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WG1: Data Sheets 7-9

Connections in Fire

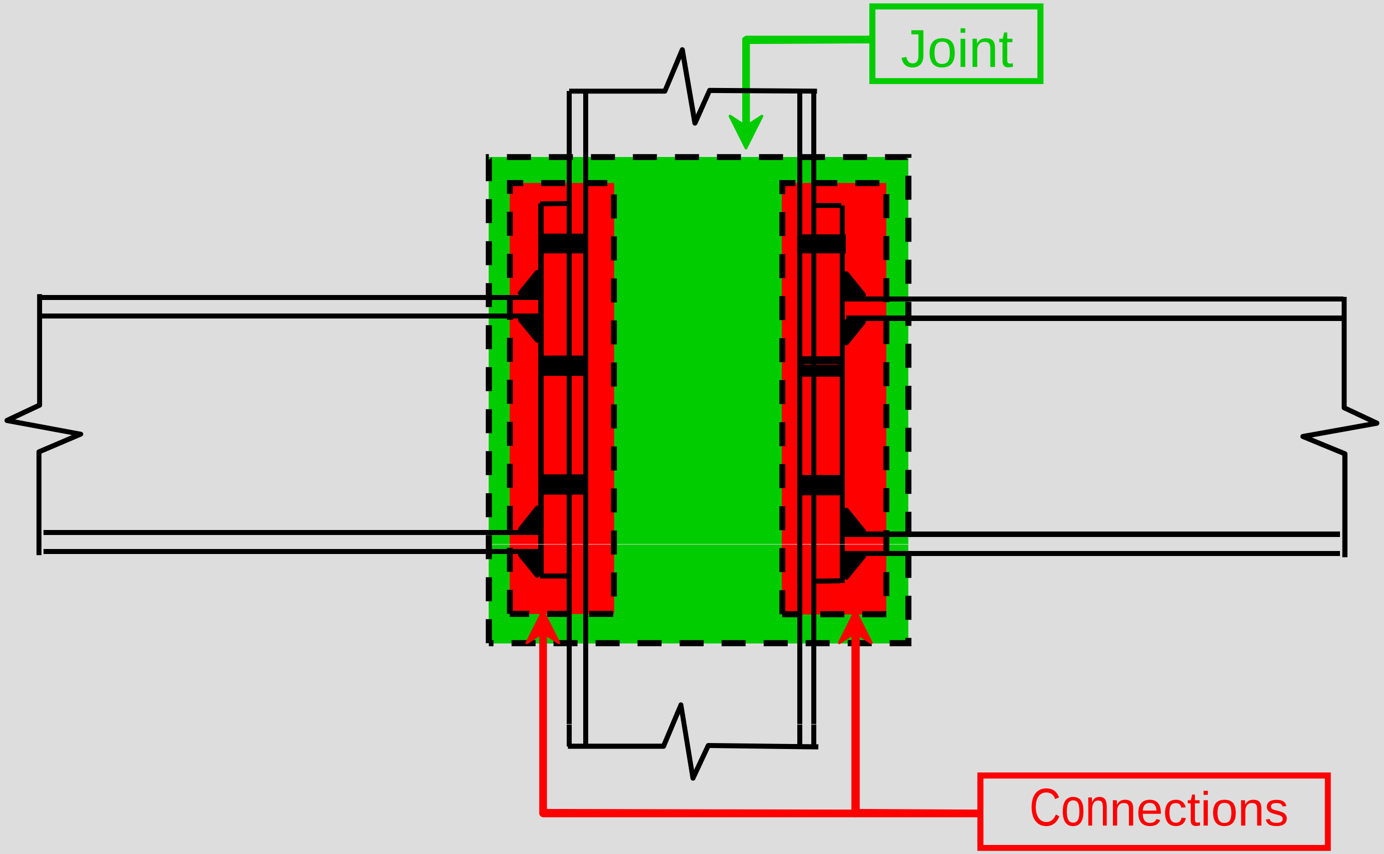
Ian Burgess

Design

WG1: Data Sheet 9

DESIGN PROCEDURES FOR STEEL AND COMPOSITE JOINTS IN FIRE

Definition of joint and connection



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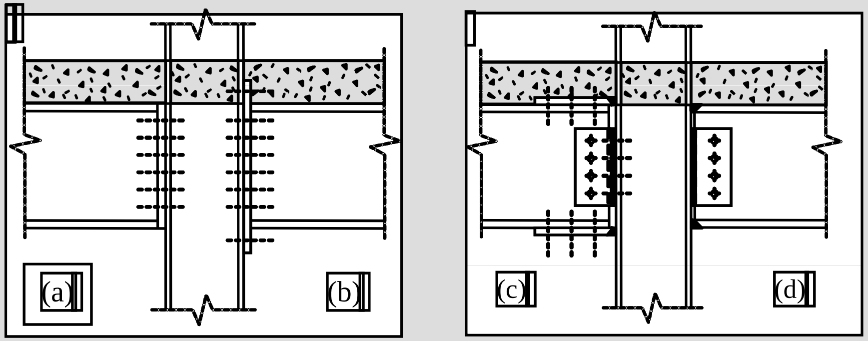
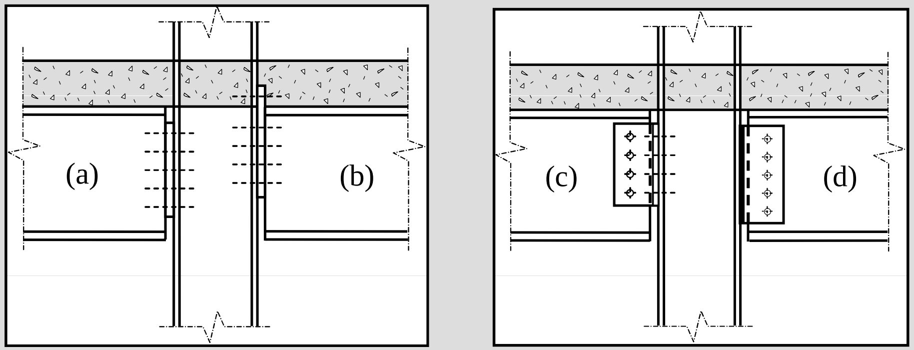
Joint classification at ambient temperature



Semi-rigid & rigid joints

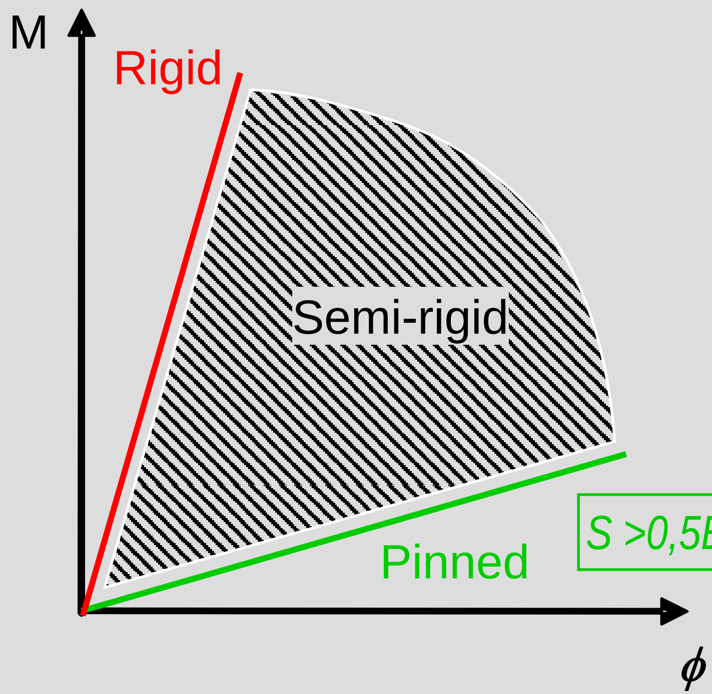


Simple (pinned) joints

$S > k_b EI_b/L_b$

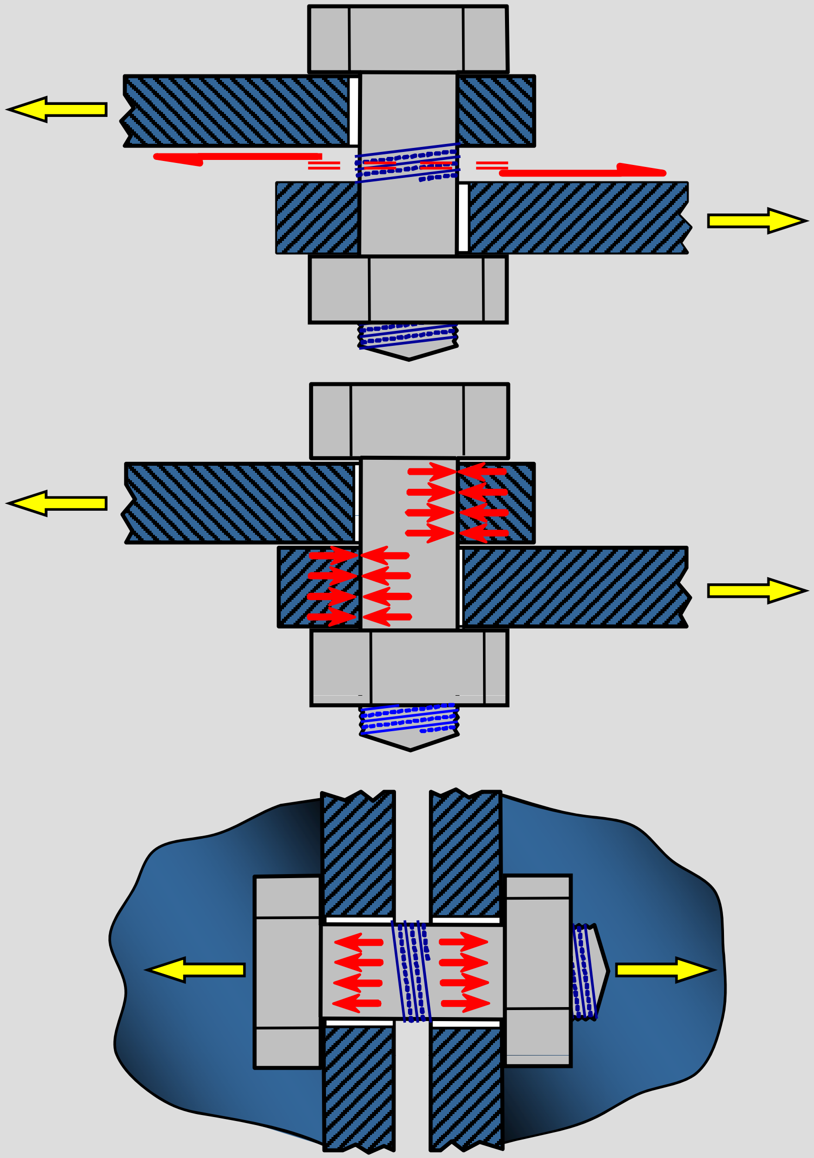
K_b=8 (braced frames)

