Fire Behaviour of Steel and Composite Floor Systems

Review of Real Fires

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26th of May 2011

Content of presentation

• Cardington fire tests  
  – Beam test with burners  
  – Frame test with burners  
  – Corner tests with wood cribs  
  – Demonstration tests with real office furniture

• Fire tests of open car parks  
  – Localized car fire tests

• Evidence from accidental fire in real buildings and other fire tests outside Europe  
  – Accidental fires  
  – Other fire tests
Cardington fire tests

• Eight storey steel framed building

Cardington fire tests

Main parameters of the building

- Length: 42 m in 5 spans of 9 m
- Width: 21 m in 3 spans of 6 m, 9 m and 6 m
- Height of storey: 4.2 m
- Steel members: UB for beams and UC for columns
- Composite slab: lightweight concrete with a total depth of 130 mm and a trapezoidal steel deck
- Steel mesh: 142 mm²
- Steel joints: fin-plates for beam-beam joints and flexible end plates for beam-column joints
- Applied load: sand bags
Cardington fire tests

- **Restrained beam test**: span = 9.0 m

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

- **Restrained beam test**: experimental results

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

- **Observation**
  - Maximum heating ≈ 900 °C
  - Deflection of the beam: < 250 mm
Cardington fire tests

• Comparison with standard furnace fire test

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Frame test</th>
<th>Standard furnace test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
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<tr>
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<td>600</td>
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<td>800</td>
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<tr>
<td>1000</td>
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</tbody>
</table>

Deflection = Span/30

• Conclusion
  – No sign of failure in global composite floor system
  – Collapse at θ ≈ 650 °C if simply supported

Cardington fire tests

• Plane frame beam test
Cardington fire tests

- **Plane frame test**: experimental results

  ![Graph showing experimental results](graph.png)

  - **Observation**
    - Maximum heating ≈ 750 °C
    - Deflection of the beam ≈ 300 mm

- **Cardington fire tests**

- **Fire tests of open car parks**

- **Evidence from accidental fire**

- **Conclusion**
  - Squashing of unprotected part of column
  - No further collapse despite above local failure
Cardington fire tests

- Corner compartment test

Corner compartment test: set-up

Walls of the compartment with hollow breeze-blocks

Fire load with wood cribs equals to 45 kg/m²
Cardington fire tests

- Corner compartment test: experimental results

- Observation
  - Maximum heating of steel ≈ 1014 °C
  - Maximum deflection of the floor ≈ 428 mm

Fire during the test

Deformed floor after the test

Maximum steel temperature

Maximum vertical displacement

Time (mins)
Cardington fire tests

- Corner compartment test: structure after test

  - Deformed state of the heated part of the composite floor
  - Deformed state of steel members around protected steel column

- Conclusion
  - No sign of global failure of the floor as well as limited deflection of the floor despite important heating of steel

Cardington fire tests

- Demonstration test (an area of more than 130 m²)

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Cardington fire tests

- **Demonstration test**: set-up
  - Openings with normal glazed windows
  - Fire load with real office furniture

Cardington fire tests
- Fire tests of open car parks
- Evidence from accidental fire

- **Demonstration test**: experimental results
  - Fully developed fire
  - Early stage of fire
**Cardington fire tests**

- **Demonstration test**: experimental results

  ![Graph showing the change in atmospheric temperature over time.](image1)

  - **Observation**
    - Maximum gas temperature $\approx 1200^\circ C$
    - Maximum heating of steel $\approx 1150^\circ C$

- **Cardington fire tests**

  - Fire tests of open car parks
  - Evidence from accidental fire

  ![Graph showing the change in steel temperature over time.](image2)

  - **Observation**
    - Important deflection of the floor $\approx 640$ mm
    - No collapse of the floor
Cardington fire tests

- **Demonstration test**: structure after test

  ![Demonstration test](image1)

  ![Demonstration test](image2)

  Deformed state of the heated part of the composite floor
  Deformed state of steel members around protected steel column

  **Conclusion**
  - No sign of global failure of the floor **despite important heating of steel and deflection of the floor**

Cardington fire tests

- **Other fire tests**
  - Second corner test
  - Large compartment test
  - New corner test
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Cardington fire tests

• General remarks
  – Large number of severe fire tests performed in this steel framed building without collapse of the global structure
  – Much better fire performance observed with respect to ordinary standard fire tests with isolated steel members
  – Excellent global behaviour of composite floor even if steel beams were heated up to more than 1000 °C
  – Obvious enhancement of fire resistance of the composite floor owing to induced membrane effect under large deflection
  – Good structural robustness of the composite floor system in case of important concrete cracking

Fire tests of open car parks

• One storey steel framed building
Fire tests of open car park

• One storey steel framed building

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

• Main parameters of the structure

– Length: 32 m in 2 spans of 16 m
– Width: 15 m in 3 spans of 5 m
– Height of storey: 3.0 m
– Steel members: IPE for beams and H for columns
– Composite slab: normal weight concrete with a total depth of 120 mm and a re-entrant steel deck
– Steel mesh:
– Steel joints: double angle web cleats for beam-beam joints and end plates for beam-column joints
– Applied load: real cars
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Review of real fires

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

Fire tests of open car park

- Two fire tests involving three cars in each

Direction of wind

Test 1

Test 2

16 m

5 m

IPE400  IPE500  IPE550

Edge columns: HEA 180
Central columns: HEB200

0 min

Fire tests of open car park

- Experimental results (test 1)
Fire tests of open car park

- Experimental results (test 1)

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

10 min

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

33 min
Fire tests of open car park

- Experimental results (test 1)

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

62 min

Fire tests of open car park

- Experimental results (test 2)

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

0 min
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Fire tests of open car park

• Experimental results (test 2)

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

10 min

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

25 min

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire
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Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

Fire tests of open car park

- Experimental results (test 2)

Cardington fire tests
Fire tests of open car parks
Evidence from accidental fire

Fire tests of open car park

- Experimental results: gas temperature

Fire temperature (°C)

0 30 60 90 120 150 180 210

Time (min)

0 200 400 600 800 1000 1200

Test 1
Test 2
**Experimental results**: steel temperature

![Steel temperature graph](image)

- Cardington fire tests
- Fire tests of open car parks
- Evidence from accidental fire
Fire tests of open car park

- Effects of 3D membrane effect

- Conclusion
  - Reduction of displacements with 3D membrane effect compared to 2D portal frame behaviour

Accidental fires and other fire tests

- Broadgate fire
  - 14 storey-office building with composite floor system
  - Fire temperature more than 1000 °C
  - Important deflection of the floor (more than 600 mm) but no collapse
Accidental fires and other fire tests

- **Australian fire tests**
  - Full scale composite floor system
  - Fire load: 52 kg/m² of wood cribs
  - Fire temperature more than 1228 °C
  - No collapse of the floor

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire