




 Education and Culture DG
 Lifelong Learning Programme
 LEONARDO DA VINCI



 1&4
 ANEFOR

FRATCOF
Fire Behaviour of Steel and Composite Floor Systems
Review of Real Fires
 Dr. Renata Obiala 26th of May 2011



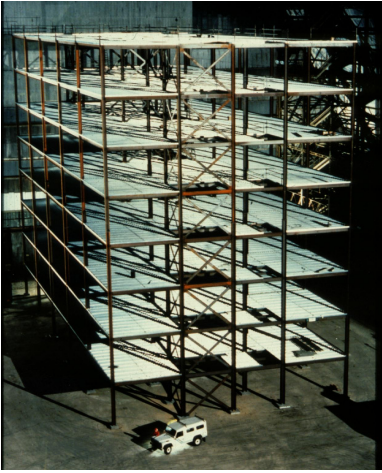









 Content of presentation

- **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


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<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <p style="text-align: center;">Cardington fire tests</p> 
	<ul style="list-style-type: none"> • Eight storey steel framed building <div style="display: flex; justify-content: space-around;"> <div>  </div> <div>  <p style="text-align: center;">Beam to beam joint</p> </div> <div>  <p style="text-align: center;">Beam to column joint</p> </div> </div>
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">3</p>

<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <p style="text-align: center;">Cardington fire tests</p> 
	<ul style="list-style-type: none"> • Main parameters of the building <ul style="list-style-type: none"> – 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
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">4</p>



Cardington fire tests

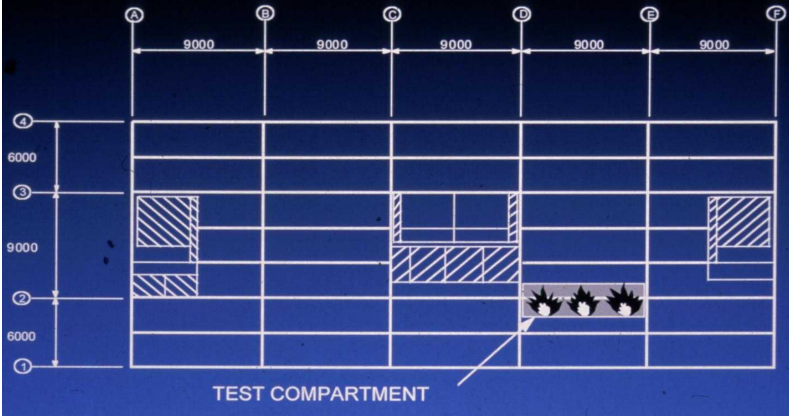


- Restrained beam test : span = 9.0 m


Cardington fire tests

Fire tests of open car parks


Evidence from accidental fire



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Cardington fire tests

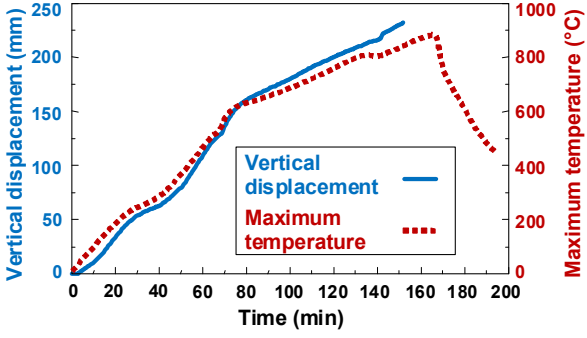


- Restrained beam test : experimental results

Cardington fire tests

Fire tests of open car parks


Evidence from accidental fire



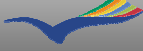
Time (min)	Vertical displacement (mm)	Maximum temperature (°C)
0	0	0
20	40	100
40	60	200
60	100	400
80	150	600
100	180	700
120	200	800
140	220	900
160	240	900
180	230	600
200	220	400

- Observation
 - Maximum heating $\approx 900\text{ }^{\circ}\text{C}$
 - Deflection of the beam: $< 250\text{ mm}$