K_b=25 (other frames)



$S > 0,5EI_b/L_b$

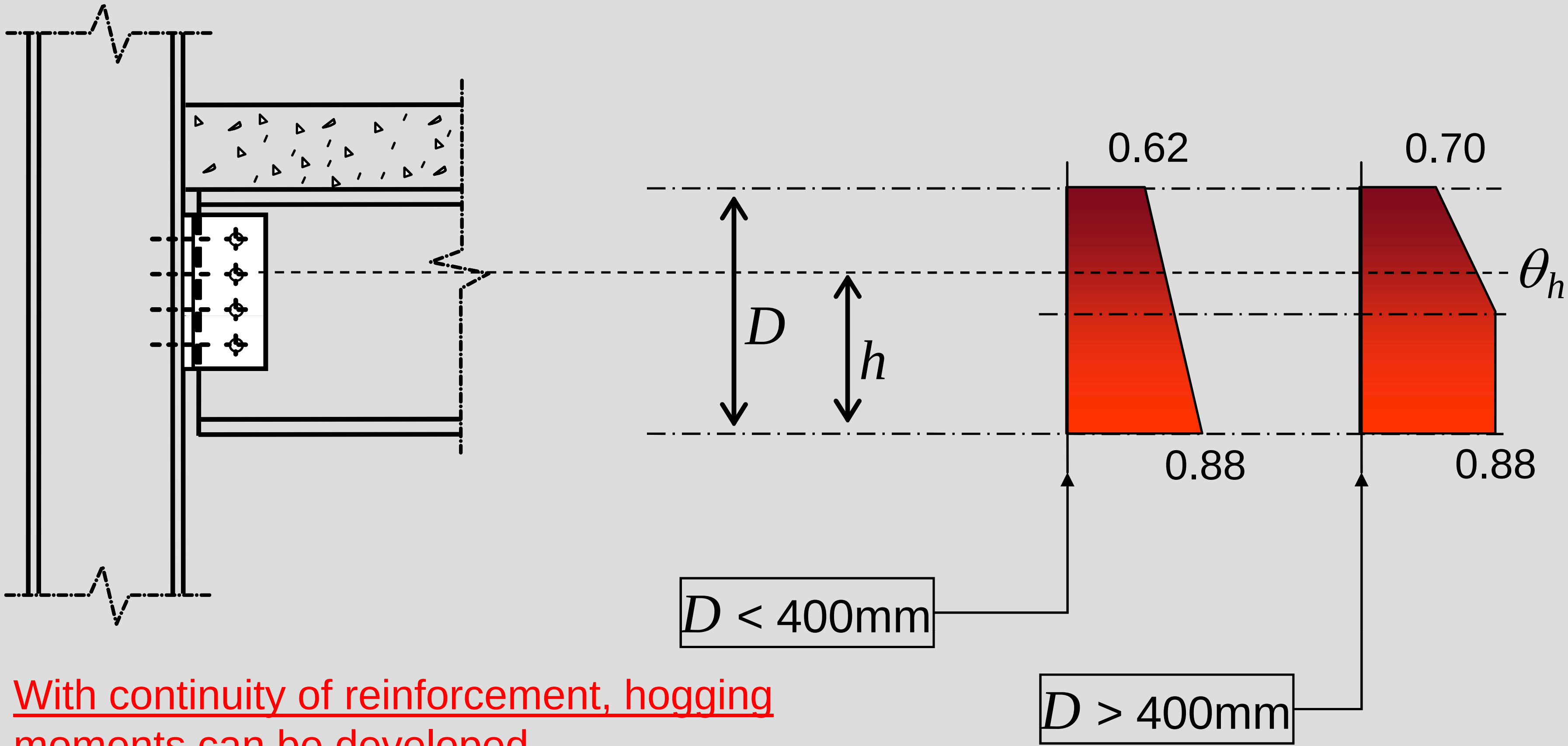
EN1993-1-2 joint design in fire



- No provision for semi-rigid behaviour.
- **Annex D** is “informative” only
  - Bolt strength reduction the same for:
    - Shear
    - Bearing
      - No friction
      - 40% reduction if slotted holes
  - Different strength reduction for:
    - Tension
      - Assumes pre-tension lost
    - Reduction factors lower than for structural steel
  - Weld strength reduction
    - Table of reductions for fillet welds
    - Full Penetration butt welds
      - Strength of weaker part joined.
      - Reduction factors over 700°C

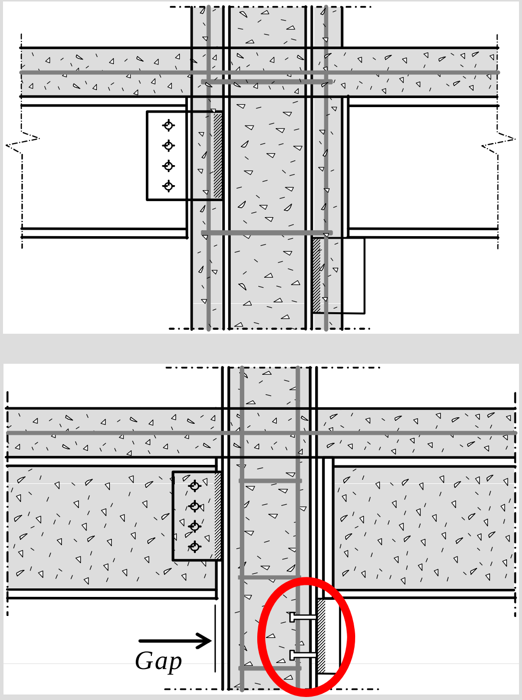
Temperature distributions in joints

1. Use EC3 incremental temperature analysis on individual connection elements
2. Uniform temperature based on highest element temperature in 1
3. Linearised temperature distribution for beams supporting concrete floor
    - Proportions of beam bottom flange temperature



With continuity of reinforcement, hogging moments can be developed.

Connecting to concrete-encased and web-infilled columns



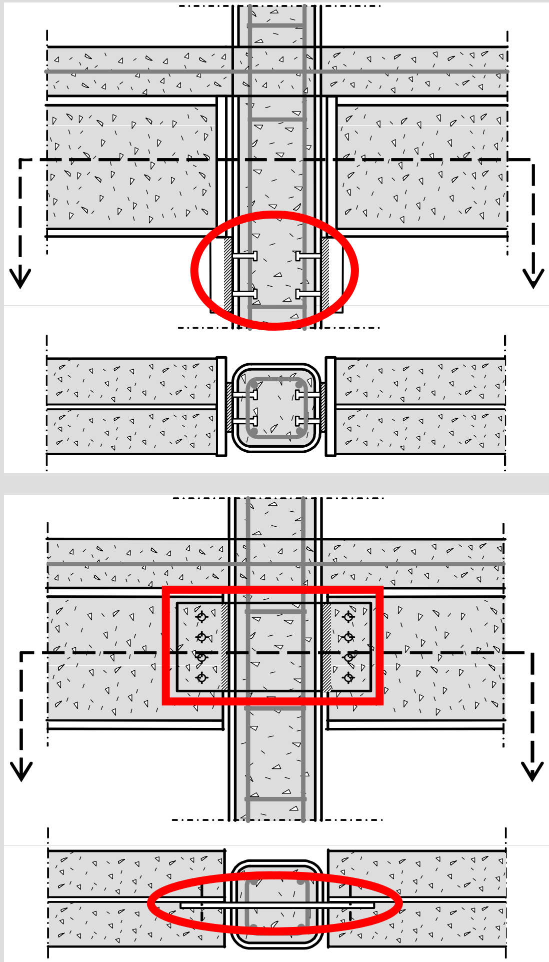
Web-infilled columns

General problem in all cases of composite columns:

- Transfer of vertical shear from beam to the concrete in the column when exposed steel parts are hot.
- Only details in EN1994-1-2 are Fin Plates and Bearing Blocks, pre-welded to column.

Solutions:

- Shear connectors (studs) on column face into infill.
- Single fin plate slotted through hollow section.



Concrete-filled hollow-section columns

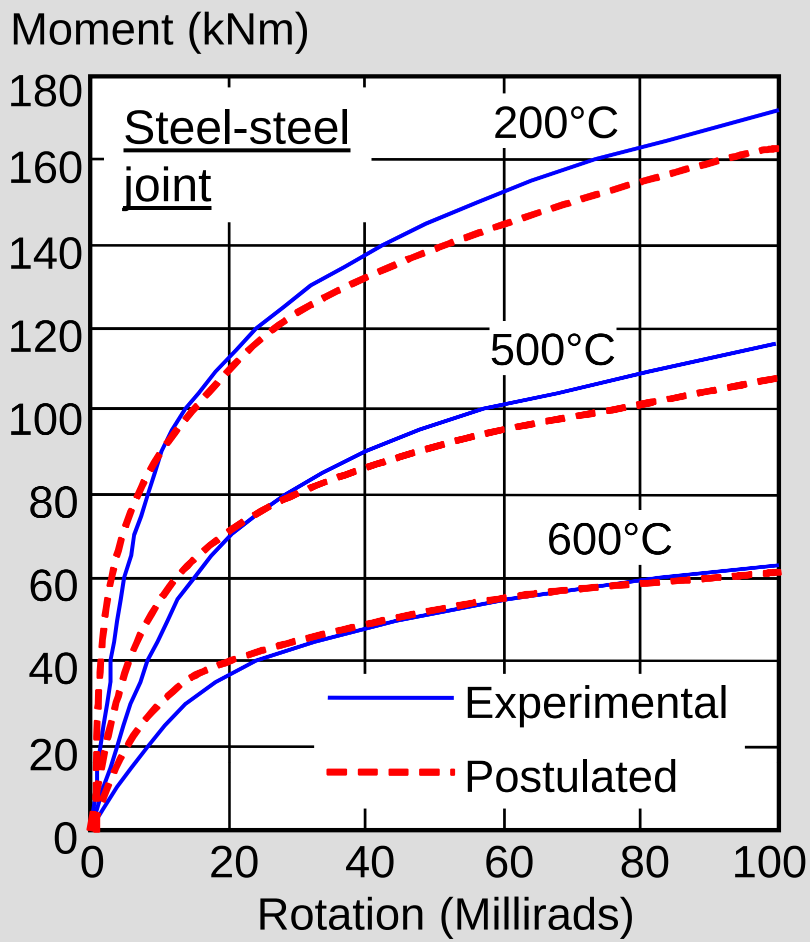
Connection Behaviour

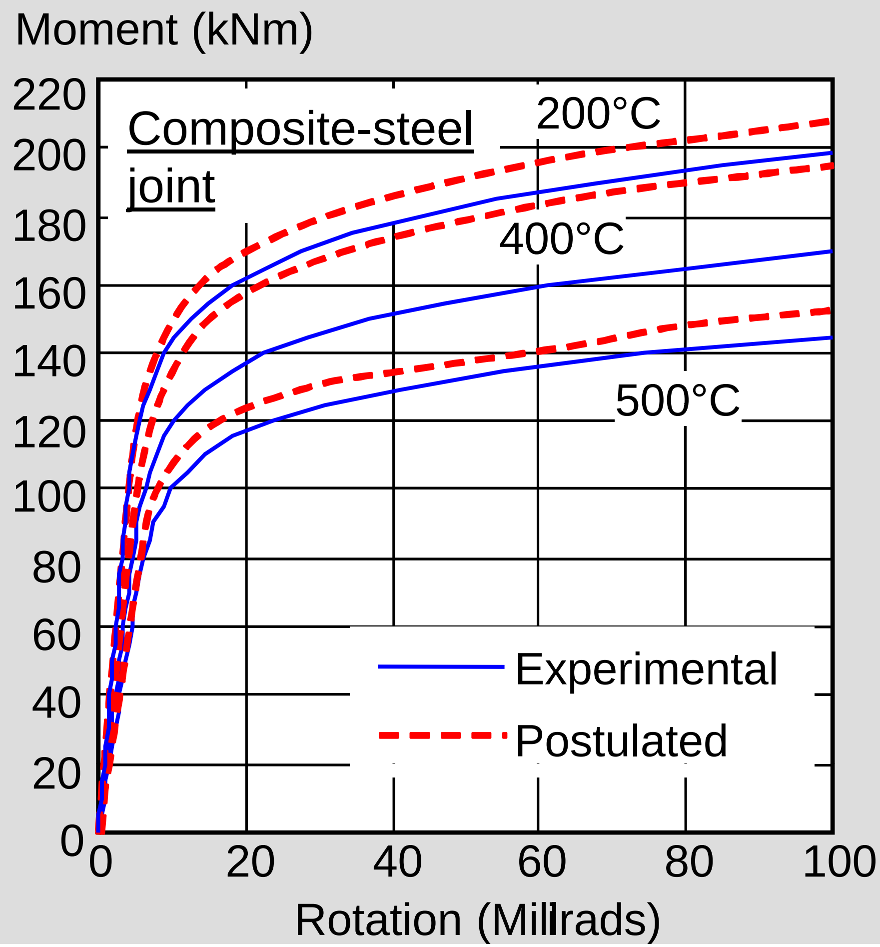
WG1: Data Sheet 7

BEHAVIOUR OF STEEL AND COMPOSITE JOINTS IN FIRE

Moment-rotation at high temperature

- Cruciform tests from early 1990s
- Originally, joints being cooler than beams considered to be a design advantage for beams in fire
- Semi-empirical rules for M-ϕ by Al-Jabri (2004)

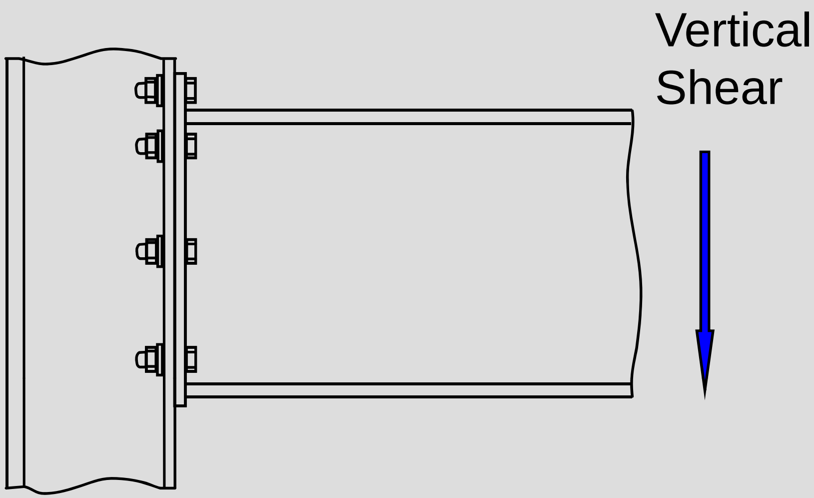




Behaviour in real buildings in fire

Observations from Cardington and other full-scale tests, and from accidental fires show:

- Buckling of lower flange of connected beam.
- Shear buckling in web of connected beam.
- Large beam deflections (high joint rotations.
- Some bolt fracture.



Ambient temperature:

- Connection subjected mainly to vertical shear.

Behaviour in real buildings in fire

Observations from Cardington and other full-scale tests, and from accidental fires show:

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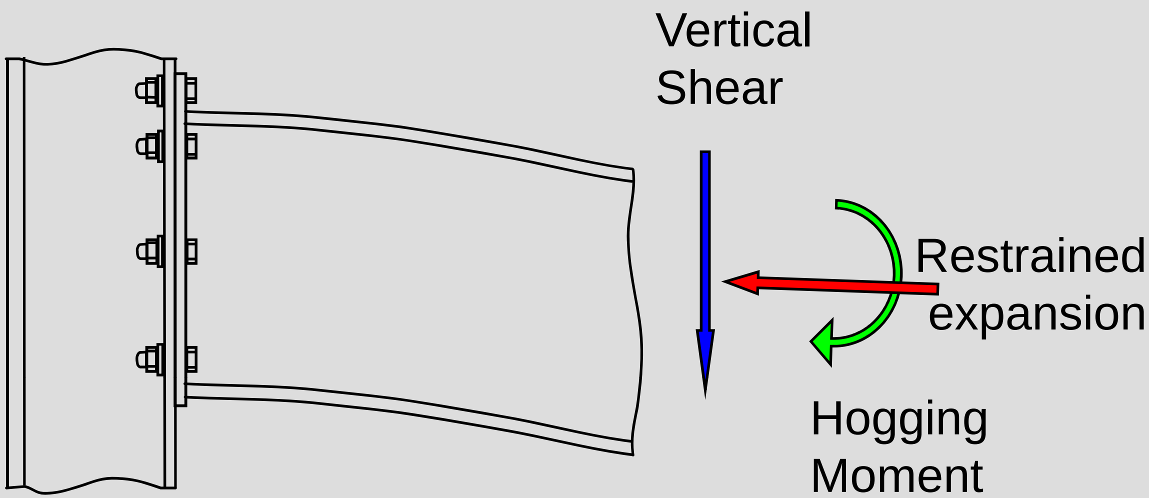

Initial heating stage:

- Beam attempts to expand – columns and adjacent structure resist. Net compression caused.
- Thermal curvature generates rotation and hogging moments.

