Research Fund
for Coal & Steel

MACS^{+}

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?

- **Background**
  - Cardington fire tests
    - Excellent fire performance under natural fire condition
    - Max θ of steel ≈ 1150 °C, fire duration ≈ 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

Objectives

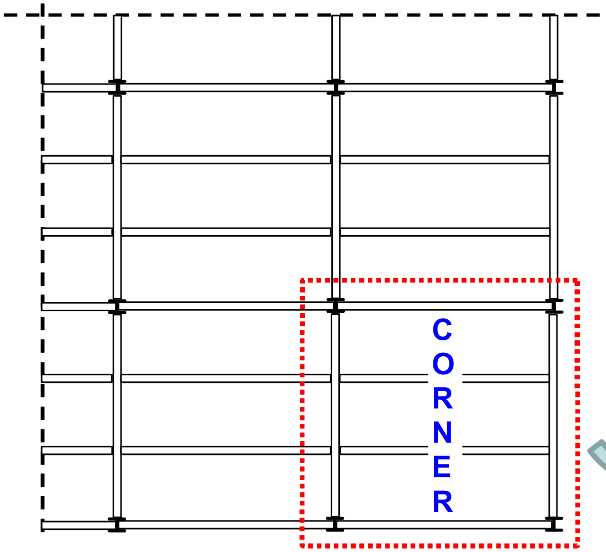
Test set-up

Experimental results & Observation

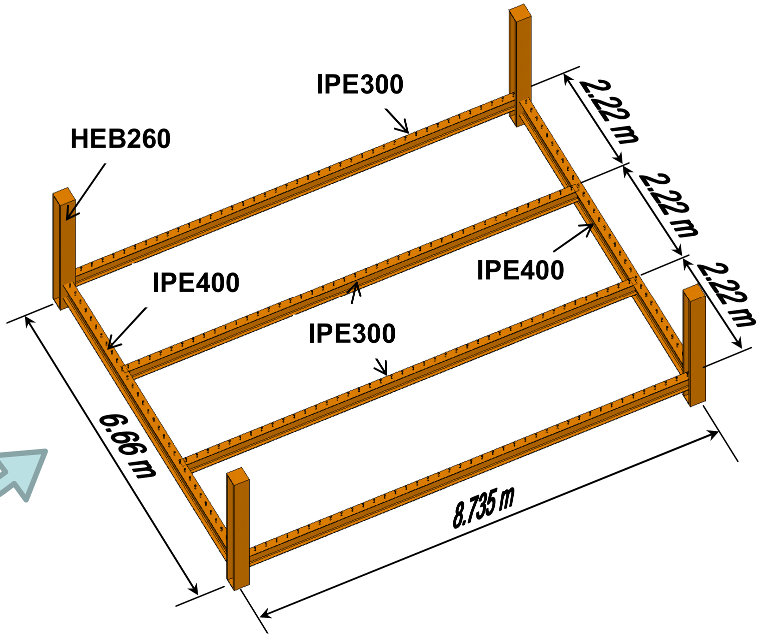
Comparison with simple design methods

Conclusion

- **Test 1 (FRACOF)**



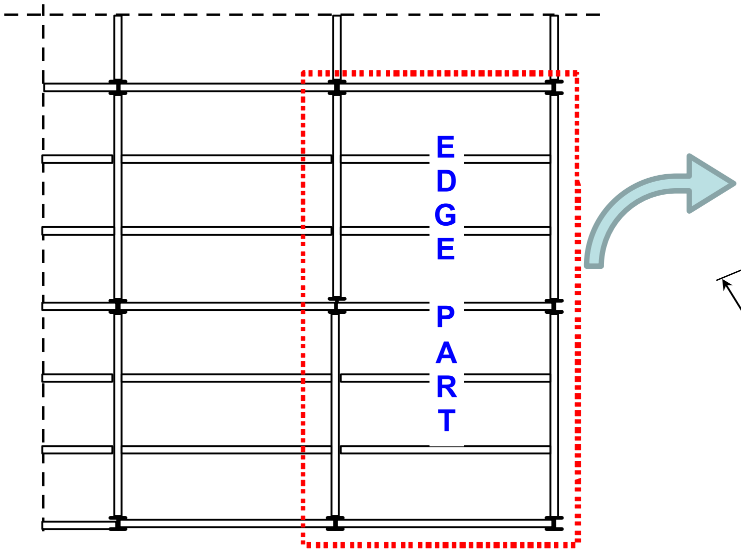
Structure grid of a real building



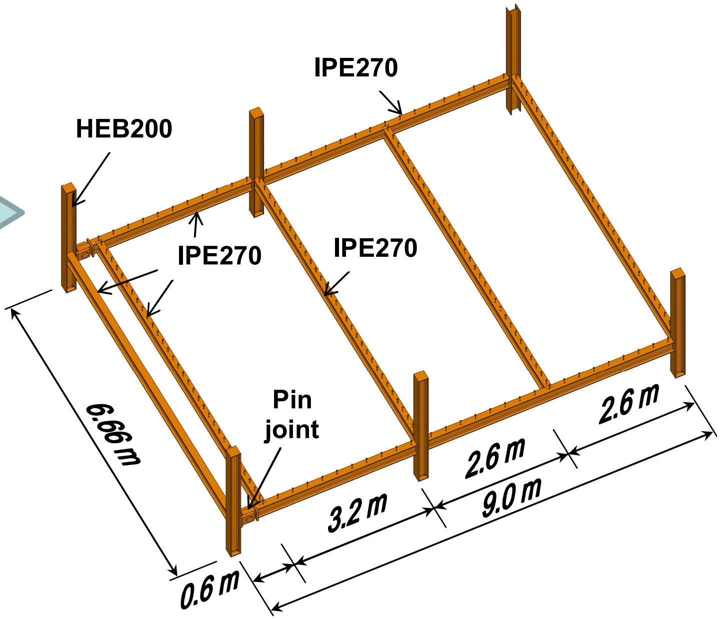
Adopted steel frames for fire Test 1

Design of test specimens

- **Test 2 (COSSFIRE)**



Structure grid of a real building



Adopted steel frames for fire Test 2

Design of test specimens

Objectives

Test set-up

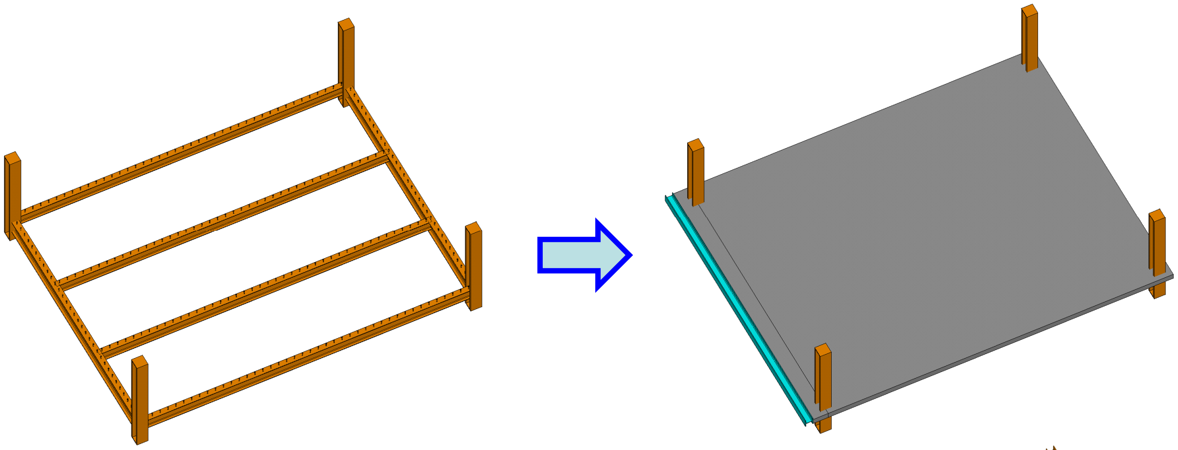
Experimental results & Observation

Comparison with simple design methods

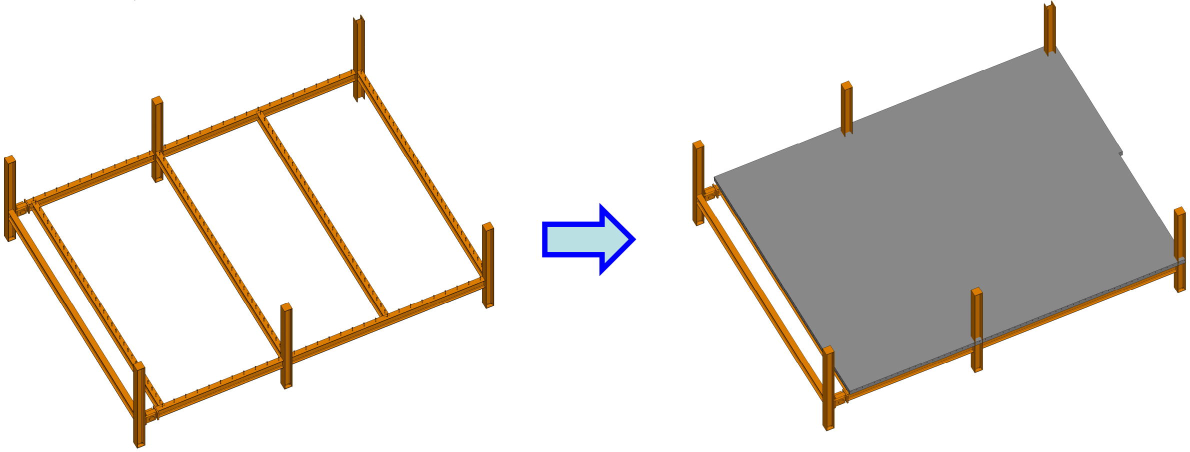
Conclusion

- **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

Objectives

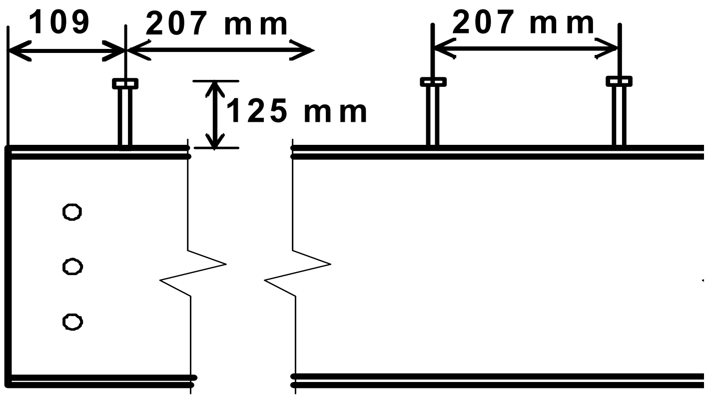
Test set-up

Experimental results & Observation

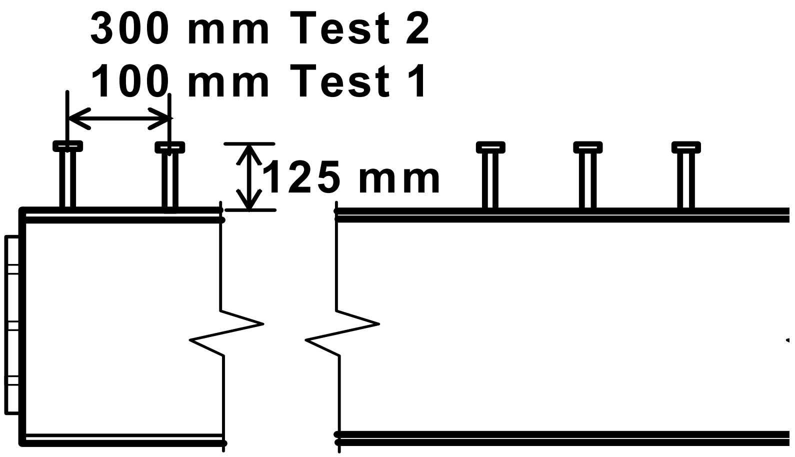
Comparison with simple design methods

Conclusion

- **Arrangement of headed studs over steel beams**



Secondary beams



Primary beams

- **Type of steel studs**
