Behaviour of fin-plate connections of a composite beam subjected to different fire scenarios

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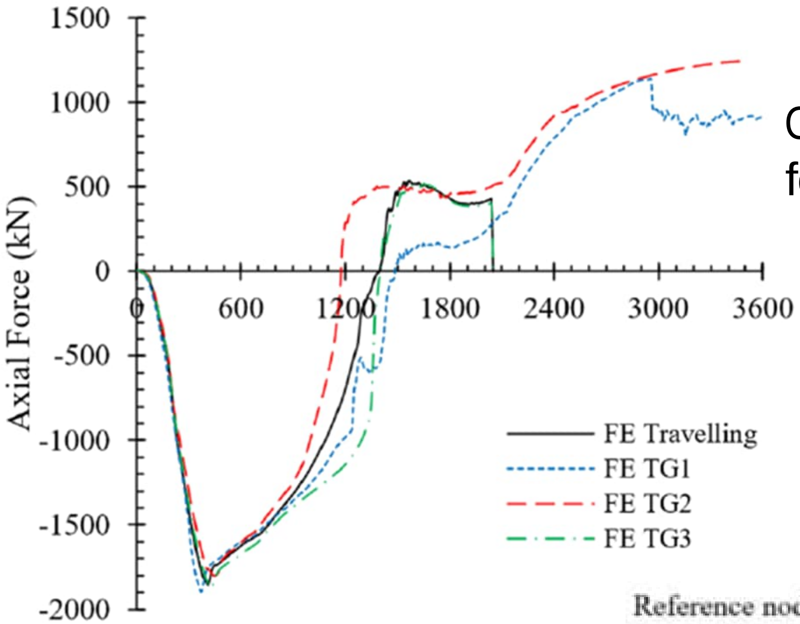
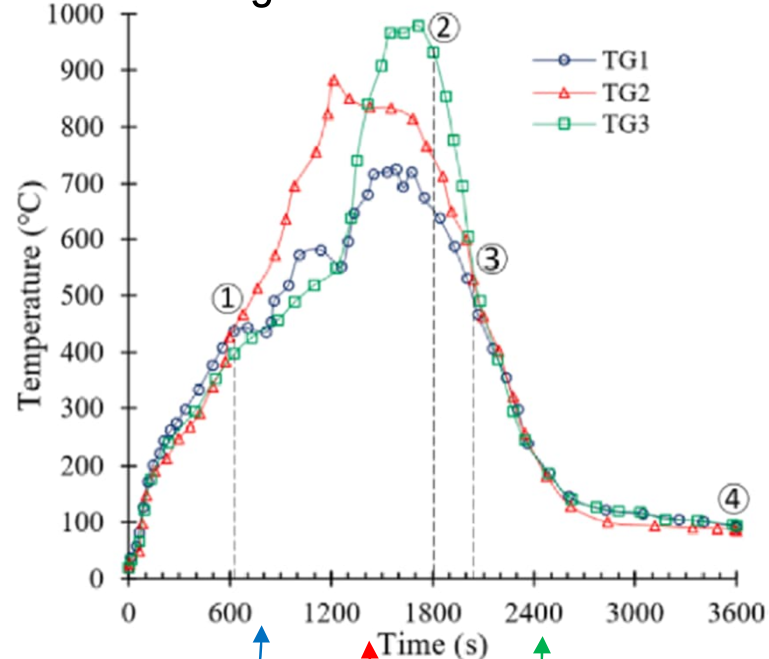
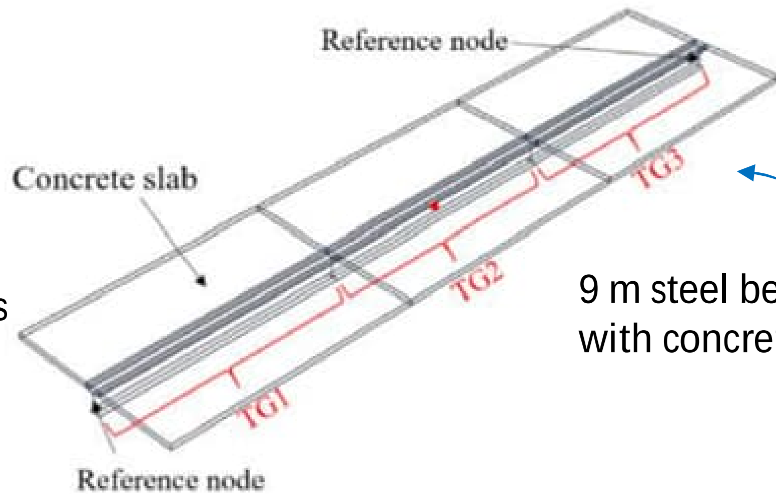
Background and objectives



Oscillated axial force (TG1)