Behaviour in real buildings in fire

Observations from Cardington and other full-scale tests, and from accidental fires show:

- Buckling of lower flange of connected beam.
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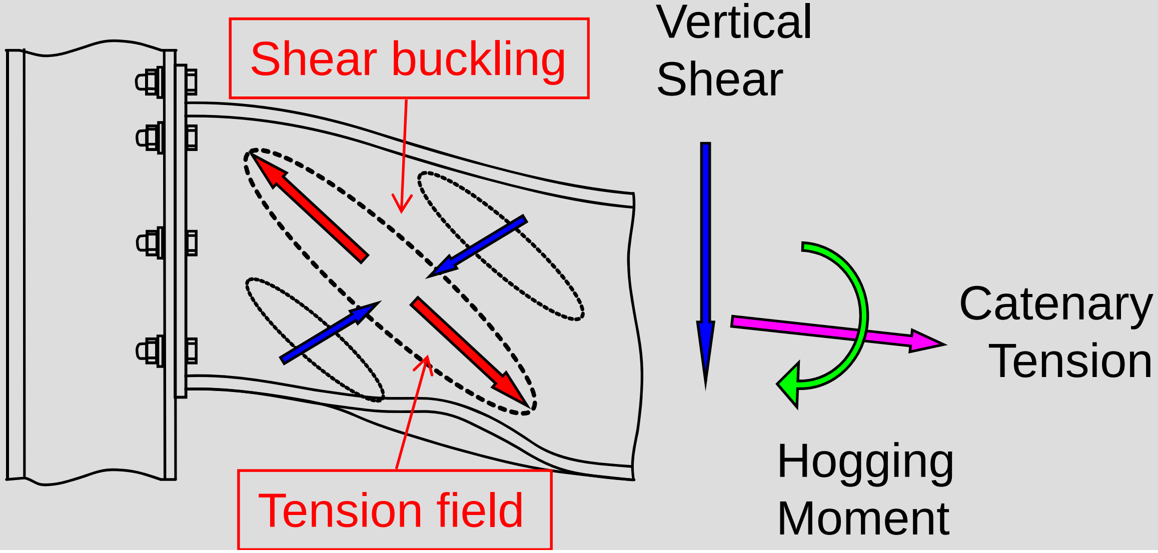
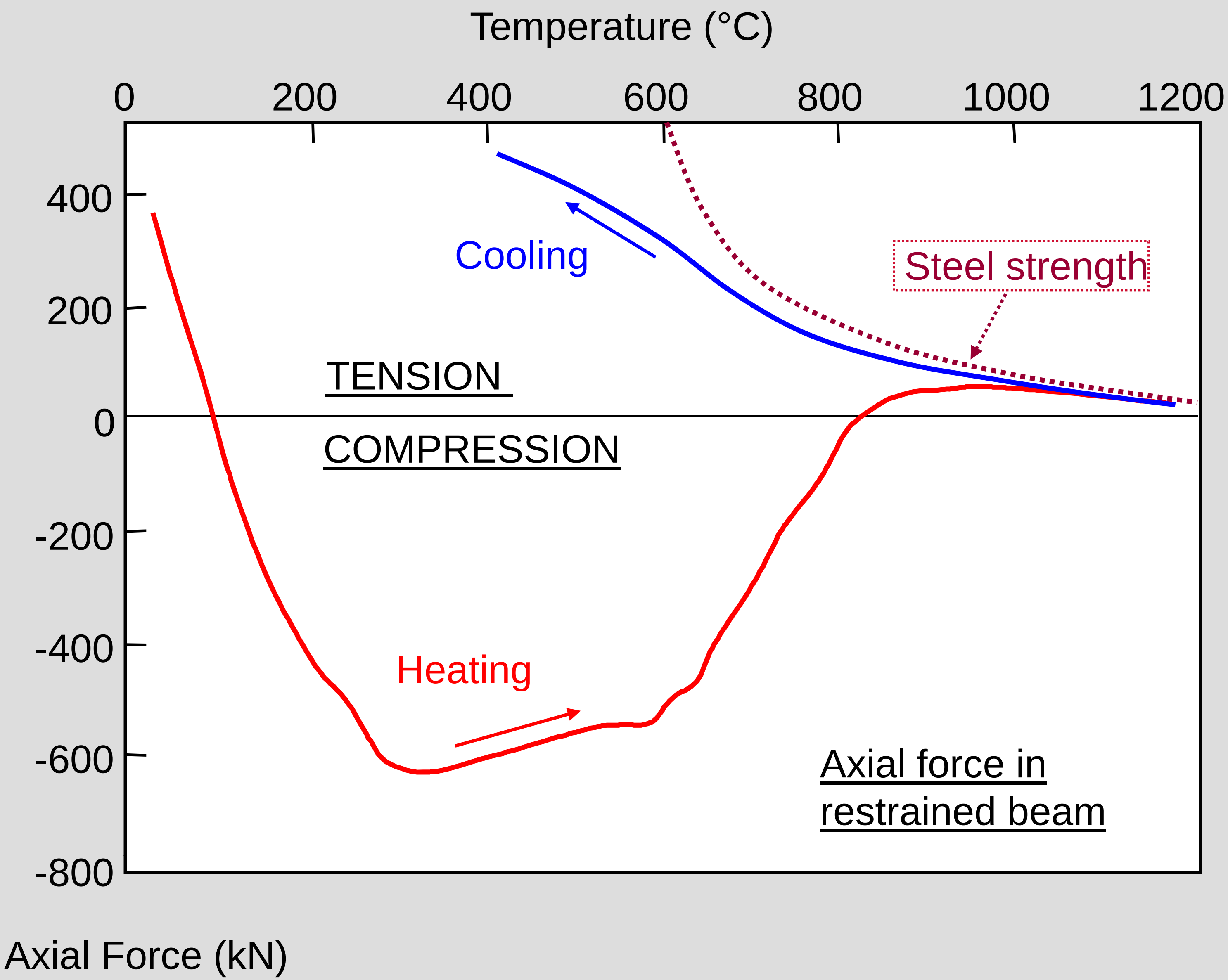


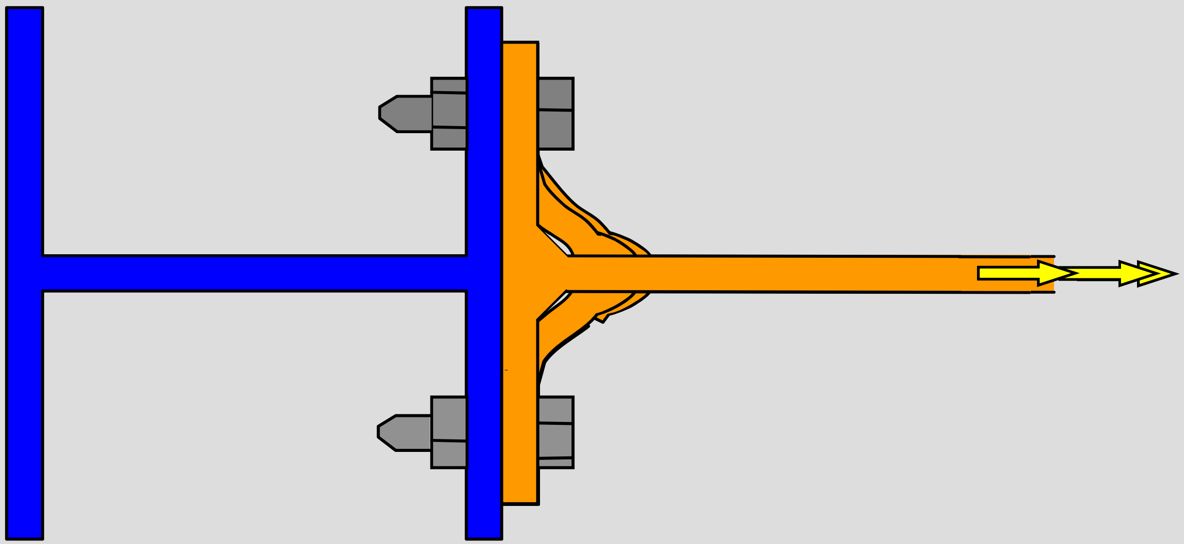
<u>High beam temperature:</u>

- Beam loses strength in bending – hangs in catenary. Joints have to resist catenary tension.
- Large hogging rotation caused locally by catenary action.

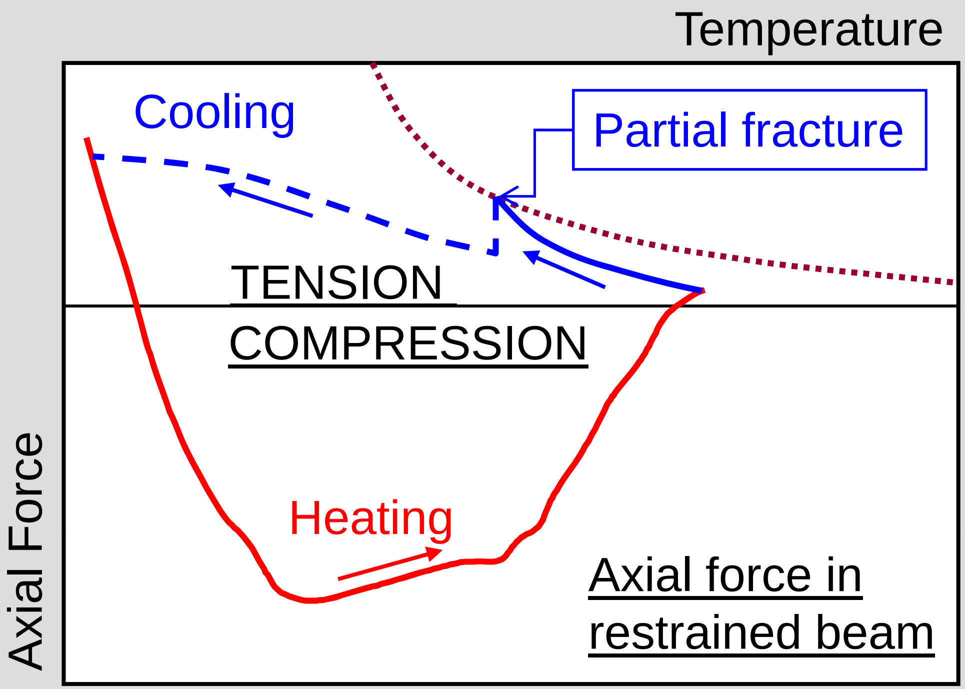
Axial force in steel downstand of composite beam



Fracture in cooling at Cardington



- One-sided failure of partial-depth end plates during cooling phase of fire.
- Reduced stiffness retains the integrity of the joint.
- Shear failure of bolts also observed in fin-plate beam-beam connections during cooling.



