



Education and Culture DG

Lifelong Learning Programme
LEONARDO DA VINCI



Fire Behaviour of Steel and Composite Floor Systems

Review of Real Fires

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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

Fire tests of open car parks

Evidence from accidental fire



Beam to beam joint



Beam to column joint



Cardington fire tests



Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

- **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

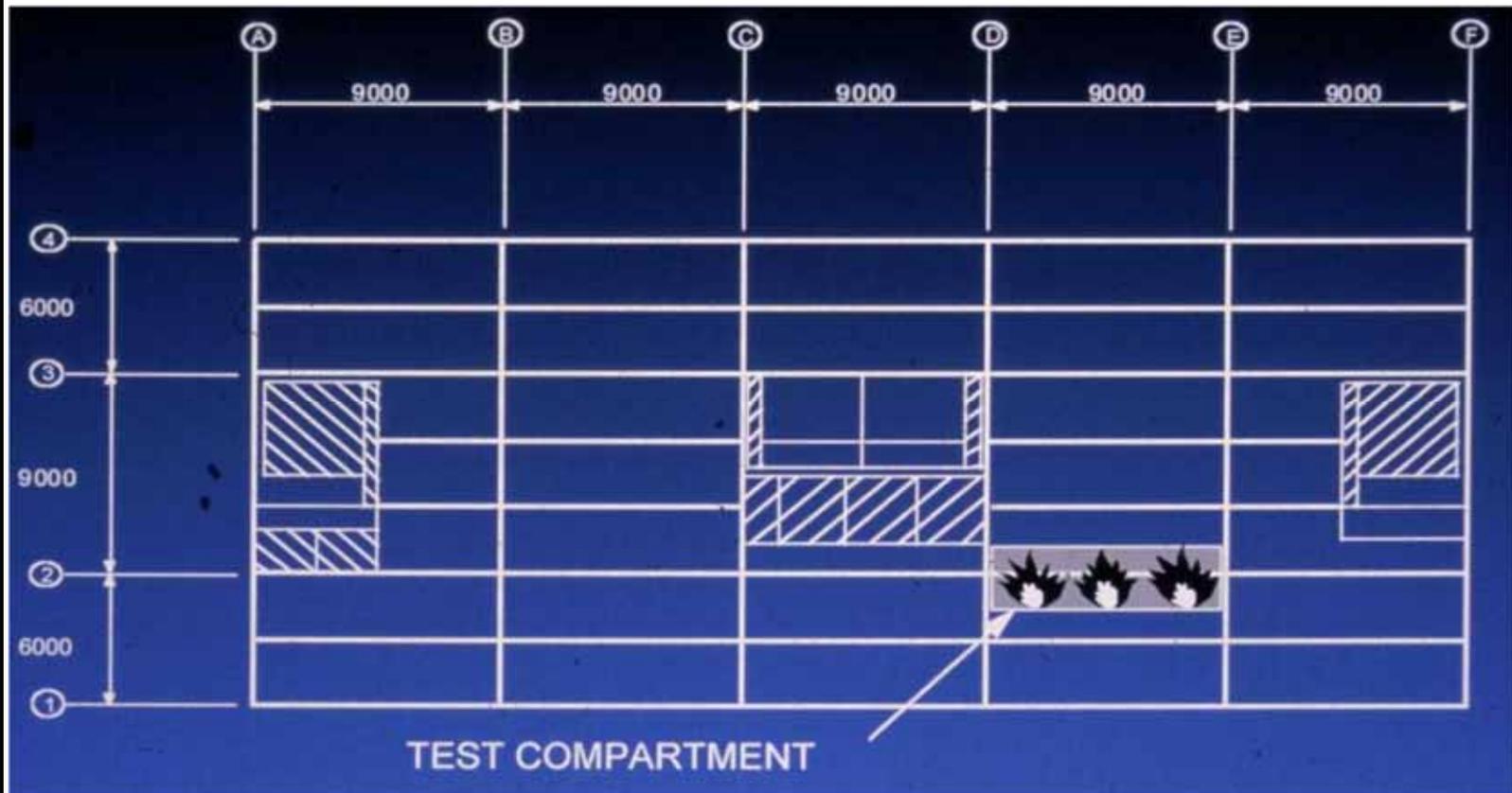


- **Restrained beam test : span = 9.0 m**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

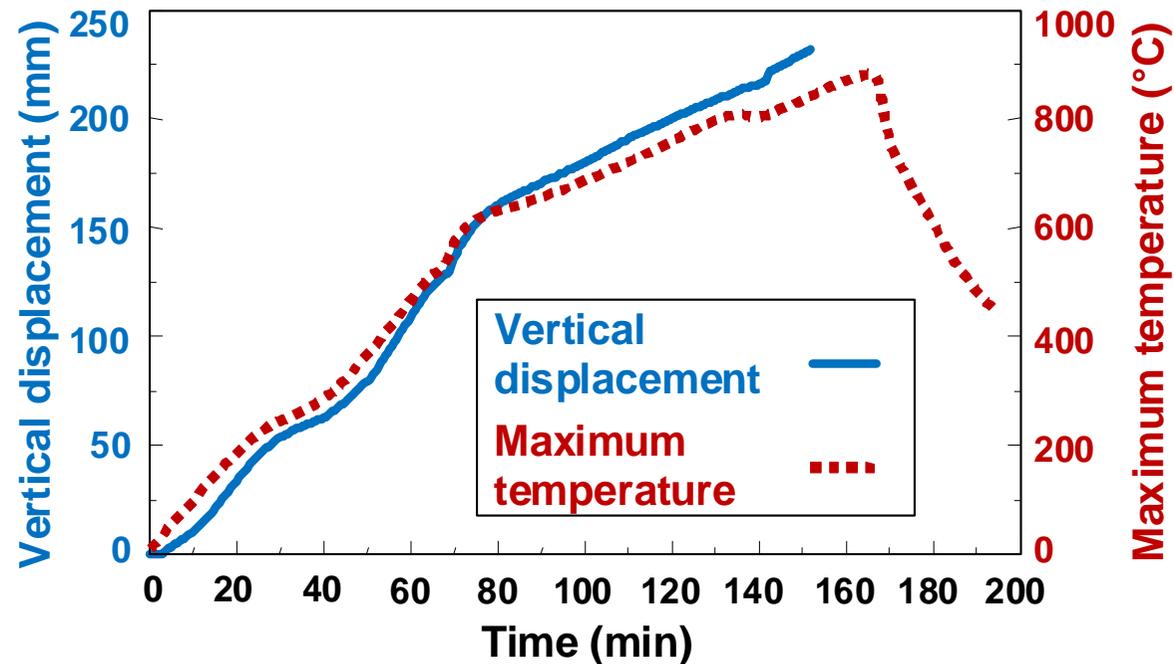




Cardington fire tests



- **Restrained beam test : experimental results**



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

Cardington fire tests

Fire tests of open car parks

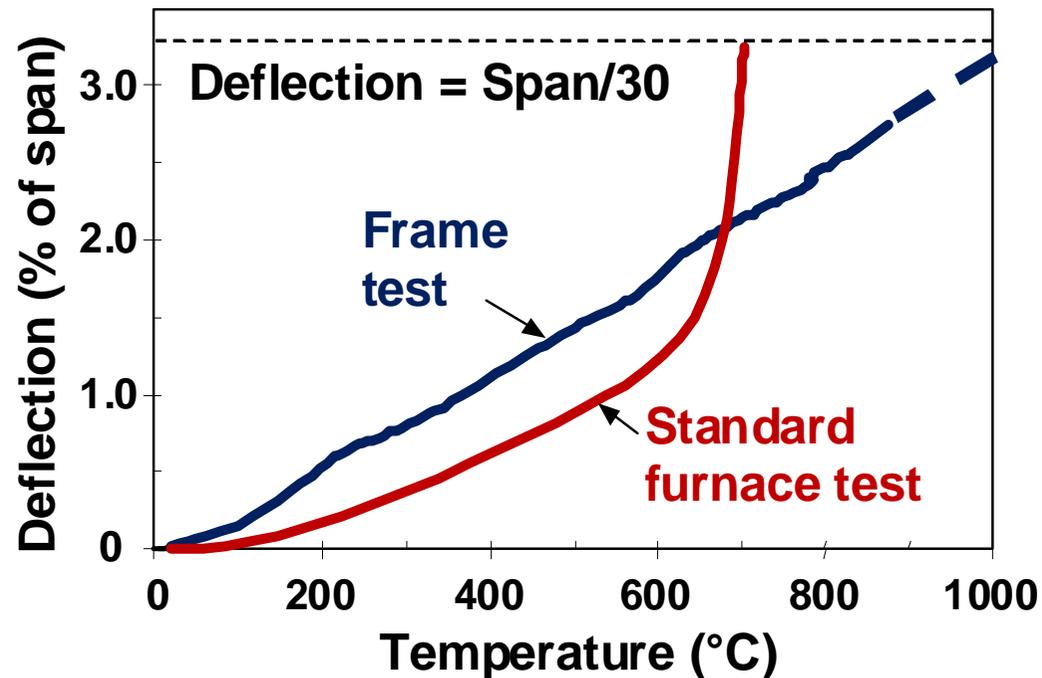
Evidence from accidental fire



Cardington fire tests



- Comparison with standard furnace fire test



- Conclusion
 - No sign of failure in global composite floor system
 - Collapse at $\theta \approx 650$ °C if simply supported

