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Parametric studies of simple connections in a sub-frame structure exposed to fire

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EPSRC

Engineering and Physical Sciences Research Council

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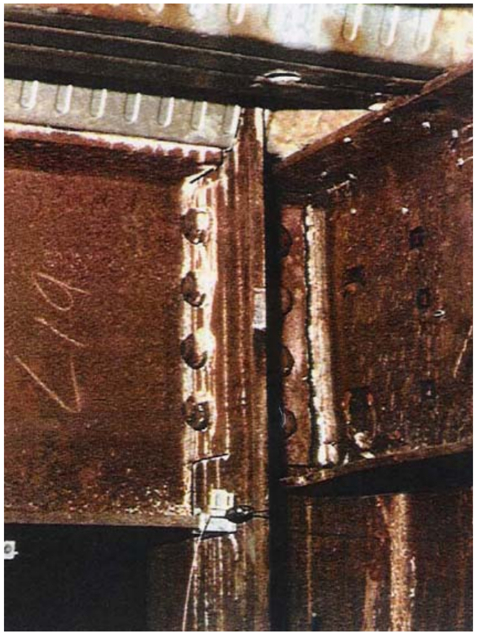
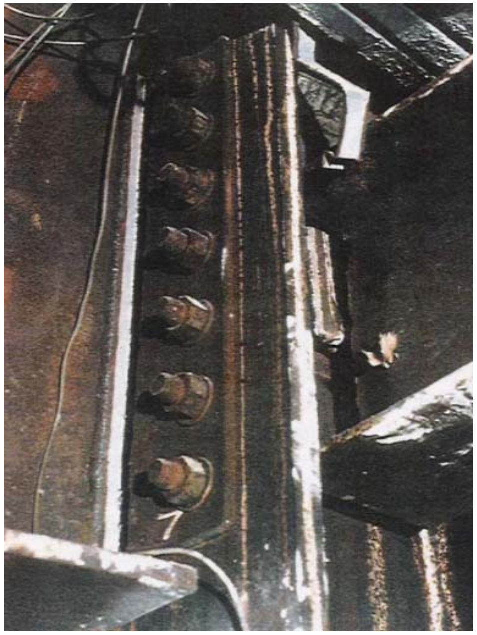
Background



Test 1

Test 2



Test 5

- Failed connections in the full-scale fire tests at Cardington

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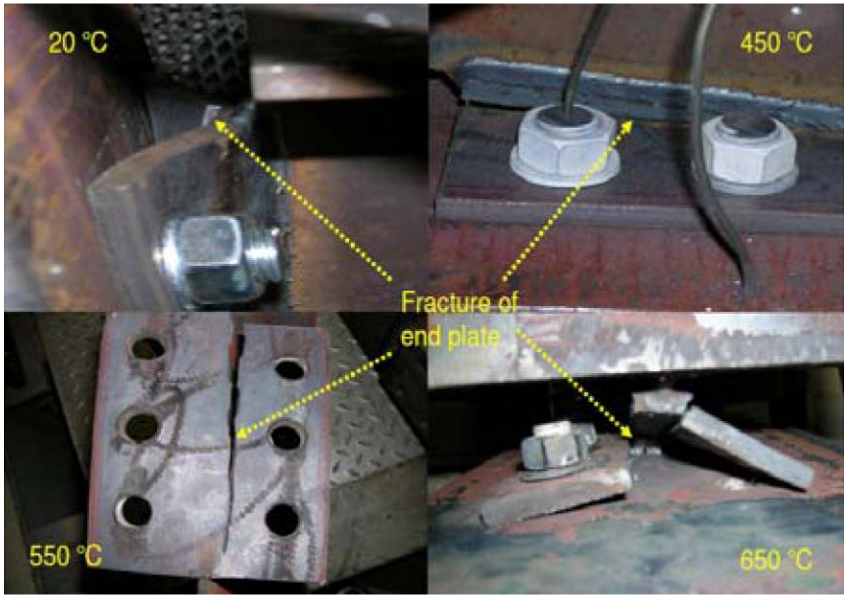
Background

Failed connections in the collapse of WTC buildings



Endplate connections fractured in this robustness project

- The connection failure mechanism is closely associated with failure of brittle components under fire conditions

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Background

Fin plates by Yu et al.

Web cleat connections by Yu et al.

Summary

- Isolated connection tests (Yu et al. and Hu et al.) demonstrate that ductility of simple steel connections (except for web cleats) is very limited under fire conditions (fin plates and flush endplates).
- Connection failure mechanism is closely associated with failure of brittle components under fire conditions
- According to experimental tests on flexible endplate connections, failure of these connections is due to rupture of endplates along the welds.
- Failure of fin plates is usually due to shear failure of 8.8 bolts

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Objectives of this parametric study

Performance of connections in *Isolated connection* testing and *in a structure* is different due to presence of axial forces in a fire situation.

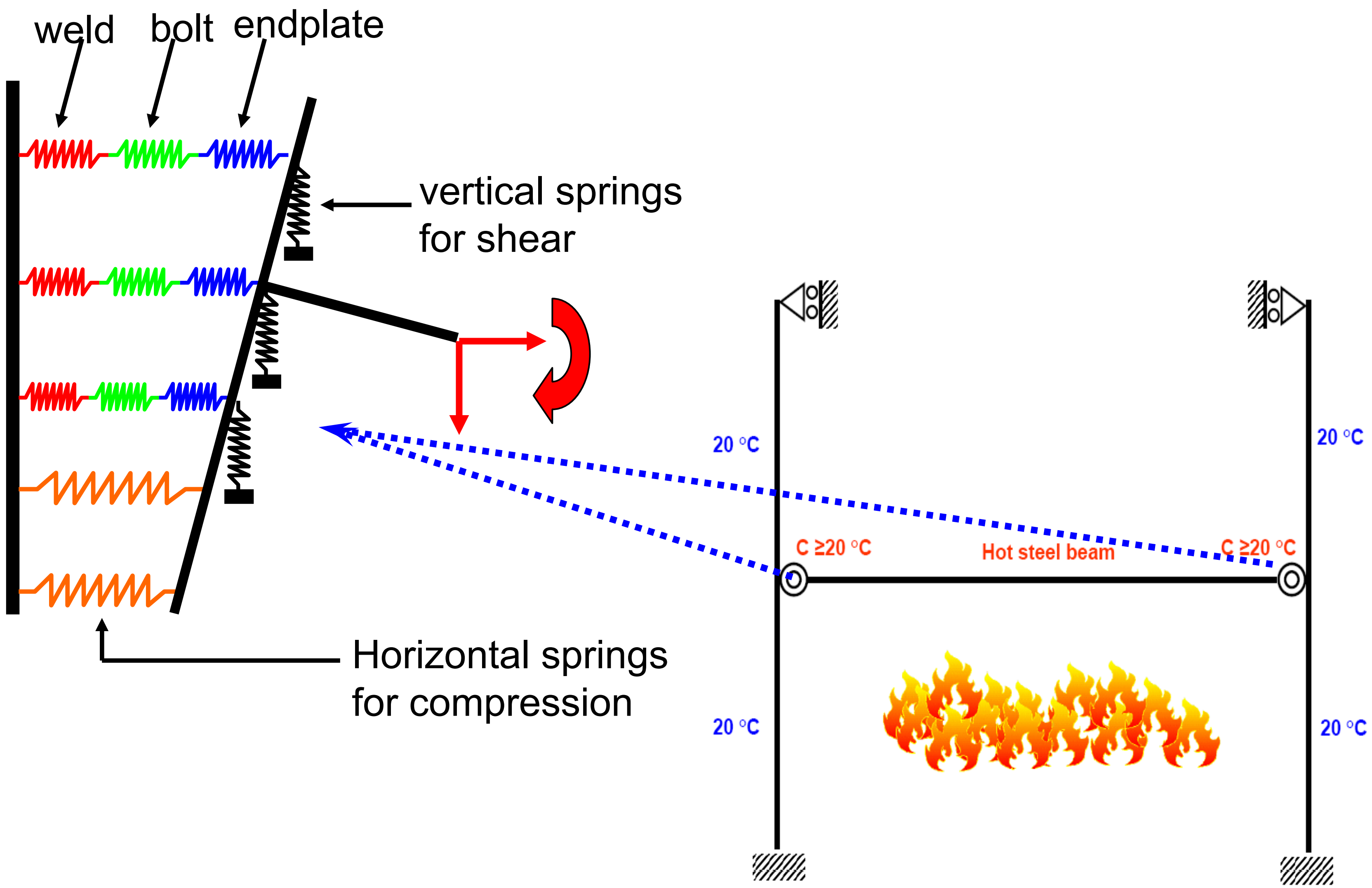
Study investigates:

a) failure mechanism of connections in a sub-frame under fire conditions

b) effects of different parameters
- **load ratios,**
- **load types,**
- **beam span,**
- **different level of axial restraint**
- **connection temperatures**

c) mechanisms of developing catenary actions in a structure

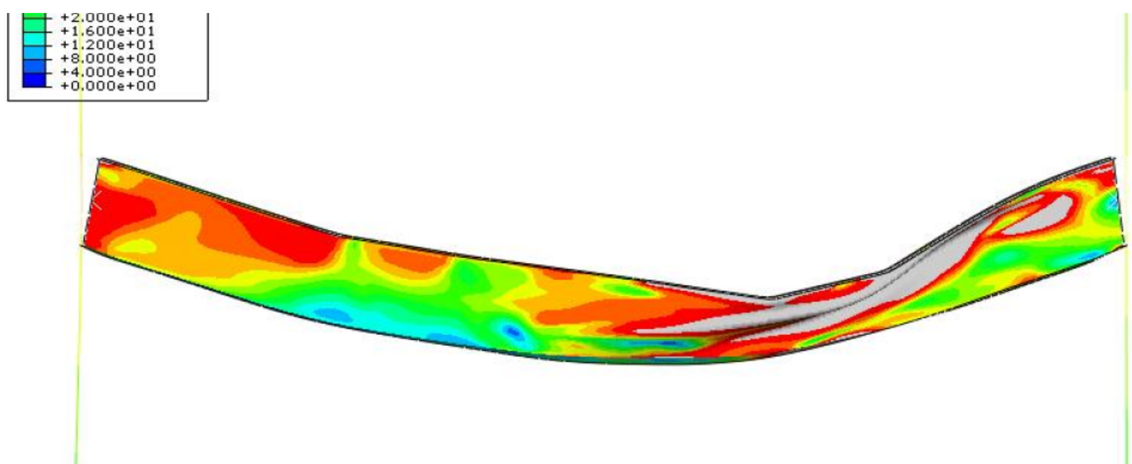
Establishment of a numerical model



Validation of Manchester Fire Test 2

178x102UB19

254x254UC73



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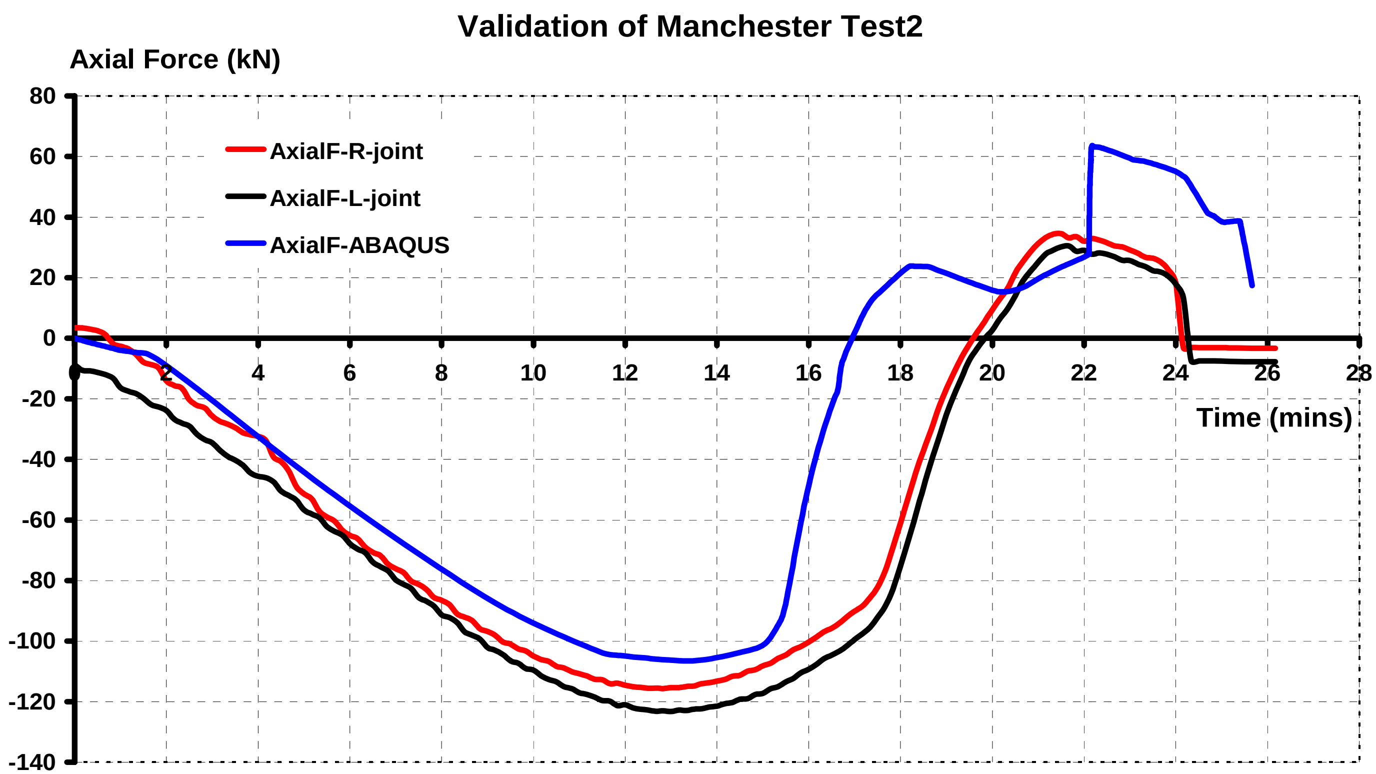
Validation of Manchester Fire Test 2