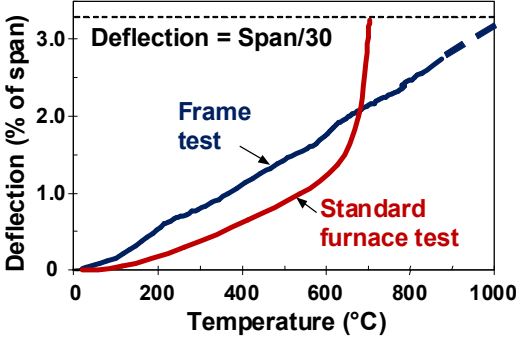
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Cardington fire tests




- Comparison with standard furnace fire test




The graph plots Deflection (% of span) on the y-axis (0 to 3.0) against Temperature (°C) on the x-axis (0 to 1000). A blue line represents the 'Frame test', showing a gradual increase in deflection to approximately 3.0% at 1000°C. A red line represents the 'Standard furnace test', showing a sharp increase in deflection starting around 600°C, reaching 3.0% at approximately 700°C. A horizontal dashed line at the top of the graph is labeled 'Deflection = Span/30'.

- Conclusion
 - No sign of failure in global composite floor system
 - Collapse at $\theta \approx 650^\circ\text{C}$ if simply supported

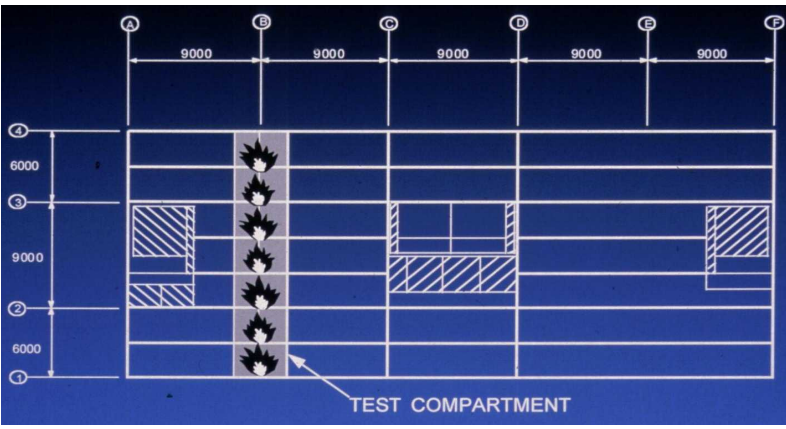
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Cardington fire tests




- Plane frame beam test




The diagram shows a structural frame with columns labeled A through F and beams labeled 1 through 4. The horizontal distance between columns is 9000 units. The vertical height of the beams is 6000 units. A 'TEST COMPARTMENT' is indicated at the bottom, with fire symbols shown on the beams between columns B and C, and between columns C and D.

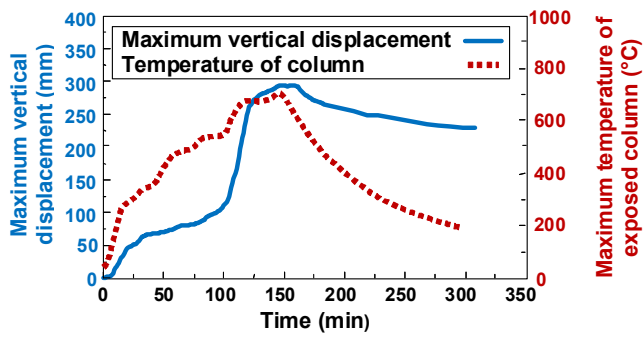
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Cardington fire tests




- **Plane frame test : experimental results**




Time (min)	Maximum vertical displacement (mm)	Maximum temperature of exposed column (°C)
0	0	0
50	75	400
100	125	600
150	300	750
200	275	500
250	250	350
300	240	250