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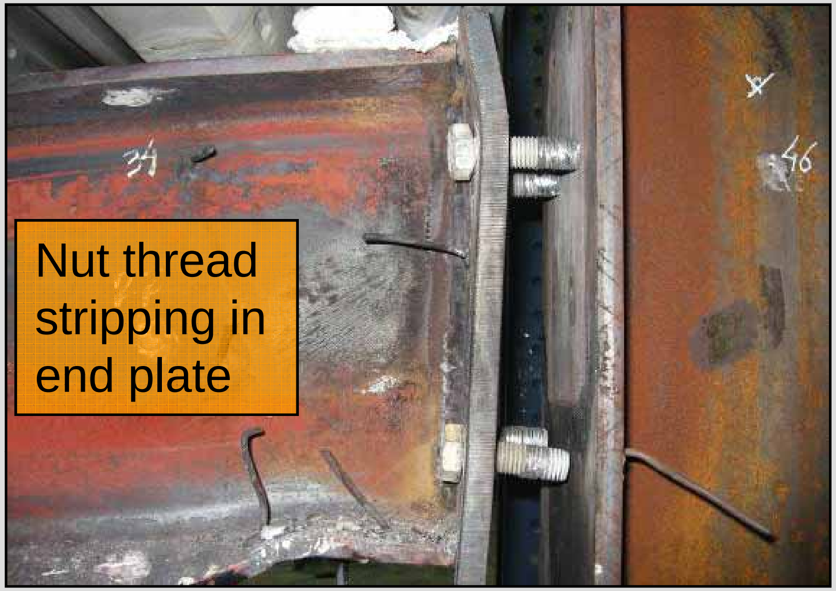
Joint failures in cooling

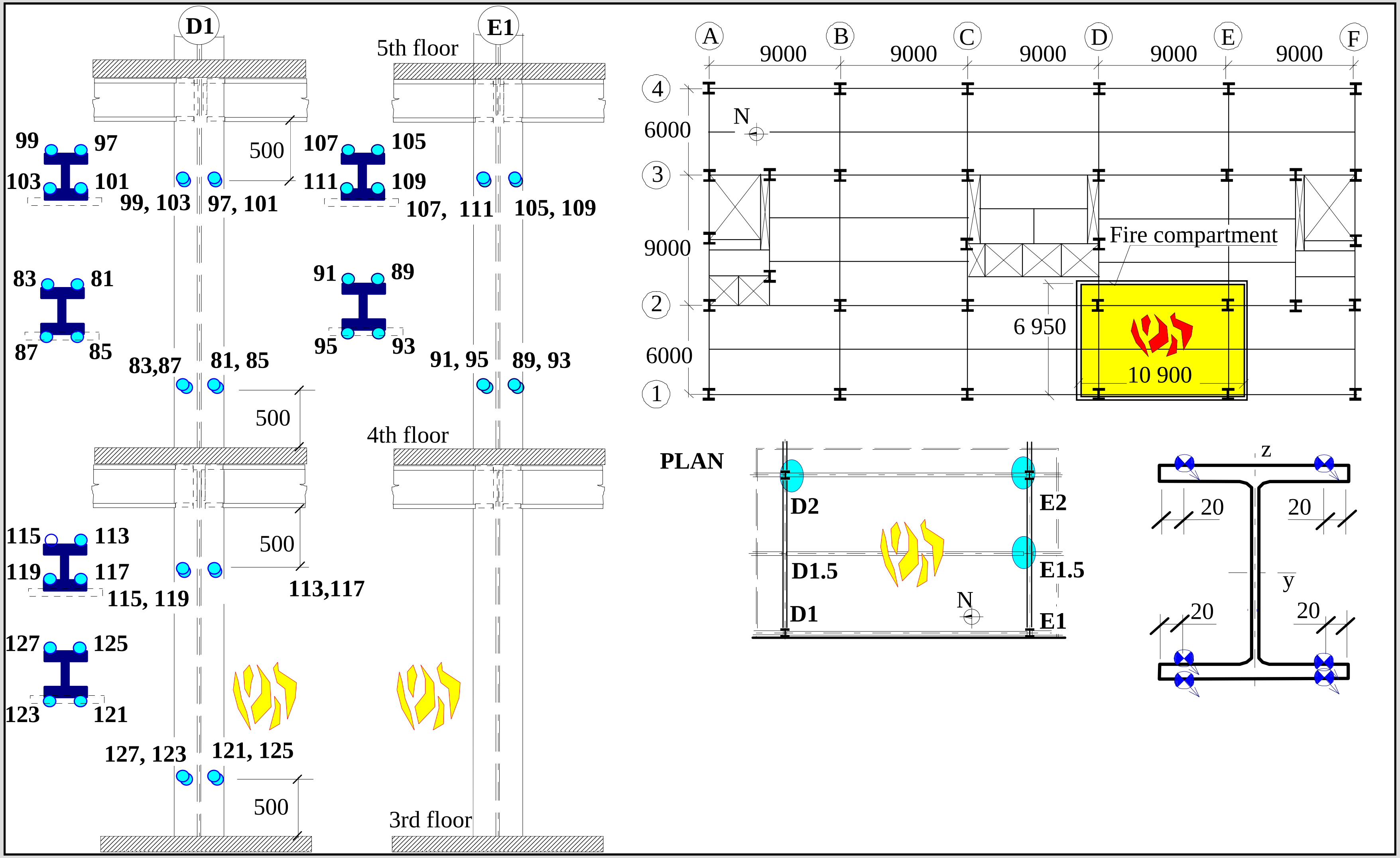
One-sided failures of partial-depth end plates

Bolt shear in fin plate



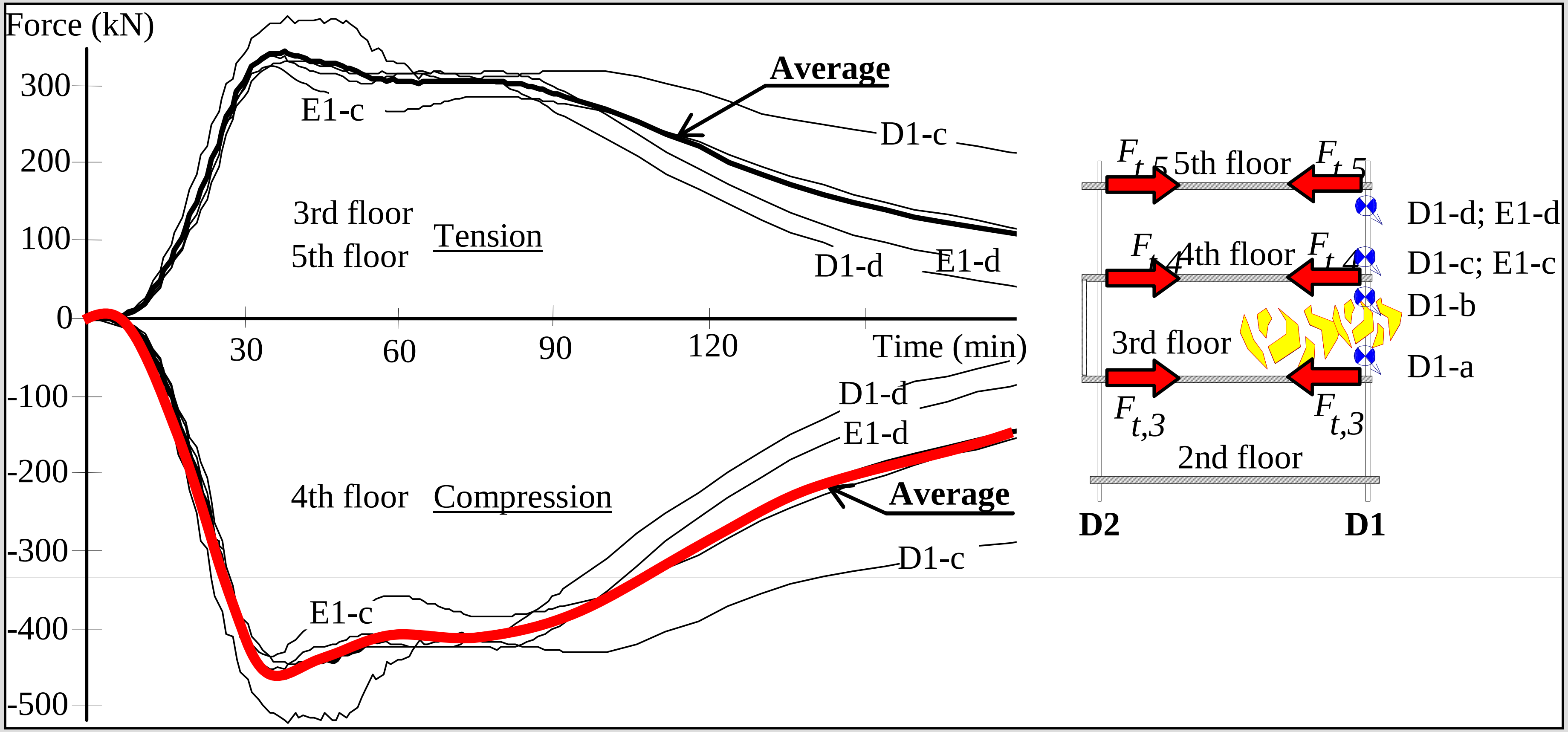
Nut thread stripping in end plate

A research study of joint forces in fire



“Cardington 7” Wald *et al.* (2003)

Measured joint forces in natural fire



- General shape of compression curve is as usual.
- This is plotted in terms of time, not temperature – no reversal.
- In a particular natural fire curve the fire characteristics, load levels etc. determine whether the beam goes into tension