  - TRW Nelson KB 3/4" – 125 (Φ = 19mm; h = 125 mm; f_y = 350 N/mm^2; f_u = 450 N/mm^2)

Steel joints

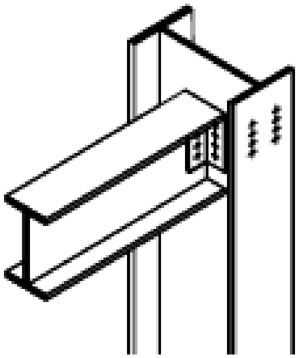
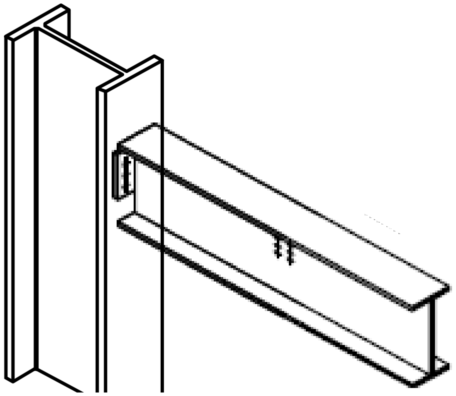
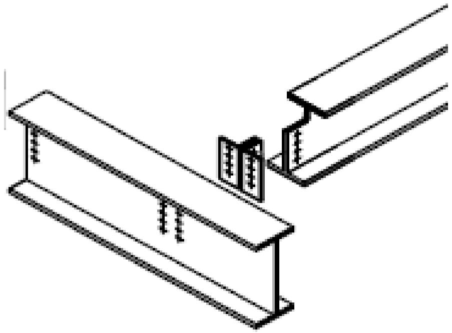
Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Beam to column		Beam to beam
Secondary beam	Primary beam	
Double angle web cleats	Flexible end plate	Double angle web cleats
		

Grade of steel bolts: 8.8

Diameter of steel bolt: 20 mm

Sizes of structural members

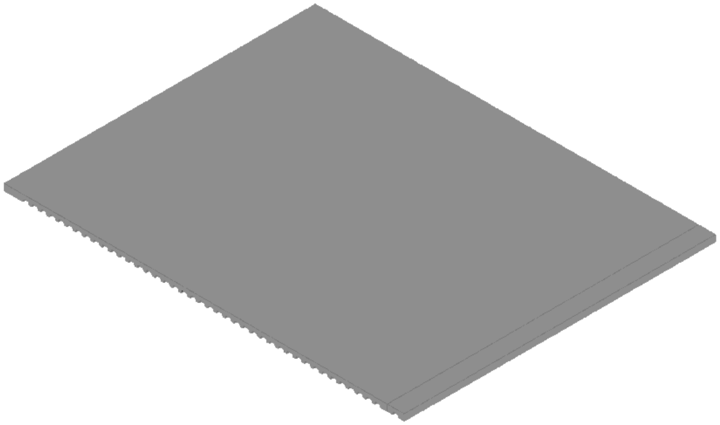
Objectives

Test set-up

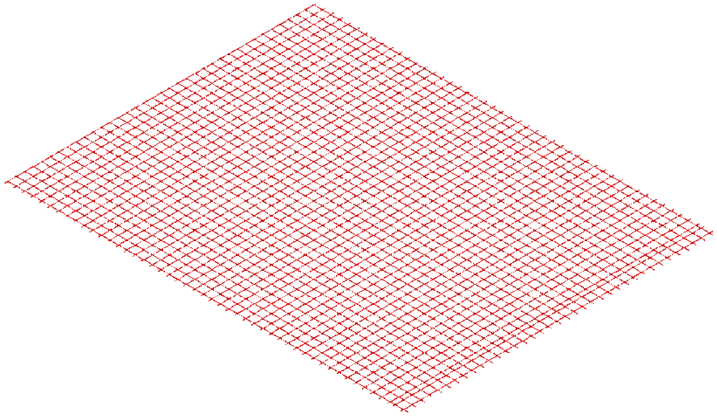
Experimental results & Observation

Comparison with simple design methods

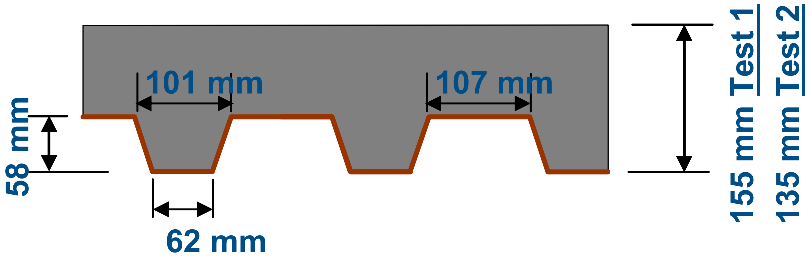
Conclusion



Composite slab



Reinforcing steel mesh



Steel deck: COFRAPLUS60 – 0.75 mm

Concrete quality: C30/37

Mesh size: 150x150

Diameter: 7 mm

Steel grade: S500

Axis distance from top of the slab:

- 50 mm Test 1
- 35 mm Test 2

Mechanical loading condition

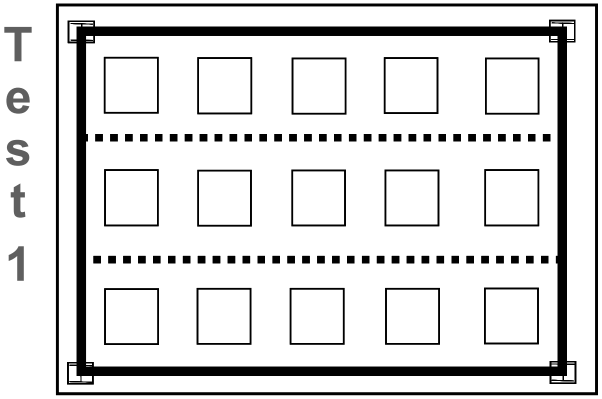
Objectives

Test set-up

Experimental results & Observation

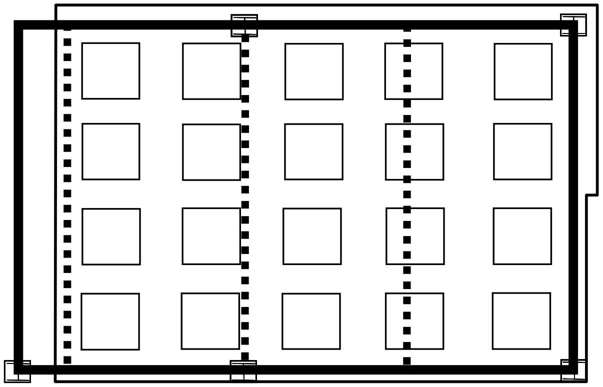
Comparison with simple design methods

Conclusion



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

1

2

3

4

Behaviour of the floor during fire

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Structure of the Test 3 (FICEB)