- **Observation**
 - Maximum heating $\approx 750\text{ }^{\circ}\text{C}$
 - Deflection of the beam $\approx 300\text{ mm}$


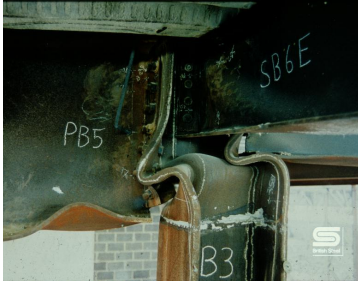
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Cardington fire tests




- **Deformed state of heated part of the floor**





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

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Cardington fire tests

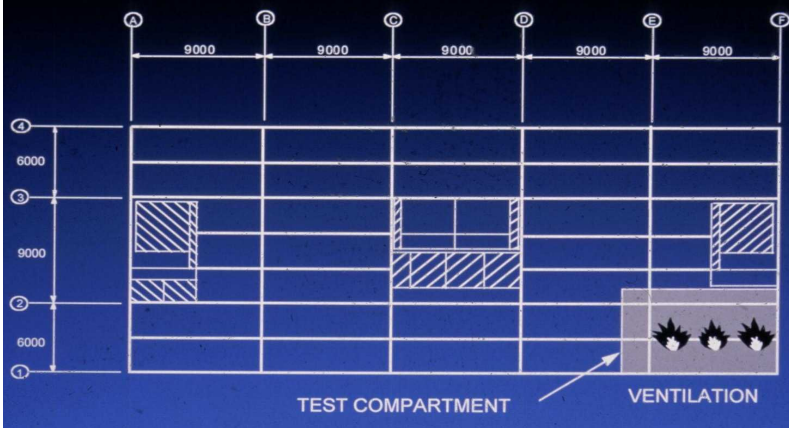


- **Corner compartment test**


Cardington fire tests

Fire tests of open car parks


Evidence from accidental fire



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Cardington fire tests




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

Cardington fire tests


Fire tests of open car parks

Evidence from accidental fire




Fire load with wood cribs equals to 45 kg/m²


Walls of the compartment with hollow breeze-blocks



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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



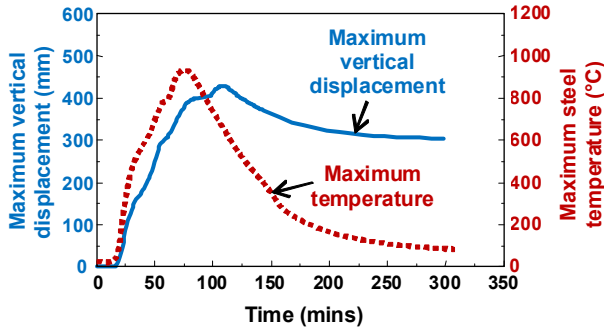
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Cardington fire tests




- **Corner compartment test : experimental results**

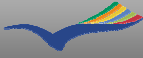


- **Observation**
 - Maximum heating of steel $\approx 1014\text{ }^{\circ}\text{C}$
 - Maximum deflection of the floor $\approx 428\text{ mm}$


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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

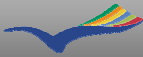
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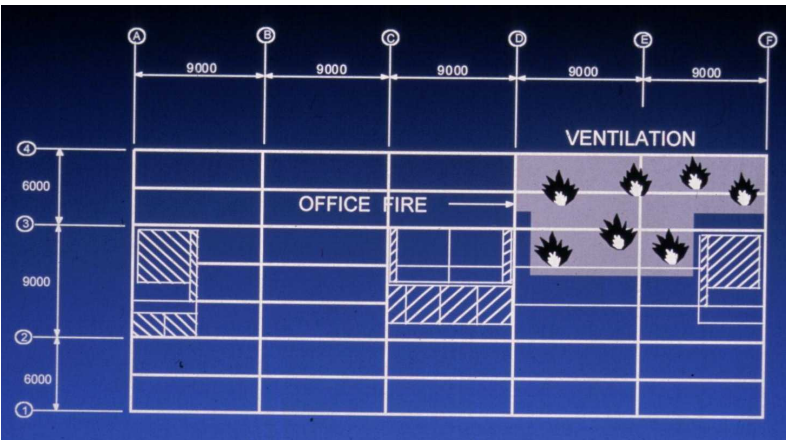
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Cardington fire tests