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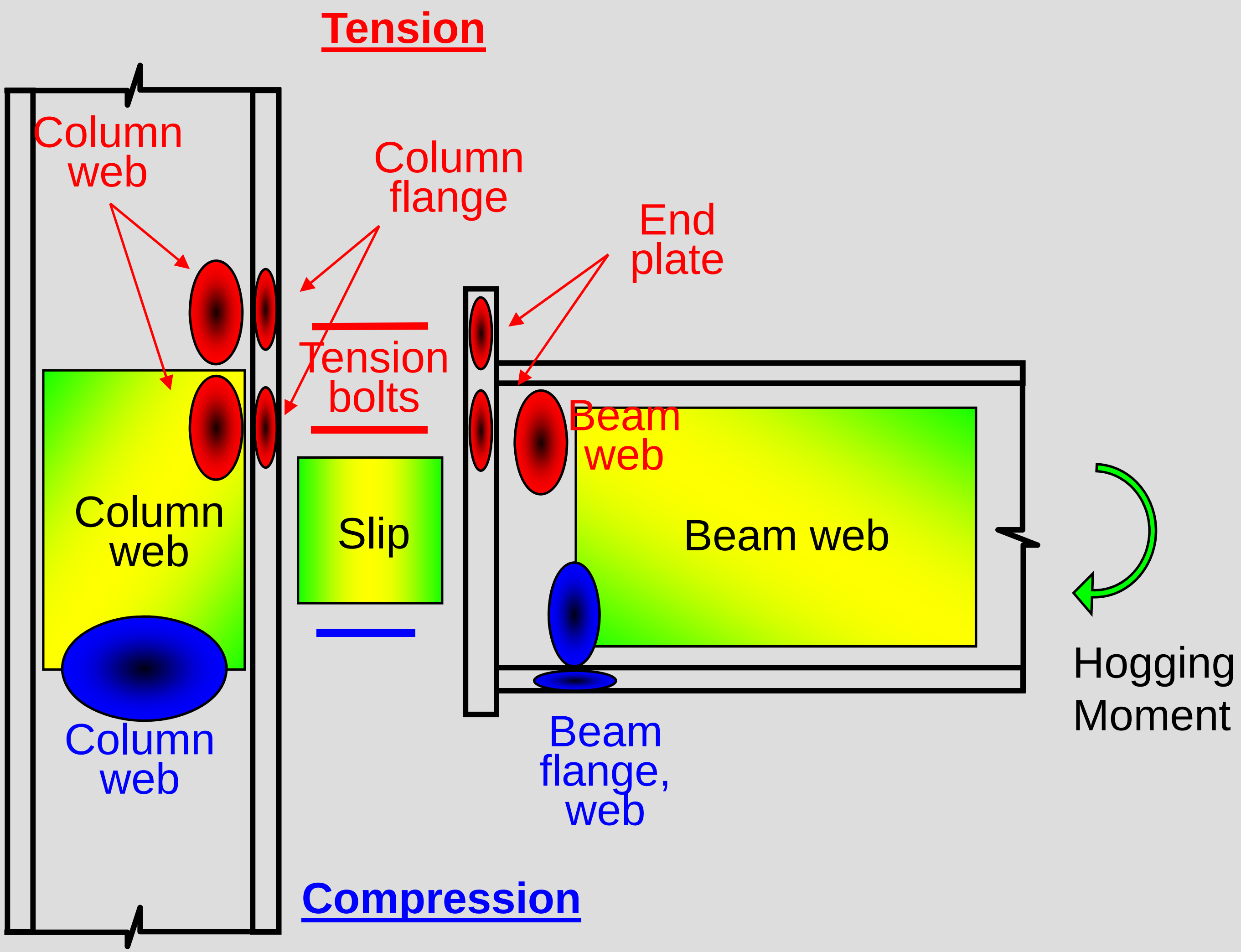
Component Approaches