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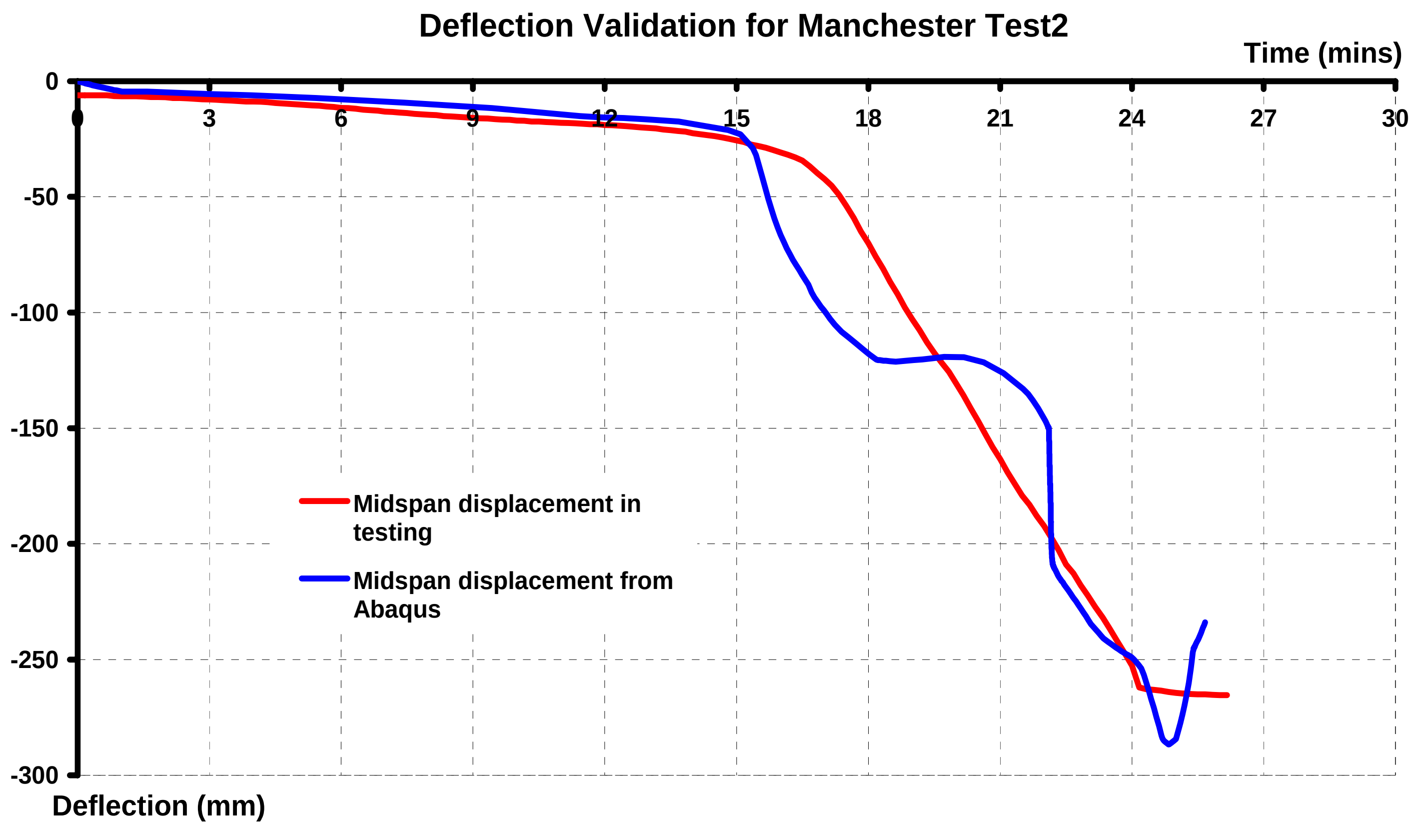
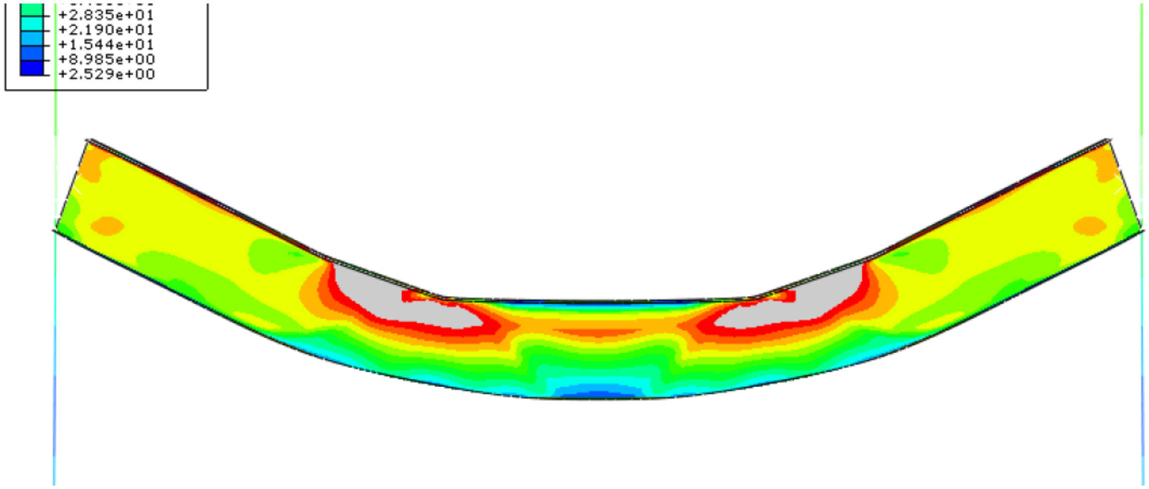
Validation of Manchester Fire Test 2



Validation of Manchester Fire Test 7

178x102UB19

152x152UC23



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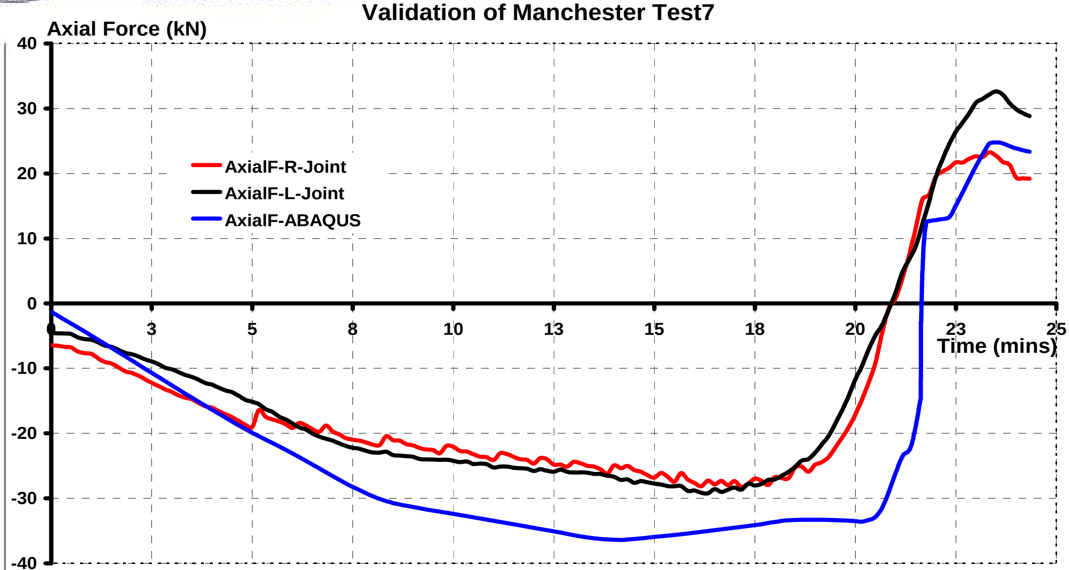
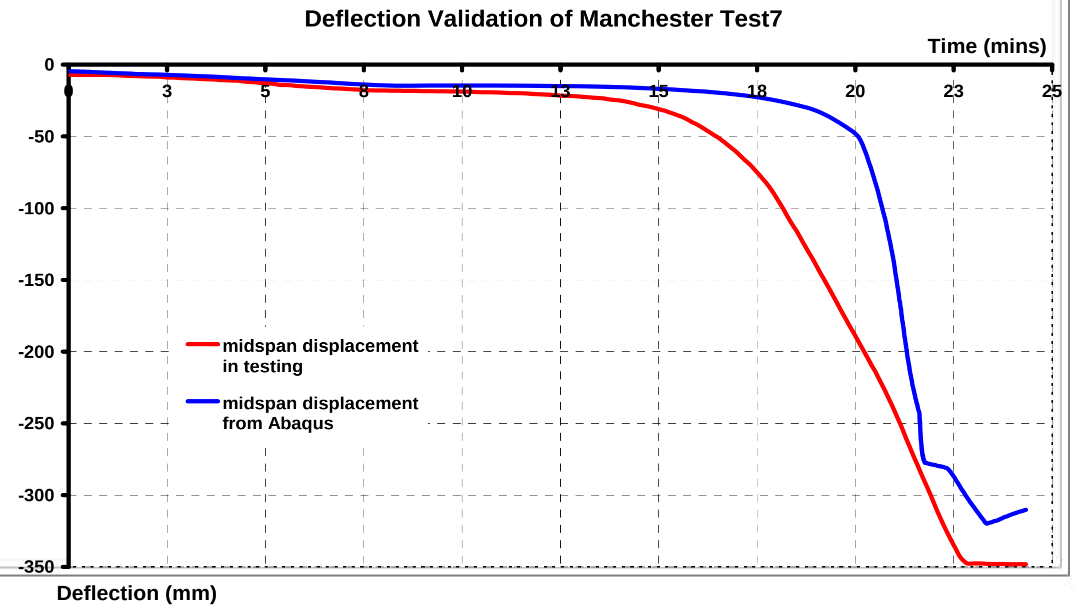
Validation of Manchester Fire Test 7





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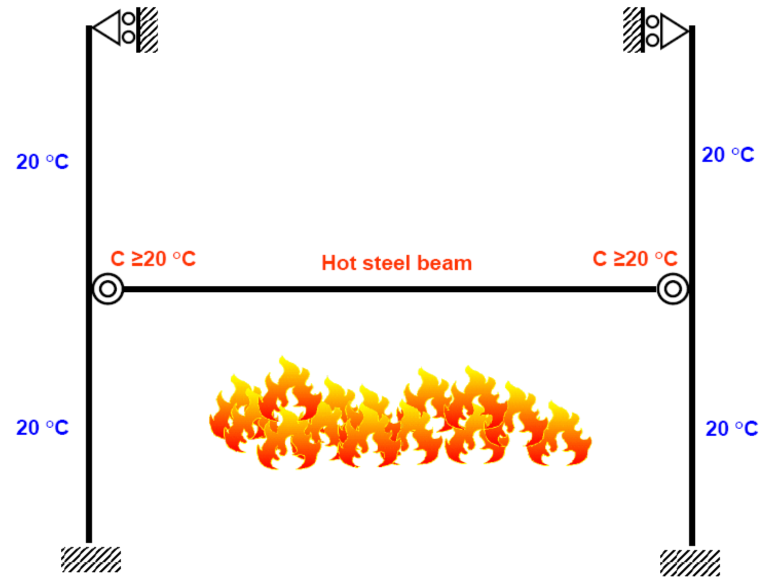
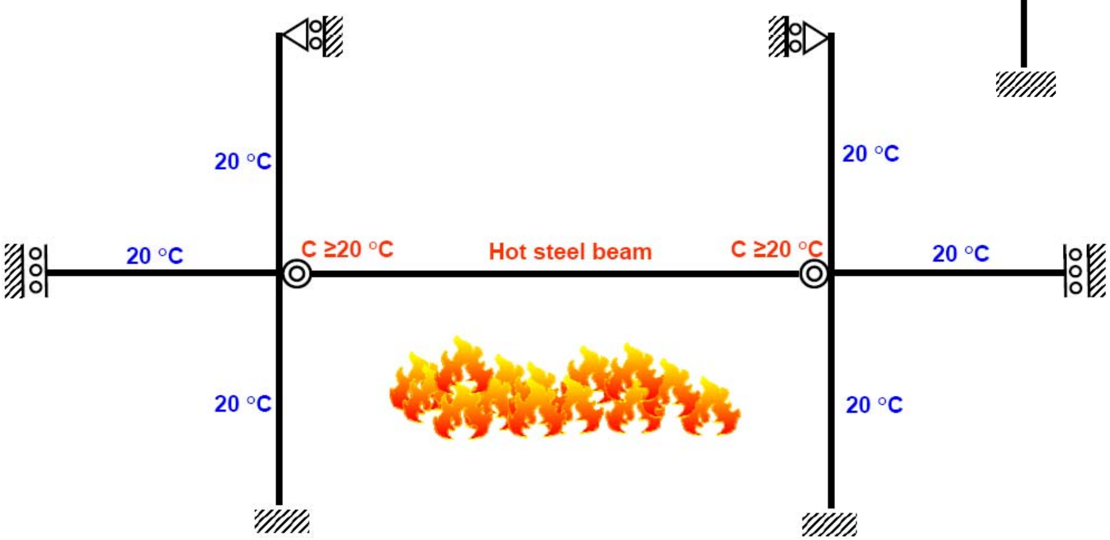
Parametric studies

- load types
- load ratios
- connection temperatures
- different spans
- different levels of axial restraint



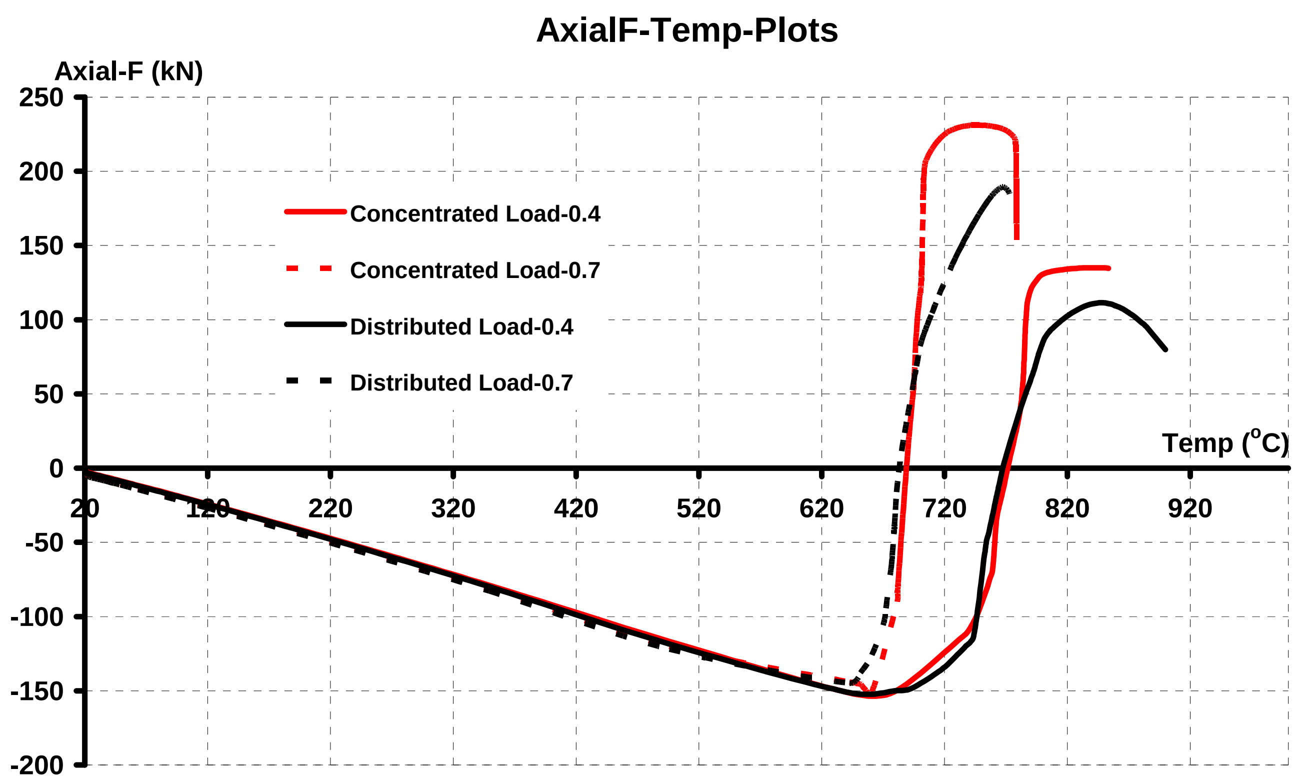


Parametric studies

Load types: distributed and concentrated loading

Span = 5m, $\theta_c <= 400\ °C$

Bending moments in the mid-span are the same for tow different load types

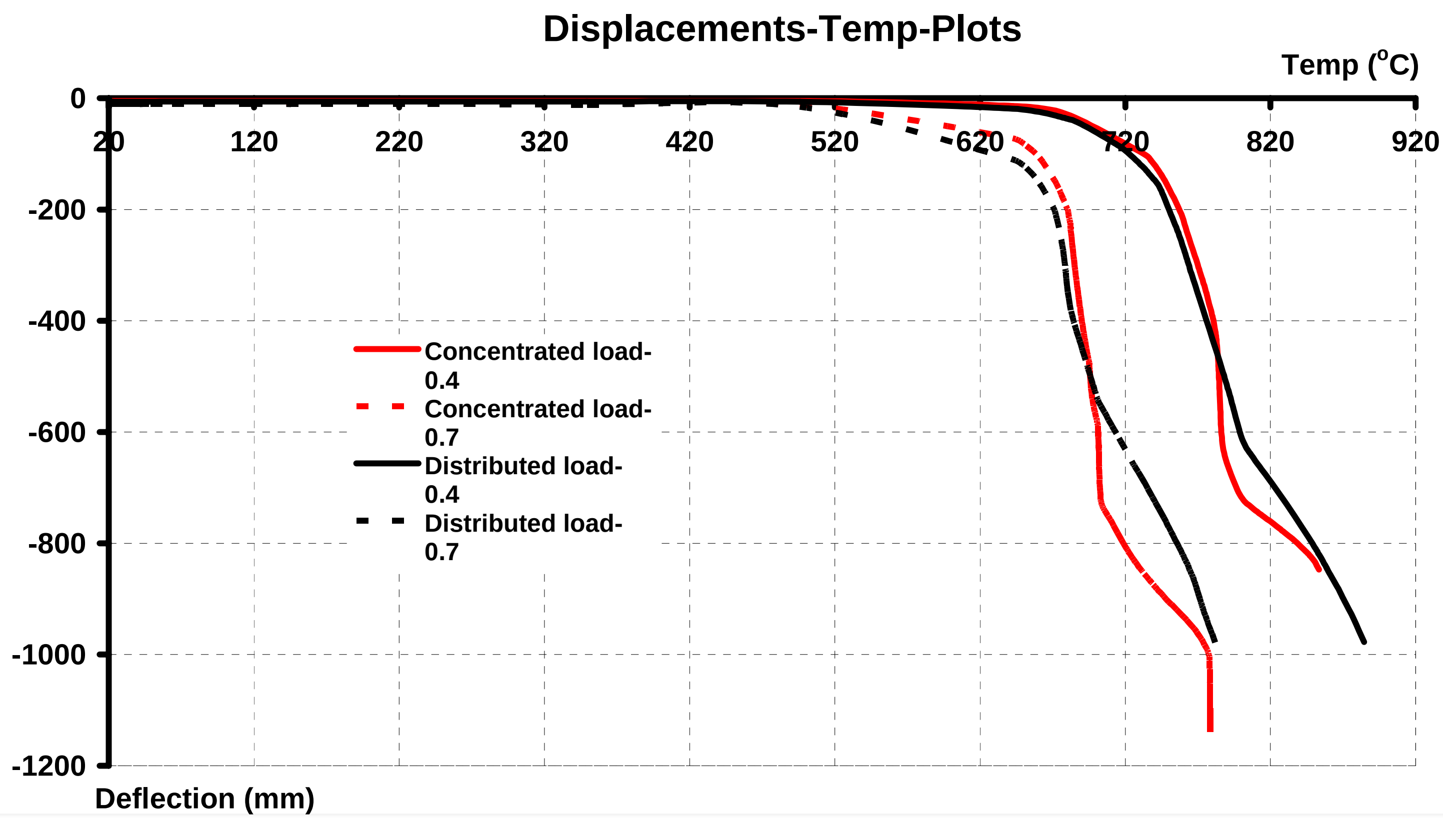


Parametric studies

Load types: distributed and concentrated loading

Span = 5m, θ_c < = 400 °C

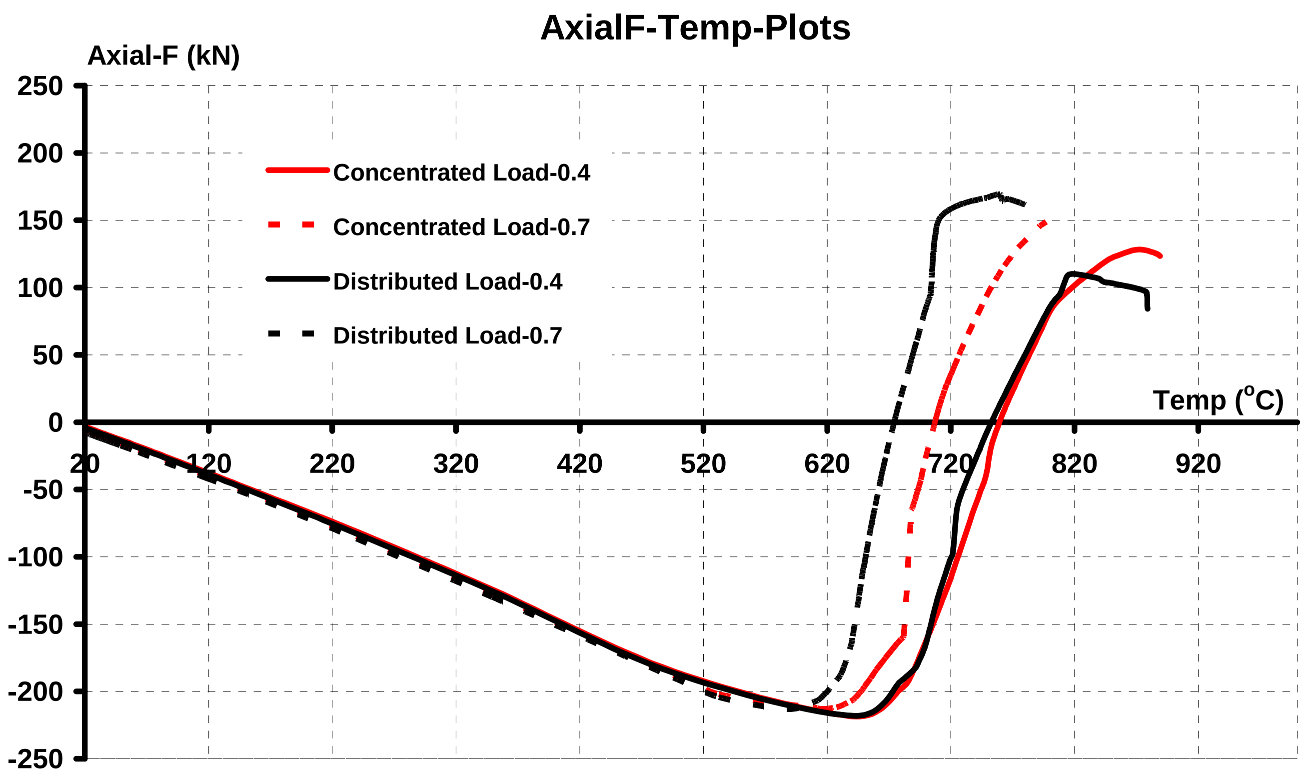
Bending moments in the mid-span are the same for tow different load types



Parametric studies

Load types: distributed and concentrated loading

Span = 8m, θ_c < = 400 °C



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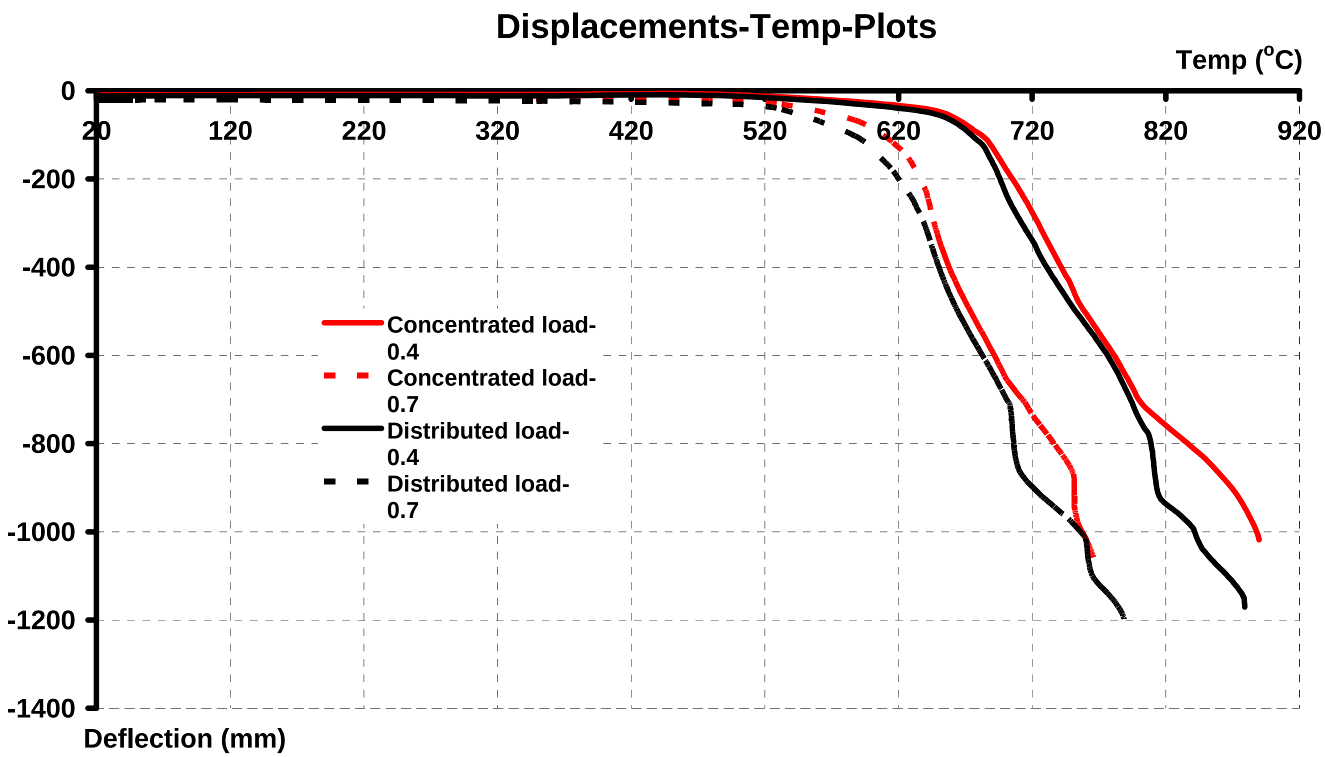
Parametric studies

Load types: distributed and concentrated loading

Span = 8m, θ_c < = 400 °C



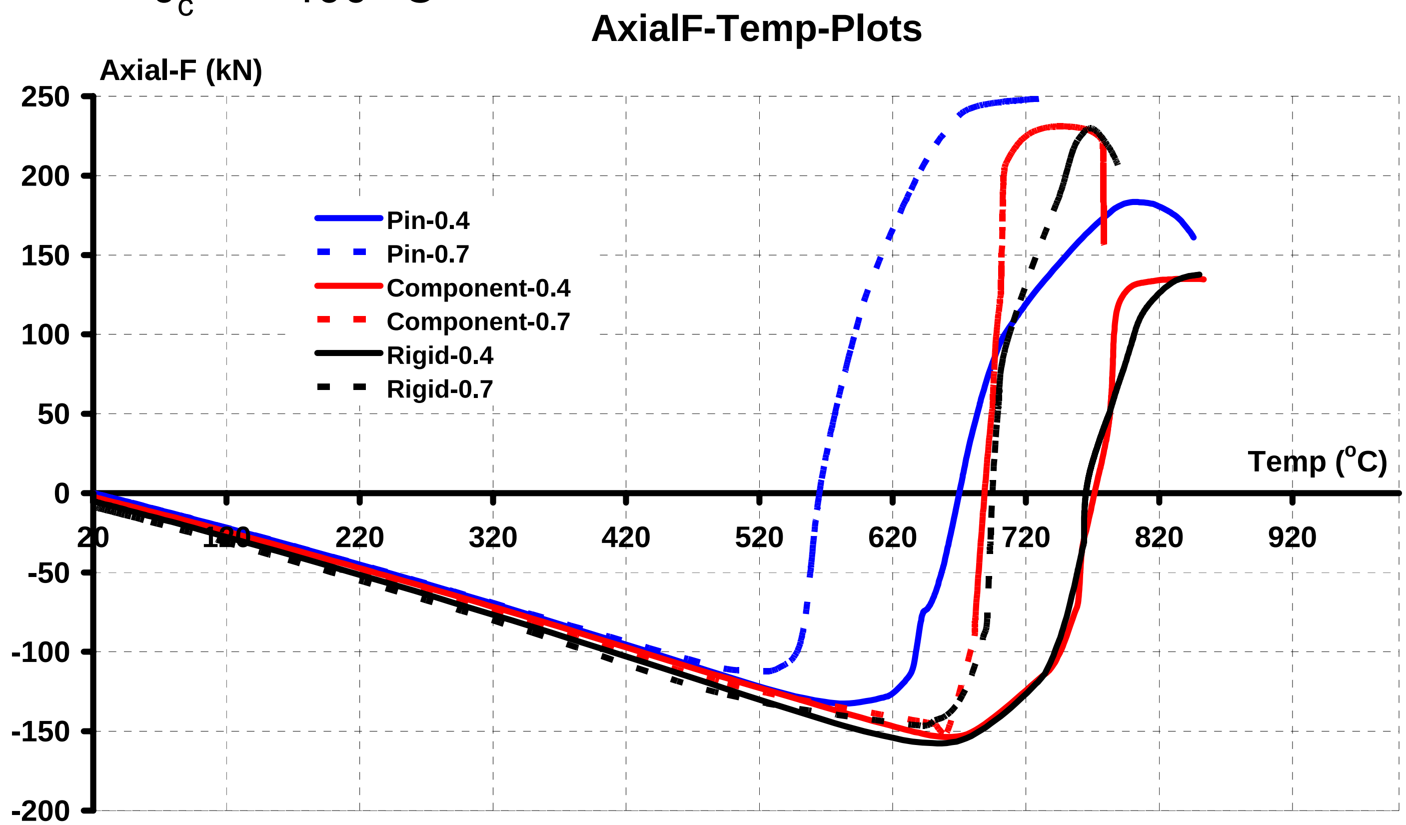
The influence of load types is very small

Parametric studies

Pin, rigid assumptions and component connection model

Span = 5m

θ_c < = 400 °C



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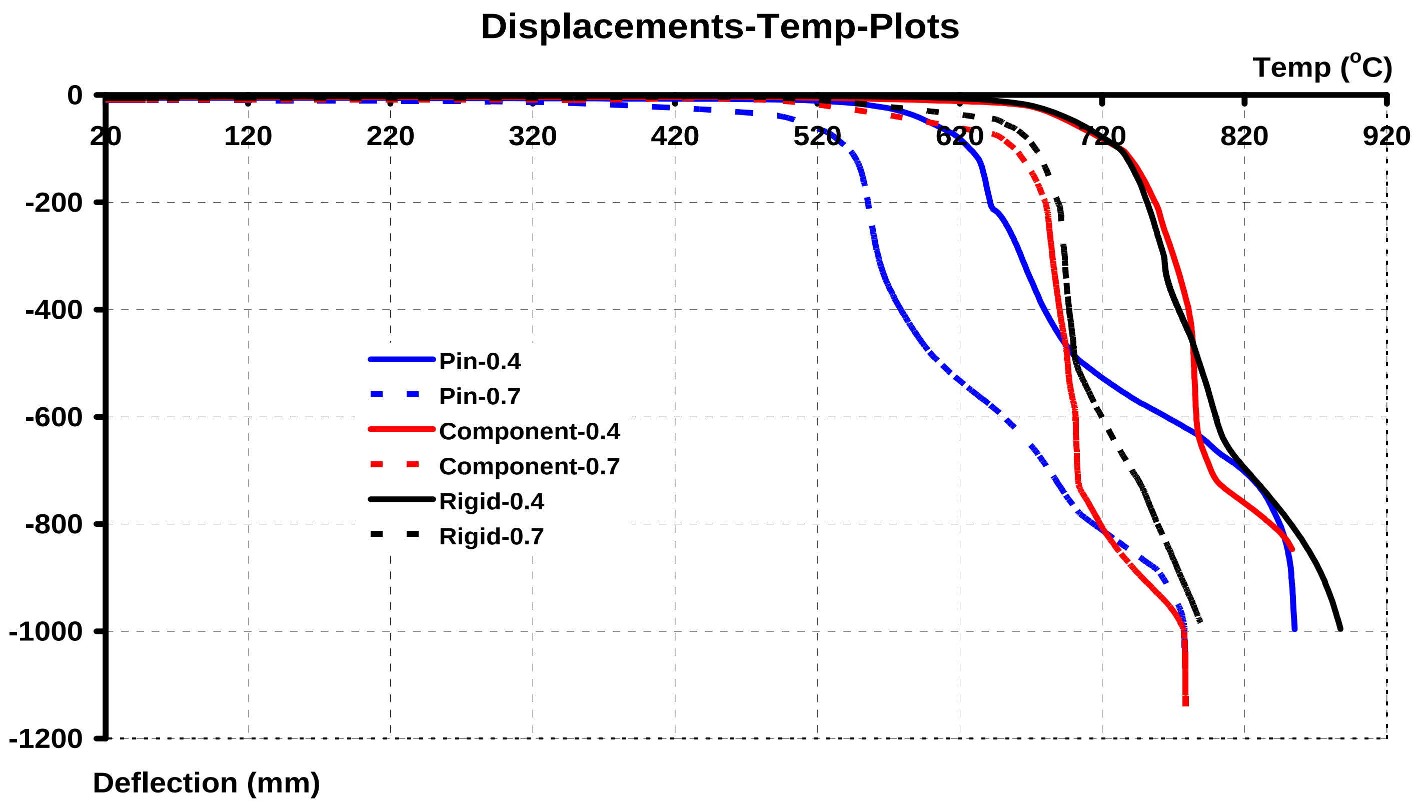
Parametric studies