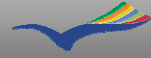


- **Demonstration test (an area of more than 130 m²)**


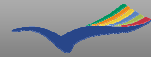




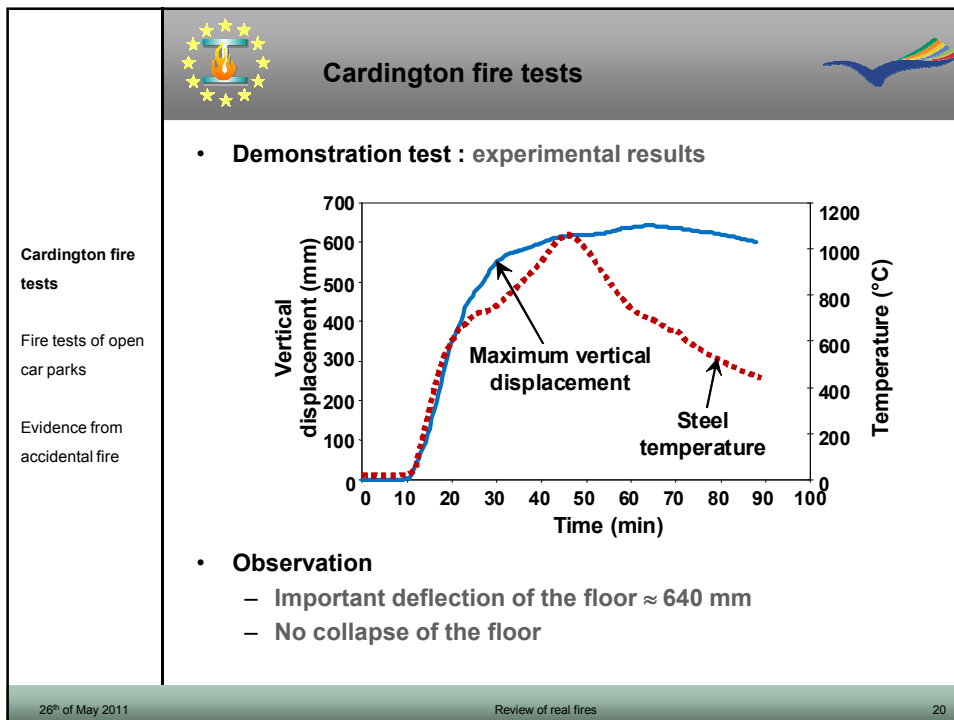
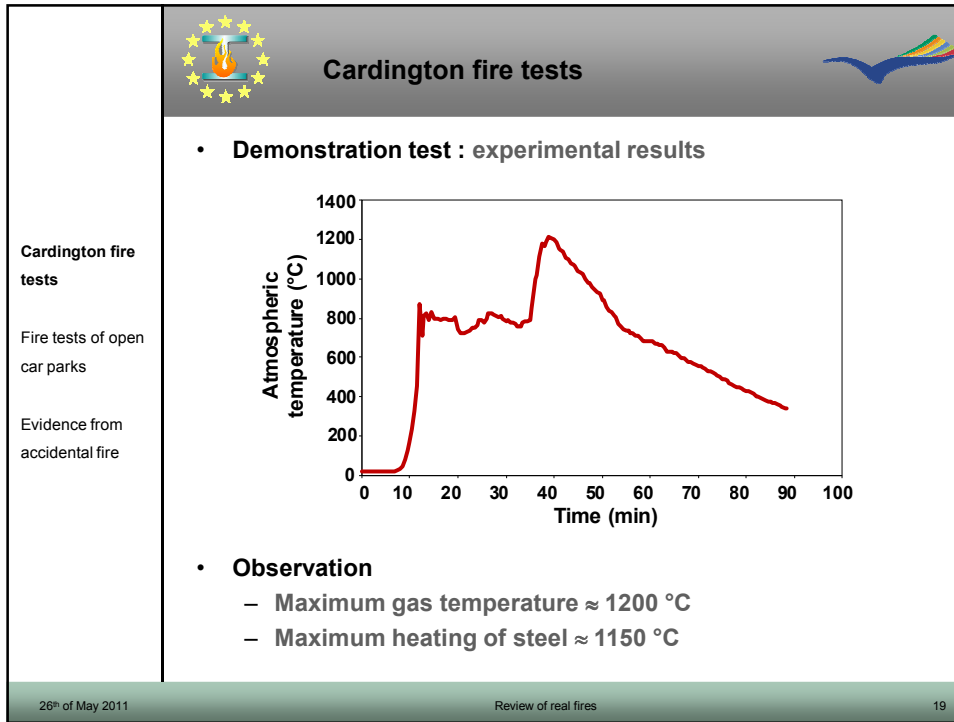
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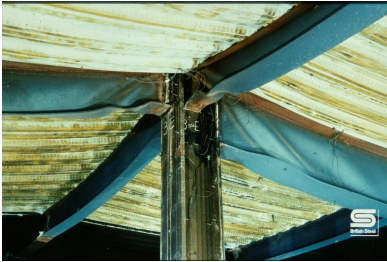
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<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <p style="text-align: center;">Cardington fire tests</p> 
	<ul style="list-style-type: none"> Demonstration test : set-up <div style="display: flex; justify-content: space-around;"> <div>  <p style="text-align: center;">Fire load with real office furniture</p> </div> <div> <p style="text-align: center;">Openings with normal glazed windows</p>  </div> </div>
<p>26th of May 2011 Review of real fires 17</p>	