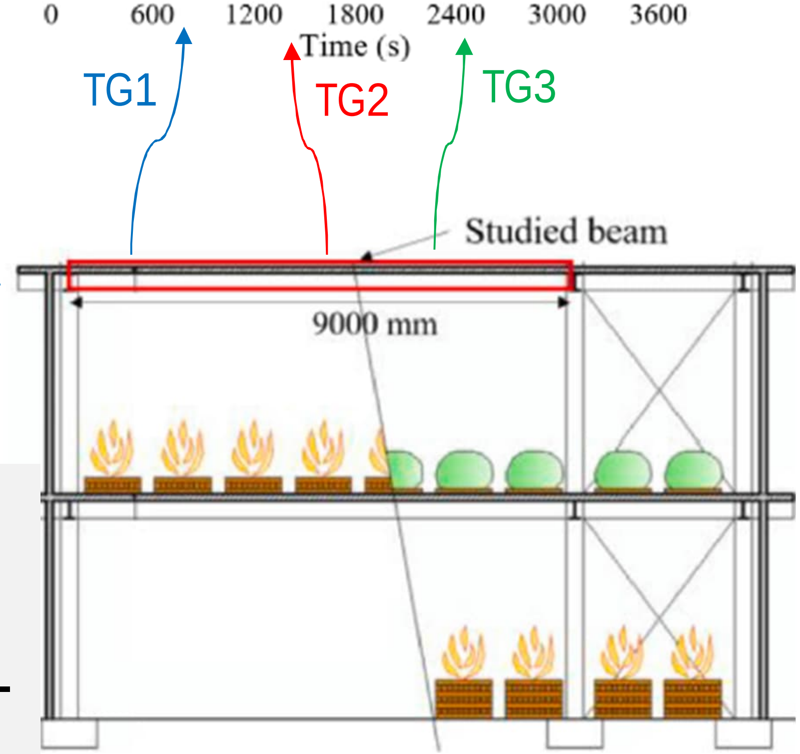
Non-uniform temperature along the beam





Connection was modelled as a reference node

9 m steel beam with concrete slab

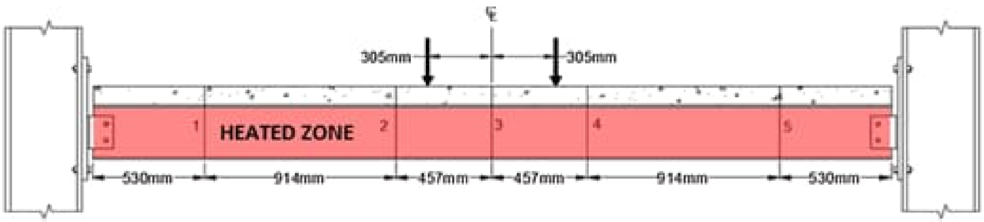


Travelling fire tests

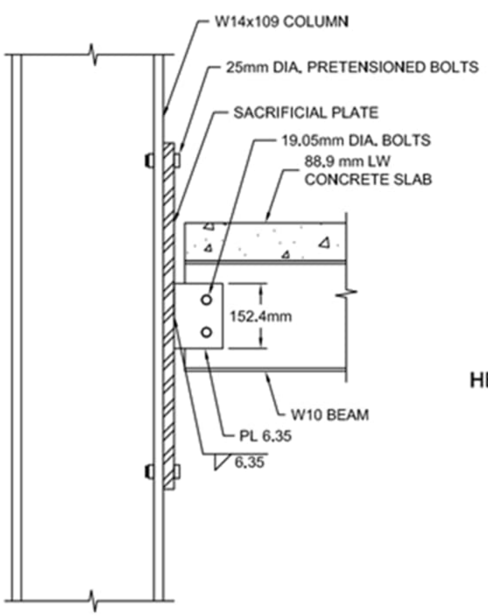
- How do heating-cooling cycles affect connection behaviour?
- At which location of the beam is its heating-cooling more dangerous to connections?

FE models based on the tests presented in the literature

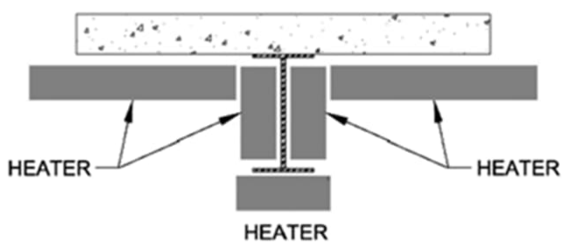
Test: composite beams exposed to fires by E.C. Fischer, S.L. Kristi, A.H. Varma [20]



A load of 156 kN applied to the beam



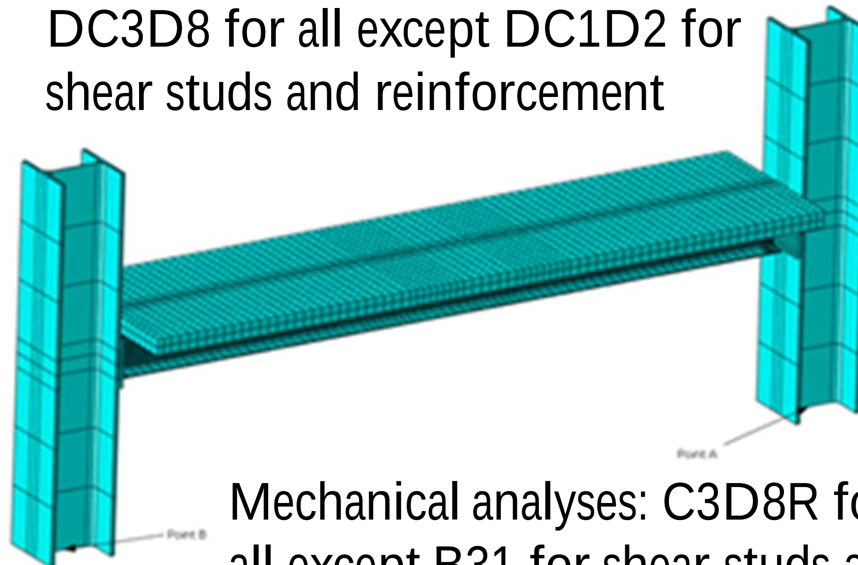
Connection details



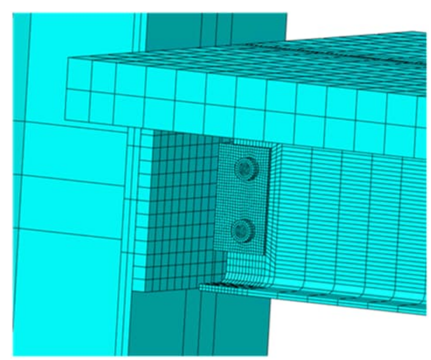
Heating the beam

FE models by Abaqus/Standard and Explicit

Element types for thermal analyses: DC3D8 for all except DC1D2 for shear studs and reinforcement



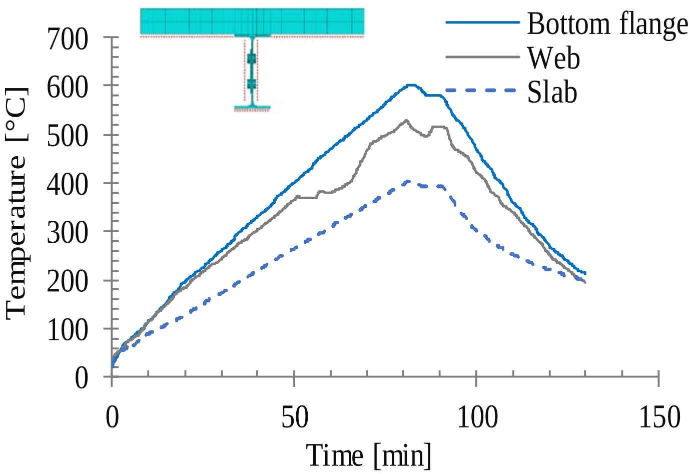
Mechanical analyses: C3D8R for all except B31 for shear studs and T3D2 for reinforcement