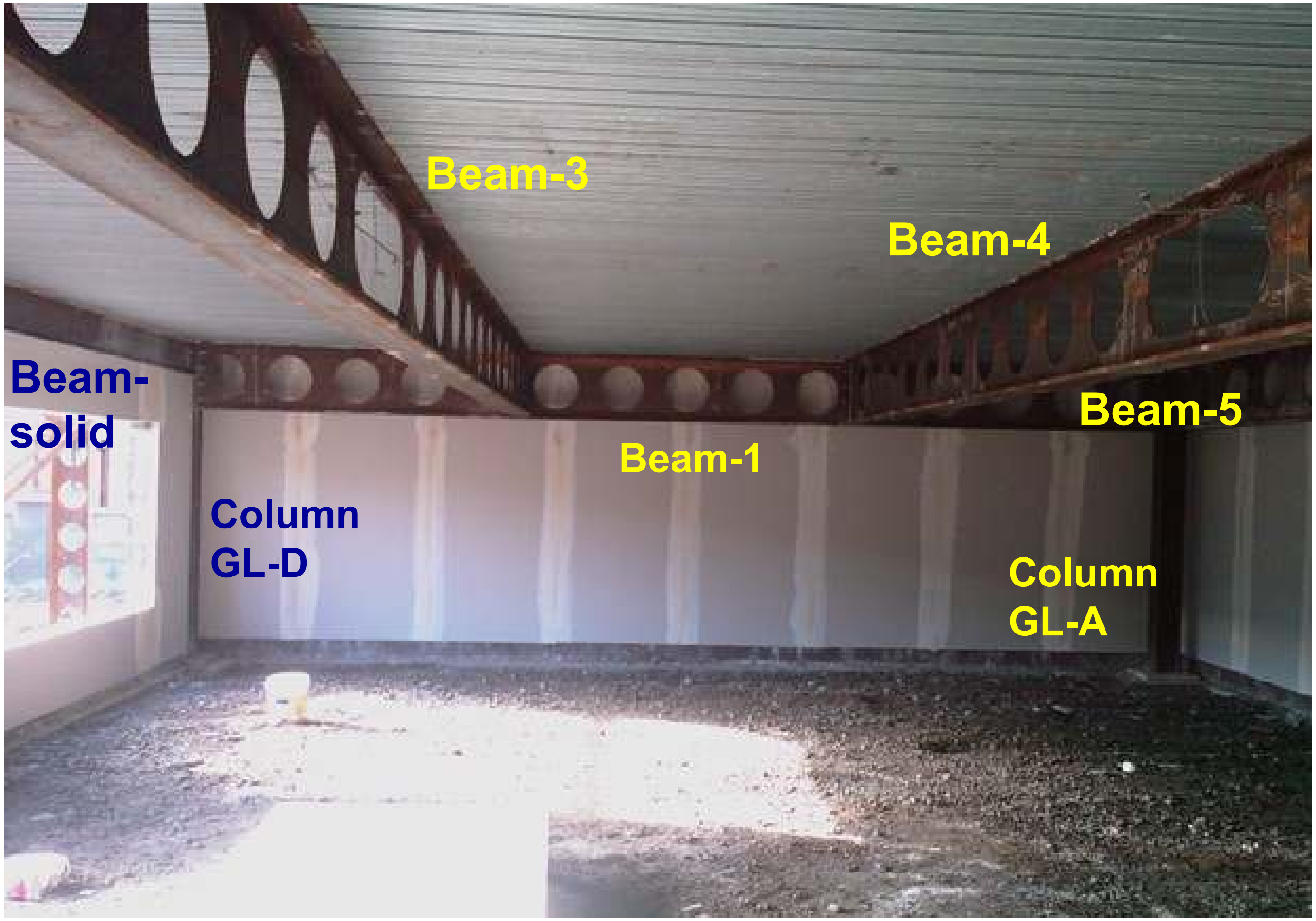
Objectives

Test set-up

Experimental results & Observation

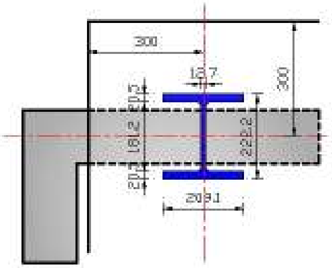
Comparison with simple design methods

Conclusion

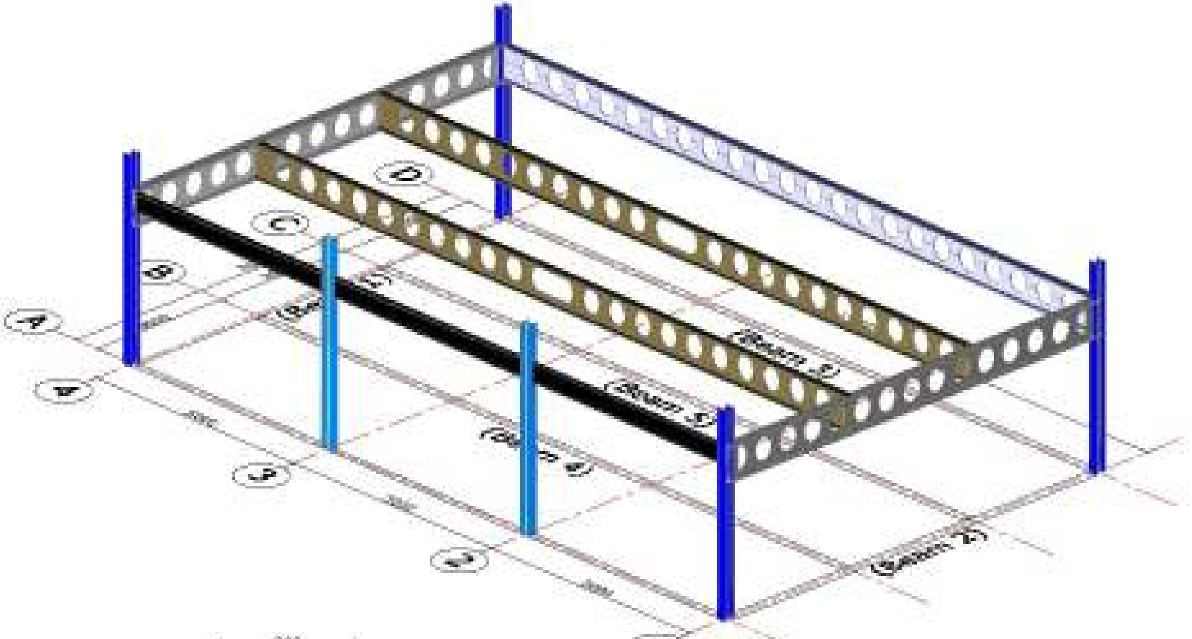


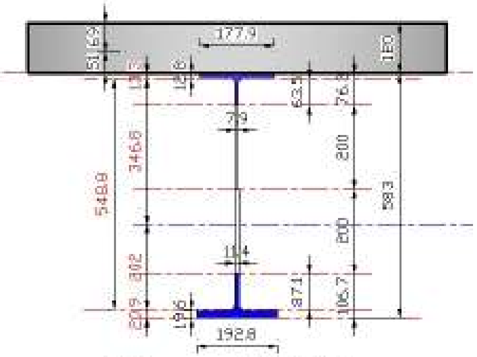
Structure of the Test 3

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

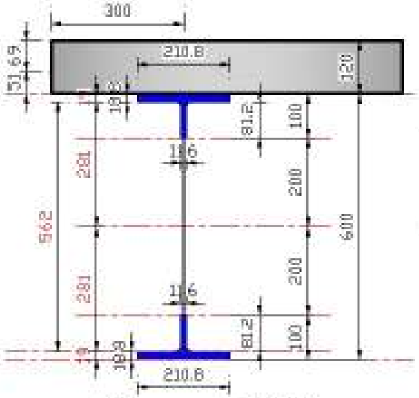


(Column GL-A)

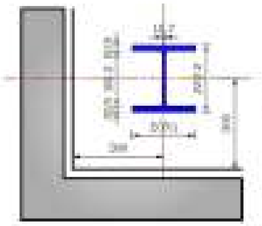




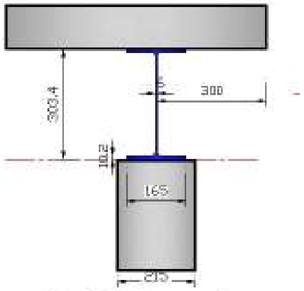
(Beam 3/4/5)



(Beam 1/2)



(Column GL-D)



(Solid Beam)