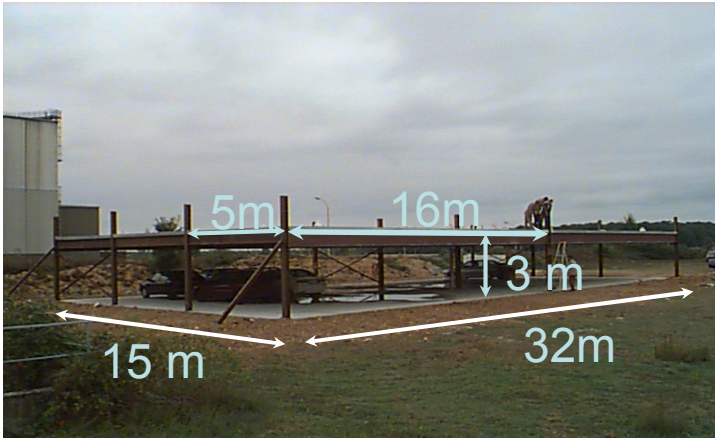
<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <p style="text-align: center;">Cardington fire tests</p> 
	<ul style="list-style-type: none"> Demonstration test : experimental results <div style="display: flex; justify-content: space-around;"> <div>  <p style="text-align: center;">Early stage of fire</p> </div> <div> <p style="text-align: center;">Fully developed fire</p>  </div> </div>
<p>26th of May 2011 Review of real fires 18</p>	