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Cardington fire tests

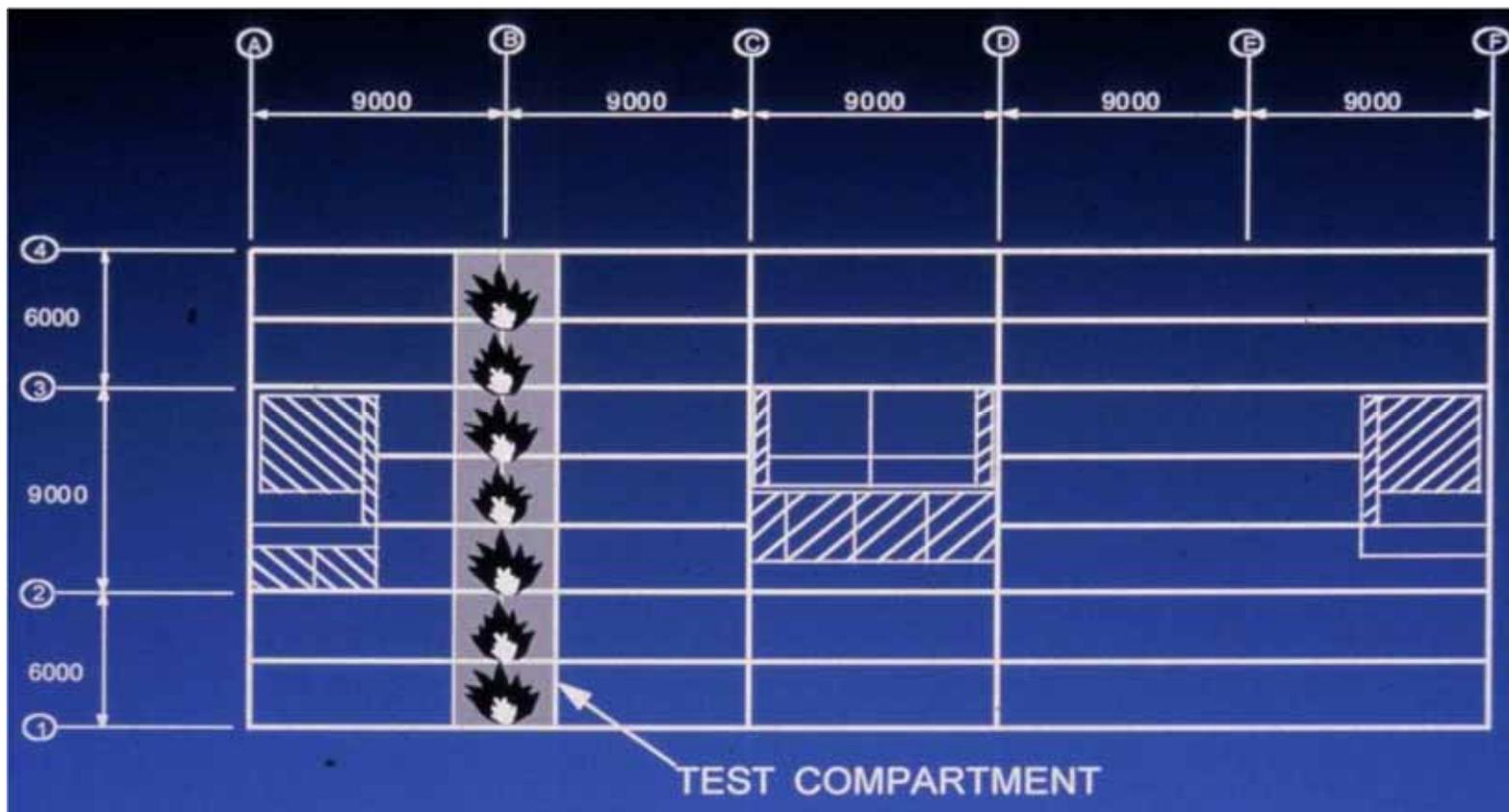


- Plane frame beam test

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

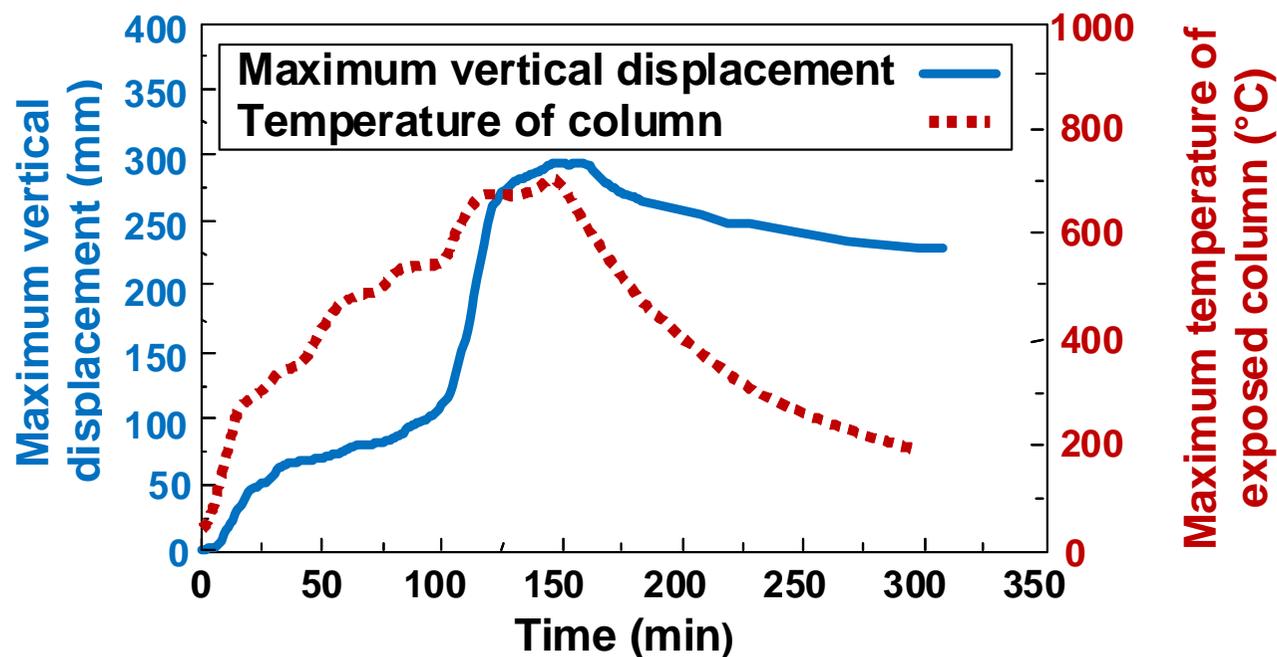




Cardington fire tests



- **Plane frame test : experimental results**



Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

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



Cardington fire tests



- Deformed state of heated part of the floor

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

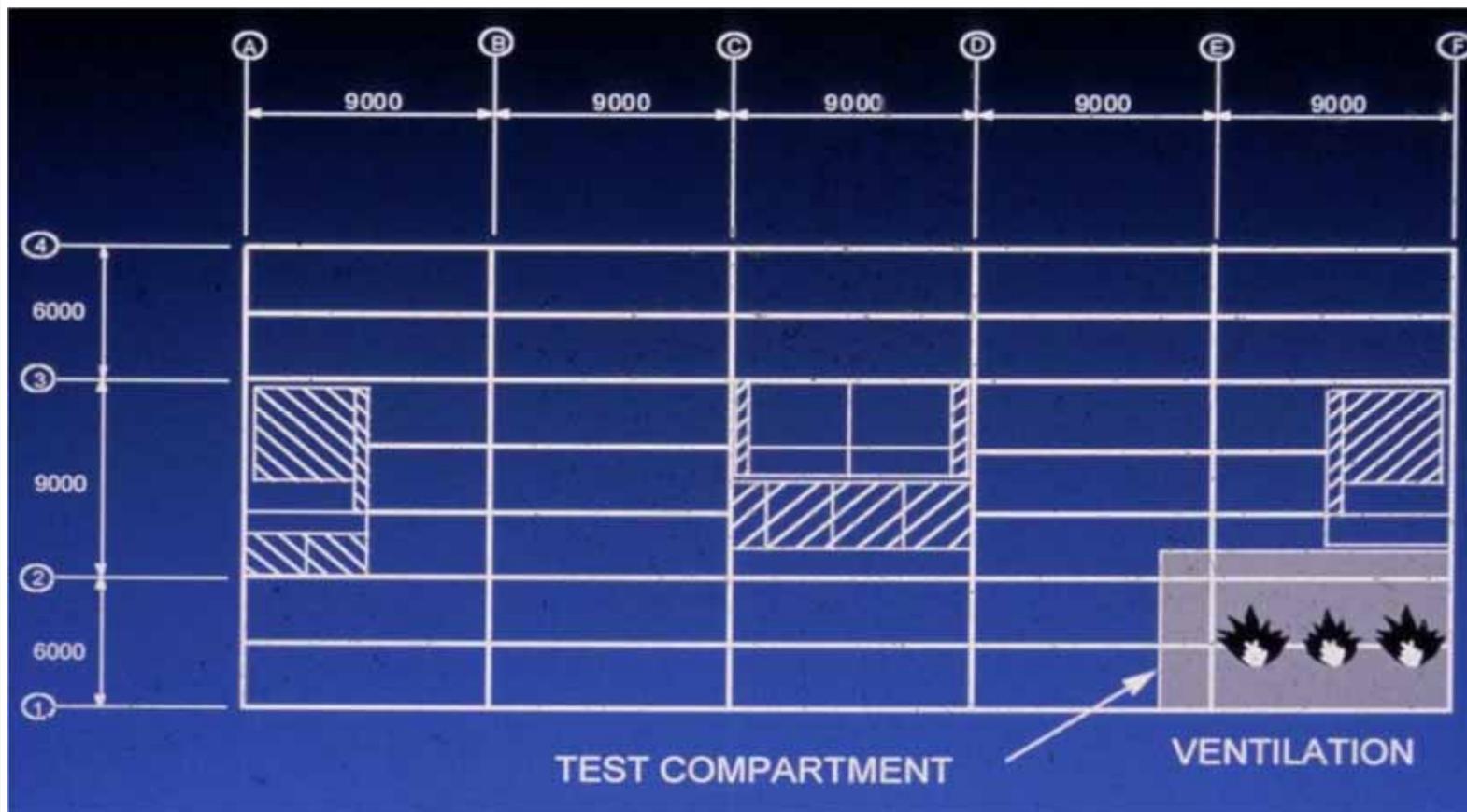


- **Corner compartment test**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire





Cardington fire tests



- **Corner compartment test : set-up**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



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**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Fire during the test

