Investigation into Methods for Predicting Connection Temperatures

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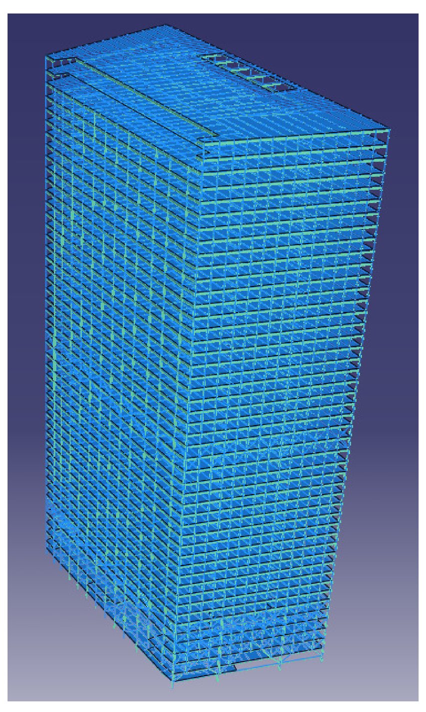
ABSTRACT

Structural fire design codes are largely based on single member tests implying the behaviour of the structure as a whole is not usually considered. A major element that is neglected in the single member approach is the connections.



Some advanced modelling techniques consider overall structural behaviour which shifts the focus from single member response to the collective response of all components.

For this to be a suitable design approach, it is important not only to understand the heated response of each structural component but also the collective response.

Connections have been shown to have lower temperatures than surrounding steel members. Even with these lower temperatures, connections have still been shown to fail in fire for example in the Cardington full scale tests. Connections during fire will undergo increasing forces due to thermal expansion and catenary action but suffer loss of strength due to material degradation.

HEAT TRANSFER MODELLING

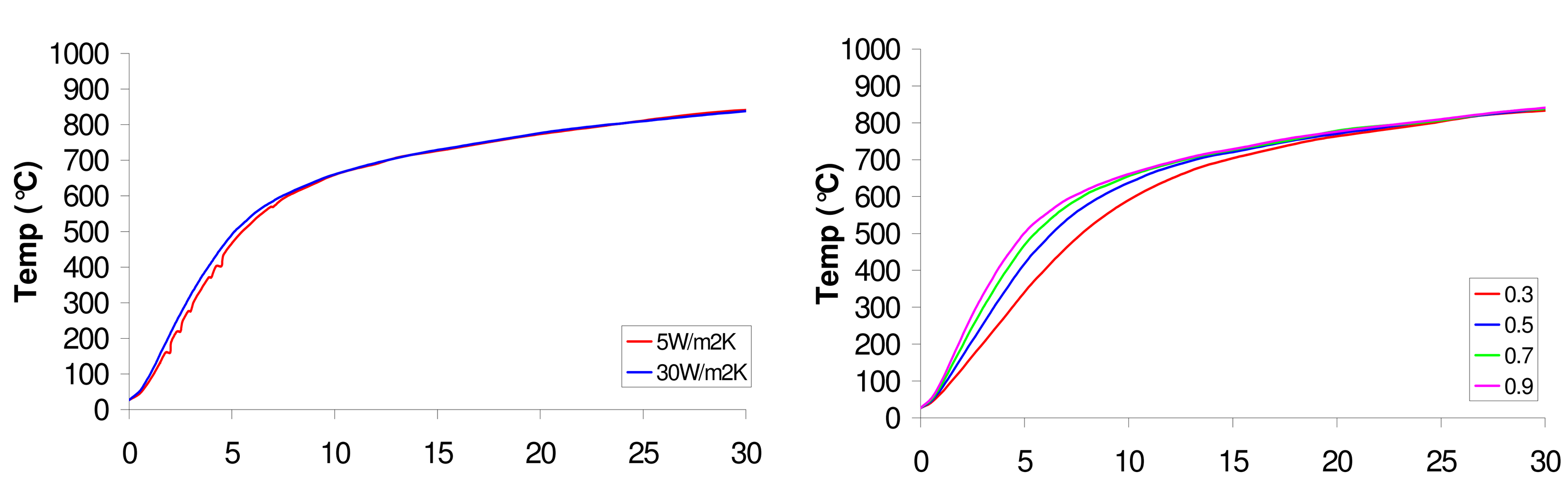
A heat transfer model was created in the finite element software Abaqus to predict connection temperatures.