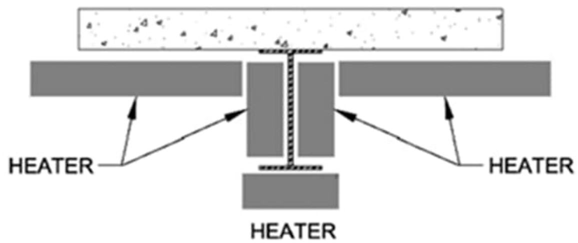


Connection model

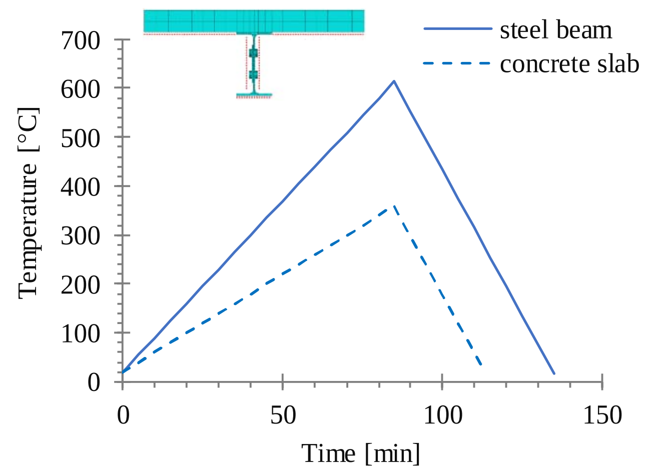
Validation: thermal analyses

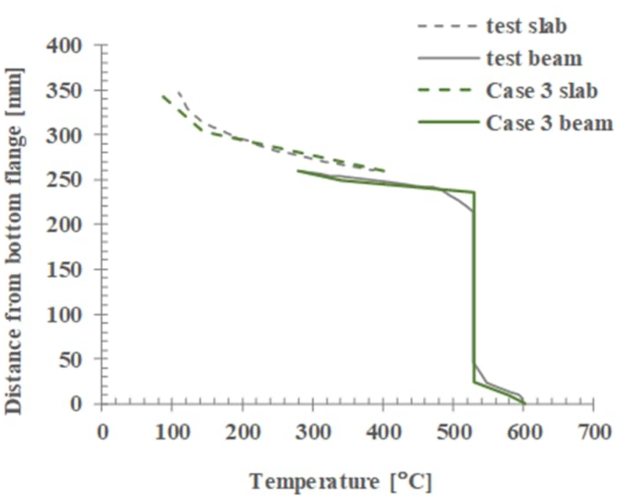
Case 2 and 3: Surface temperatures

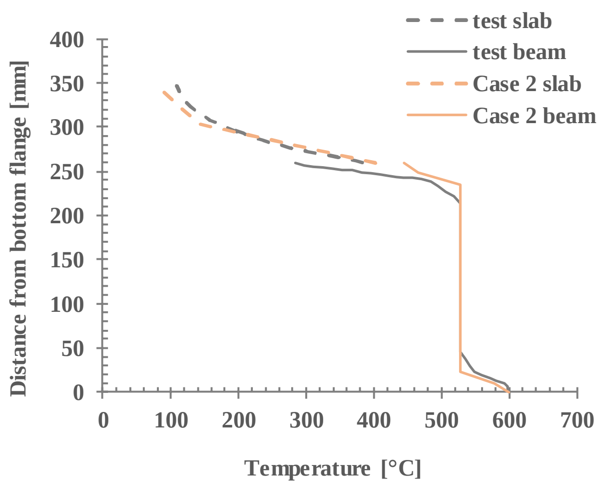


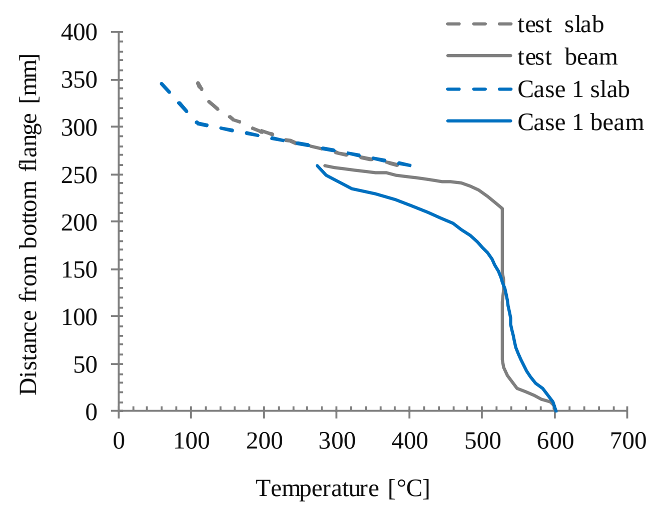


Case 1: Heat flux





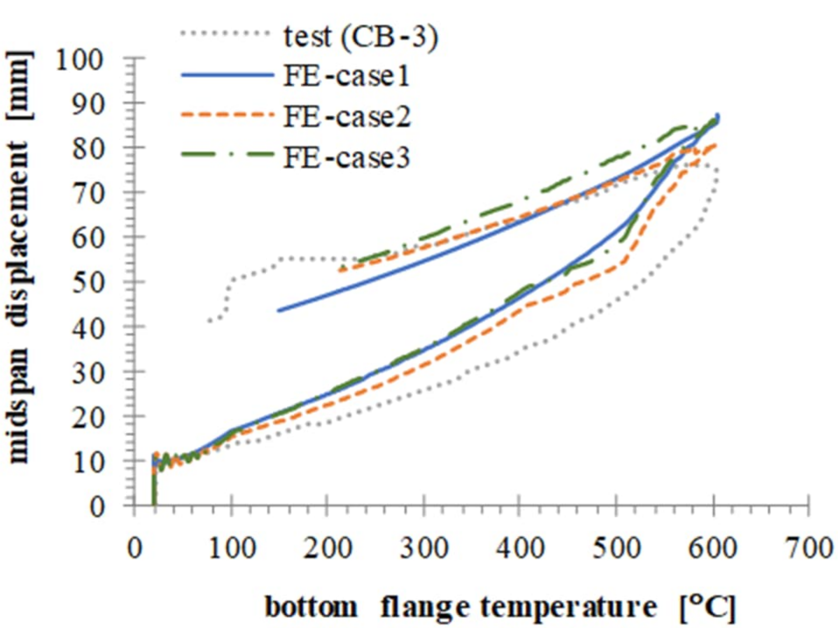


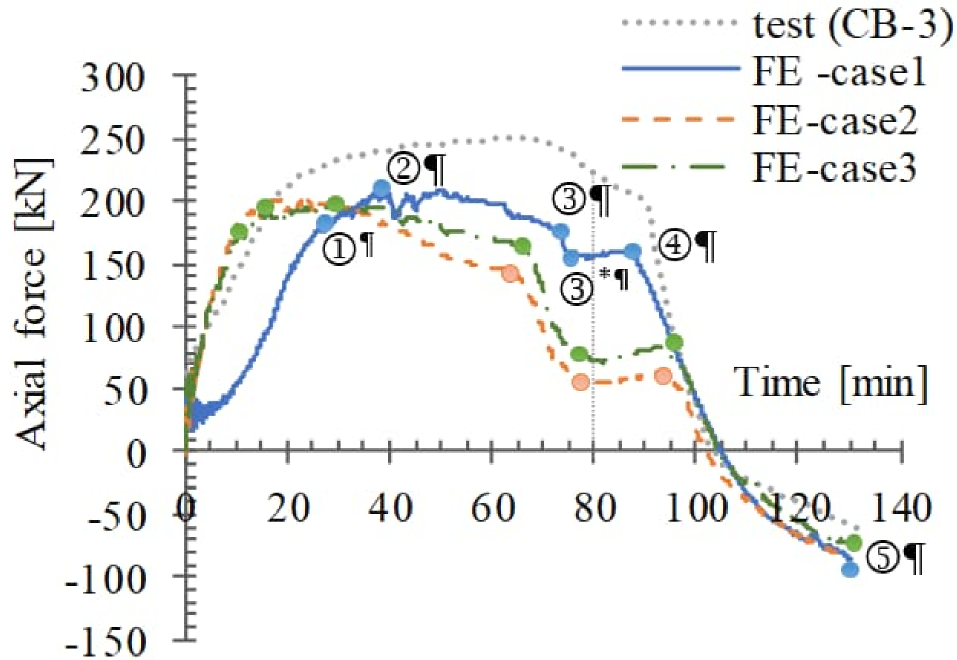


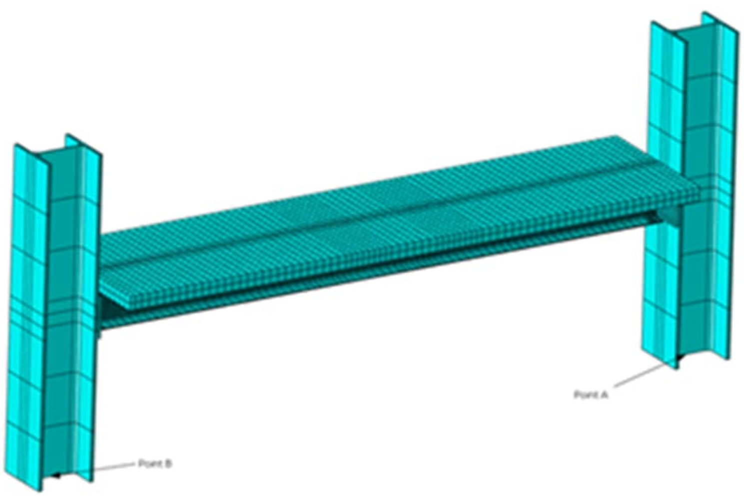
Case 3 predicted temperatures at steel beam and concrete slab closely to the test results