Deformed floor after the test

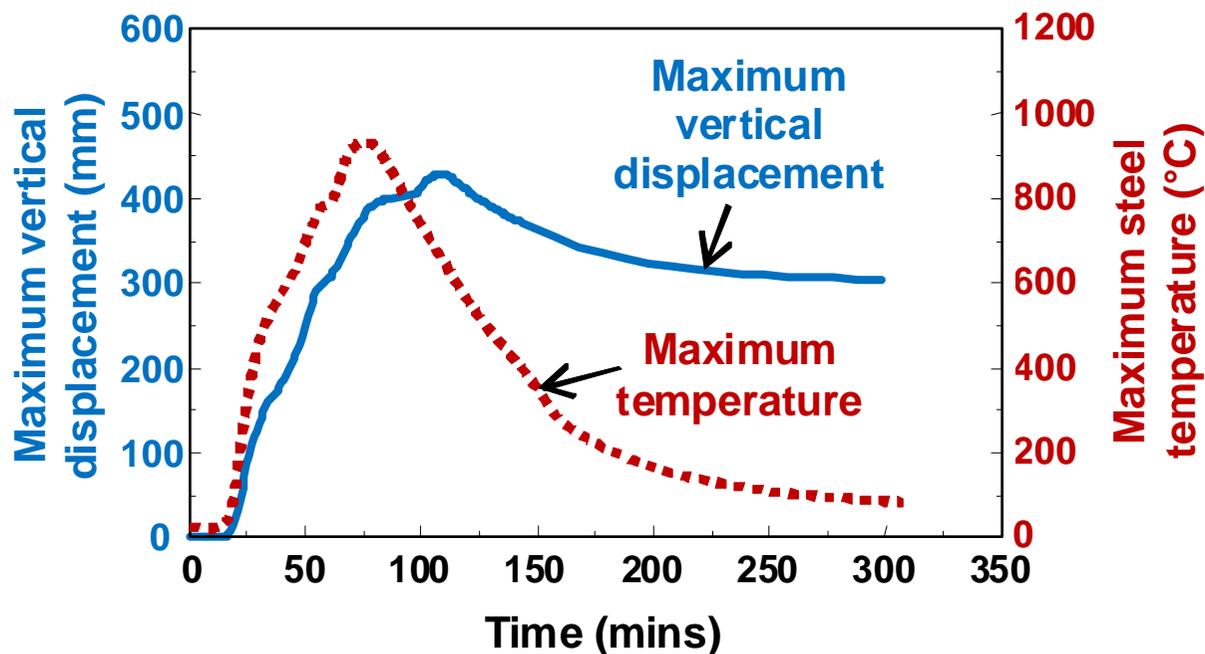




Cardington fire tests



- **Corner compartment test : experimental results**



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

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



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

Fire tests of open
car parks

Evidence from
accidental fire



Cardington fire tests

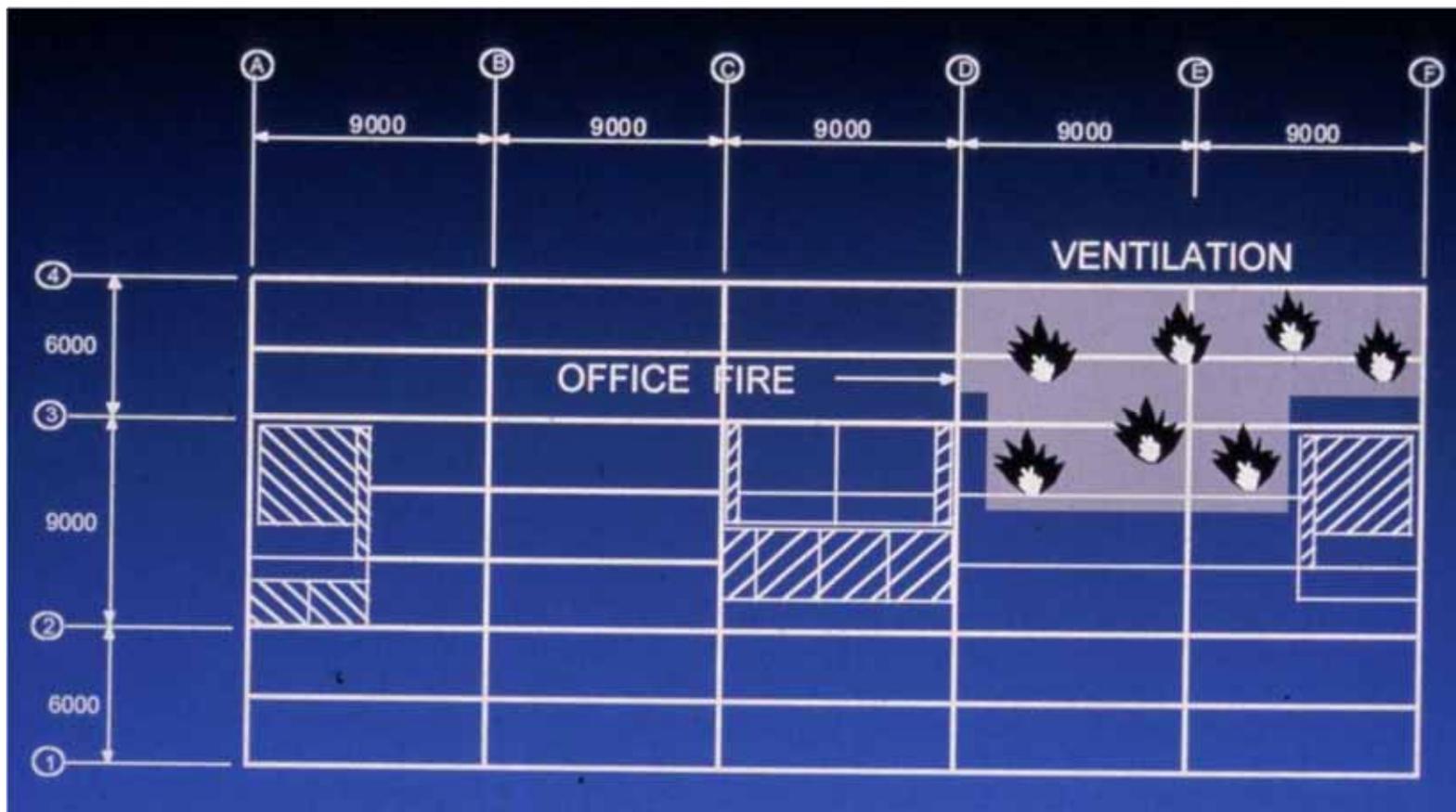


- **Demonstration test (an area of more than 130 m²)**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire





Cardington fire tests



- **Demonstration test : set-up**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Fire load with real office furniture

Openings with normal glazed windows





Cardington fire tests



- **Demonstration test : experimental results**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Early stage of fire