SENSITIVITY STUDY

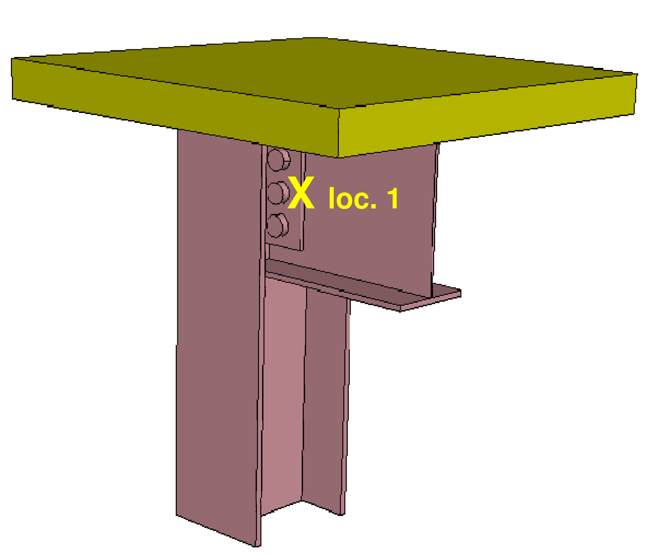
Initially, a sensitivity study was created to look at the variables which most affect the prediction of connection temperatures. The key parameters investigated were:

- The inclusion of the concrete slab above the connection
- The convective heat transfer coefficient
- The radiative emissivity

The connection temperatures were monitored in location 1 as marked on the figure below



These graphs show the variation in temperature at loc. 1 when altering heat transfer co-efficient and radiative emissivity. The temperatures were most affected in the first 30 minutes of analysis.



RESULTS:

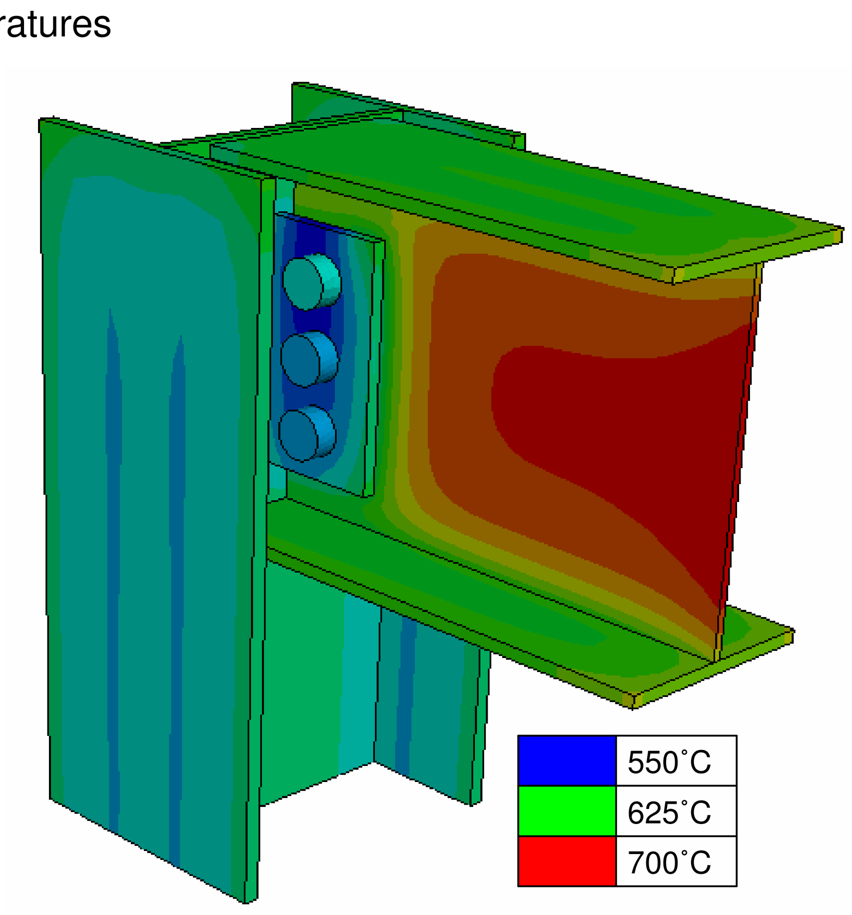
- **The inclusion of the concrete slab has negligible effect on connection temperatures**
- The value of convective heat transfer co-efficient has little bearing on temperatures, especially in the later stages
- The value of radiative emissivity noticeably affects the temperatures