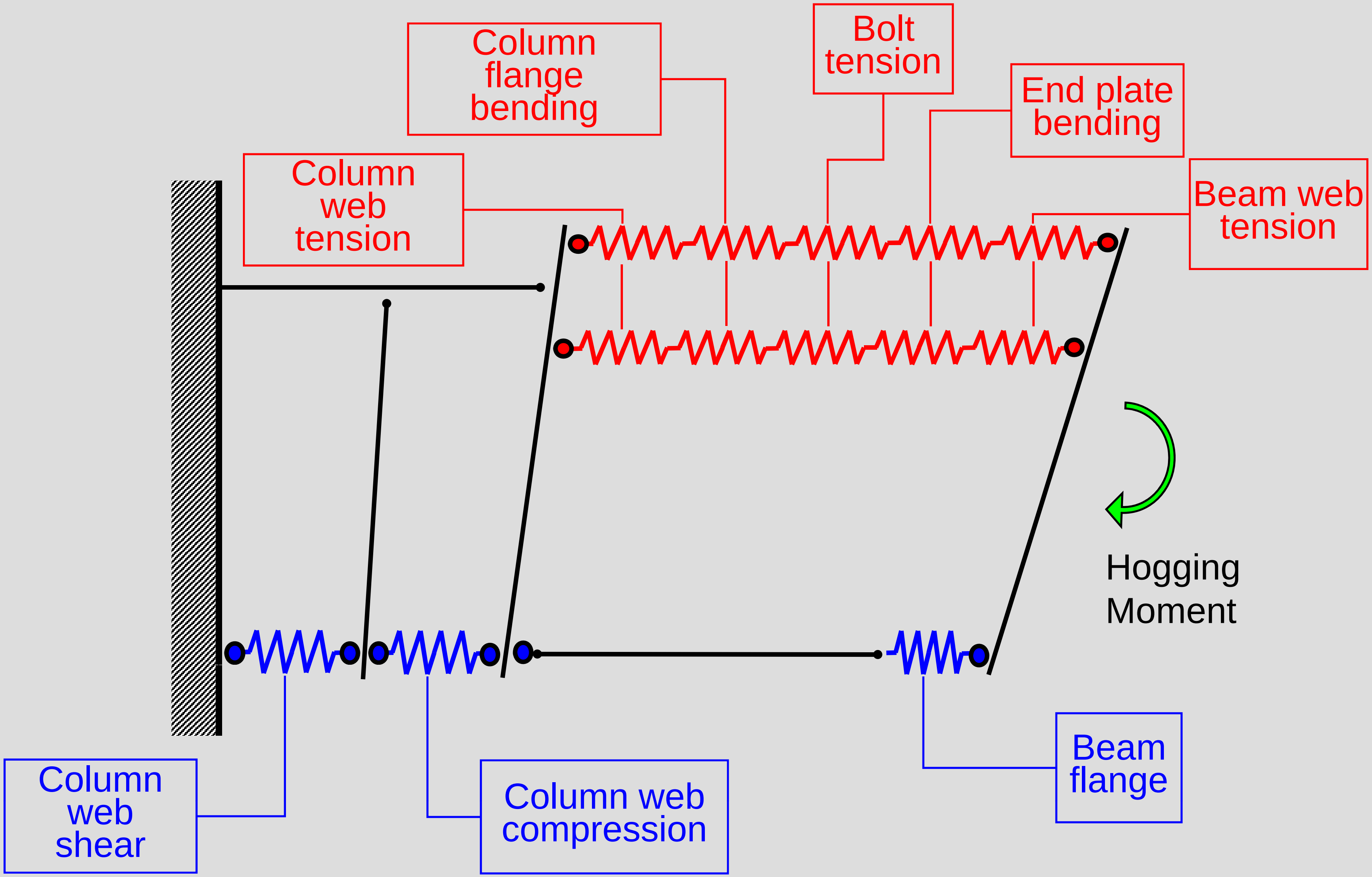
WG1: Data Sheet 8

COMPONENT-BASED APPROACHES TO STEEL AND COMPOSITE JOINTS IN FIRE

Principal component zones of end-plate

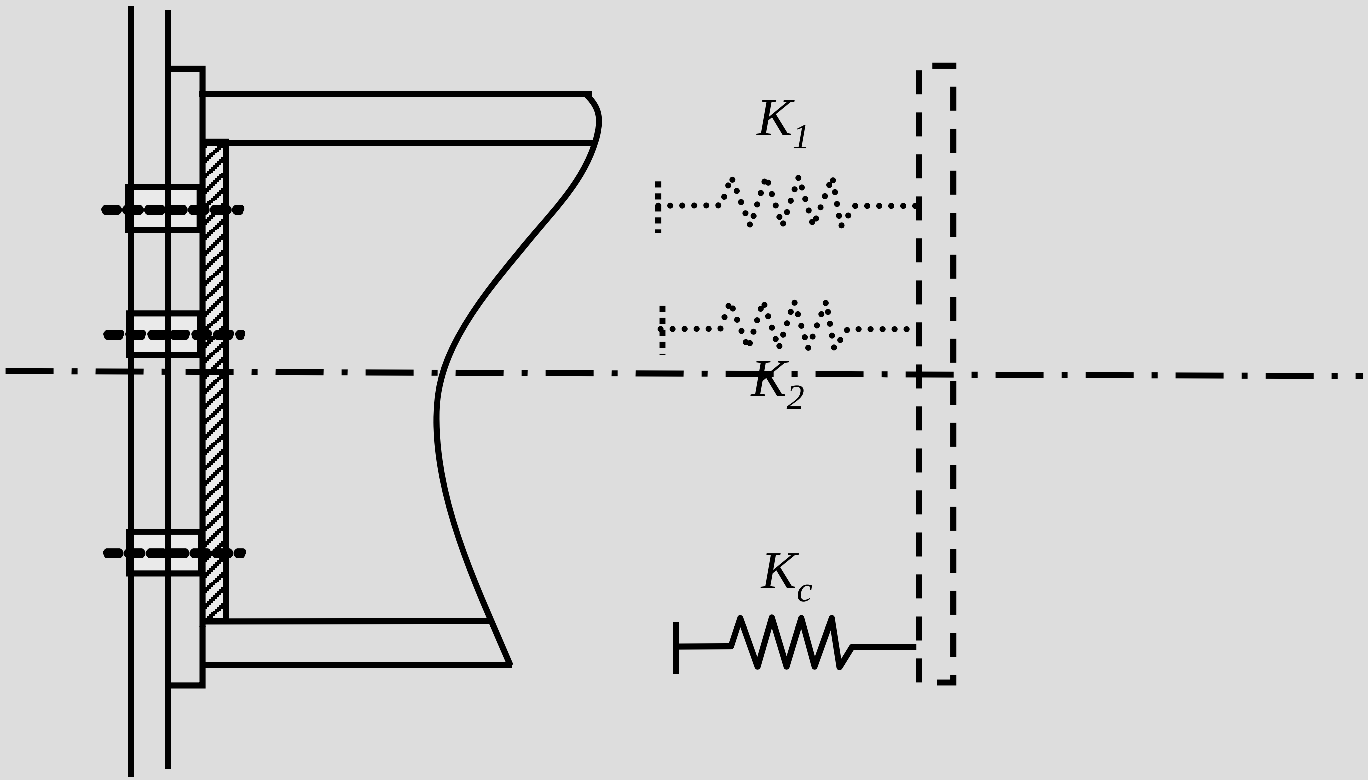


EC3-1.8 extended end-plate joint model



The “Component” method with axial force

- Component model deals with load combinations automatically, though M-ϕ curves change due to thrust.



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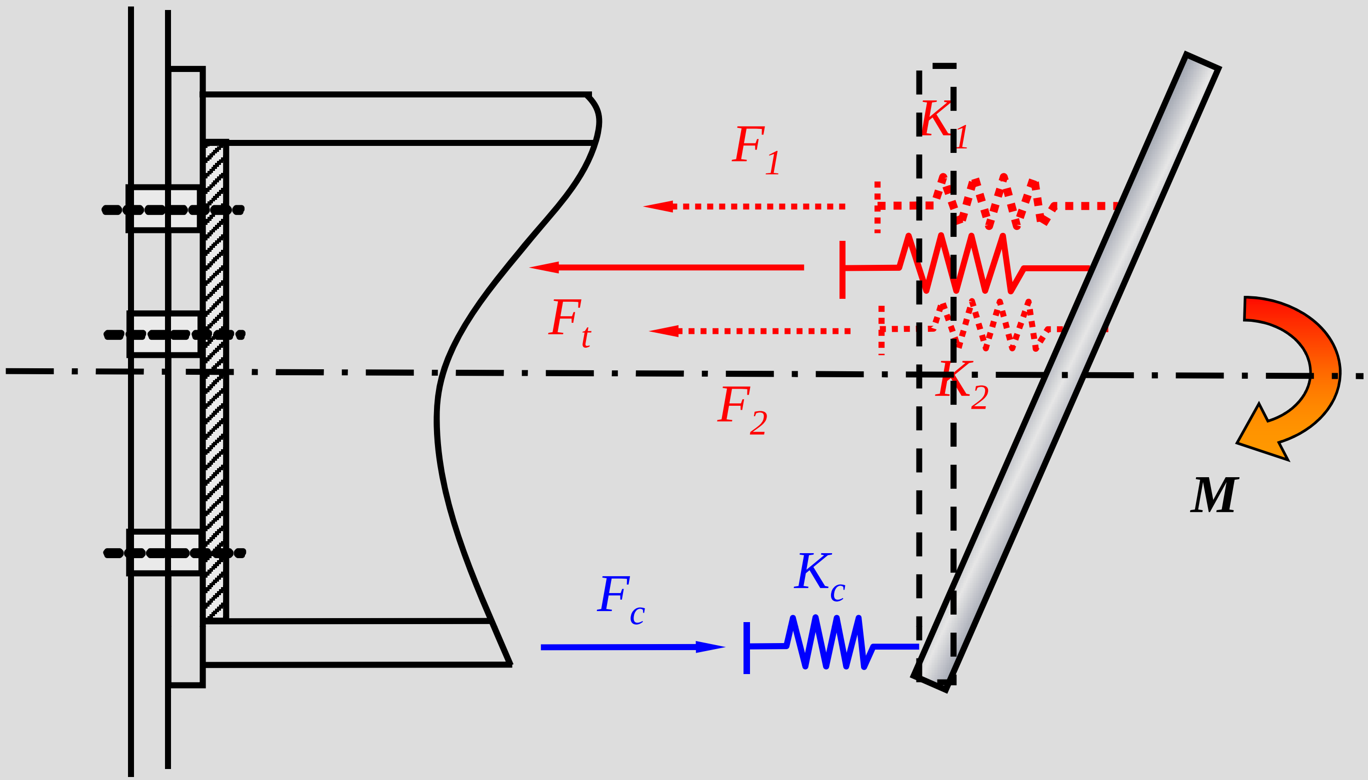
The "Component" method with axial force

- Component model deals with load combinations automatically, though M-ϕ curves change due to thrust.



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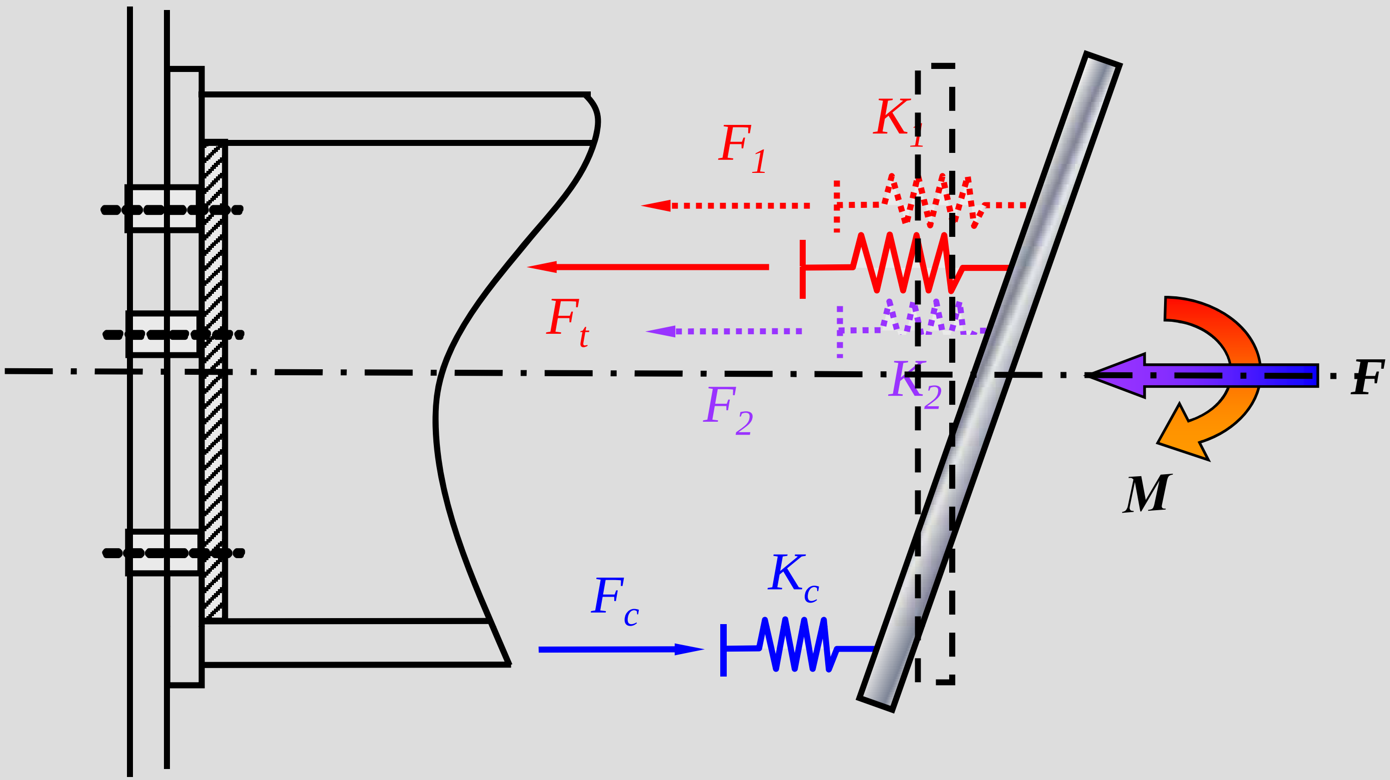