Fully developed fire

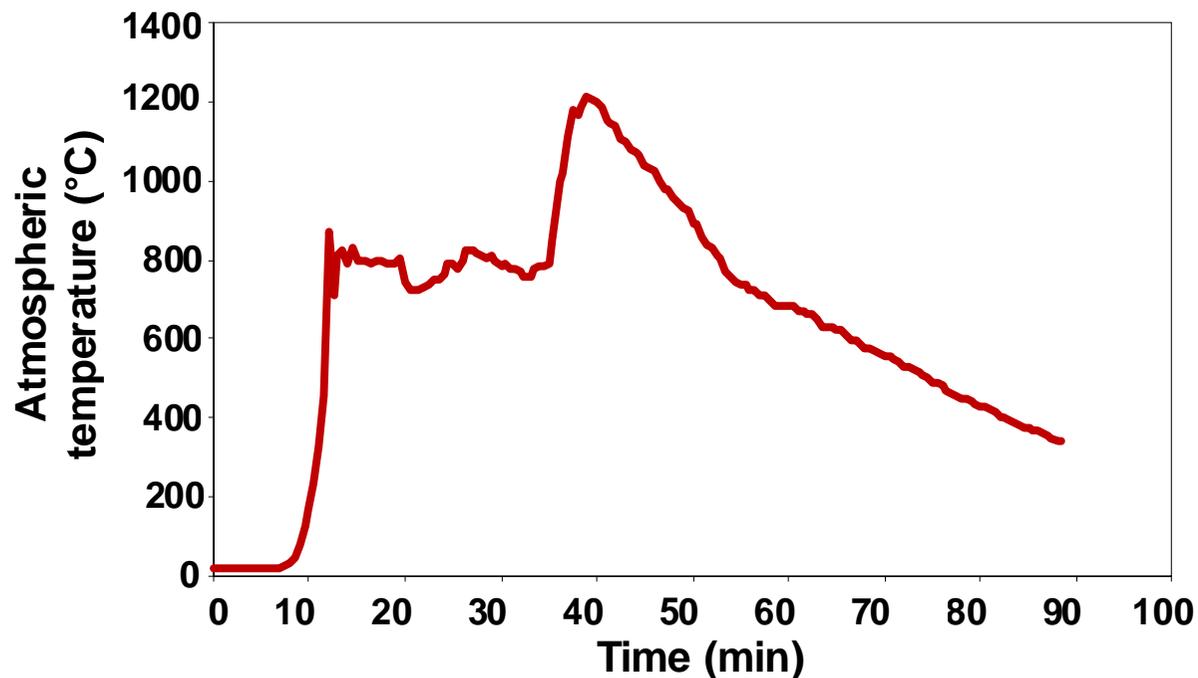




Cardington fire tests



- **Demonstration test : experimental results**



Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

- **Observation**

- Maximum gas temperature ≈ 1200 °C
- Maximum heating of steel ≈ 1150 °C



Cardington fire tests

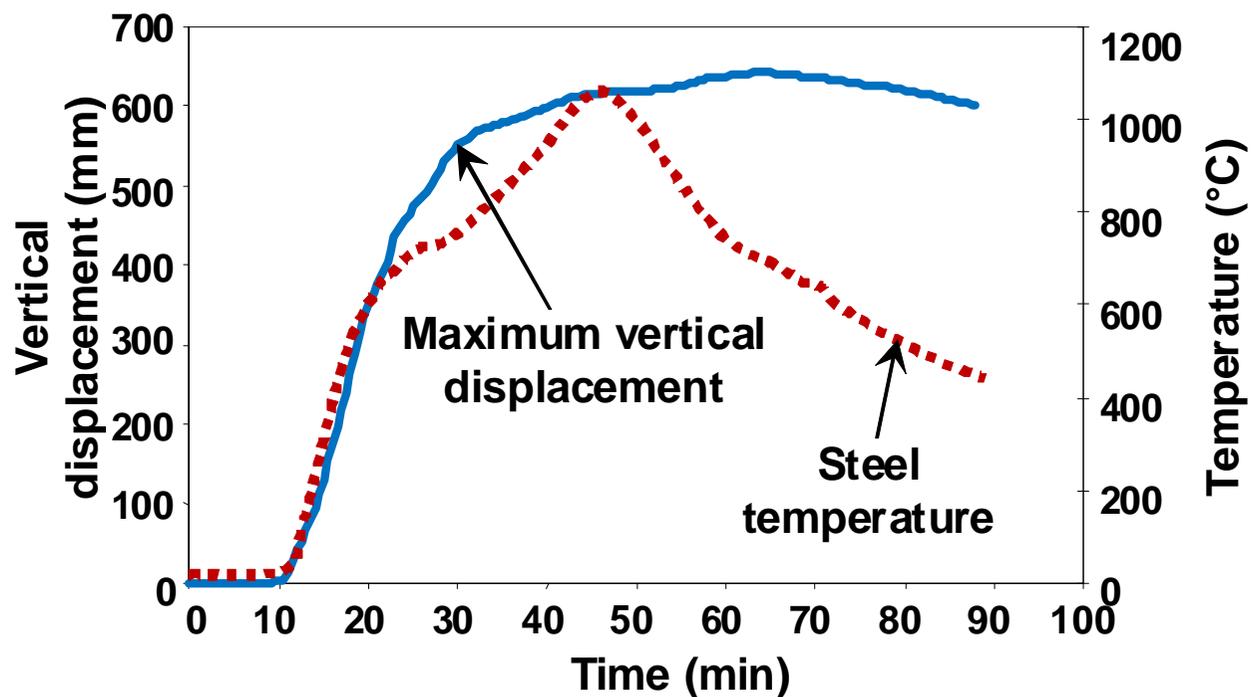


- **Demonstration test : experimental results**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



- **Observation**

- Important deflection of the floor \approx 640 mm
- No collapse of the floor



Cardington fire tests



- **Demonstration 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 despite important heating of steel and deflection of the floor**

Cardington fire
tests

Fire tests of open
car parks

Evidence from
accidental fire



Cardington fire tests



Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

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



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

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Fire tests of open car park

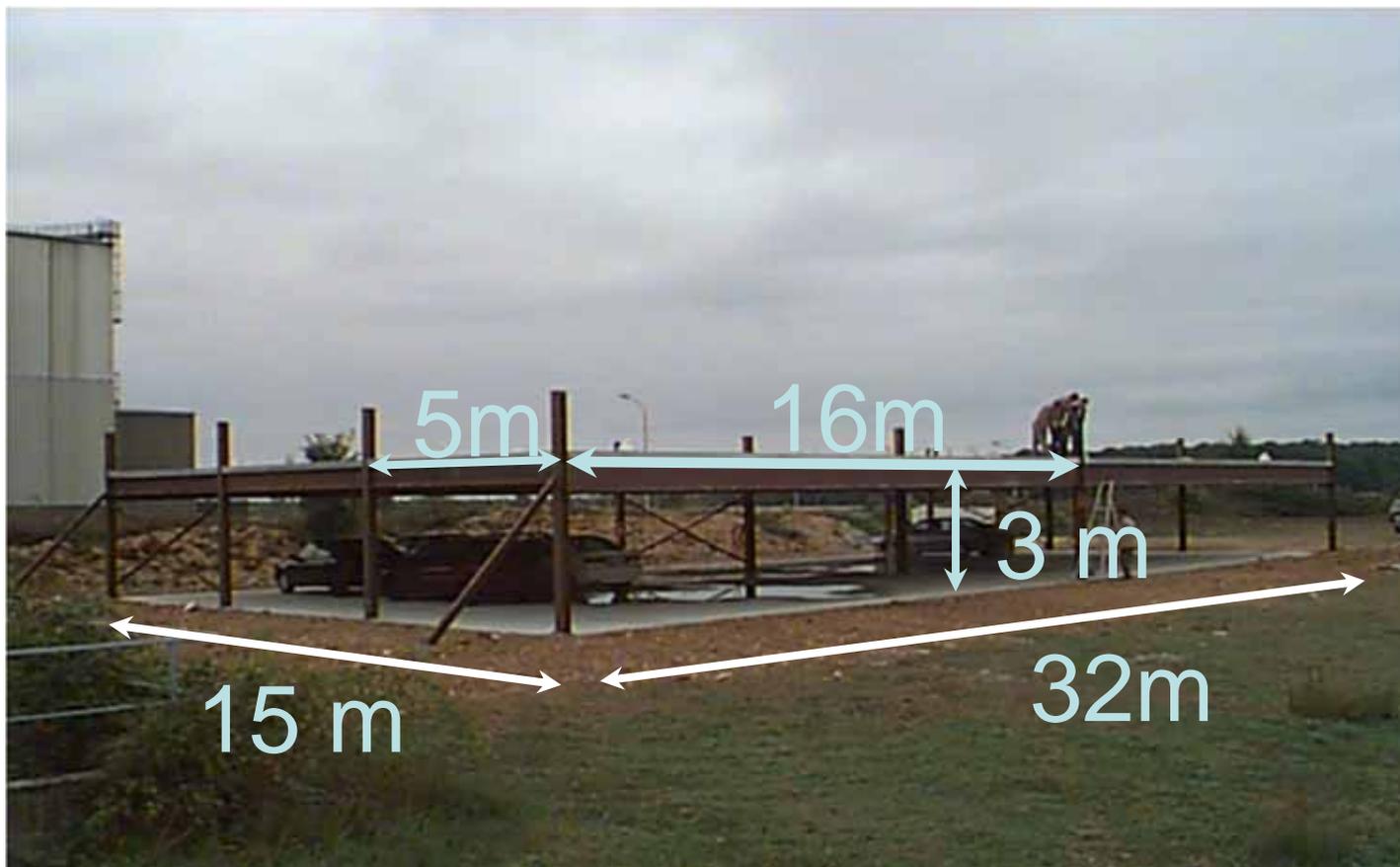


- **One storey steel framed building**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire





Fire tests of open car park

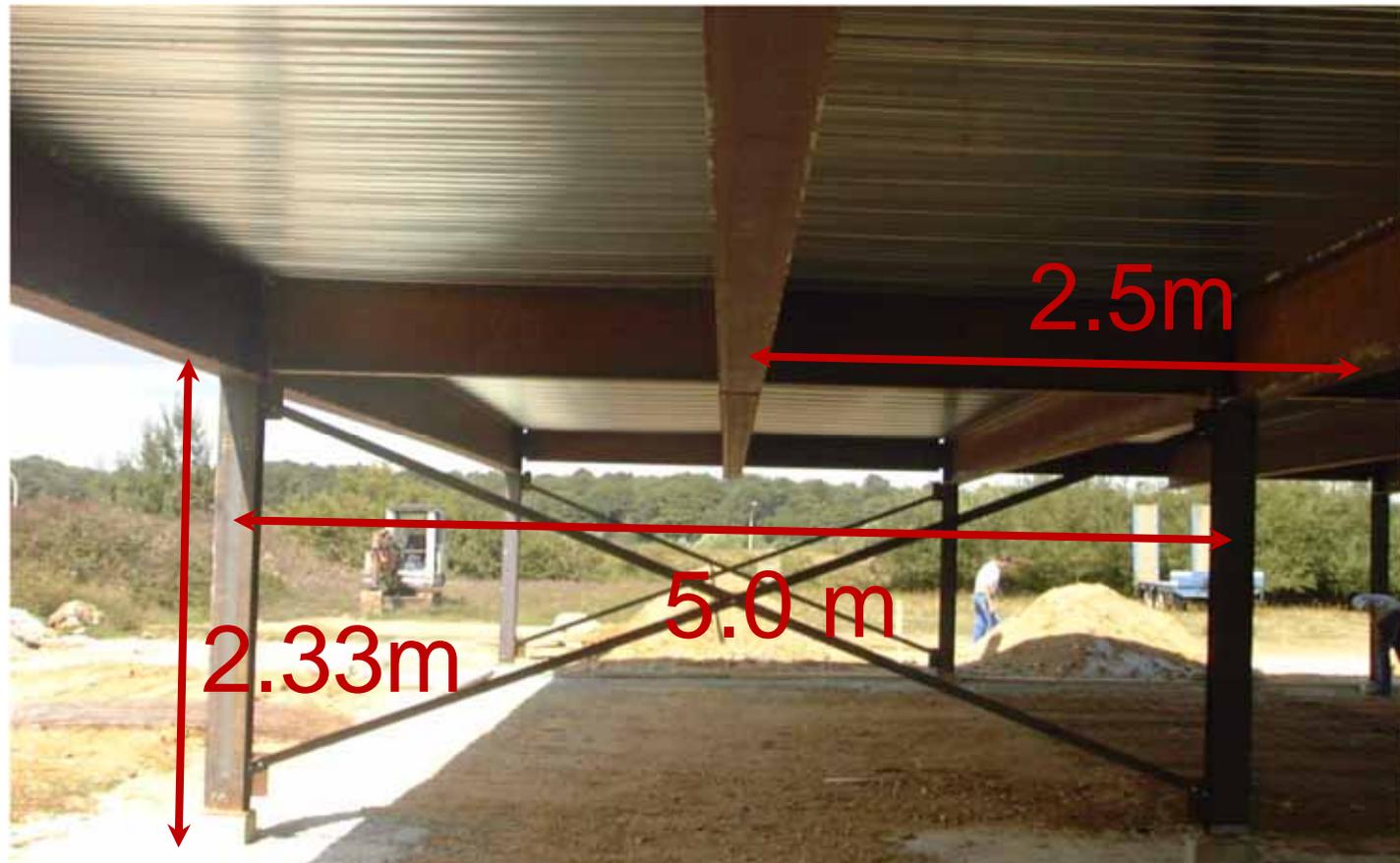


- One storey steel framed building

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire





Fire tests of open car park



- **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**

Cardington fire
tests

**Fire tests of open
car parks**

Evidence from
accidental fire



Fire tests of open car park



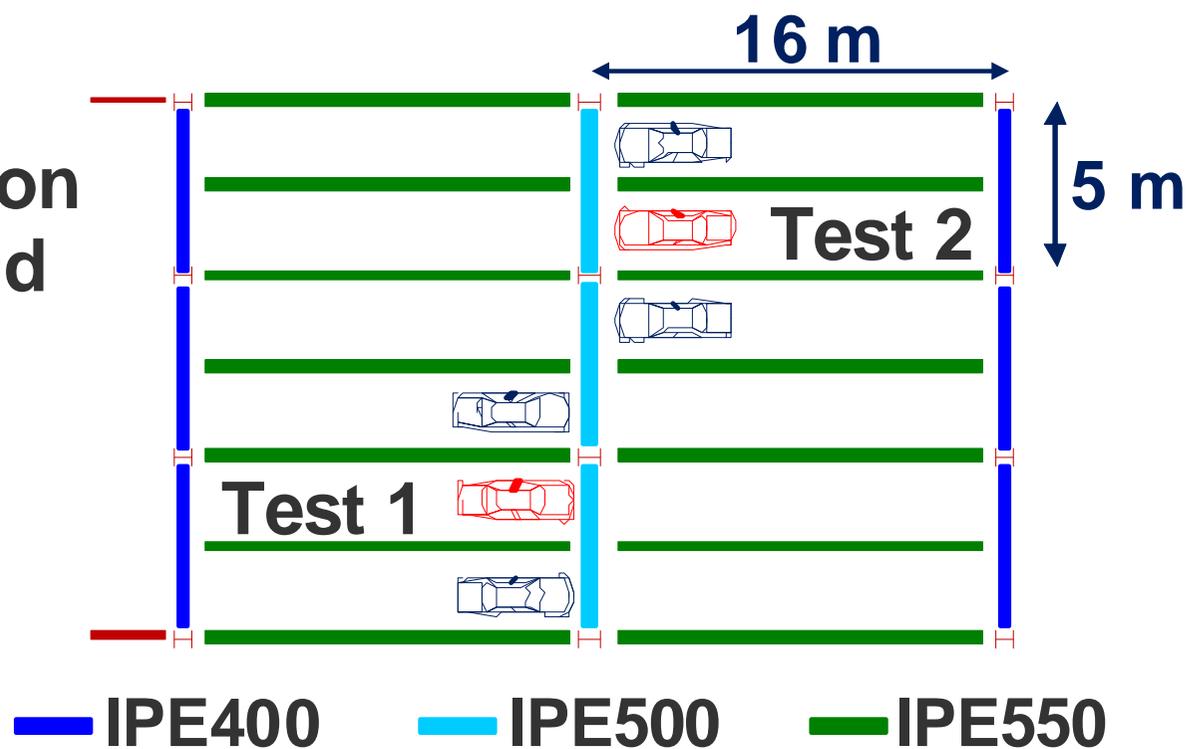
- Two fire tests involving three cars in each

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

Direction of wind



Edge columns: HEA 180
Central columns: HEB200



Fire tests of open car park



- **Experimental results (test 1)**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

0 min





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





Fire tests of open car park



- **Experimental results (test 1)**

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





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





Fire tests of open car park



- **Experimental results (test 2)**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