Validation: mechanical analyses

Results of FE analyses and tests matched reasonably





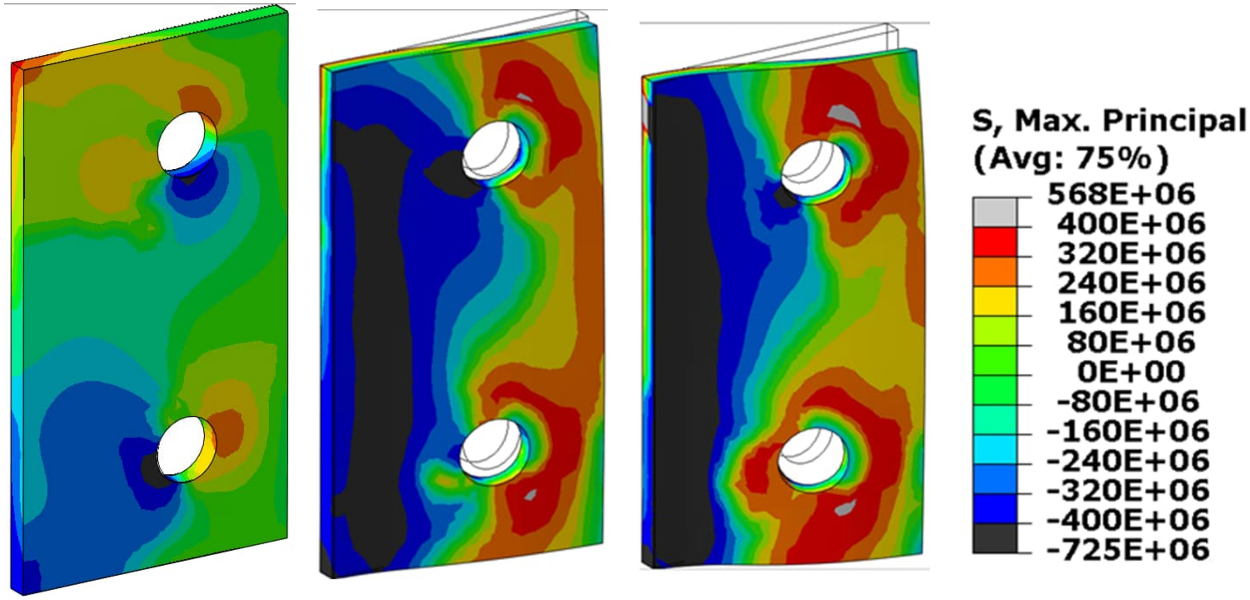


4-stage load transfer mechanism inside beam

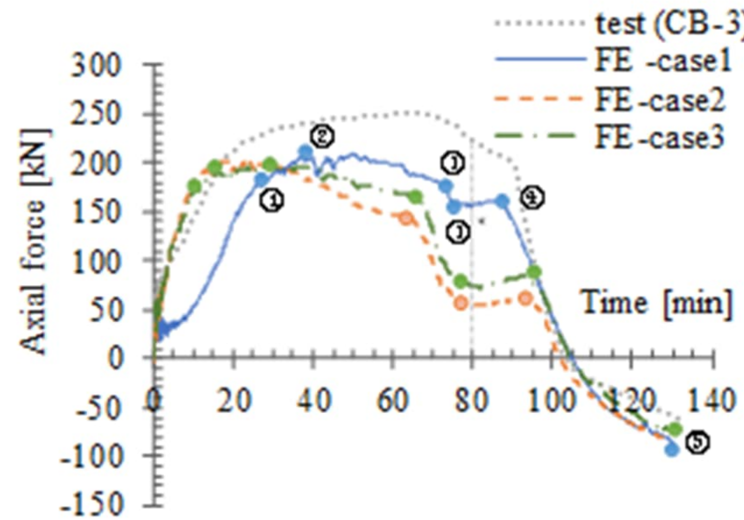
- 0-1: development of compression force
- 1-3: transition to bending-controlled behaviour (material degradation)
- 3-4: activation of tension-controlled behaviour (large deformation & cooling)
- 4-5: development of catenary action

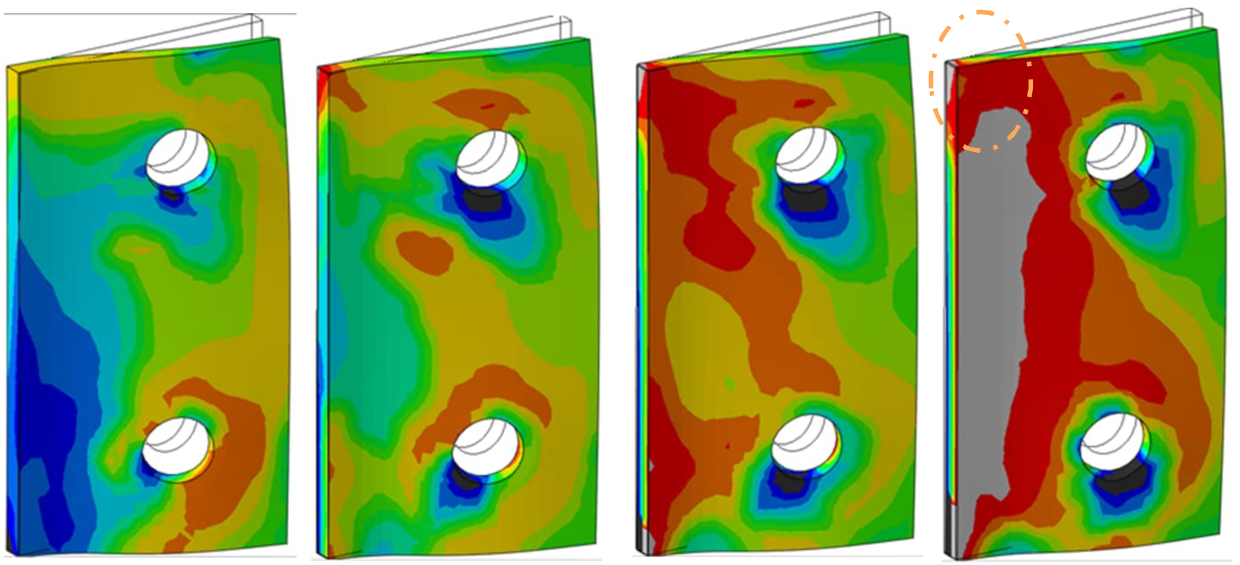
Maximum principal stresses inside the connection plate