Pin, rigid assumptions and component connection model

Span = 5m

θ_c < = 400 °C

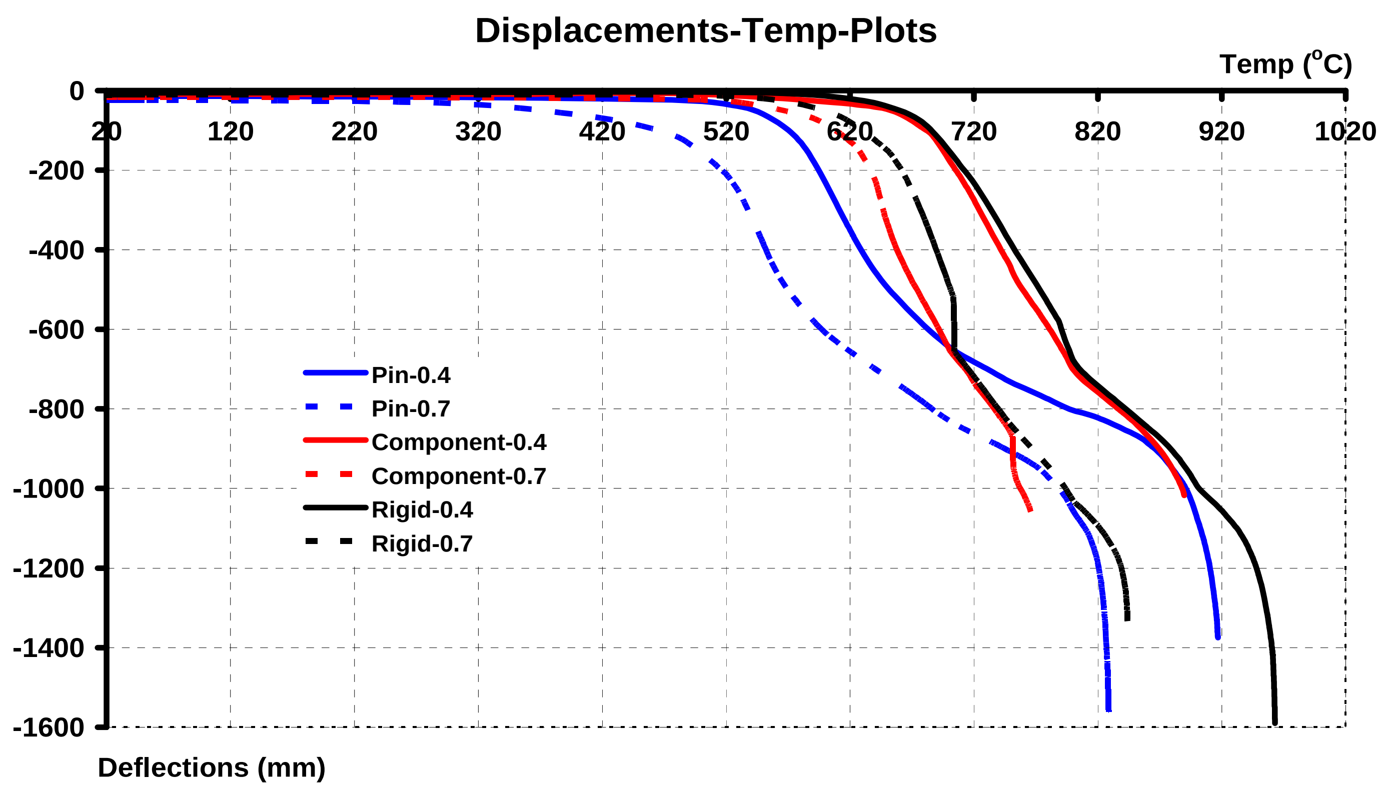


Parametric studies

Pin, rigid assumptions and component connection model

Span = 8m

θ_c < = 400 °C



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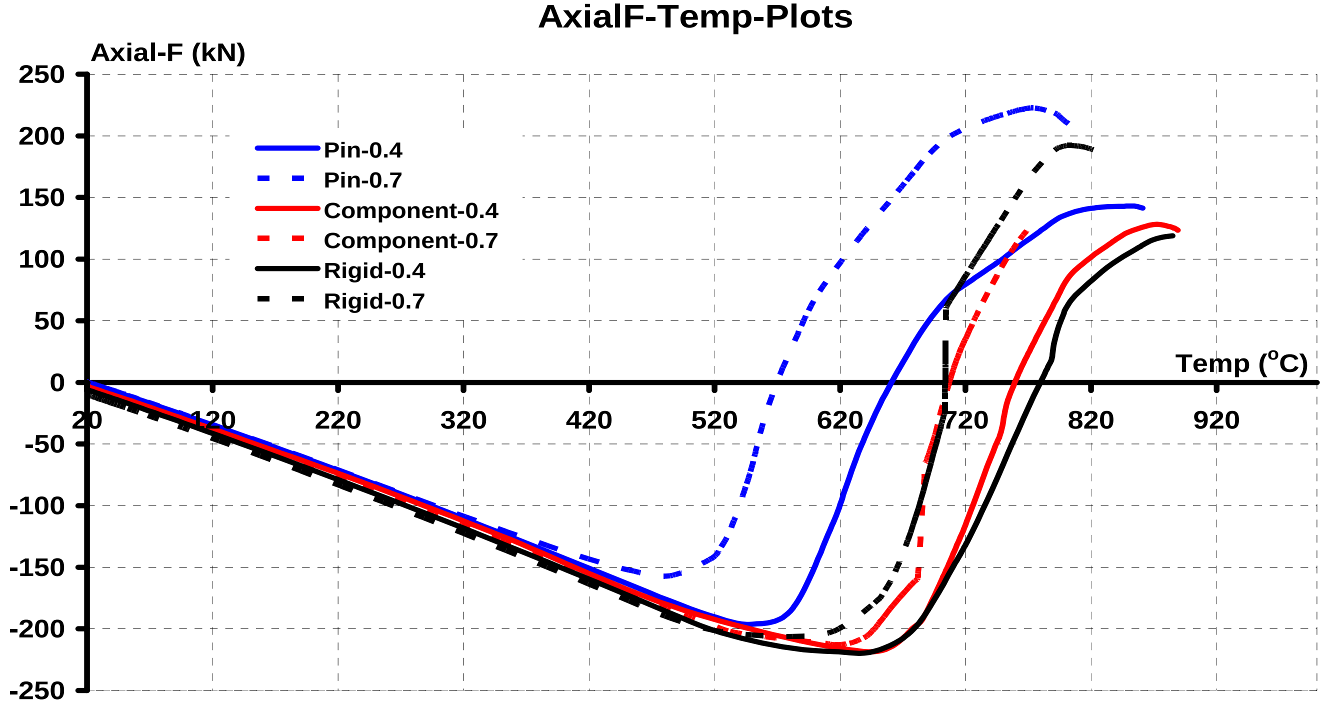
Parametric studies