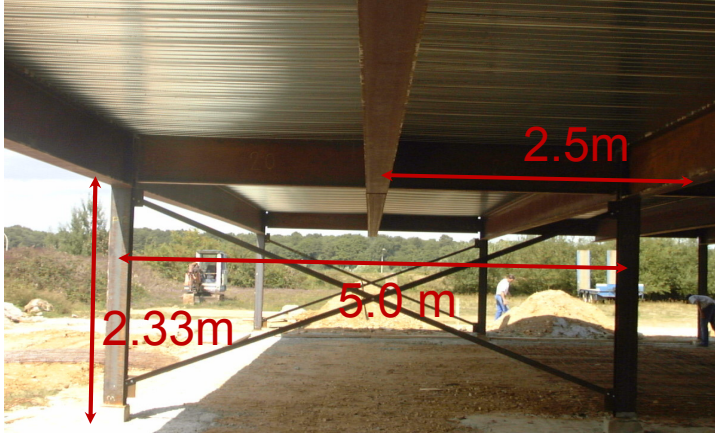




<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <h3 style="text-align: center;">Cardington fire tests</h3> 
	<ul style="list-style-type: none"> • Demonstration test : structure after test <div style="display: flex; justify-content: space-around;"> <div>  <p style="text-align: center;">Deformed state of the heated part of the composite floor</p> </div> <div>  <p style="text-align: center;">Deformed state of steel members around protected steel column</p> </div> </div> <ul style="list-style-type: none"> • Conclusion <ul style="list-style-type: none"> – No sign of global failure of the floor <u>despite important heating of steel and deflection of the floor</u>
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">21</p>


<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <h3 style="text-align: center;">Cardington fire tests</h3> 
	<ul style="list-style-type: none"> • Other fire tests <ul style="list-style-type: none"> – Second corner test – Large compartment test – New corner test
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">22</p>

<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <h3 style="text-align: center;">Cardington fire tests</h3> 
	<ul style="list-style-type: none"> • General remarks <ul style="list-style-type: none"> – 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
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<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <h3 style="text-align: center;">Fire tests of open car park</h3> 
	<ul style="list-style-type: none"> • One storey steel framed building 
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<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	<div style="text-align: right;">  <h3>Fire tests of open car park</h3>  </div> <ul style="list-style-type: none"> • One storey steel framed building 
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">25</p>

<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	<div style="text-align: right;">  <h3>Fire tests of open car park</h3>  </div> <ul style="list-style-type: none"> • Main parameters of the structure <ul style="list-style-type: none"> – 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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Fire tests of open car park



- Two fire tests involving three cars in each

Direction of wind →

16 m

5 m

Test 1

Test 2

— IPE400 — IPE500 — IPE550

Edge columns: HEA 180
Central columns: HEB200

Cardington fire tests


Fire tests of open car parks

Evidence from accidental fire


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Fire tests of open car park



- Experimental results (test 1)

0 min

Cardington fire tests

Fire tests of open car parks

Evidence from accidental fire




26th of May 2011




Review of real fires




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Cardington fire tests		<h3>Fire tests of open car park</h3>	
Fire tests of open car parks	<ul style="list-style-type: none"> • Experimental results (test 1) 		
Evidence from accidental fire	<p>10 min</p>		
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Cardington fire tests		<h3>Fire tests of open car park</h3>	
Fire tests of open car parks	<ul style="list-style-type: none"> • Experimental results (test 1) 		
Evidence from accidental fire	<p>33 min</p>		
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Cardington fire tests		Fire tests of open car park	
Fire tests of open car parks	• Experimental results (test 1)		
Evidence from accidental fire	62 min		
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Cardington fire tests		Fire tests of open car park	
Fire tests of open car parks	• Experimental results (test 2)		
Evidence from accidental fire	0 min		
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Cardington fire tests		Fire tests of open car park	
Fire tests of open car parks	<ul style="list-style-type: none">• Experimental results (test 2)		
Evidence from accidental fire	10 min		
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Cardington fire tests		Fire tests of open car park	
Fire tests of open car parks	<ul style="list-style-type: none">• Experimental results (test 2)		
Evidence from accidental fire	25 min		
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Fire tests of open car park