ABAQUS HEAT TRANSFER STUDY

PARAMETERS:

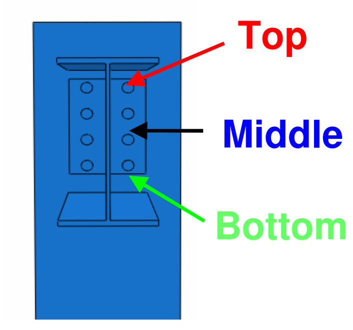
- Conductivity = 45.8W/m²K
- Specific Heat = 460J/kg.K
- Emissivity = 0.8 generally
- Emissivity = 0.3 at the connection
- Heat Transfer Co-efficient = 25W/m².K

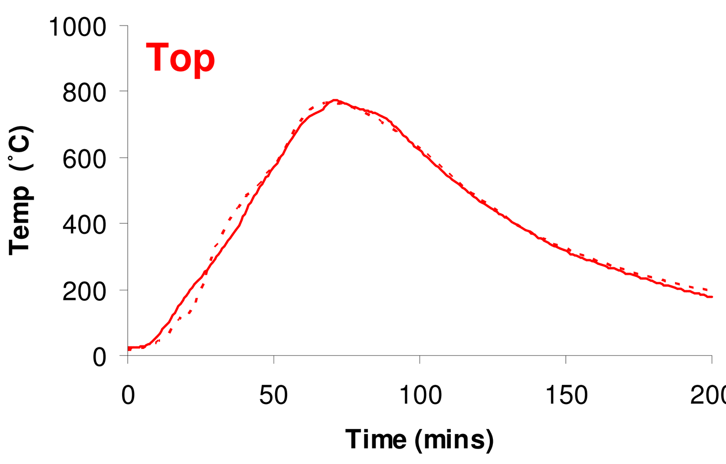
Full scale fire tests undertaken at Cardington in 2003 were used in the following heat transfer models.