Pin, rigid assumptions and component connection model

Span = 8m

$\theta_c <= 400\ °C$

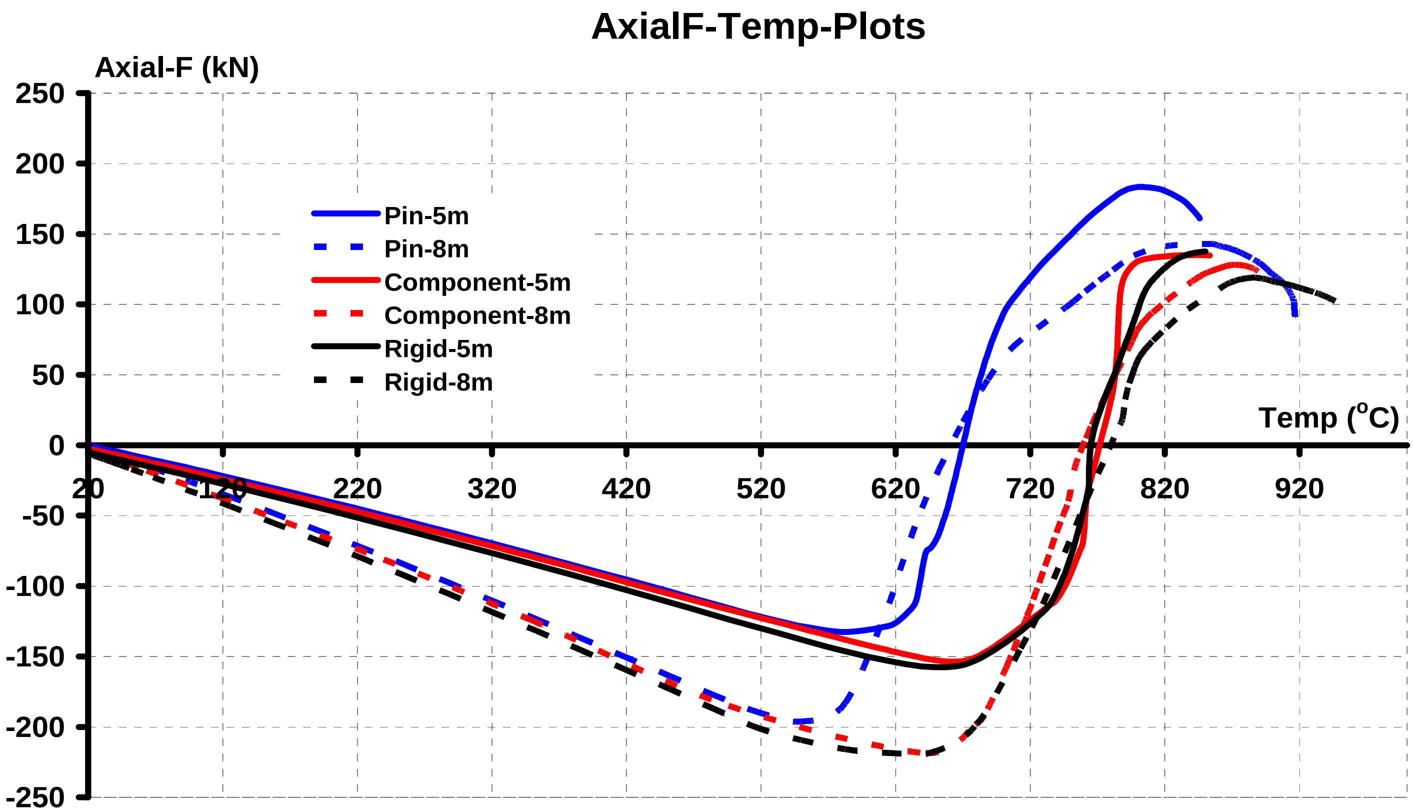


A fire-protected connection is closer to a rigid connection assumption

Parametric studies

Pin, rigid assumptions and component connection model

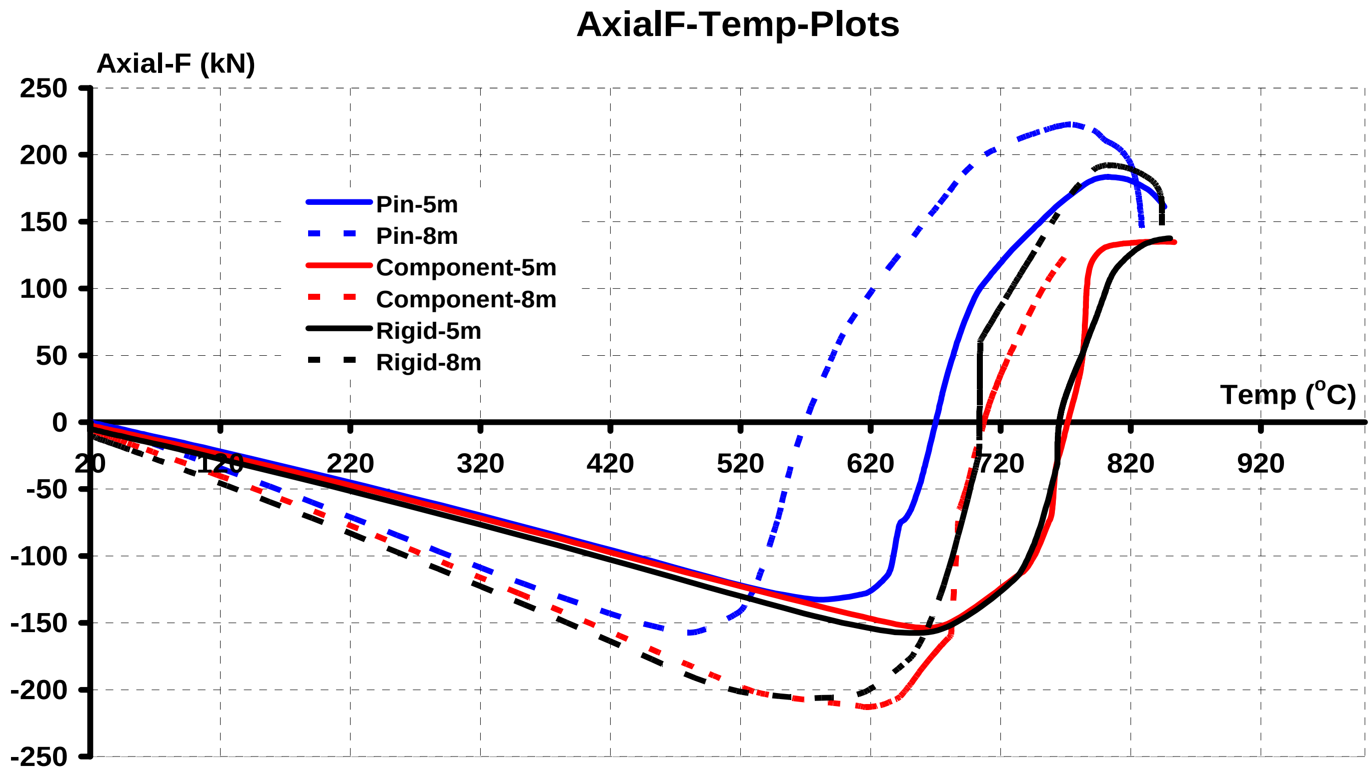
Load ratio =0.4



Parametric studies

Pin, rigid assumptions and component connection model

Load ratio =0.7

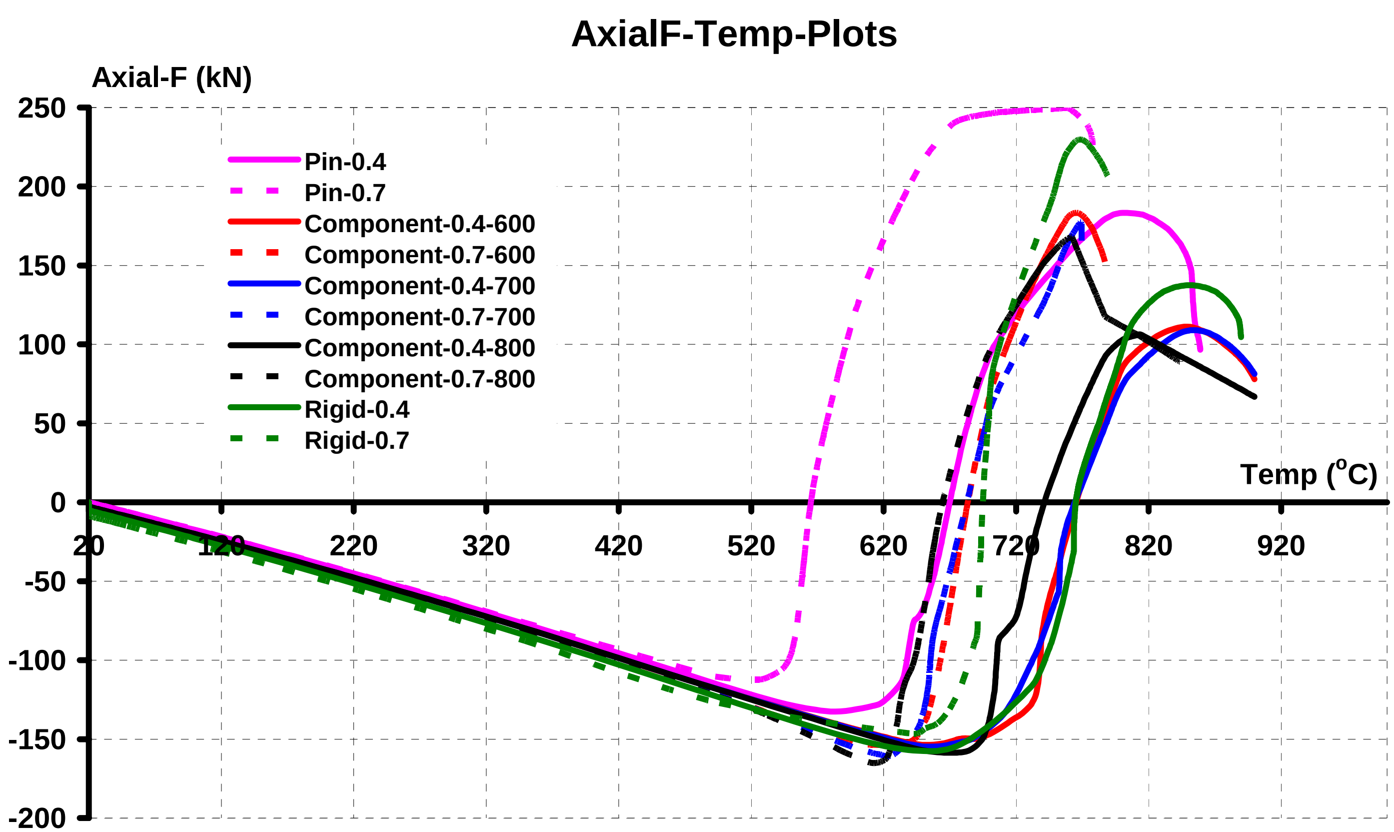


A longer span is able to produce a higher level of compressive axial forces

Parametric studies

θ_c = 600 °C, 700 °C and 800 °C

Load ratio =0.4 and 0.7, Spans = 5m



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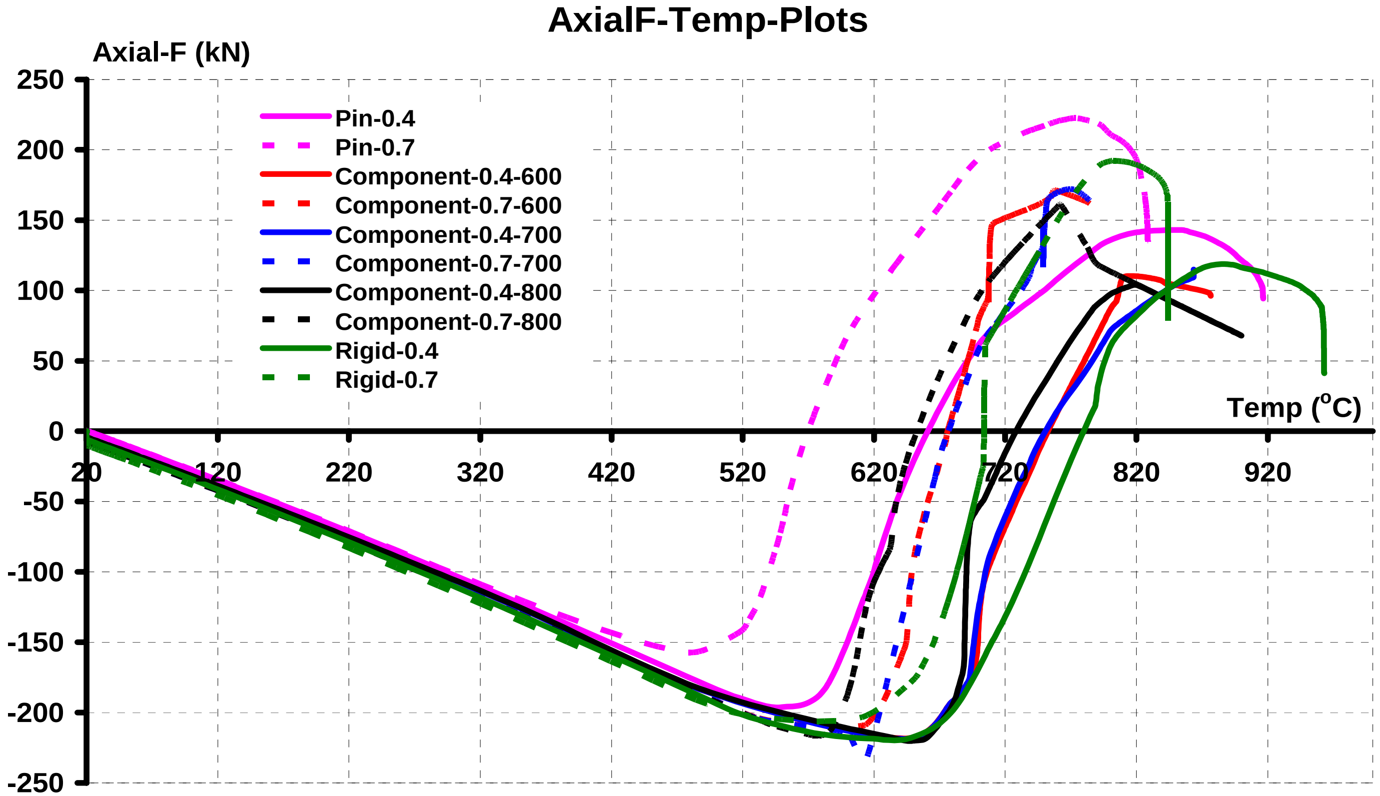
Parametric studies

θ_c = 600 °C, 700 °C and 800 °C

Load ratio =0.4 and 0.7, Spans = 8m

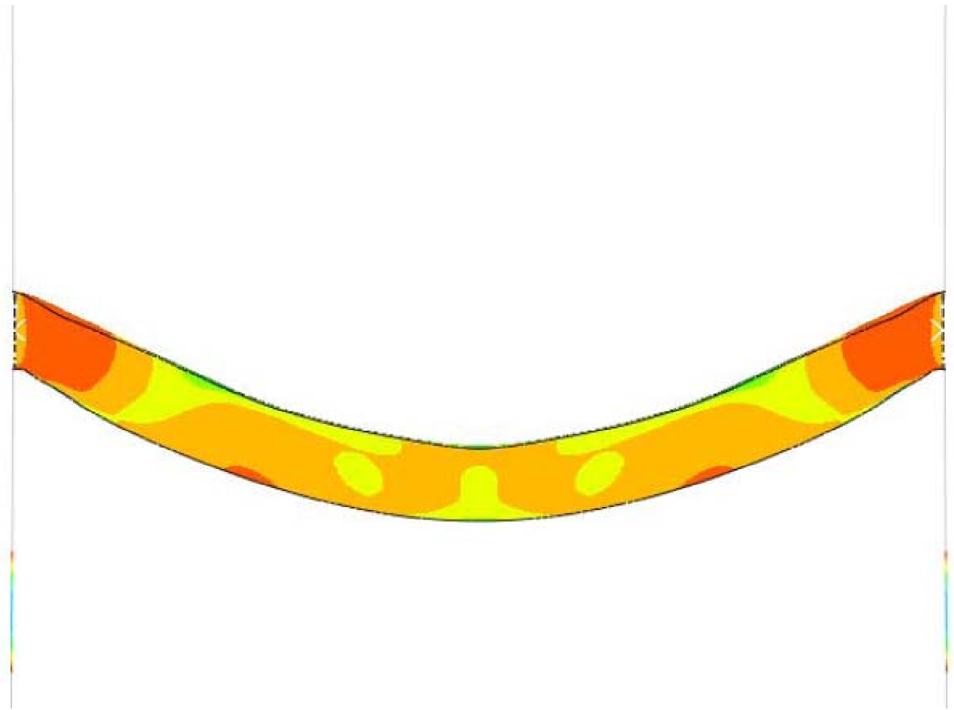


The connection performance is semi-rigid in fire

Parametric studies

The mechanisms for development of catenary actions in fire:

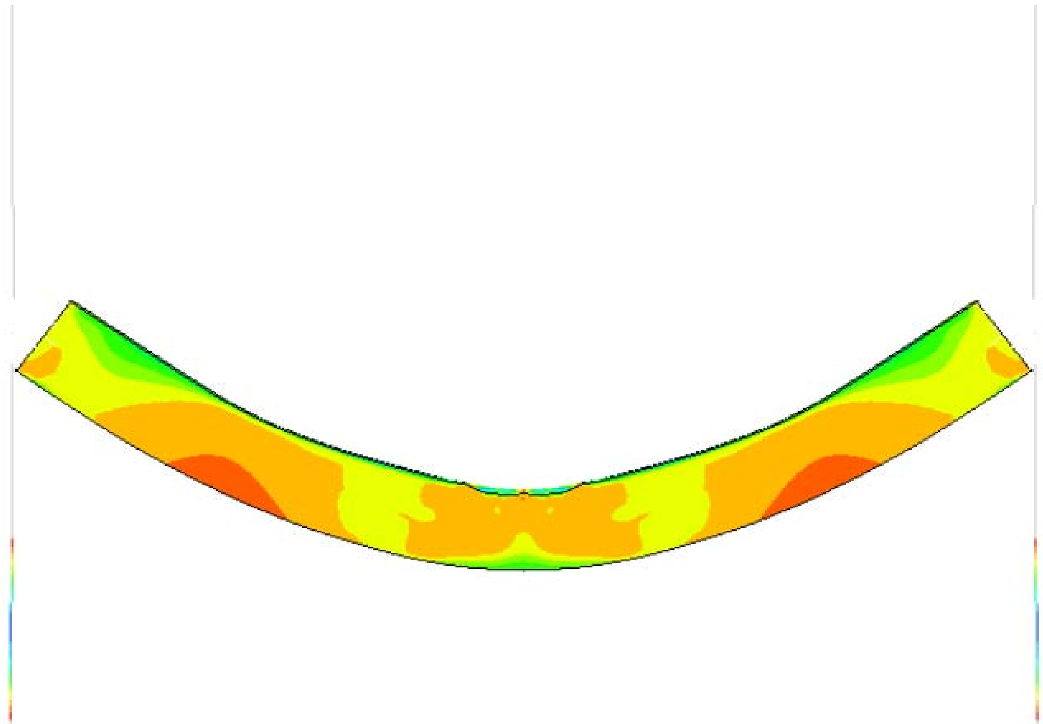
a) For θ_c < =400 °C , two plastic hinges within connections



Parametric studies

The mechanisms for development of catenary actions in fire:

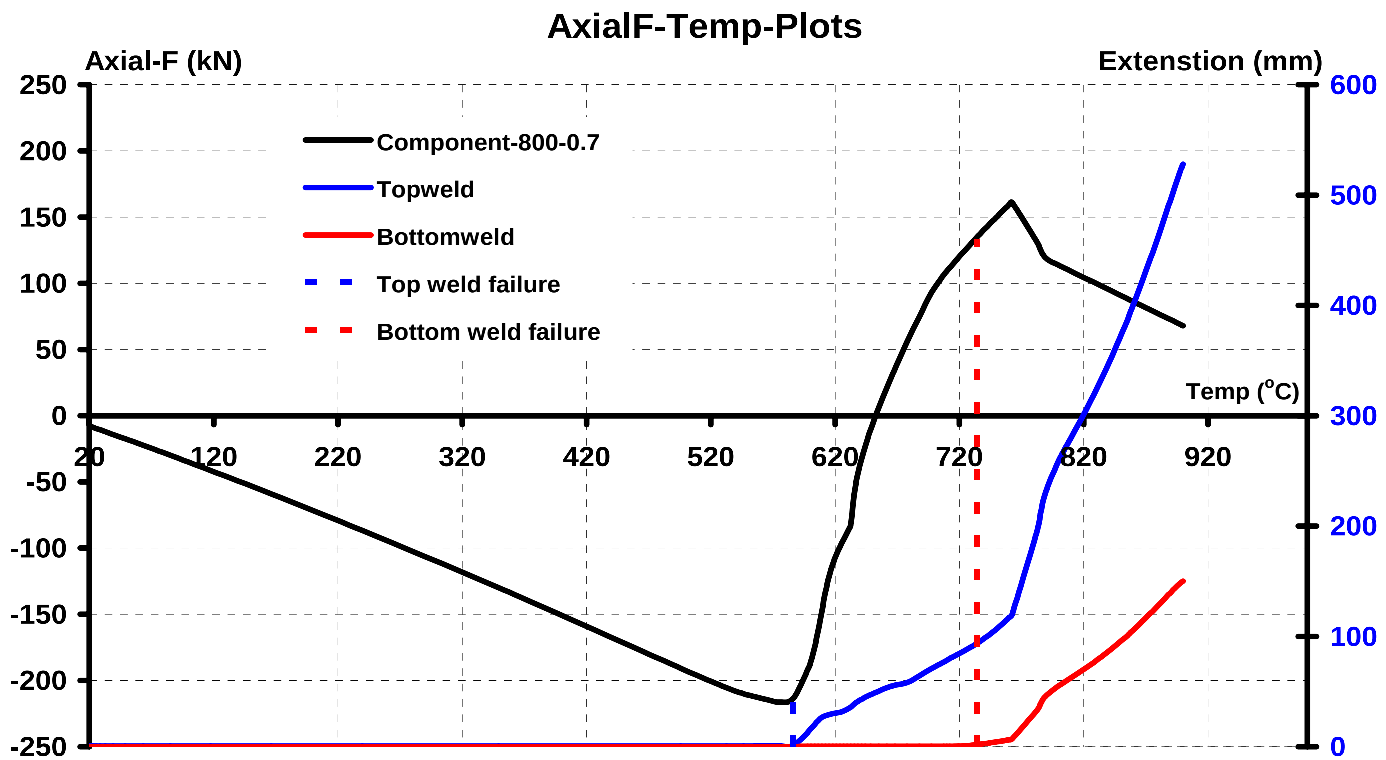
b) For θc >400 °C, two plastic hinges formed within connections



Parametric studies: mechanism of failure

In the previous numerical analysis, a weld component is assumed to behave in a elastic – plastic manner.

The assumption for failure of each bolt row is that elongation of a weld component is beyond the range of 0.71 mm -1.93mm (Kanvinde, et al.) span =5m



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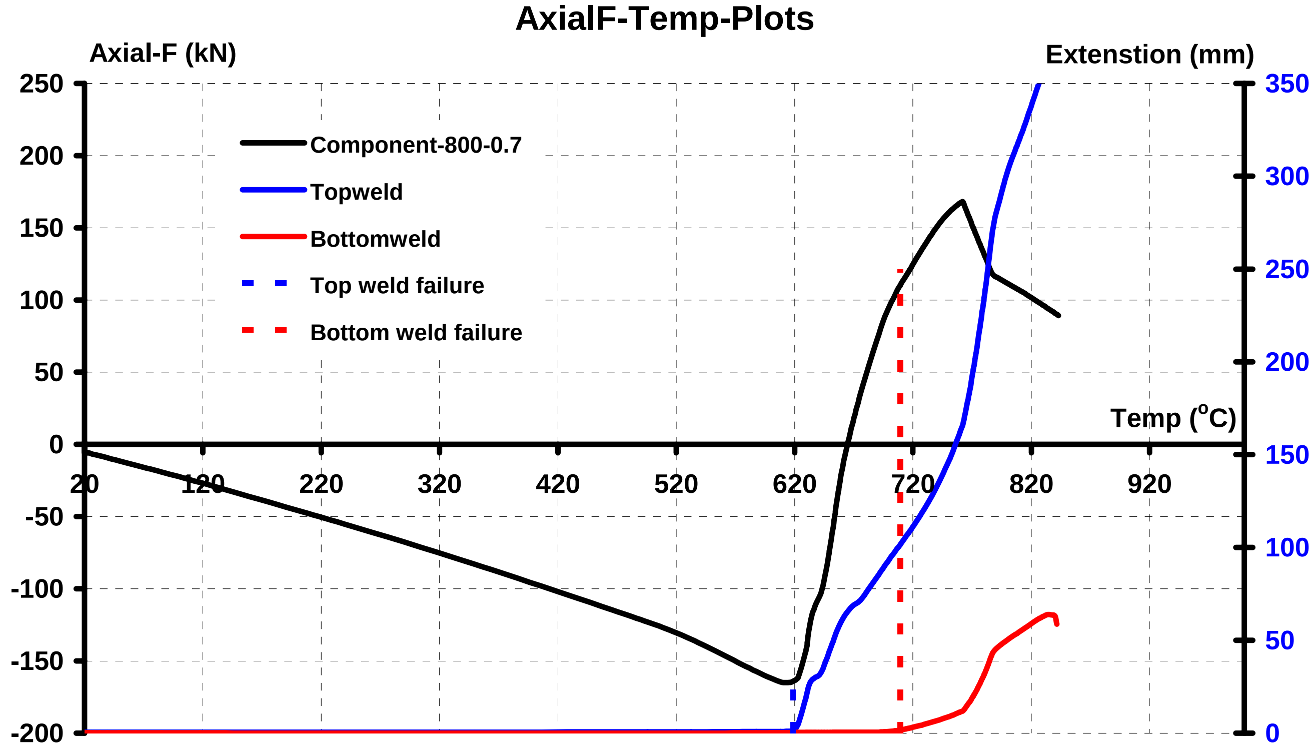
Parametric studies: mechanism of failure

The assumption for failure of each bolt row is that elongation of a weld component is beyond the range of 0.71 mm -1.93mm, span =8m



The top bolt row start to fail when a steel beam is in the expansion phase in a fire and the bottom one failed in catenary actions

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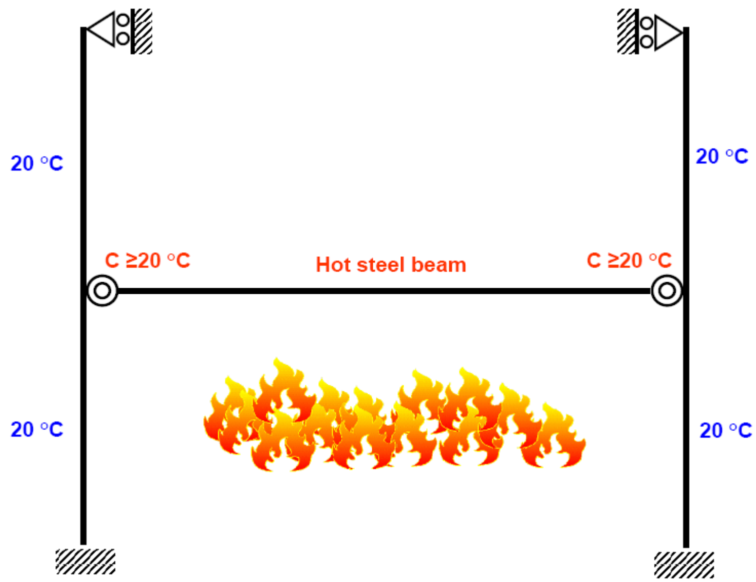
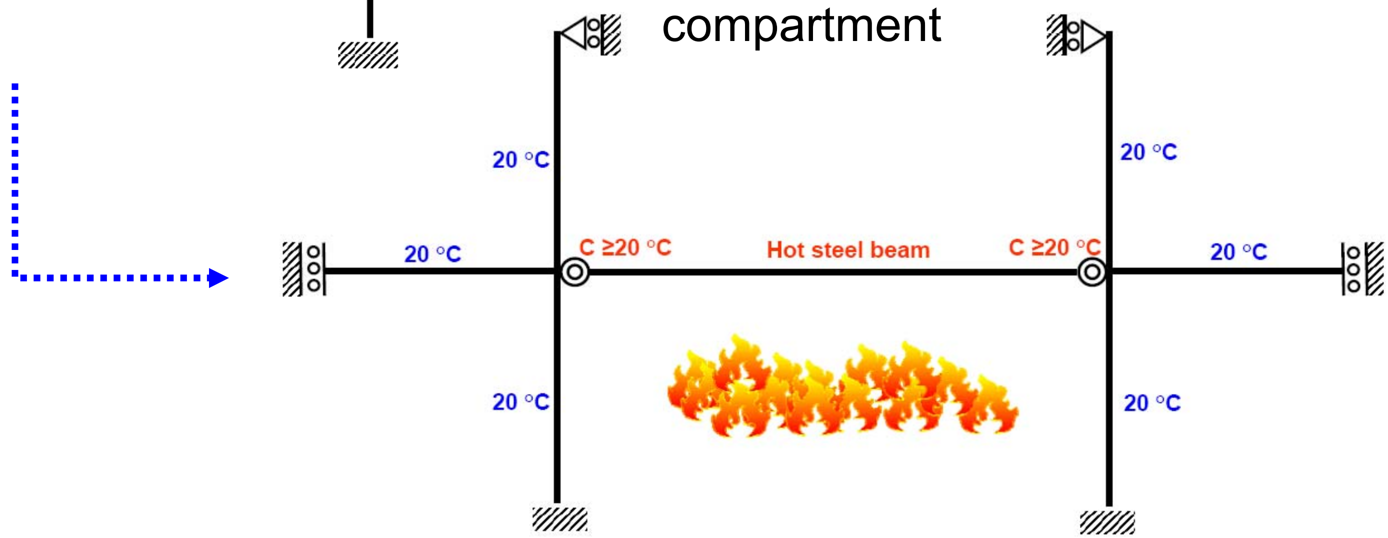
Parametric studies: different levels of axial restraint