Structure of the Test 3

Objectives

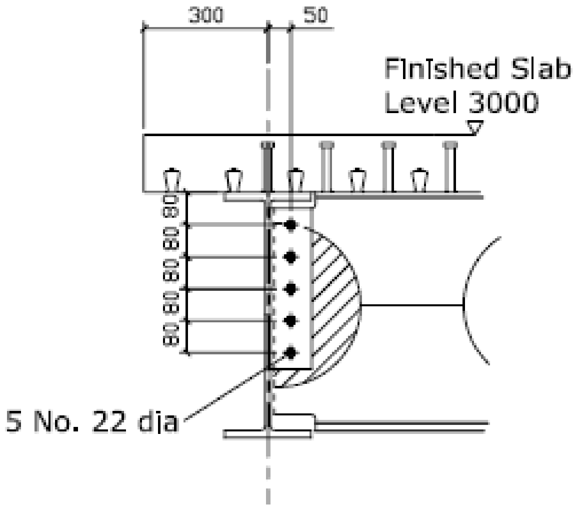
Test set-up

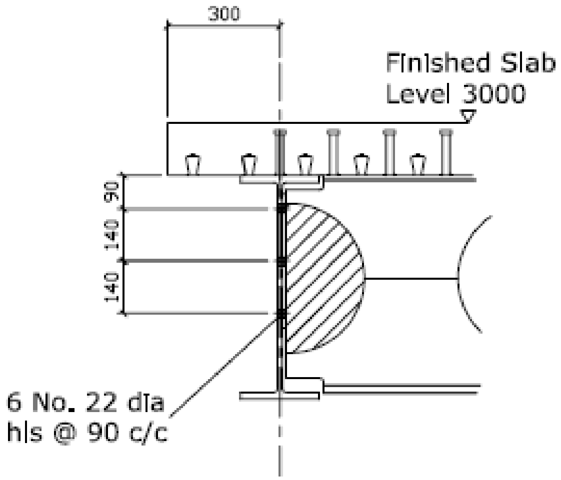
Experimental results & Observation

Comparison with simple design methods

Conclusion

Beam - Beam Connections





Structure of the Test 3

Objectives

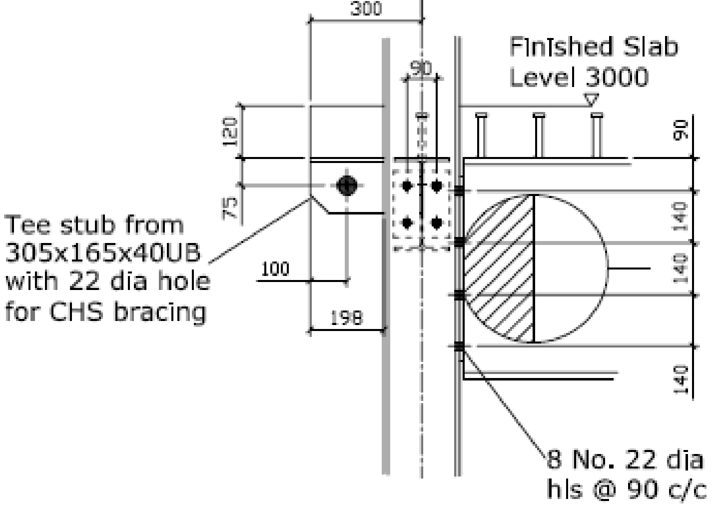
Test set-up

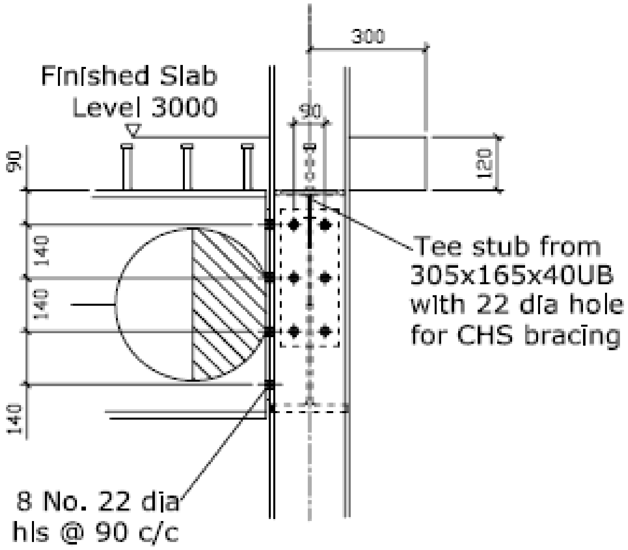
Experimental results & Observation

Comparison with simple design methods

Conclusion

Beam - Column Connections





Structure of the Test 3

Objectives

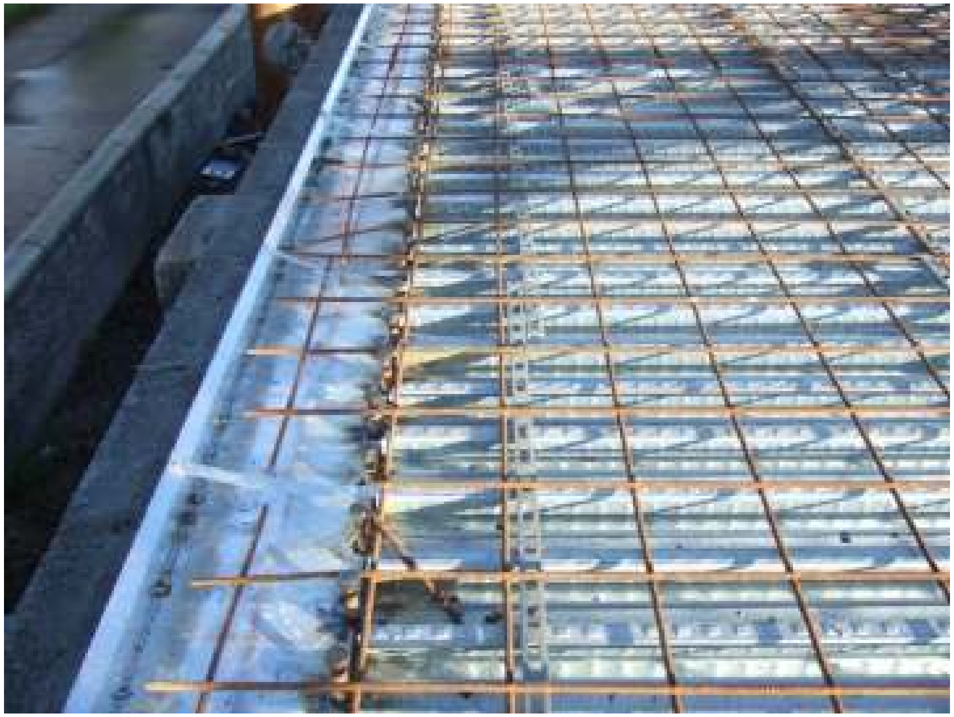
Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

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 reinfor. Detail requirement for Ambient Temp.

Structure of the Test 3

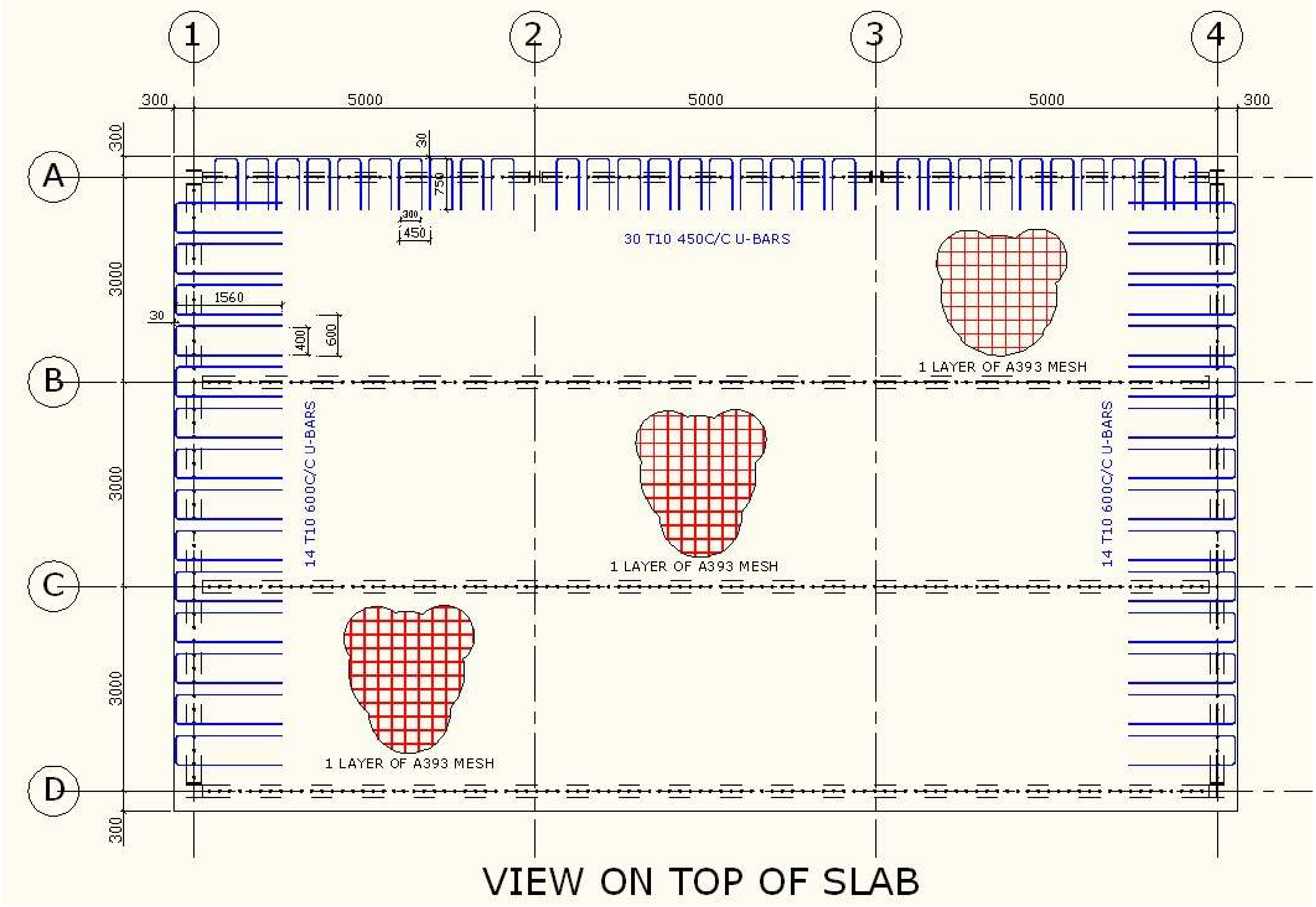
Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion



Structure of the Test 3

Objectives

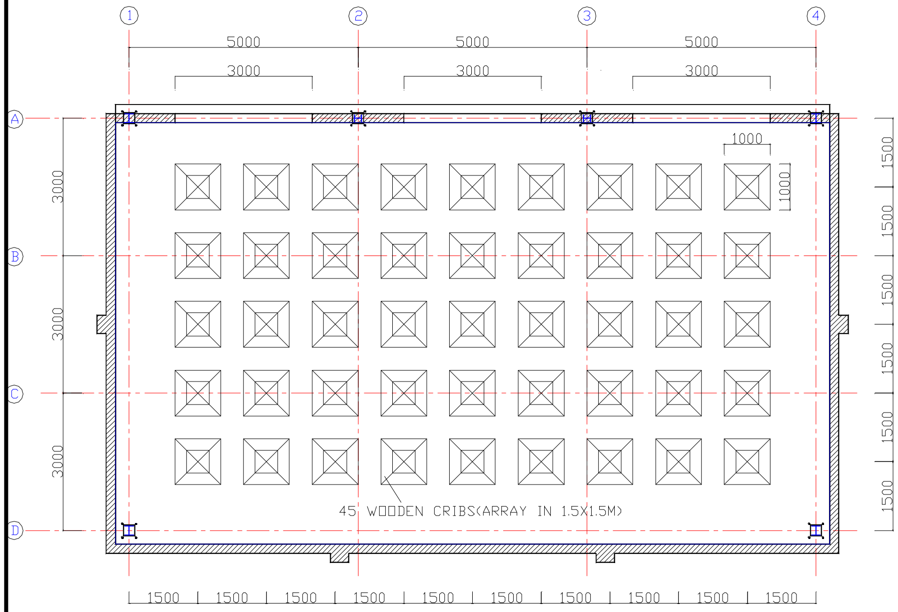
Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Fire load energy density was700MJ/m^2
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).