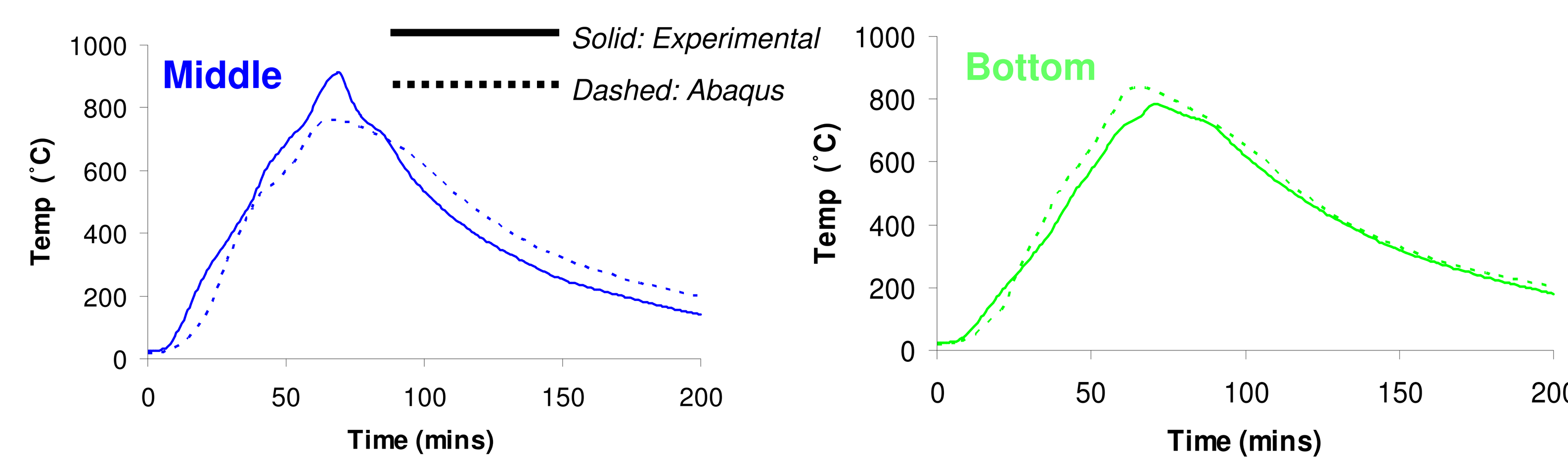


MODELLING RESULTS

A flexible end plate connection used in the Cardington experiments in 2003 was modelled in Abaqus. The results for predicted temperatures across the connection are shown here.

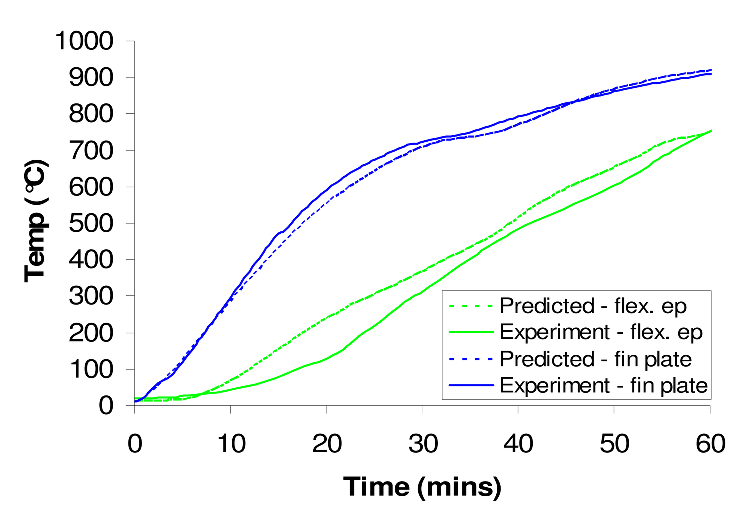






The Abaqus heat transfer modelling results show good correlation with the experimental results

LUMPED CAPACITANCE



The graph to the left uses the **lumped capacitance method** for average temperatures of a flexible end plate from the Cardington experiments and a fin plate used in tests carried out by Manchester University

$$\Delta T_s = \frac{h}{C_s (V/A)} (T_f - T_s) \Delta t$$

T_s = Steel Temperature
Tf = Fire temperature
C_s = Specific heat
A = Heated surface area
h = heat transfer co-efficient
Δt = time step
V = Volume of steel