From restrained thermal compression to tension by cooling



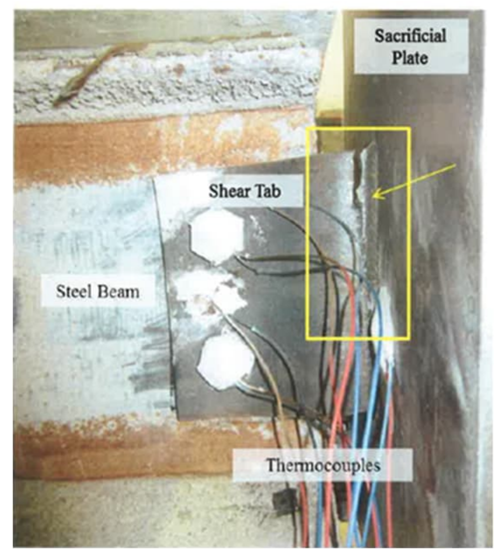
$t\ = 0min$ $t\ = 40\ min$ $t\ = 66\ min$





$t\ = 80\ min$ $t\ = 99\ min$ $t\ = 104\ min$ $t\ = 120\ min$

Fracture failure at welds

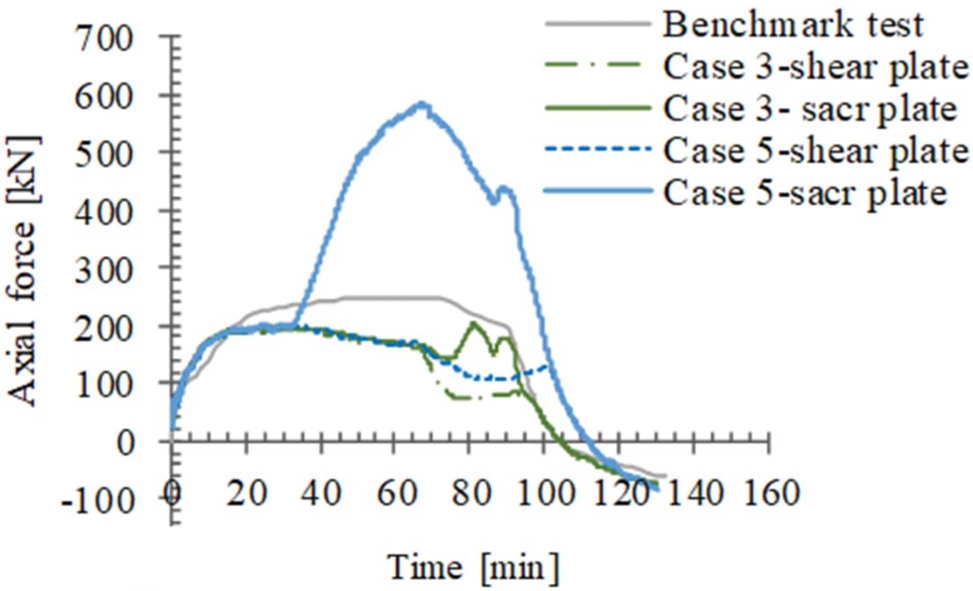


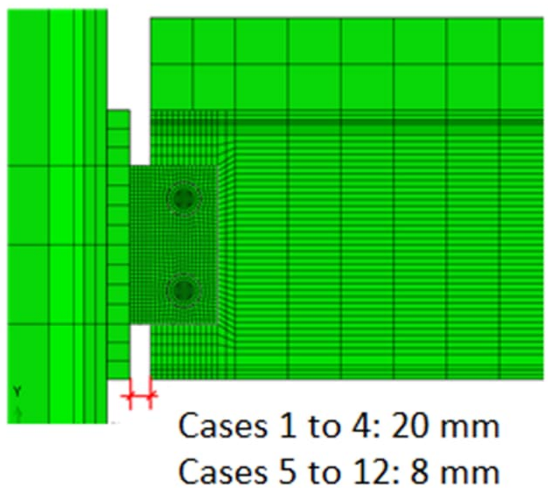
Overview of parametric studies

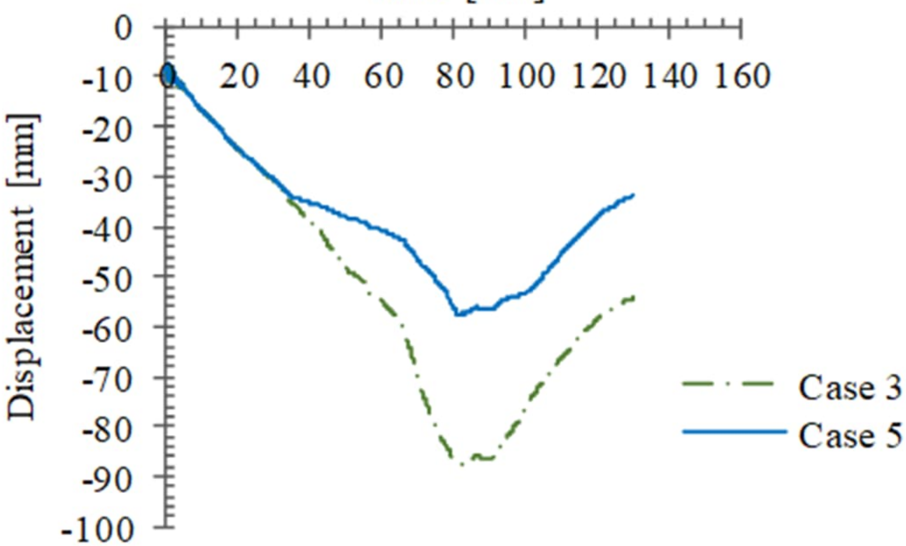
Cases¤	Duration¶ [min]¤	Fire·scenarios·as·in·the·tests¤	Heating·location¤	Max-temp· [°C]¤	Gap¶ [mm]¤
Case3¤	130¤	Surface·temperature¤	Beam¤	600¤	20¤
Case5¤	130¤	Surface·temperature¤	Beam¤	600¤	8¤
Case6¤	150¤	heating·and·cooling·rates¤	Beam¤	600¤	8¤
Case7¤	150¤	heating·and·cooling·rates¤	1m·to·connection¤	600¤	8¤
Case8¤	110¤	with·faster·cooling·rate¤	Beam¤	600¤	8¤
Case9¤	110¤	with·faster·cooling·rate¤	1m·to·connection¤	600¤	8¤
Case10¤	60¤	cyclic·heating·and·cooling¤	Beam¤	700¤	8¤
Case11¤	60¤	cyclic·heating·and·cooling¤	1m·to·connection¤	700¤	8¤
Case12¤	60¤	cyclic·heating·and·cooling¤	1m·at·the·centre¤	700¤	8¤