WOODEN CRIBS LOCATION

Experimental results

Objectives

Test set-up

Experimental results & Observation

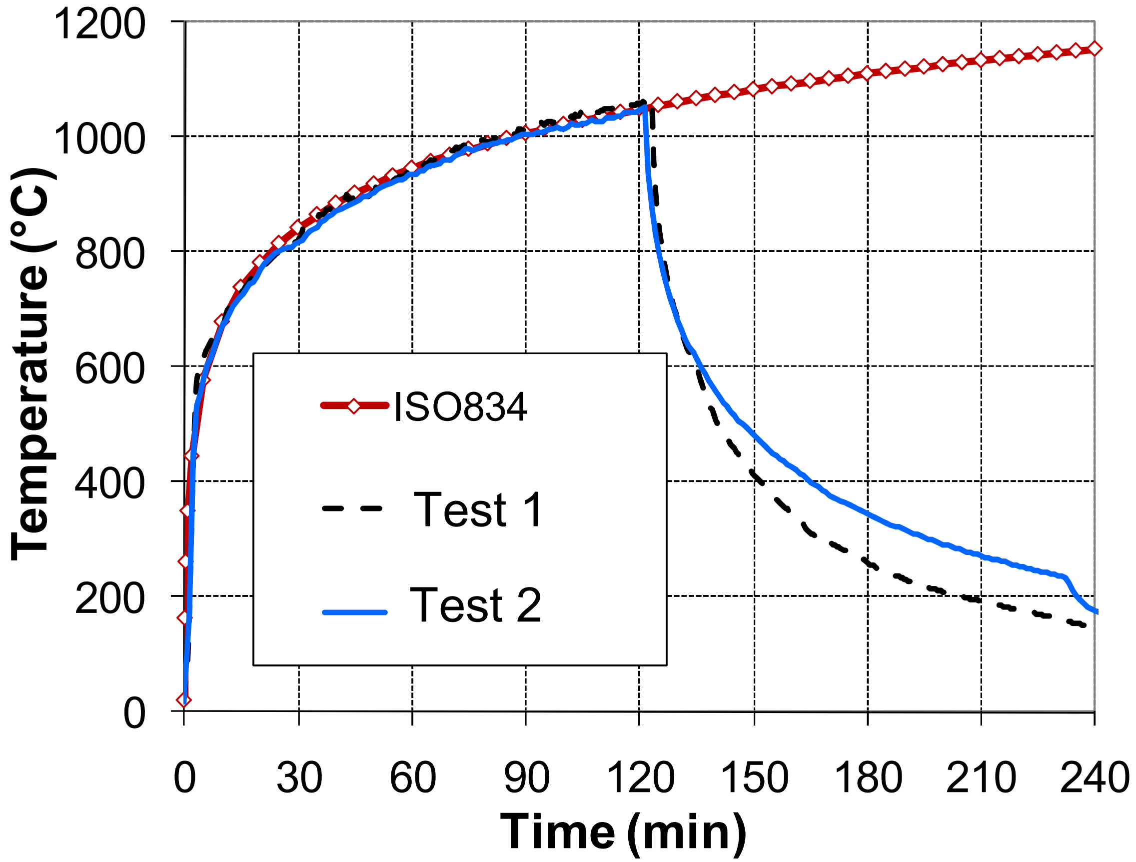
Comparison with simple design methods

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**



Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Experimental results

Objectives

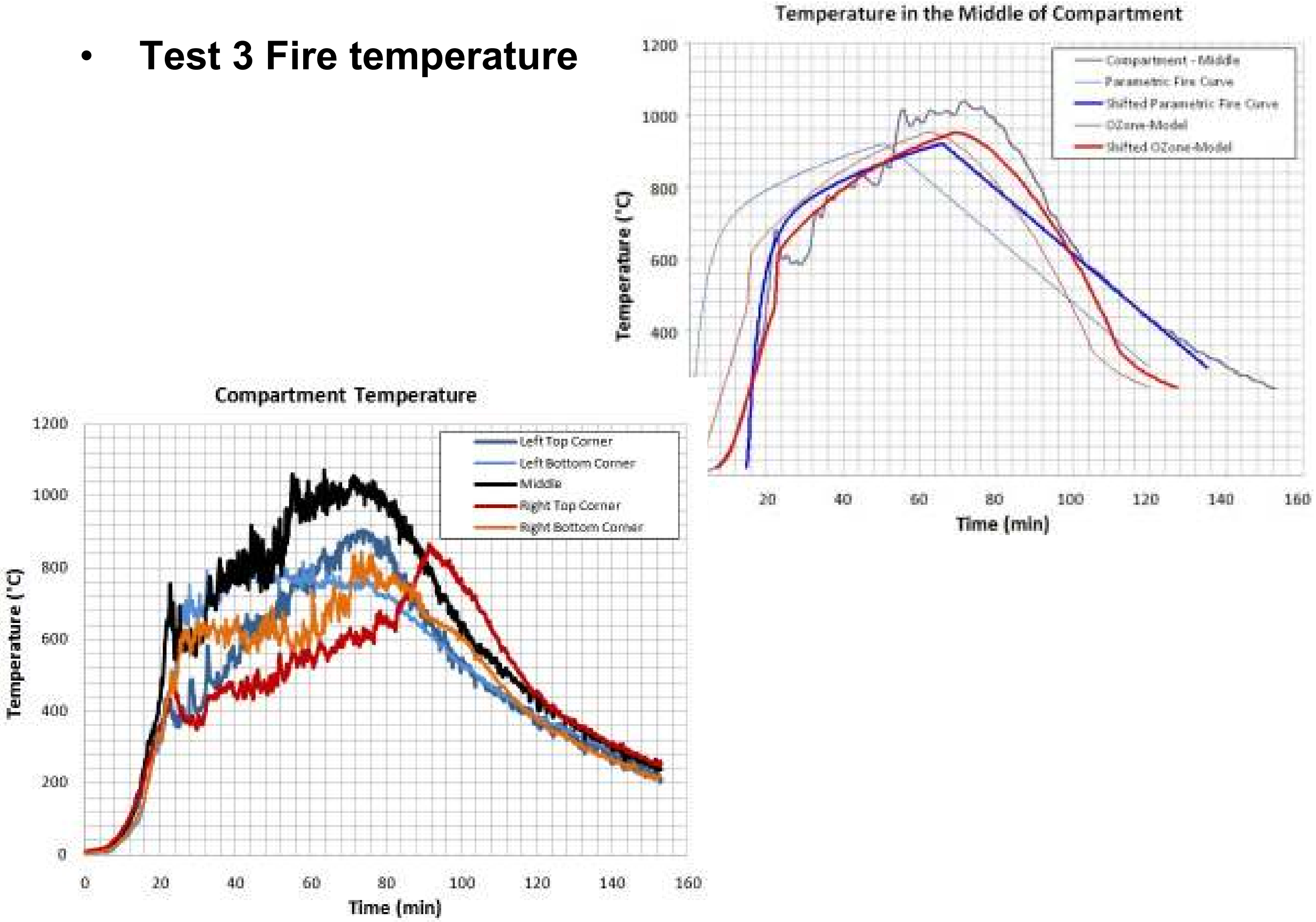
Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- **Test 3 Fire temperature**



Experimental results

- **Heating of unprotected steel beams**

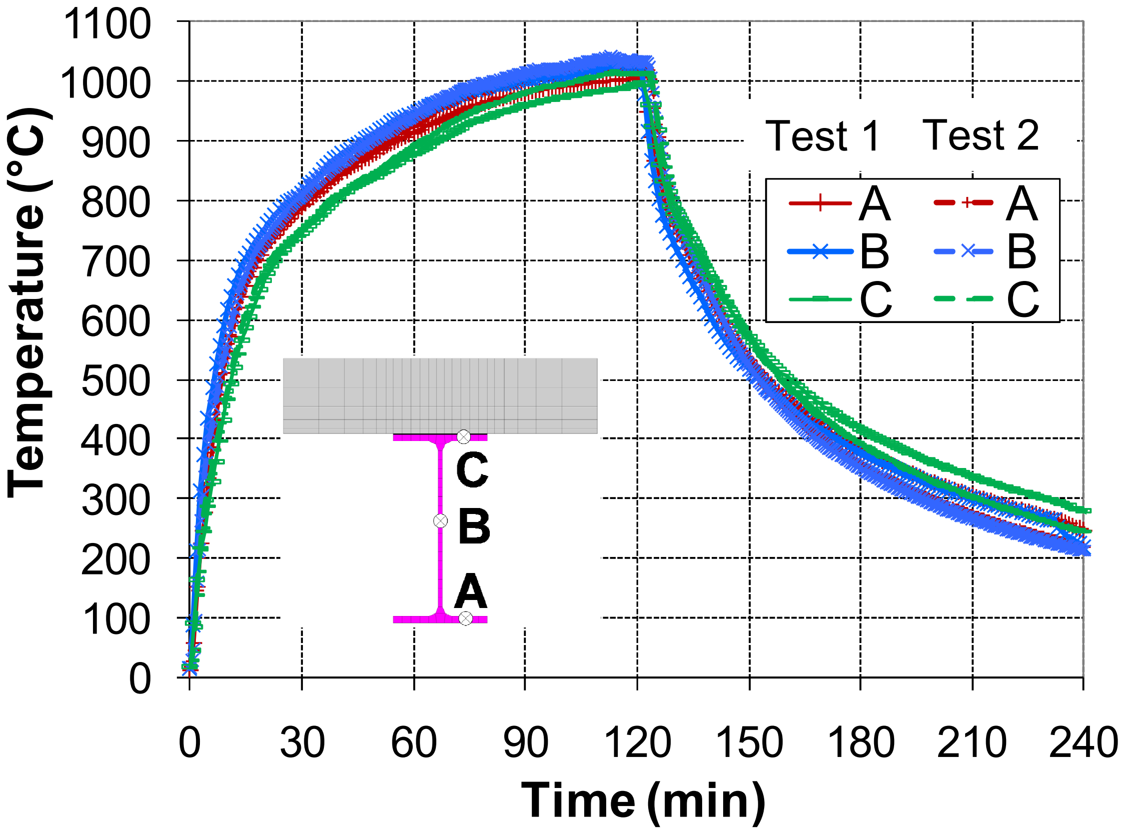
Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion



Experimental results

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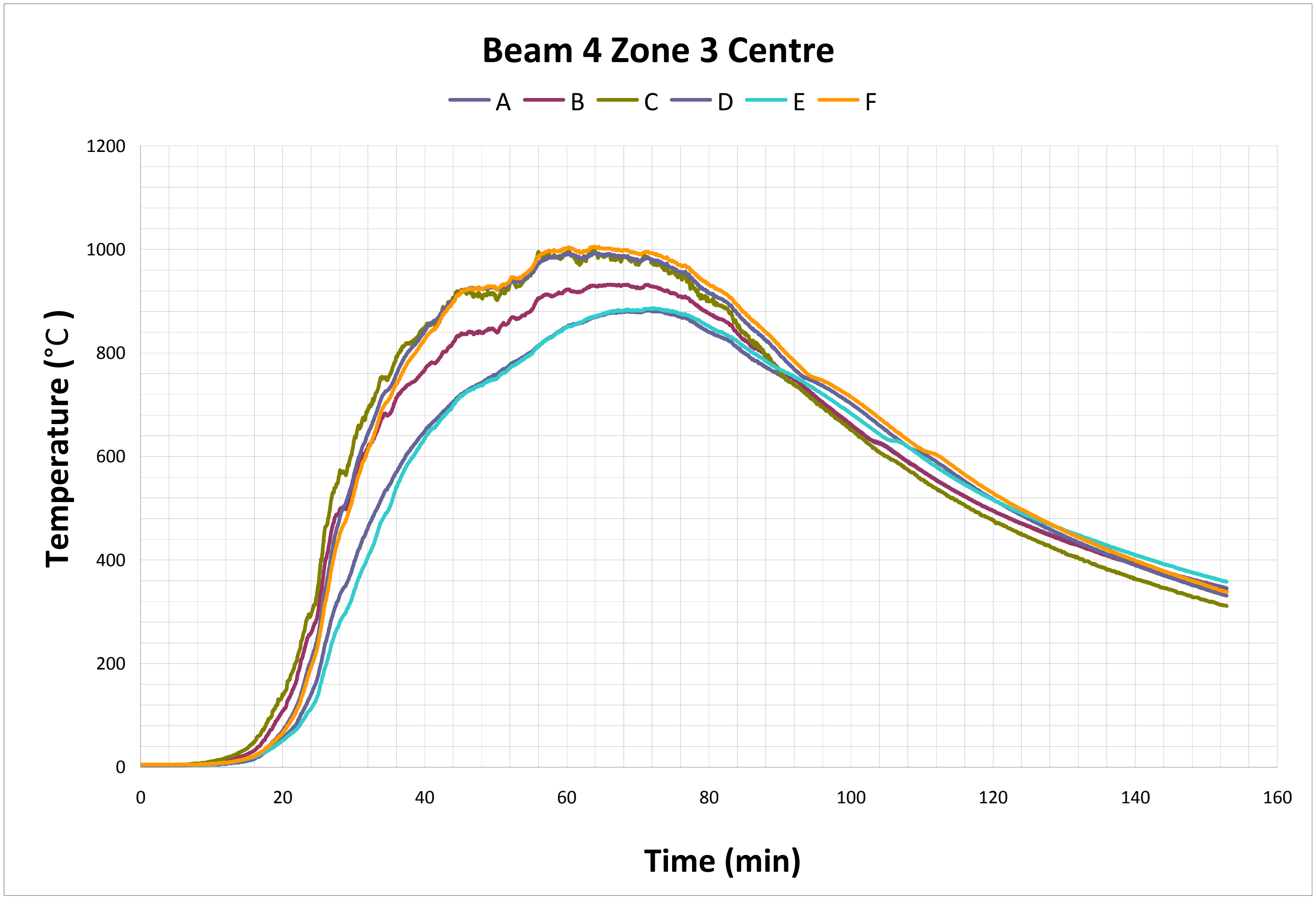
- **Test 3 Heating of unprotected steel beams**



Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Experimental results

Objectives

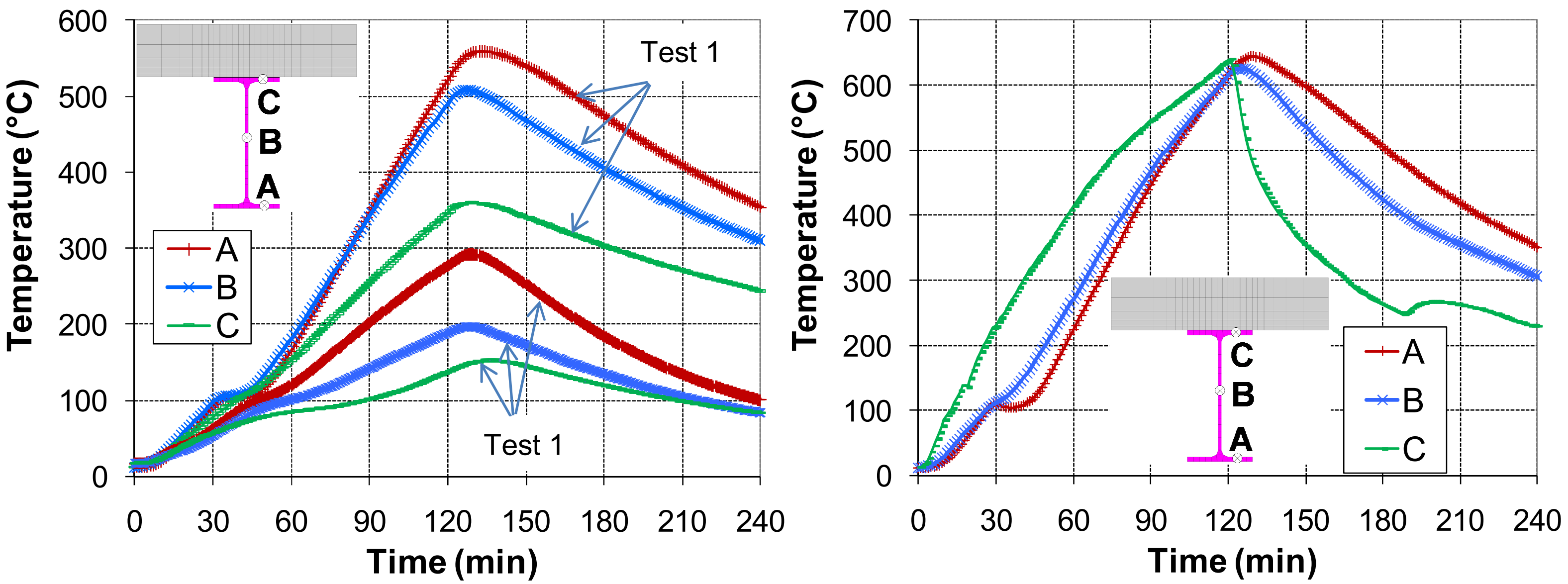
Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- **Heading of protected steel beams**