Cardington fire tests

Fire tests of open car parks


Evidence from accidental fire

- **Experimental results (test 2)**




44 min

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Fire tests of open car park

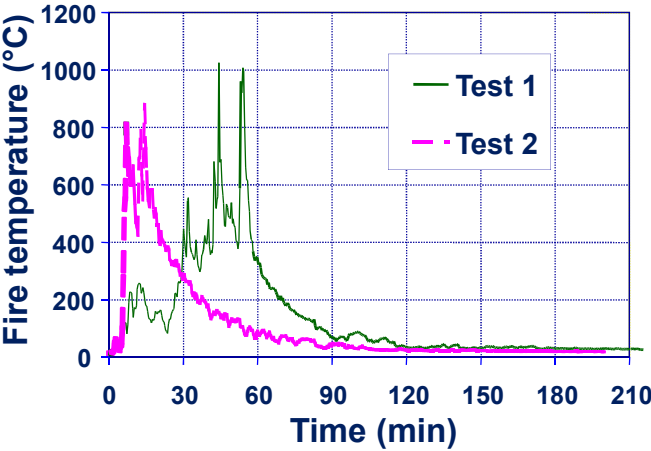


Cardington fire tests

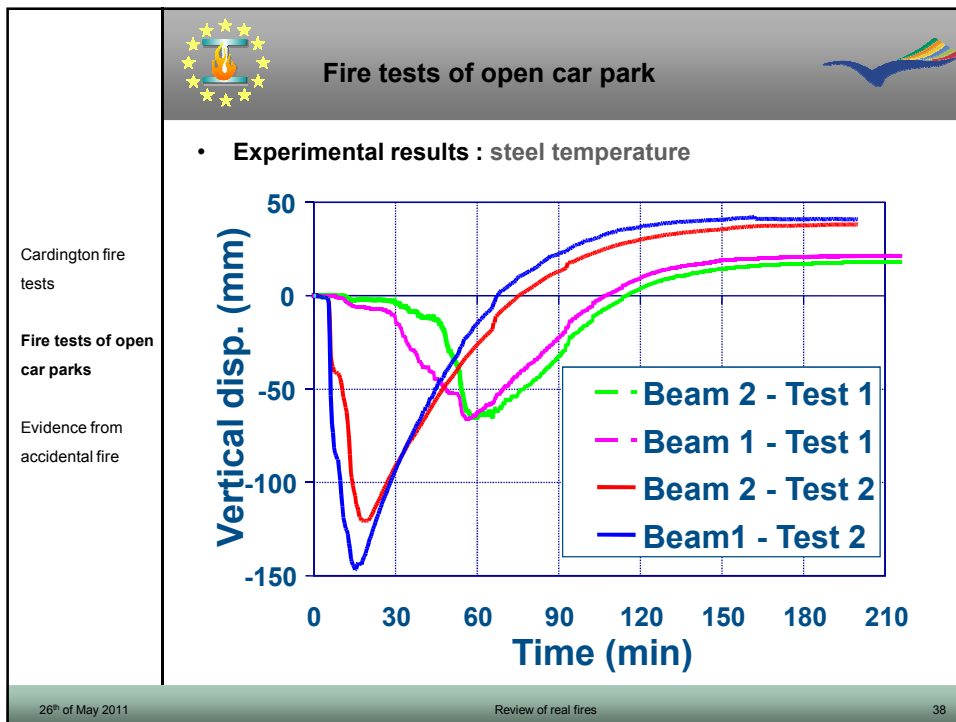
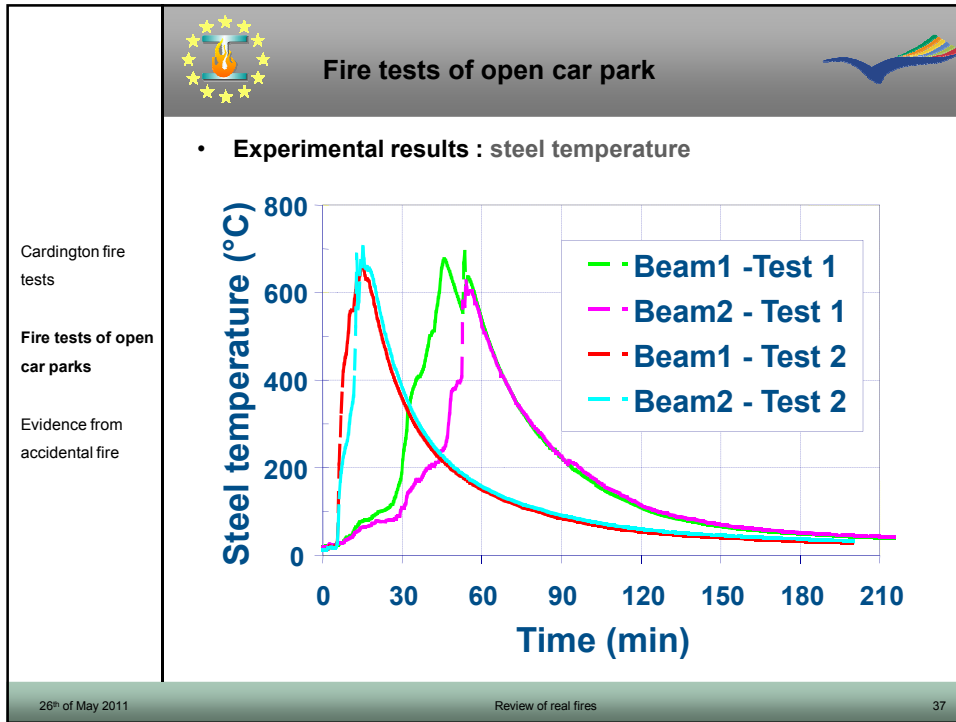
Fire tests of open car parks

