Fire test to Eurocode design
Content of presentation

- Objectives of new fire tests
- Full scale fire tests within the projects of
  - FRACOF (Test 1 ISO Fire)
  - COSSFIRE (Test 2 ISO Fire)
  - FICEB (Test 3 Natural fire & Cellular Beams)
- Test set-up
- Experimental results
  - Temperature
  - Displacement
- Observation and analysis
- Comparison with simple design methods
- Conclusion


Why more fire tests?

Objectives

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
Design of test specimens

- Test 1 (FRACOF)

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Structure grid of a real building

Adopted steel frames for fire Test 1
Design of test specimens

- Test 2 (COSSFIRE)

Structure grid of a real building

Adopted steel frames for fire Test 2
Design of test specimens

- Final composite floor systems

**Test 1**

**Test 2**
Design of structural members

Objectives

Test set-up

Experimental results & Observation

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>Secondary beam</td>
<td>Primary beam</td>
</tr>
<tr>
<td>Double angle web cleats</td>
<td>Flexible end plate</td>
</tr>
<tr>
<td>Double angle web cleats</td>
<td></td>
</tr>
</tbody>
</table>

**Grade of steel bolts: 8.8**  
**Diameter of steel bolt: 20 mm**
Sizes of structural members

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Composite slab

Reinforcing steel mesh

Mesh size: 150x150
Diameter: 7 mm
Steel grade: S500
Axis distance from top of the slab:
- 50 mm Test 1
- 35 mm Test 2

Steel deck: COFRAPLUS60 – 0.75 mm
Concrete quality: C30/37
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 fire test 2

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

New Experimental Evidences
Behaviour of the floor during fire

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

New Experimental Evidences
Structure of the Test 3 (FICEB)

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Beam-3

Beam-4

Beam-5

Beam-solid

Column GL-D

Column GL-A
Structure of the Test 3

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion
Structure of the Test 3

Beam - Beam Connections

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

New Experimental Evidences
Structure of the Test 3

Beam - Column Connections

- Objectives
- Test set-up
- Experimental results & Observation
- Comparison with simple design methods
- Conclusion
Structure of the Test 3

A393 Mesh Reinforcement, dia 10mm

Full Interaction: between slab & beams, achieved by Shear connectors, dia 19, h=95mm
U-bars reinf. around the slab was added to ensure correct reinf. Detail requirement for Ambient Temp.
Structure of the Test 3

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

VIEW ON TOP OF SLAB

New Experimental Evidences
Fire load energy density was 700 MJ/m²
The fire load can be achieved using 45 standard wooden cribs (1m x 1m x 0.5 m high), positioned evenly around the compartment (9.0m x 15.0m).
Experimental results

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- 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

![Graph showing temperature vs. time for different tests and methods.]

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

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

• Test 3 Fire temperature
Experimental results

- Heating of unprotected steel beams

Objectives
Test set-up
Experimental results & Observation
Comparison with simple design methods
Conclusion
• Test 3 Heating of unprotected steel beams

Beam 4 Zone 3 Centre

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>200</td>
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<tr>
<td>140</td>
<td>1400</td>
</tr>
<tr>
<td>160</td>
<td>1600</td>
</tr>
</tbody>
</table>

A, B, C, D, E, F
 Experimental results

- **Heating of protected steel beams**

![Graphs showing temperature over time for different test cases.]

- **Observation**
  - Much hotter beams in Test 2 ≈ 550 °C and one edge secondary beam heated up to > 600 °C
Experimental results

- Heating of composite slab

Test 1

Test 2
Experimental results

- Test 3 Heating of composite slab

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion
**Experimental results**

- **Displacement transducers for deflection**

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**Objectives**

**Test set-up**

**Experimental results & Observation**

**Comparison with simple design methods**

**Conclusion**

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**Test 1**

**Test 2**

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New Experimental Evidences
Experimental results

- Deflection of the floors

Vertical displacement (mm) vs. Time (min) for different tests.

**Test 1**

**Test 2**

Extrapolated results
- Test 3 Displacement transducers for deflection
Experimental results

- Test 3 Deflection of the floors

**Beam5 Deflection (LVDT 12-8)**

- 30min
- 60min
- 90min
- 120min
- 150min
- 1 Day
-Unload

<table>
<thead>
<tr>
<th>Span(m)</th>
<th>Left to Right</th>
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<tbody>
<tr>
<td>0.00</td>
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</tr>
<tr>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>7.50</td>
<td></td>
</tr>
<tr>
<td>11.25</td>
<td></td>
</tr>
<tr>
<td>15.00</td>
<td></td>
</tr>
</tbody>
</table>

Deflection(mm)
Experimental results

- Cracking of concrete (Test 1)

- Observation
  - Excellent global stability of the floor despite the failure of reinforcing steel mesh
- Cracking of concrete (Test 3)

- Observation
  - Excellent global stability of the floor despite appearance of the crack
Experimental results

- Web instability of the beam (Test 3)
- *Crushing of concrete (Test 2)*

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

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire rating (min)</strong></td>
<td><strong>Deflection (mm)</strong></td>
</tr>
<tr>
<td>Test</td>
<td>Simple design methods</td>
</tr>
<tr>
<td>&gt; 120</td>
<td>120</td>
</tr>
<tr>
<td>450</td>
<td>366(*)</td>
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</tbody>
</table>

**Observation**
- Experimental results:
  - Fire rating > 120 minutes
• 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