- **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**

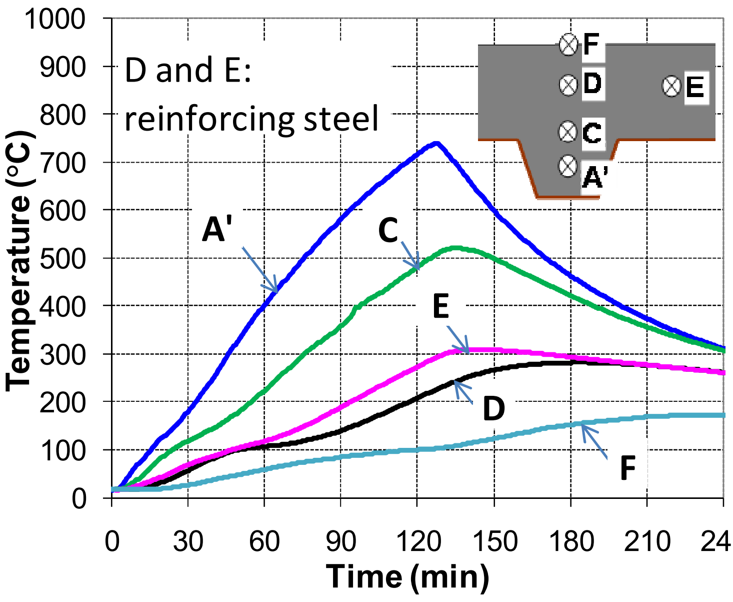
Objectives

Test set-up

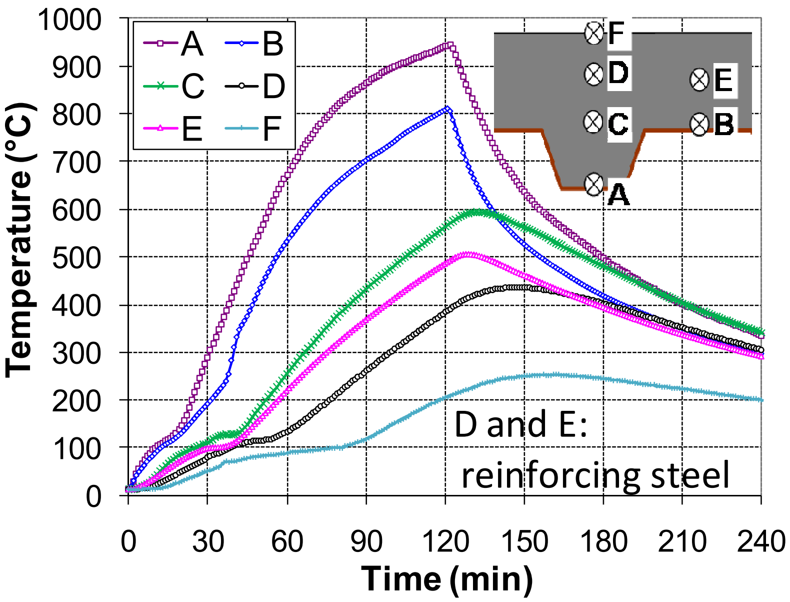
Experimental results & Observation

Comparison with simple design methods

Conclusion



Test 1



Test 2

Experimental results

- **Test 3 Heating of composite slab**

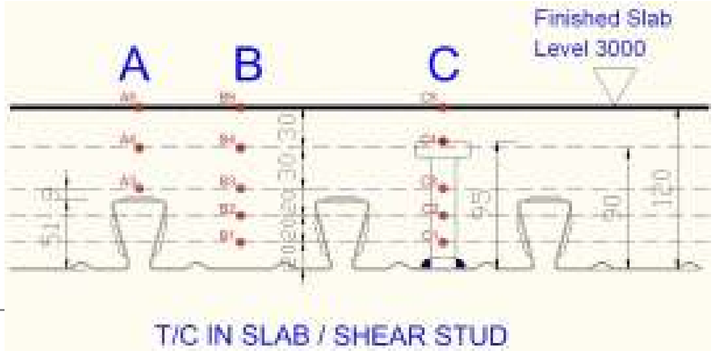
Objectives

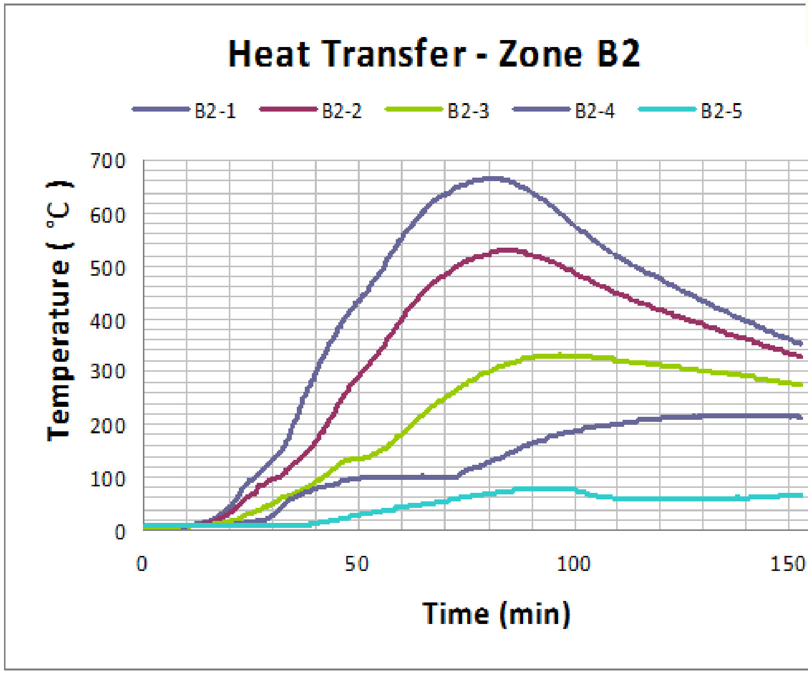
Test set-up

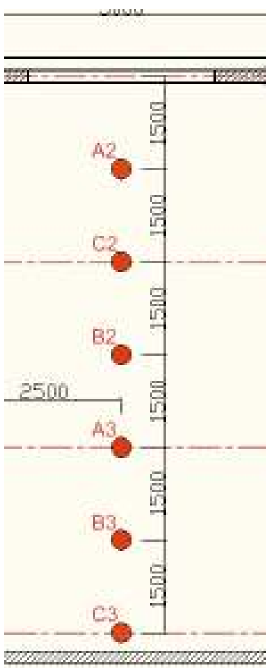
Experimental results & Observation

Comparison with simple design methods

Conclusion

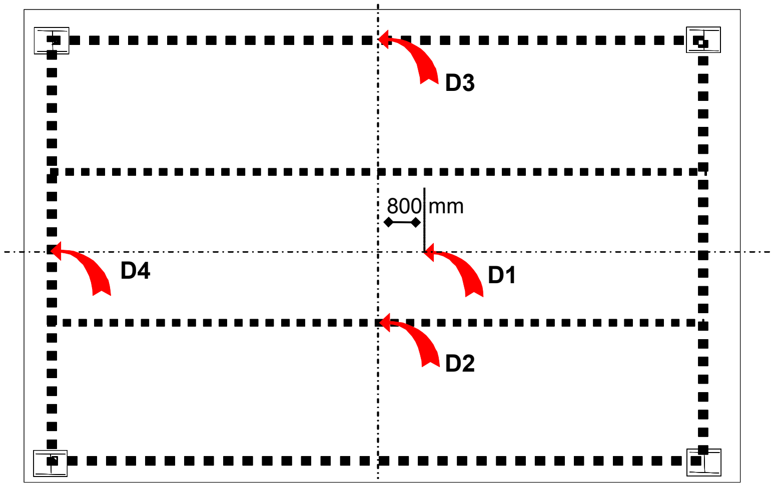




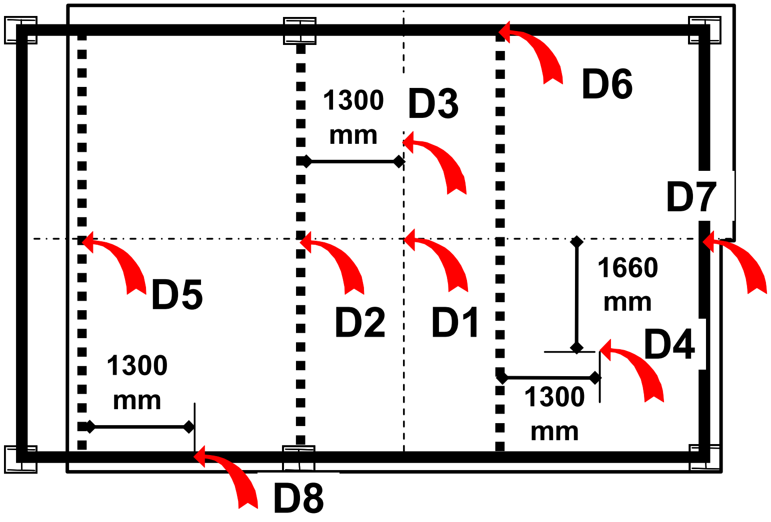


Experimental results

- **Displacement transducers for deflection**



Test 1



Test 2

Experimental results

- **Deflection of the floors**

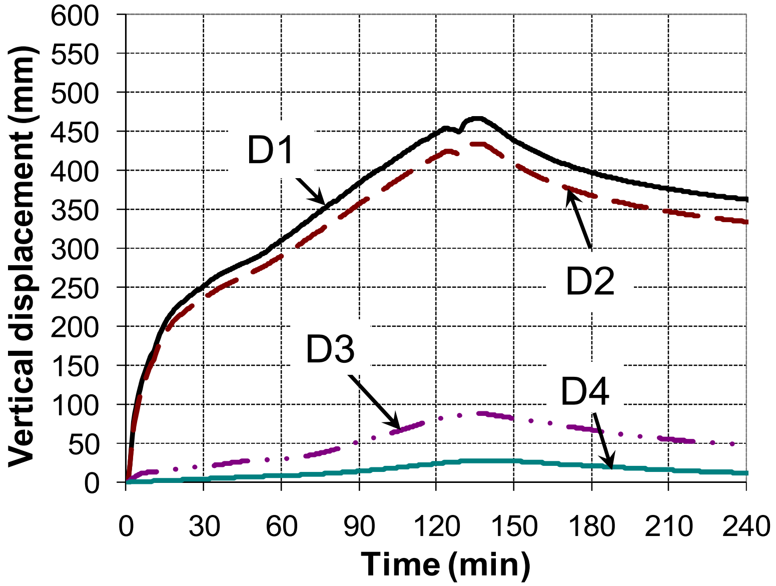
Objectives

Test set-up

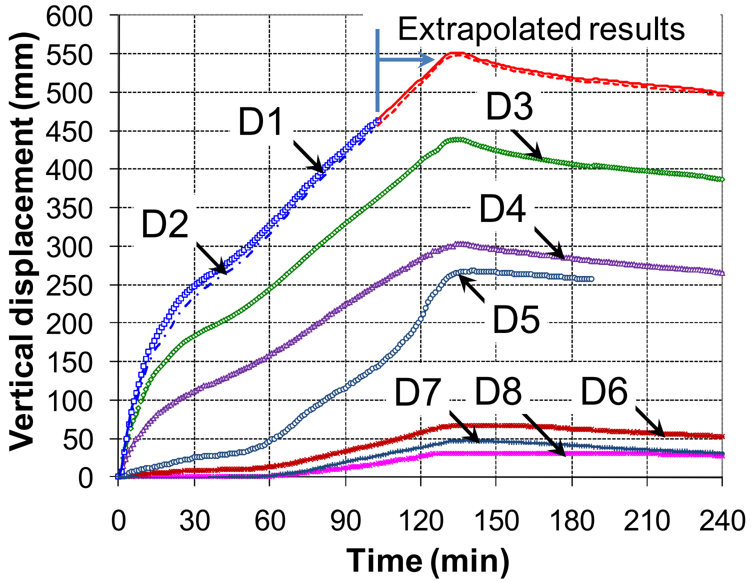
Experimental results & Observation

Comparison with simple design methods

Conclusion



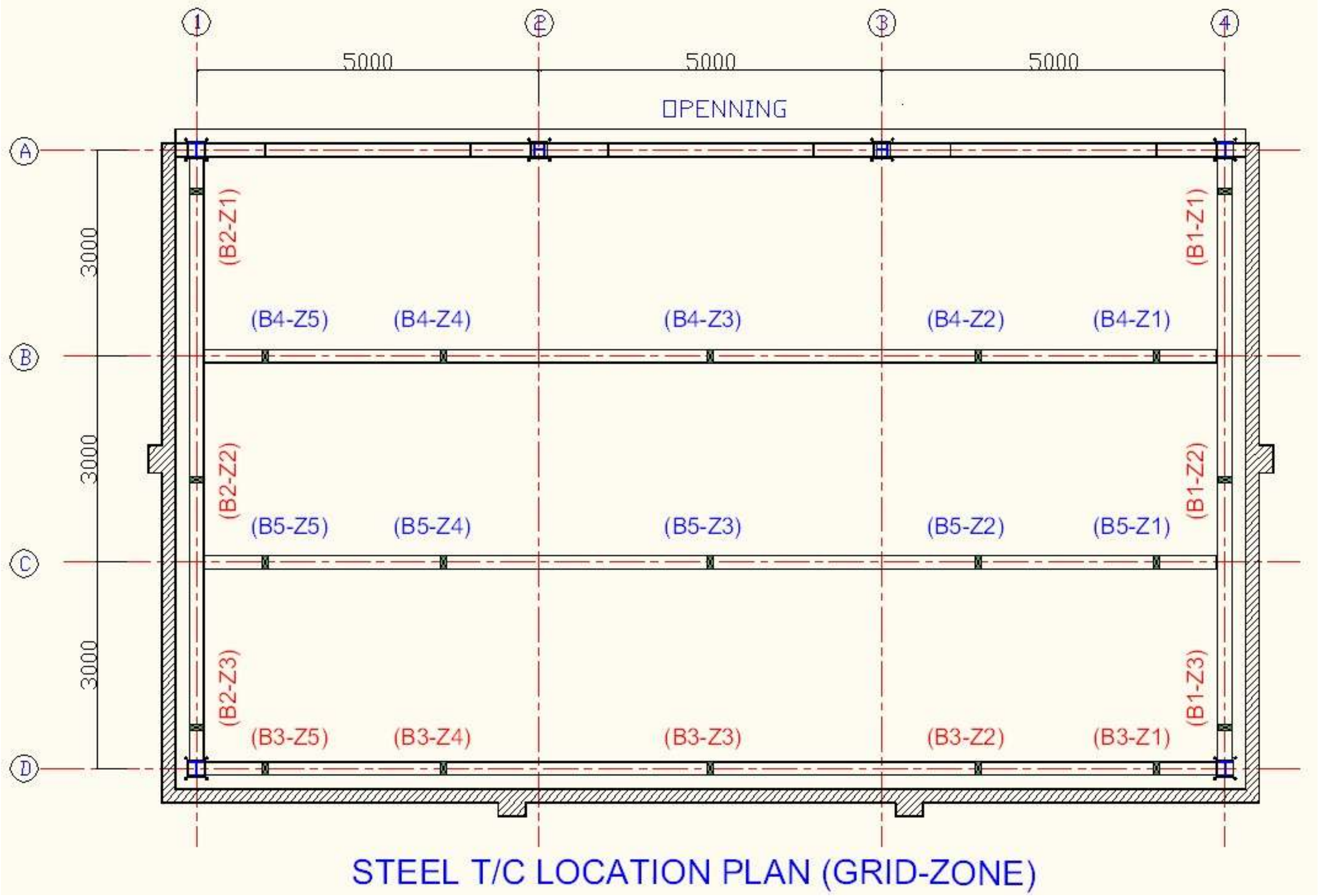
Test 1



Test 2

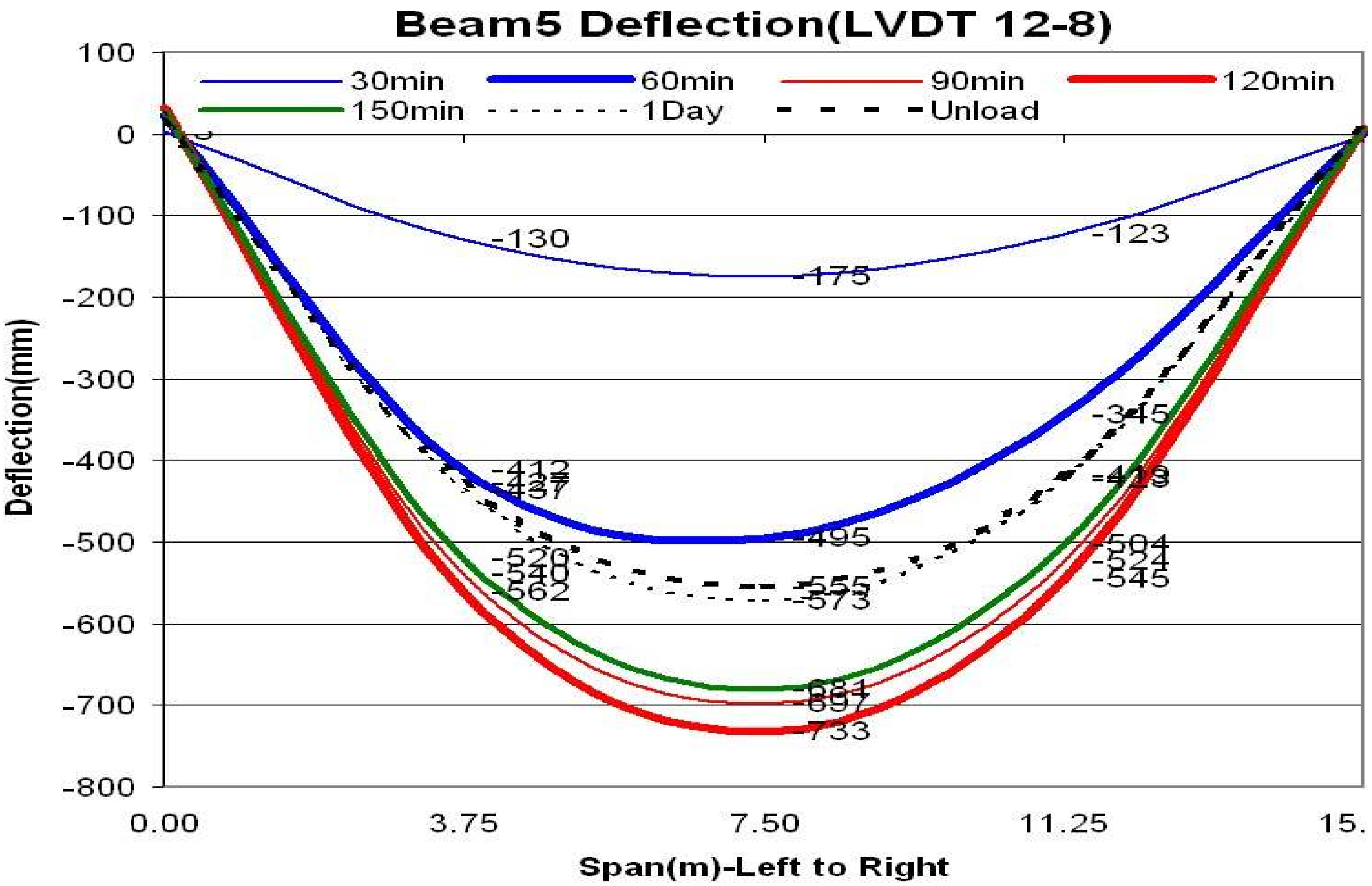
Experimental results