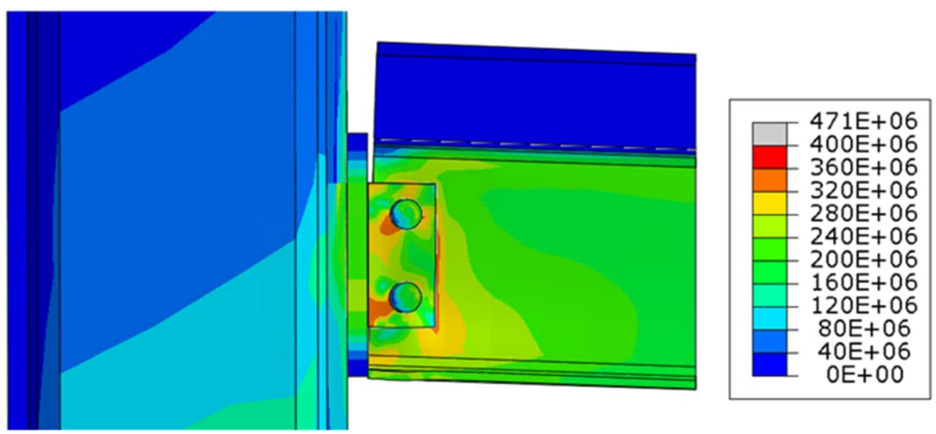
Effects of gap distance on connection behaviour

When the gap was partially closed, a hinge connection transformed into a moment connection, which reduced the beam displacement.

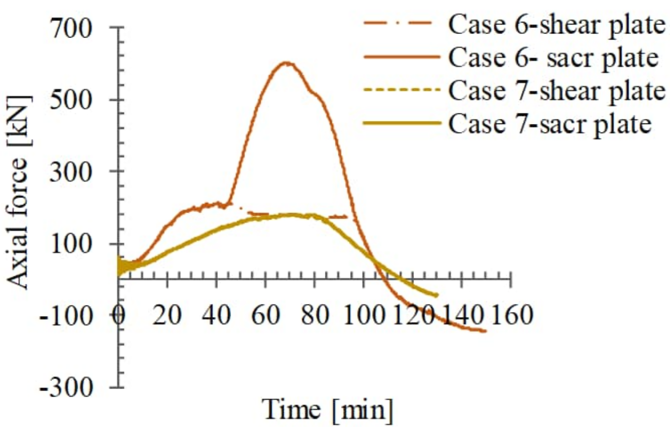




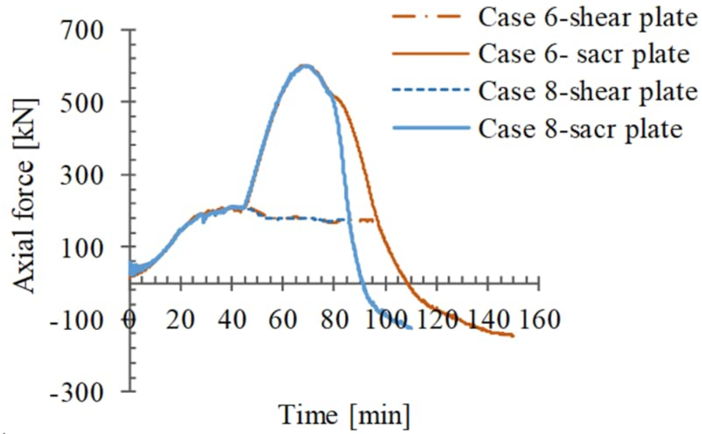




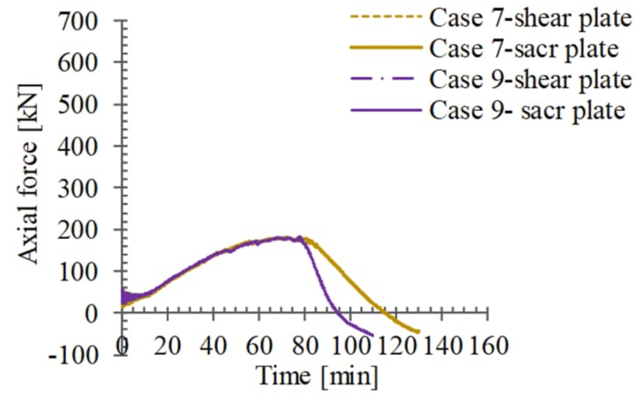
Effects of cooling regions and cooling rates



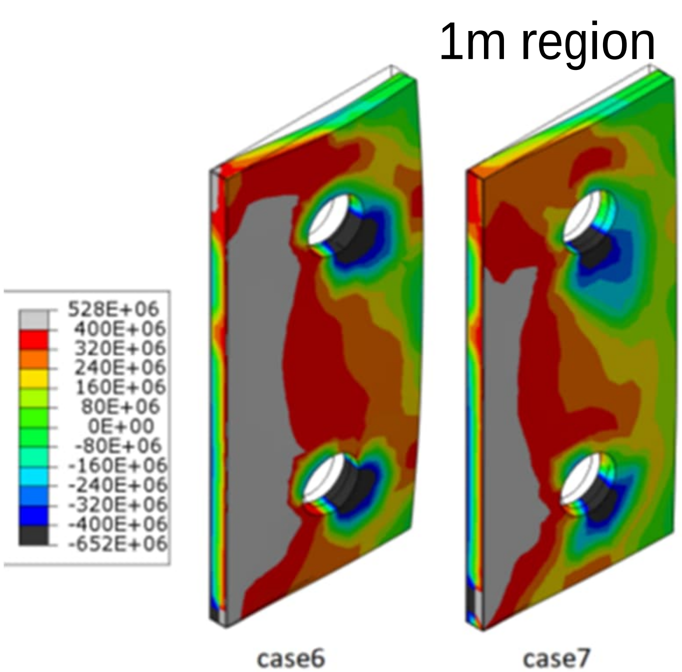
Cooling whole beam (6) or beam close to connection (7)

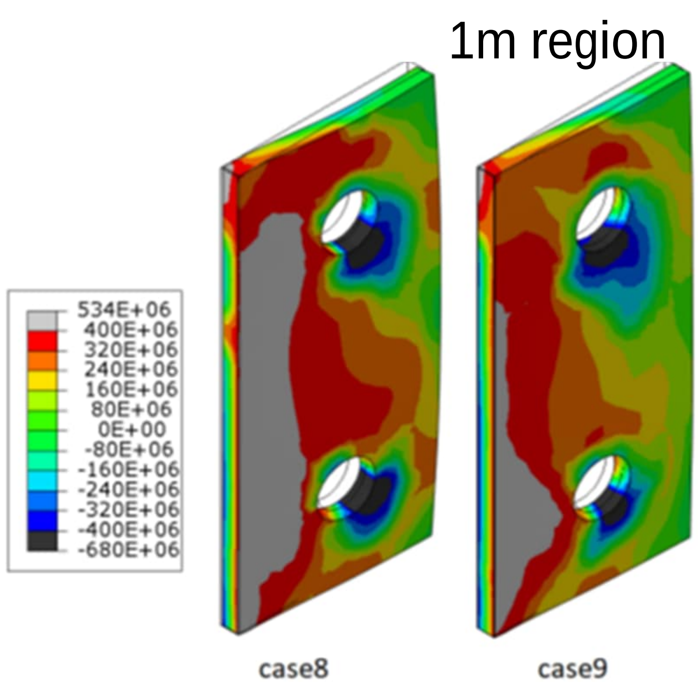


Cooling whole beam but with a faster cooling rate (8)