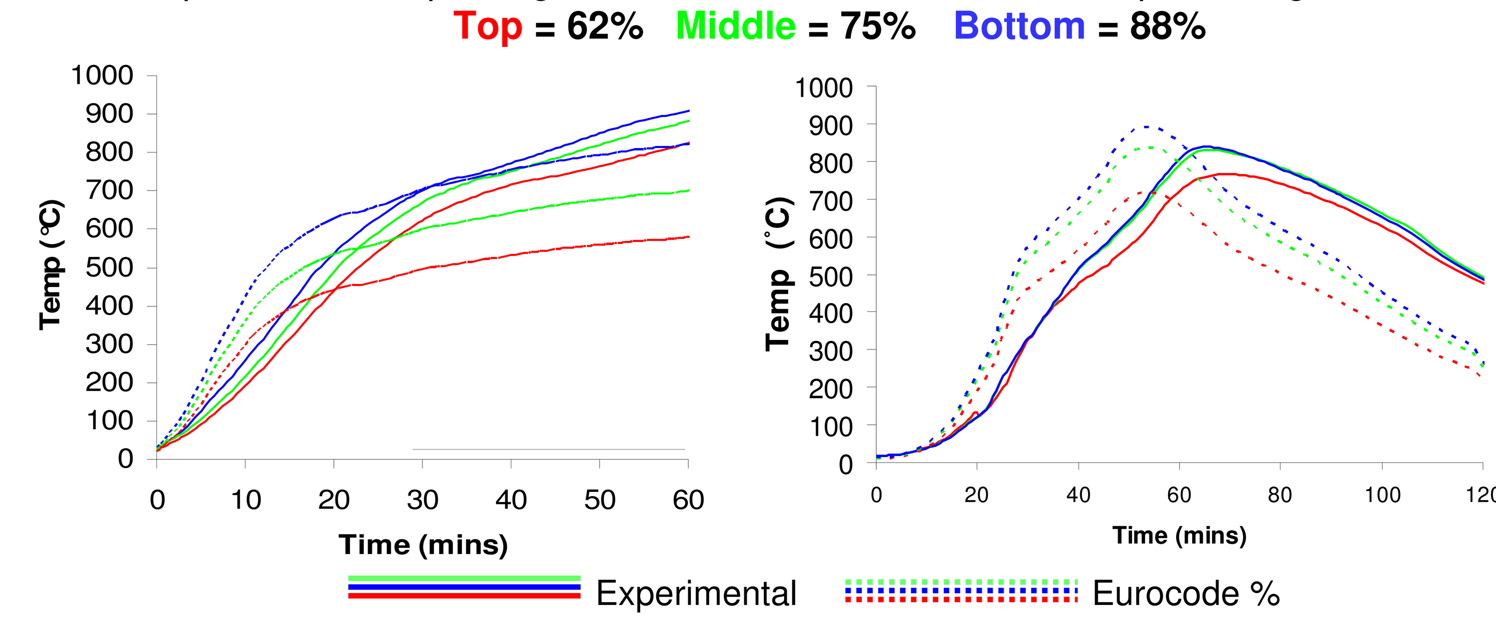
The lumped capacitance method predicts good average temperatures.

EUROCODE PERCENTAGE METHOD

Eurocode 3 states that connection temperatures can be estimated as a percentage of beam mid-span lower flange temperature.

From top to bottom, top being at the underside of the slab these percentages are:

Top = 62% Middle = 75% Bottom = 88%



Flush End Plate Temperatures: Manchester University Furnace Test

Flexible End Plate Temperatures Cardington Tests

The Eurocode percentage method is only suitable for crude calculations.

CONCLUSIONS

- **The inclusion of the concrete slab in finite element heat transfer modelling has negligible effect on connection temperatures**
- **Abaqus modelling showed good temperature predictions across the connections**
- **The lumped capacitance method predicted good average connection temperatures**
- **The Eurocode percentages method is only suitable for crude calculations**

REFERENCES

[1] Bailey, CG, Lennon, T and Moore, DB, "The behaviour of full-scale steel framed buildings subjected to compartment fires", The Structural Engineer, pp. 15-21, April 1999

[2] CEN, EC 3: Design of Steel Structures part 1.2: General rules - Structural Fire Design, BS EN 1993-1-2:2005, Brussels: CEN, European Committee for Standardisation, 2006b

[3] ABAQUS User's Manual, version 6.6, Providence, RI, USA

[4] Incropea, FP, DeWitt, DP, Bergman, TL and Lavine, AS, 'Fundamentals of Heat and Mass Transfer' John Wiley & Sons, Hoboken, USA, Sixth Edition , 2005

[5] Dai, XH, Wang, YC & Bailey, CG, 'Temperature distributions in unprotected steel connections in fire' Proc. Steel & Composite Structures, Manchester, UK , pp. 535-540, 2007

[6] Dai, XH, Wang YC & Bailey CG, 'Effects of partial fire protection on temperatures developments in steel joints protected by intumescent coating' Fire Safety J., pp. 16-32, Jan. 2009

[7] Lennon, T. and Moore, DB, 'Results and observations from full-scale fire test at BRE Cardington, 16 January 2003' BRE, Watford, UK, 2004

The authors wish to thank Arup Fire and EPSRC for funding this research. They also thank Dr. Y. Wang and Dr. X. Dai of the University of Manchester for allowing access to experimental results in advance of publication.