- **Test 3 Displacement transducers for deflection**



Experimental results

- **Test 3 Deflection of the floors**



Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Experimental results

Objectives

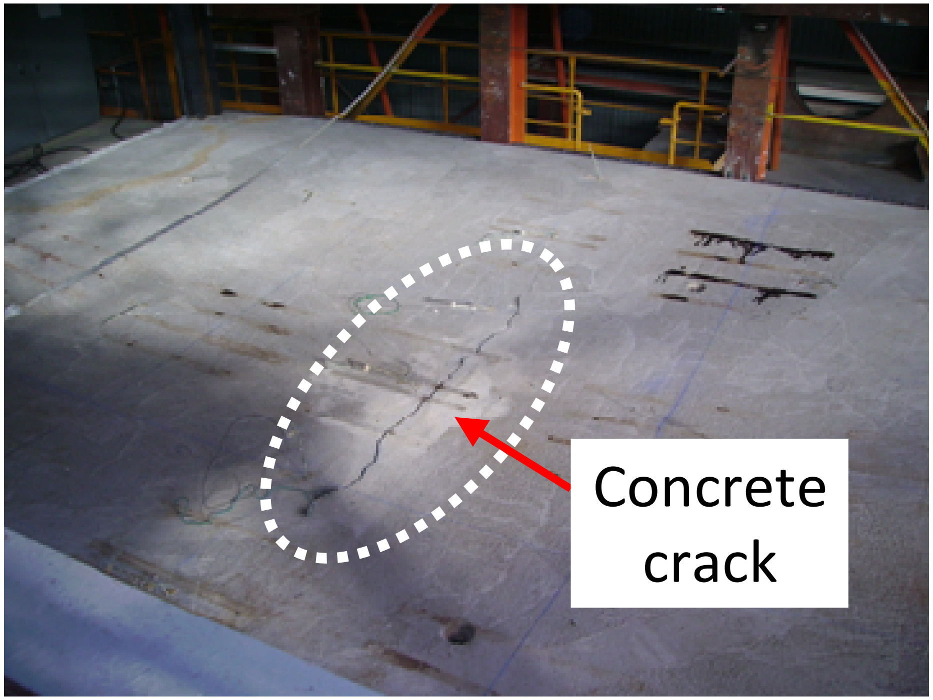
Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

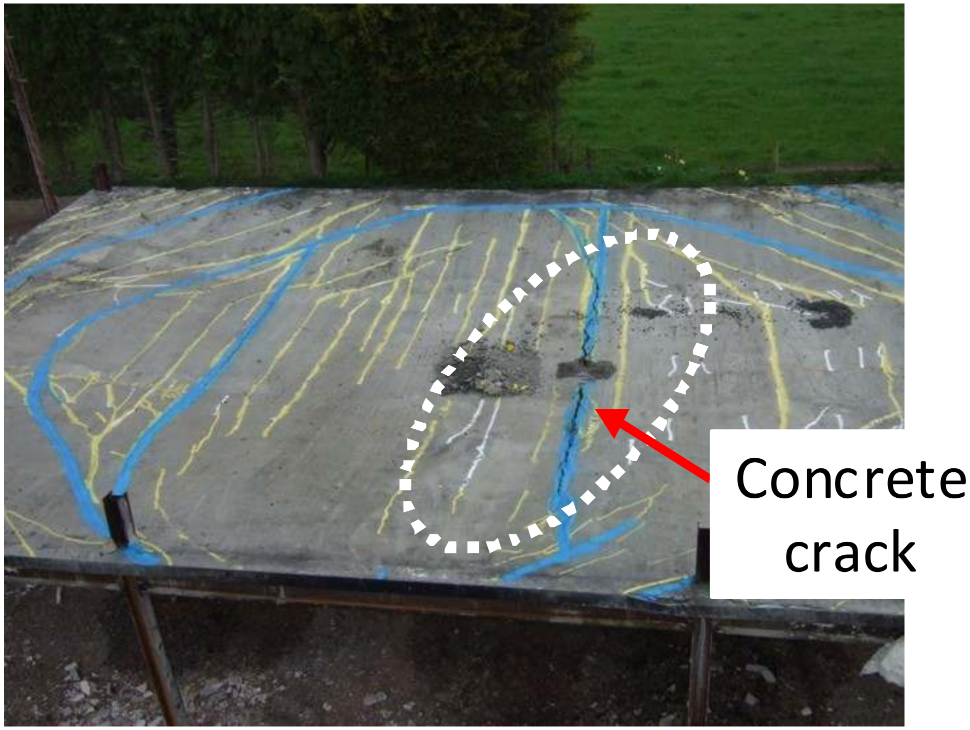
- **Cracking of concrete (Test 1)**



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

Experimental results

- **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)**

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

Experimental results

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- **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

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

	Test 1		Test 2	
	Test	Simple design methods	Test	Simple design methods
Fire rating (min)	> 120	120	> 120	96
Deflection (mm)	450	366(*)	510	376(*)

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

New experimental evidences

Objectives

Test set-up

Experimental results & Observation

Comparison with simple design methods

Conclusion

- **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