement transducers</th>
<th>FRACOF</th>
<th>COSSFIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td></td>
<td></td>
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<tr>
<td>D2</td>
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<tr>
<td>D3</td>
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<tr>
<td>D4</td>
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FRACOF  COSSFIRE

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**Experimental results**

- Deflection of the floors

![Graph showing deflection of floors with FRACOF and COSSFIRE](image)

- Cracking of concrete (FRACOF)

![Concrete crack](image)

- Observation
  - Excellent global stability of the floor despite the failure of reinforcing steel mesh
**Experimental results**

- **Crushing of concrete (COSSFIRE)**

![Concrete crushing]

- **Observation**
  - Global stability of the floor maintained appropriately despite the failure of one edge beam

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**Comparison with simple design rules**

<table>
<thead>
<tr>
<th></th>
<th>FRACOF</th>
<th>COSSFIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire rating (min)</td>
<td>&gt; 120</td>
<td>&gt; 120</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td>450</td>
<td>366(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>510</td>
</tr>
<tr>
<td></td>
<td></td>
<td>376(*)</td>
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</tbody>
</table>

- **Observation**
  - Experimental results:
    - Fire rating > 120 minutes
## New experimental evidences

<table>
<thead>
<tr>
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<tr>
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### General conclusions relative to new fire tests

- Excellent performance of the composite floor systems behaving under membrane action for long ISO fire exposure (>120 minutes)
- **High level of robustness of the composite floor system despite certain local failures**
- Specific attention to be paid to construction details with respect to reinforcing steel mesh in order to ensure a good performance of integrity criteria
- Simple design method is on the safe side in comparison with test results
- No sign of failure during cooling phase of the composite floor systems