25 min





Fire tests of open car park



- **Experimental results (test 2)**

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire

44 min

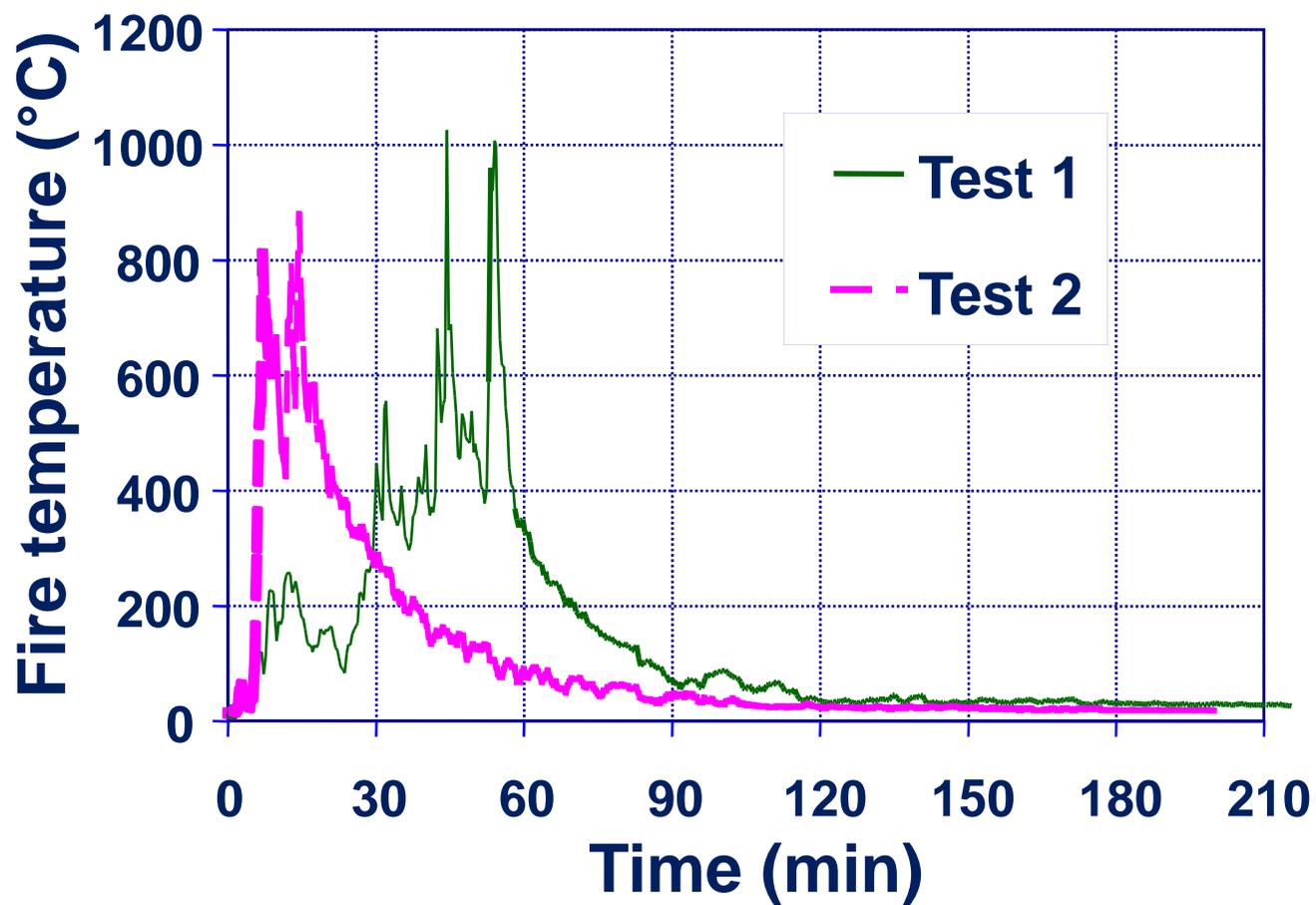




Fire tests of open car park



- Experimental results : gas temperature



Cardington fire tests

Fire tests of open car parks

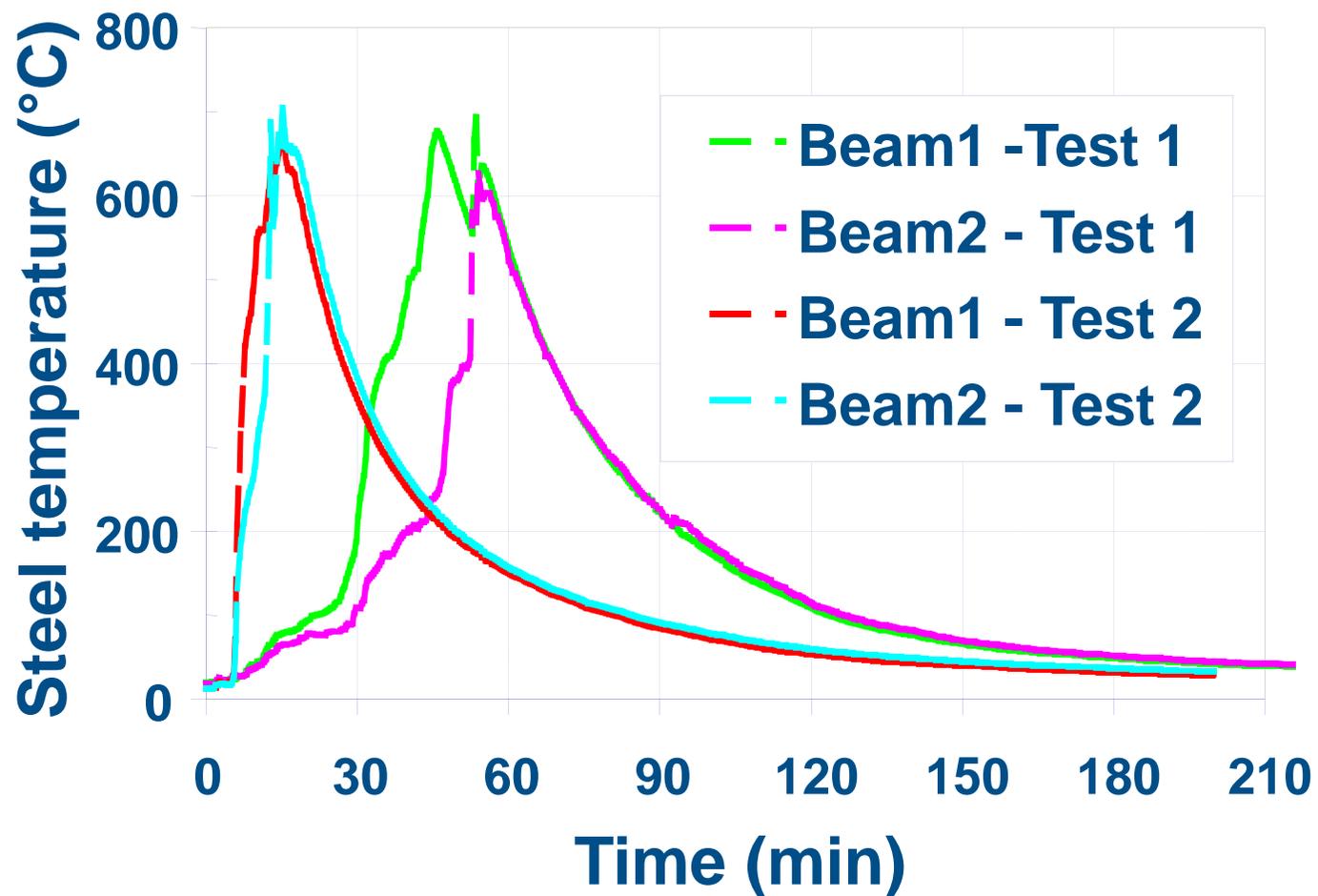
Evidence from accidental fire



Fire tests of open car park



- **Experimental results : steel temperature**



Cardington fire tests

Fire tests of open car parks

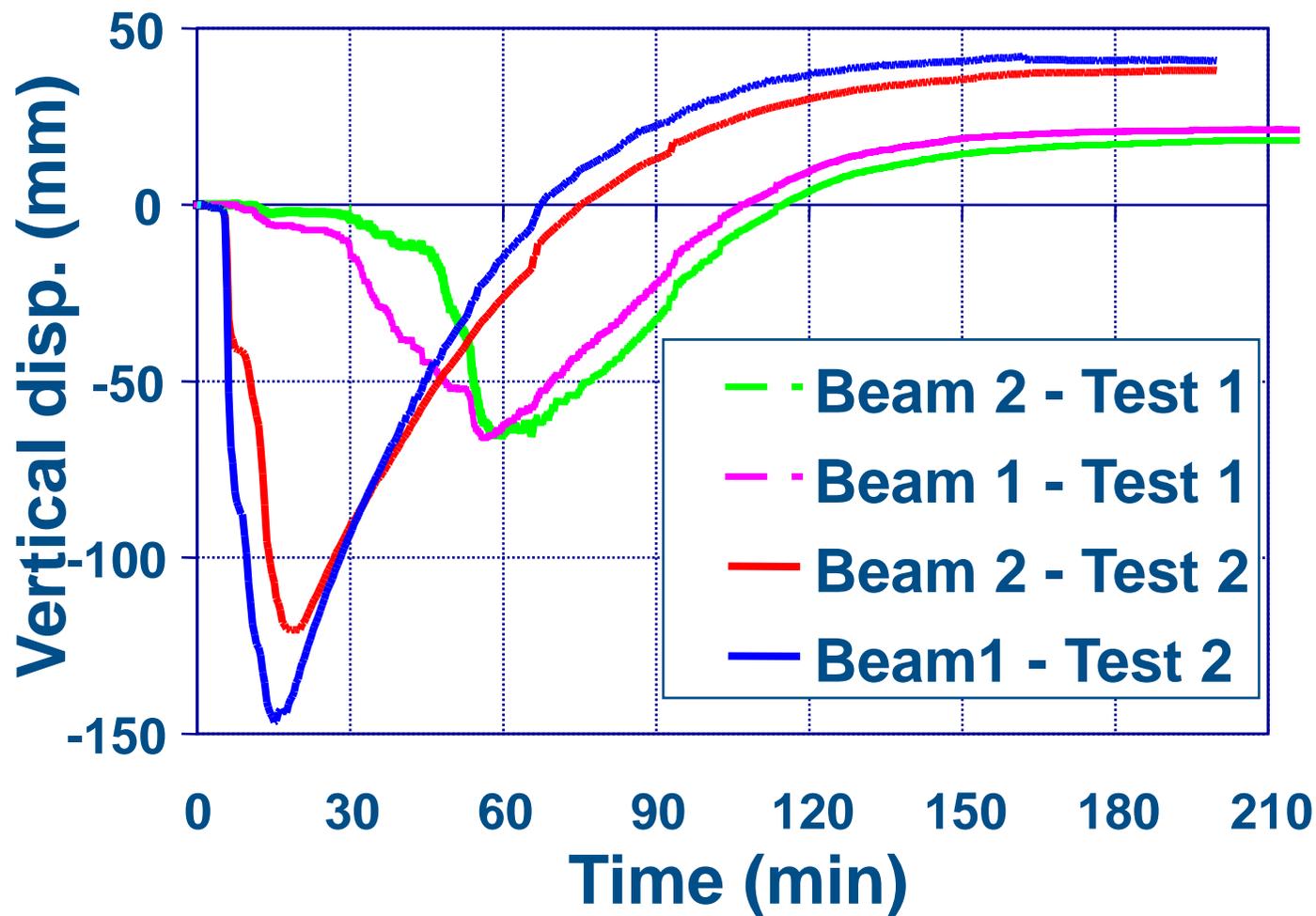
Evidence from accidental fire