Axial restraint: bending stiffness of steel columns

Axial restraint: bending stiffness of columns and horizontal stiffness of steel beams and slabs outside the compartment

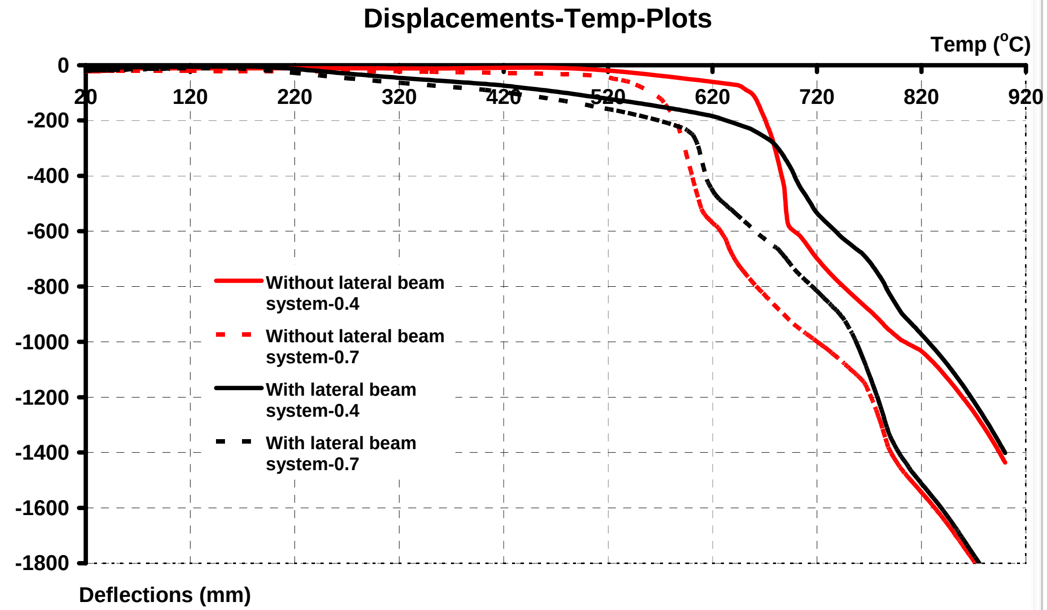


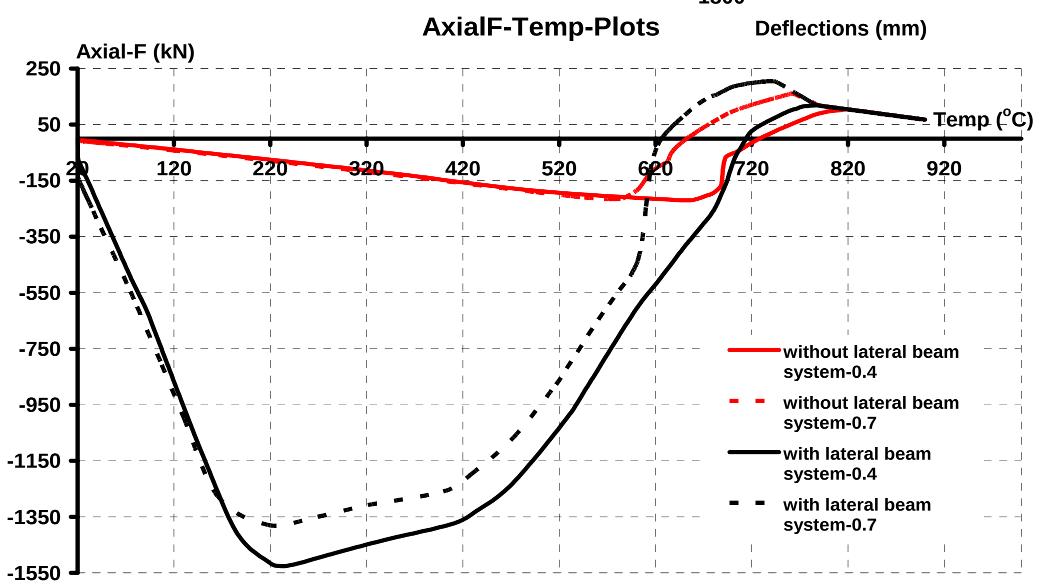
Parametric studies

Different levels of axial restraints

Span =8m

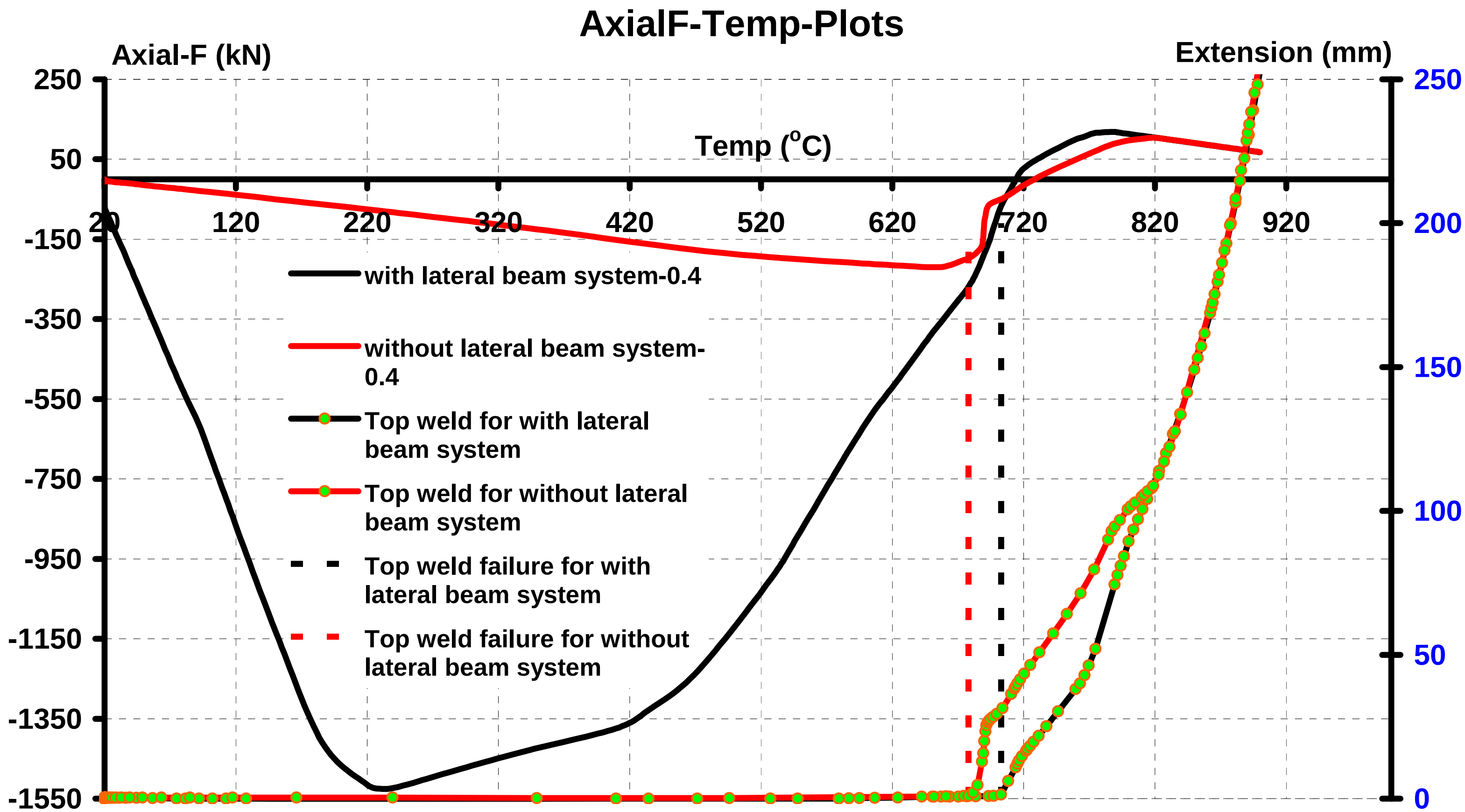
θc = 800 °C



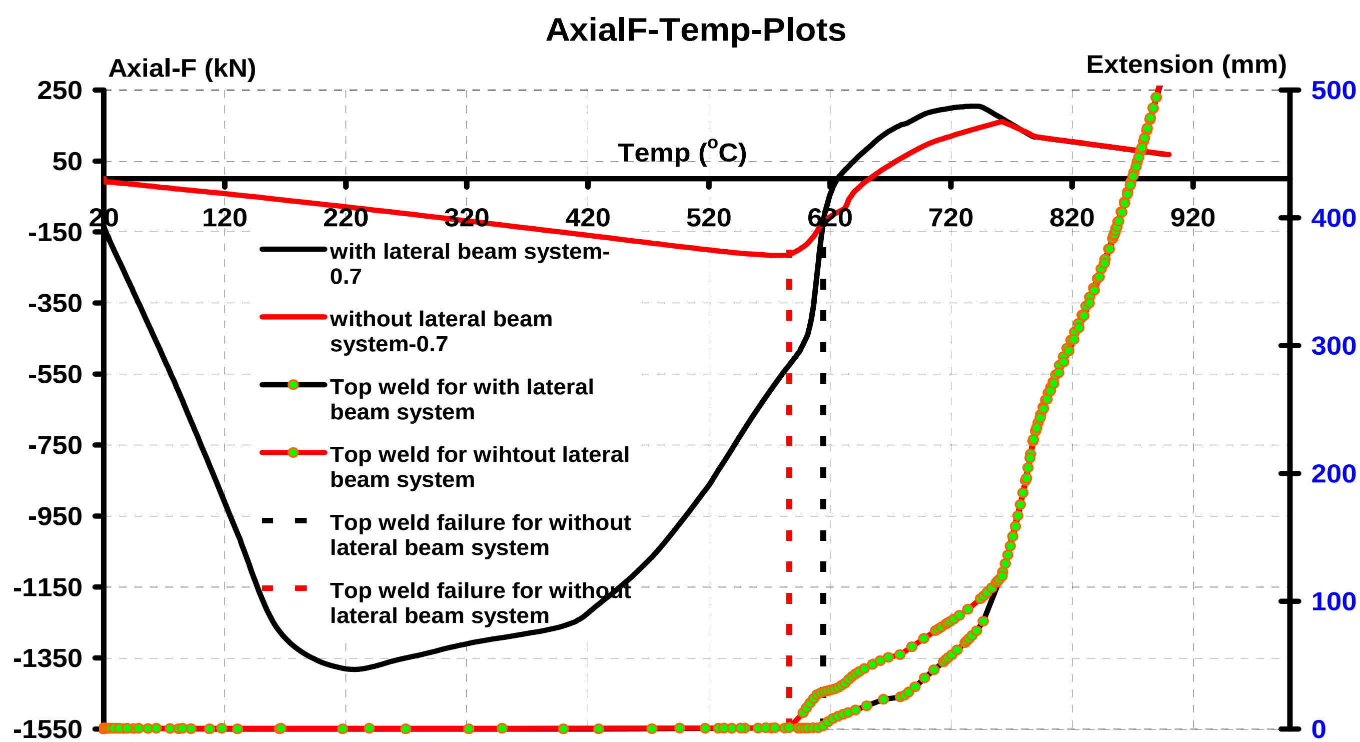


Parametric studies: failure mechanism

Study the mechanisms of failure of connections at the different levels of axial restraints



Parametric studies: failure mechanism



In the higher level of axial restraint, endplate connections started their failure in the expansion of a steel beam in fire

Conclusions and Recommendations

- Numerical analysis reveals two mechanisms of development of catenary actions:
- a) forming plastic hinges within connections (needs a ductile joint)
- b) forming plastic hinges close to ends of a steel beam.
- If connections were fully protected (connection temperatures < 400 C), connection behaviour close to a rigid connection
- If connection temperatures > 400 C, connection behaviour is neither pinned nor rigid, but semi-rigid in a fire condition.
- Possible to fail partial depth endplates in the expansion phase of a steel beam in fire due to lack of rotational capacity

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Thank You for Listening

Questions

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