Fire Behaviour of Steel and Composite Floor Systems

New Experimental Evidences

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Oct. 2010
• 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
• Background
  – Cardington fire tests
    • Excellent fire performance under natural fire condition
    • Max $\theta$ of steel $\approx 1150$ °C, fire duration $\approx 60$ 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
• FRACOF test

Structure grid of a real building

Adopted steel frames for FRACOF fire test
Design of test specimens

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- COSSFIRE test

Structure grid of a real building

Adopted steel frames for COSSFIRE fire test
Design of test specimens

- Final composite floor systems

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion
Design of structural members

Objectives

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Comparison with simple design methods

Conclusion

• **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)
Design of structural members

- Arrangement of headed studs over steel beams

- Type of steel studs
  - 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

#### Objectives

#### Test set-up

#### Experimental results & Observation

#### Comparison with simple design methods

#### Conclusion

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

**Grade of steel bolts:** 8.8  
**Diameter of steel bolt:** 20 mm
**Composite slab**

- **Steel deck**: COFRAPLUS60 – 0.75 mm
- **Concrete quality**: C30/37

**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

**Sizes of structural members**

Objectives

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Conclusion

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

Objectives

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Behaviour of the floor during fire

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion
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
Experimental results

- Fire temperature
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• Heating of unprotected steel beams

Temperature (°C)

0 100 200 300 400 500 600 700 800 900 1000 1100

Time (min)

0 30 60 90 120 150 180 210 240

FRACOF Cossfere

A
B
C

Comparison with simple design methods

Conclusion

Test set-up

Objectives

Experimental results & Observation

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Experimental

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Experimental results

- Heating of protected steel beams

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

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- Observation
  - Much hotter beams in COSSFIRE test $\approx 550 \, ^\circ C$ and one edge secondary beam heated up to $> 600 \, ^\circ C$
• Heating of composite slab

![Graph of temperature over time for FRACOF and COSSFIRE](image)

- FRACOF
- COSSFIRE
Experimental results

- Displacement transducers for deflection

Objectives

Test set-up

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Conclusion

FRACOF

COSSFIRE
• Deflection of the floors

![Graph showing deflection of floors with labels D1, D2, D3, D4, D5, D6, D7, D8. The graphs compare experimental results with extrapolated results using FRACOF and COSSFIRE software.]
Experimental results

- Cracking of concrete (FRACOF)

Objectives

Test set-up

Experimental results & Observation

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Conclusion

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

- Crushing of concrete (COSSFIRE)

- Observation
  - Global stability of the floor maintained appropriately despite the failure of one edge beam
## Comparison with simple design rules

### Objectives

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

### Test set-up

<table>
<thead>
<tr>
<th></th>
<th>FRACOF</th>
<th>COSSFIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire rating (min)</strong></td>
<td>Test: &gt; 120 Simple design methods: 120</td>
<td>Test: &gt; 120 Simple design methods: 96</td>
</tr>
<tr>
<td><strong>Deflection (mm)</strong></td>
<td>Test: 450 Simple design methods: 366(*)</td>
<td>Test: 510 Simple design methods: 376(*)</td>
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</tbody>
</table>

### Observation

- Experimental results:
  - Fire rating > 120 minutes

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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