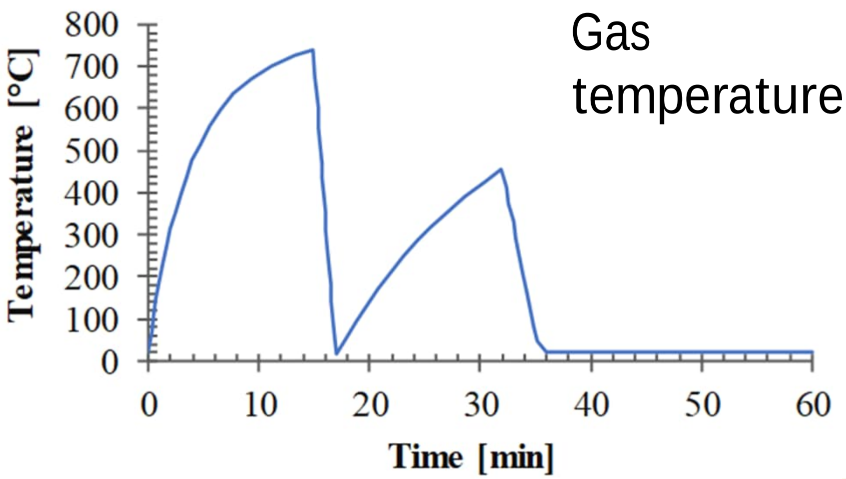
Cooling 1 m of the beam from the connection with a faster cooling rate (9)

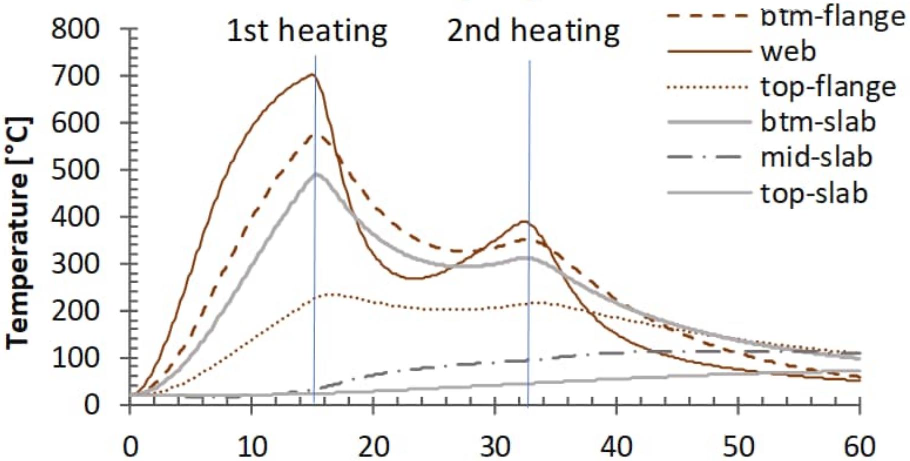


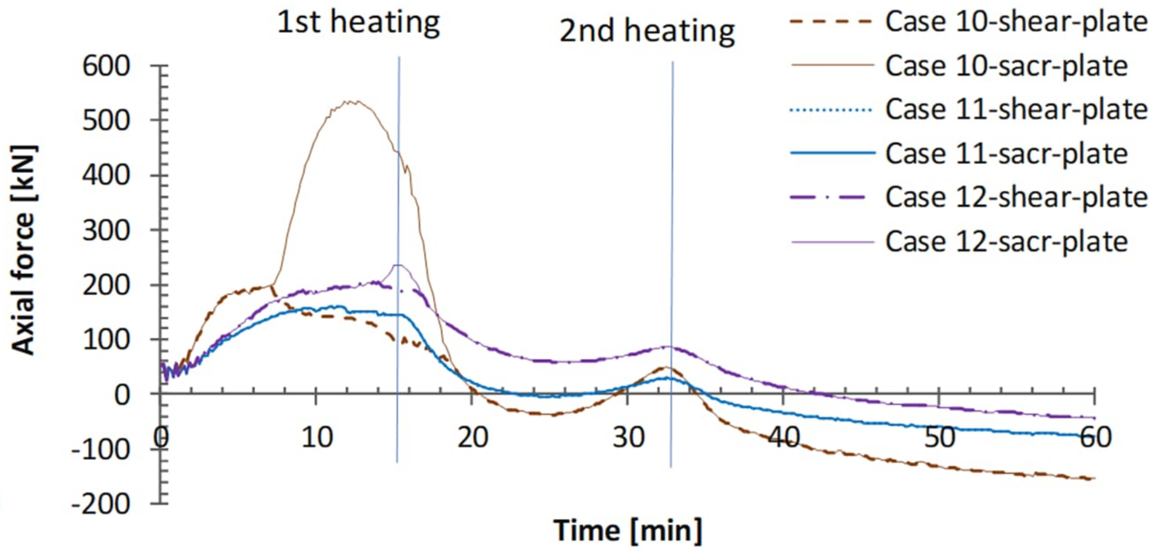


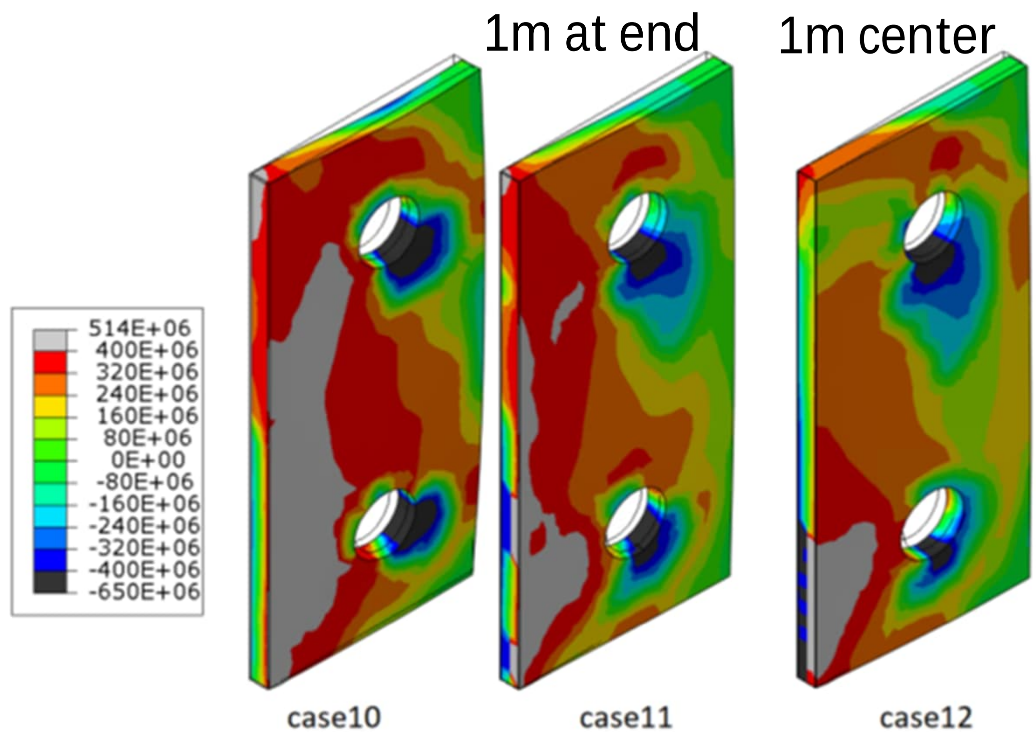
- Failure close to welds was observed
- Local heating and cooling of connections induces less axial load
- Local cooling with a faster rate endangers connection more than the other cases