Evidence from accidental fire

- **Experimental results : gas temperature**




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Cardington fire tests

Fire tests of open car parks

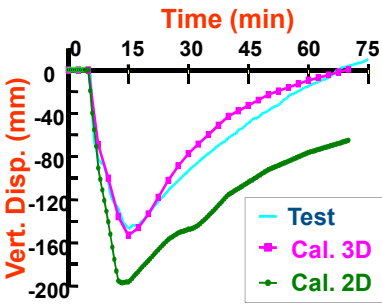
Evidence from accidental fire

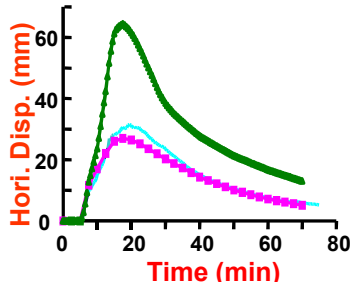


Fire tests of open car park



- **Effects of 3D membrane effect**






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

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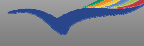
Cardington fire tests

Fire tests of open car parks



Evidence from accidental fire





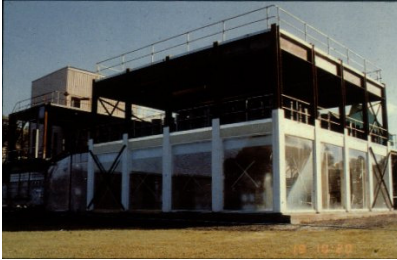

Accidental fires and other fire tests



- **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

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<p>Cardington fire tests</p> <p>Fire tests of open car parks</p> <p>Evidence from accidental fire</p>	 <h3 style="text-align: center;">Accidental fires and other fire tests</h3> 
	<ul style="list-style-type: none"> • Australian fire tests <ul style="list-style-type: none"> – Full scale composite floor system – Fire load: 52 kg/m² of wood cribs – Fire temperature more than 1228 °C – No collapse of the floor <div style="display: flex; justify-content: space-around;">   </div>
<p>26th of May 2011</p>	<p style="text-align: center;">Review of real fires</p> <p style="text-align: right;">41</p>