Fire tests of open car park



- Experimental results : steel temperature



Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



Fire tests of open car park

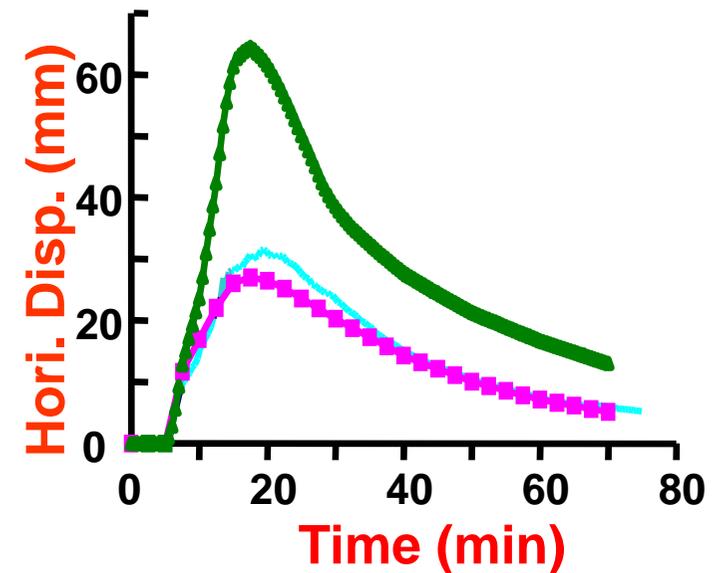
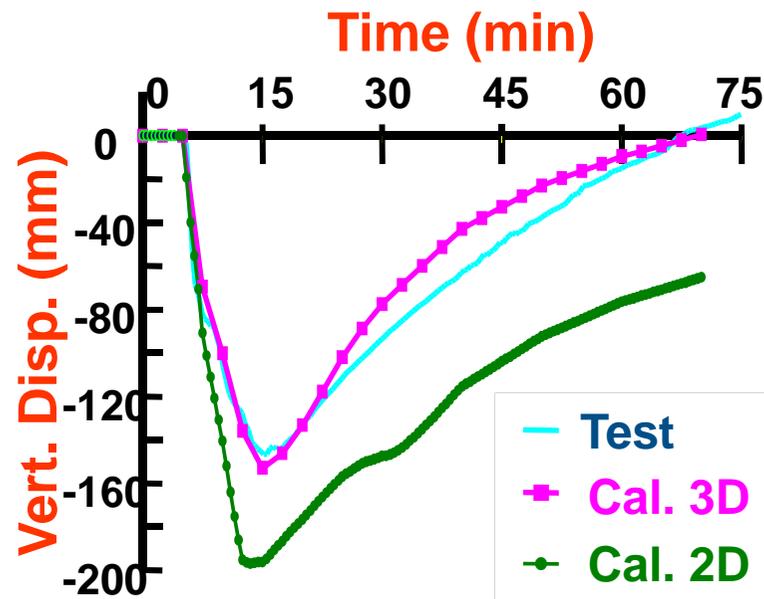


- Effects of 3D membrane effect

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire



- Conclusion

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



- **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

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire





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