Effects of heating and cooling cycles



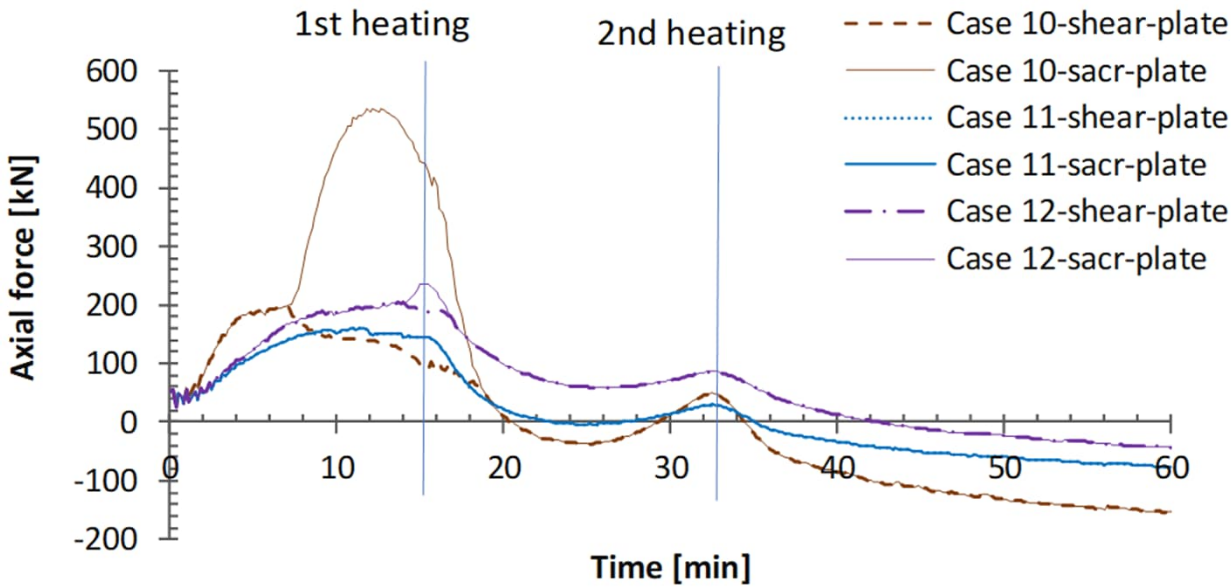


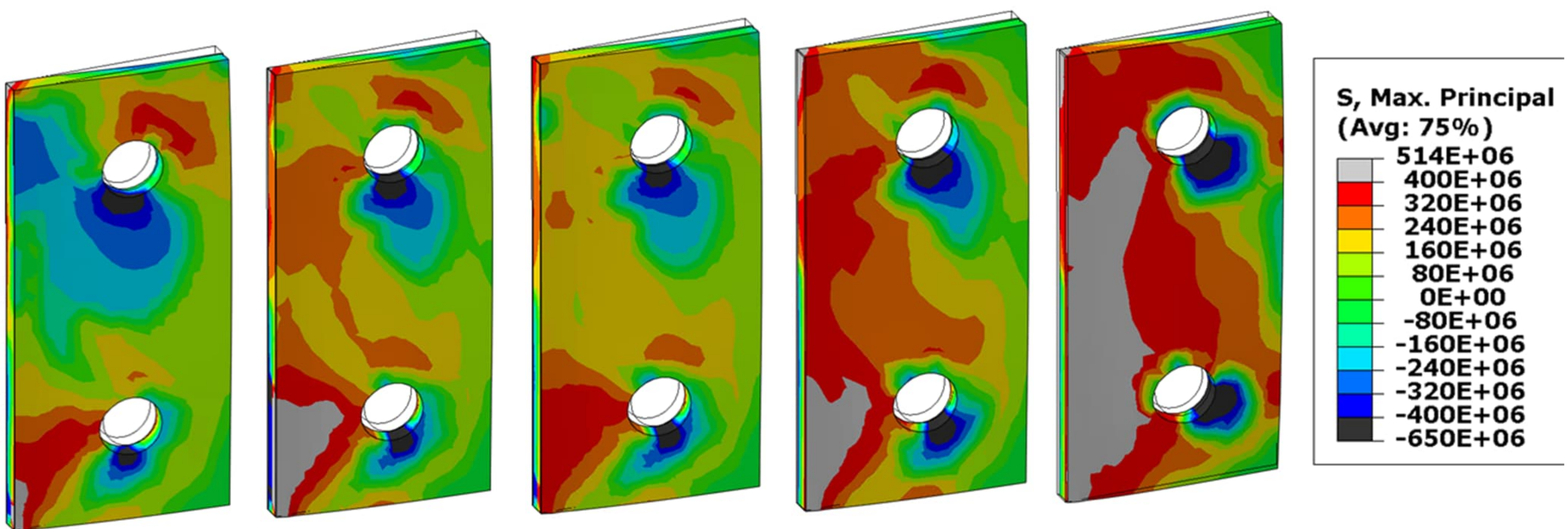




- High non-uniform temperature field was created after 1st heating-cooling cycle.
- Cyclic compression – tension load axial forces developed during cyclic heating and cooling.
- Heating-cooling the whole beam endangered the connection critically.

Cyclic stresses caused by heating – cooling cycles





$t = 20min$ $t = 25min$ $t = 28min$ $t = 37min$ $t = 60min$

Conclusions

- The contribution of shear stud and concrete slab to the load-carrying mechanism of the composite slab was clearly observed in Stage II and Stage III by varying the temperatures of the top flange of the steel beam.
- Failure by the maximum principal stress exceeding the yield strength of the fin plate well simulated the strength of the fin-plate connection.
- A simple connection at room temperature can transform into a moment connection in fire with different gap distances, which reduces the beam deflection during both heating and cooling phases.

Conclusions (continued)

- The weakest part of the connection was the shear plate close to the welds because of the high stresses and degraded material strength.
- Cooling the beam in a faster cooling rate endangered the connection more than cooling the beam locally close to the connection.
- The cyclic heating-cooling the beam induced the cyclic compression-tension stresses. In the end of the first cooling phase, the fracture initiation of the shear plate close to welds were predicted. In the end of the second cooling phase, the fracture failure were observed.
- Further studies on the connection behaviour during the cooling can improve the understanding of the failure of connections and advance the connection design.

Thank you for your attention!

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