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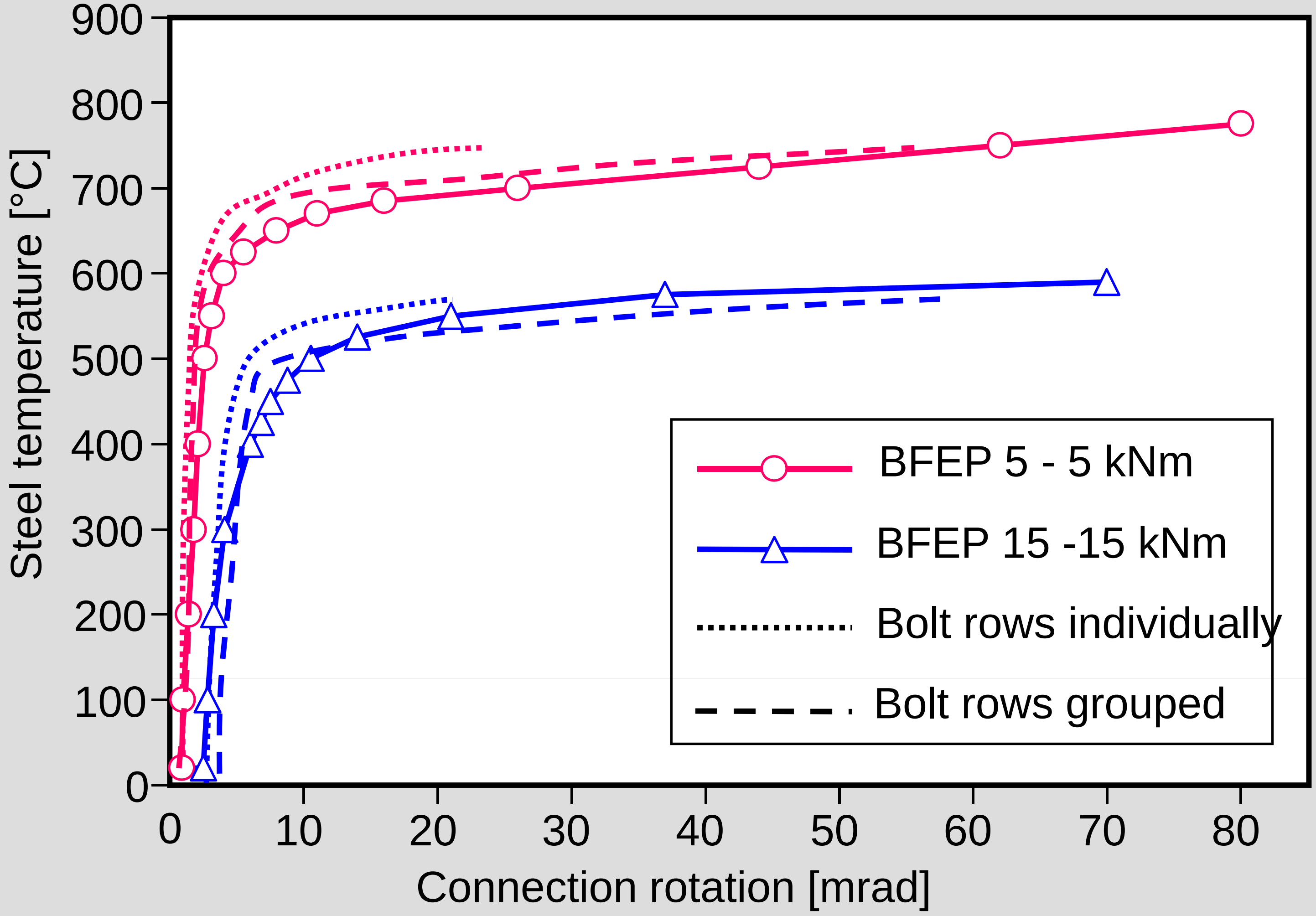
Comparison of joint element with M-ϕ-T tests by Leston-Jones



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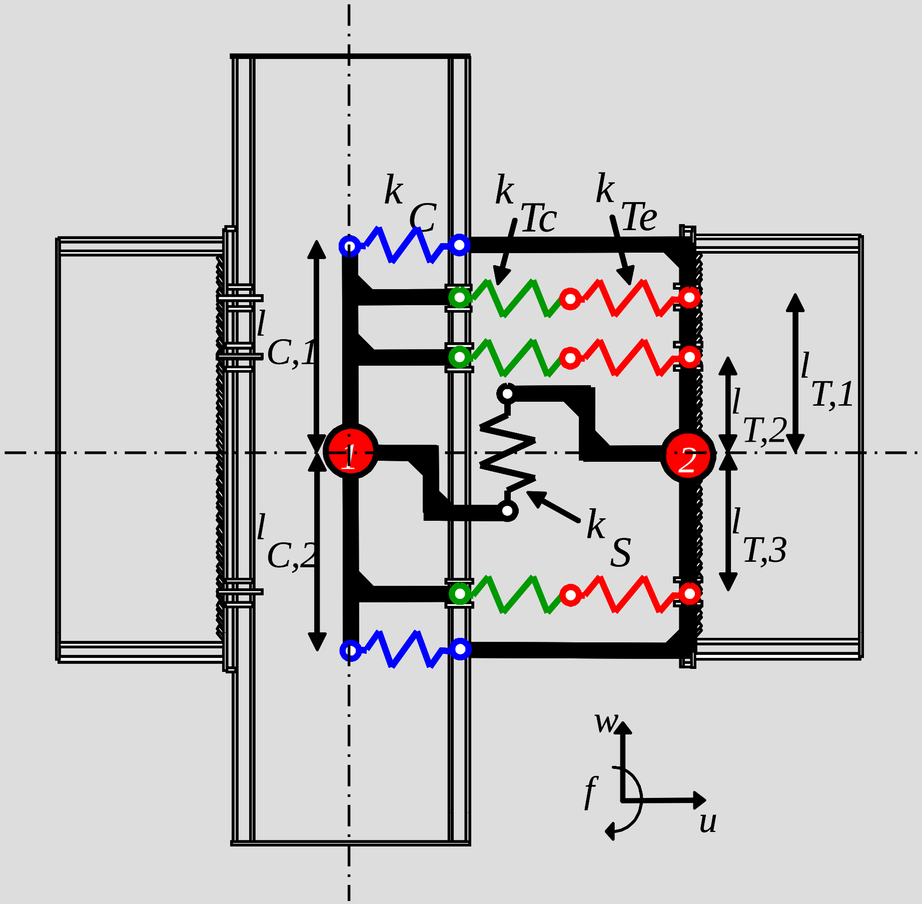
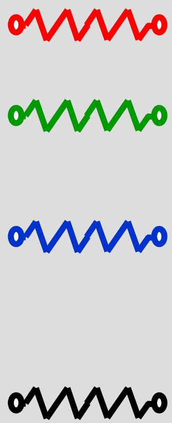
Component-Based Connection Element (Block)





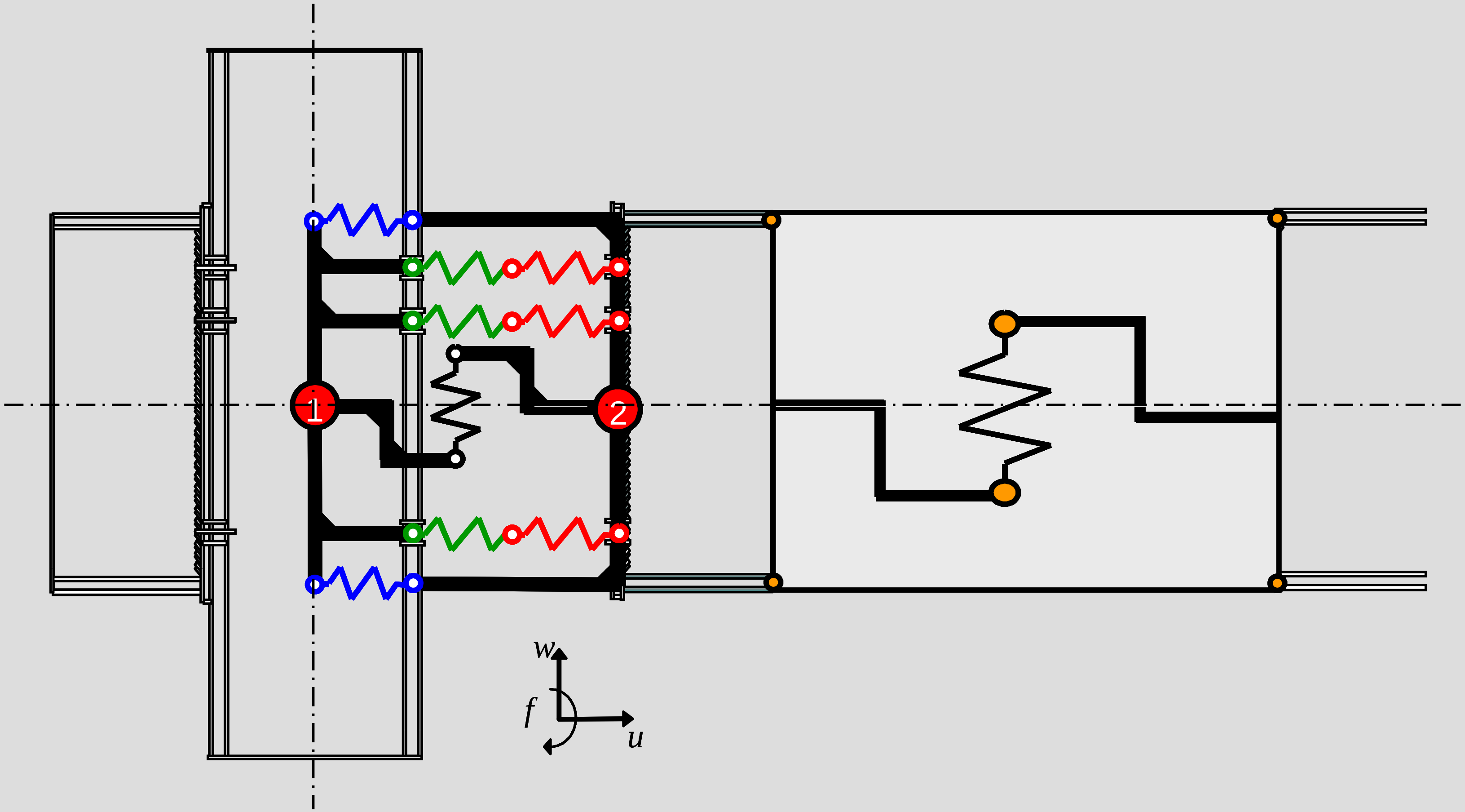
Tension Spring –

T-Stub in End-Plate

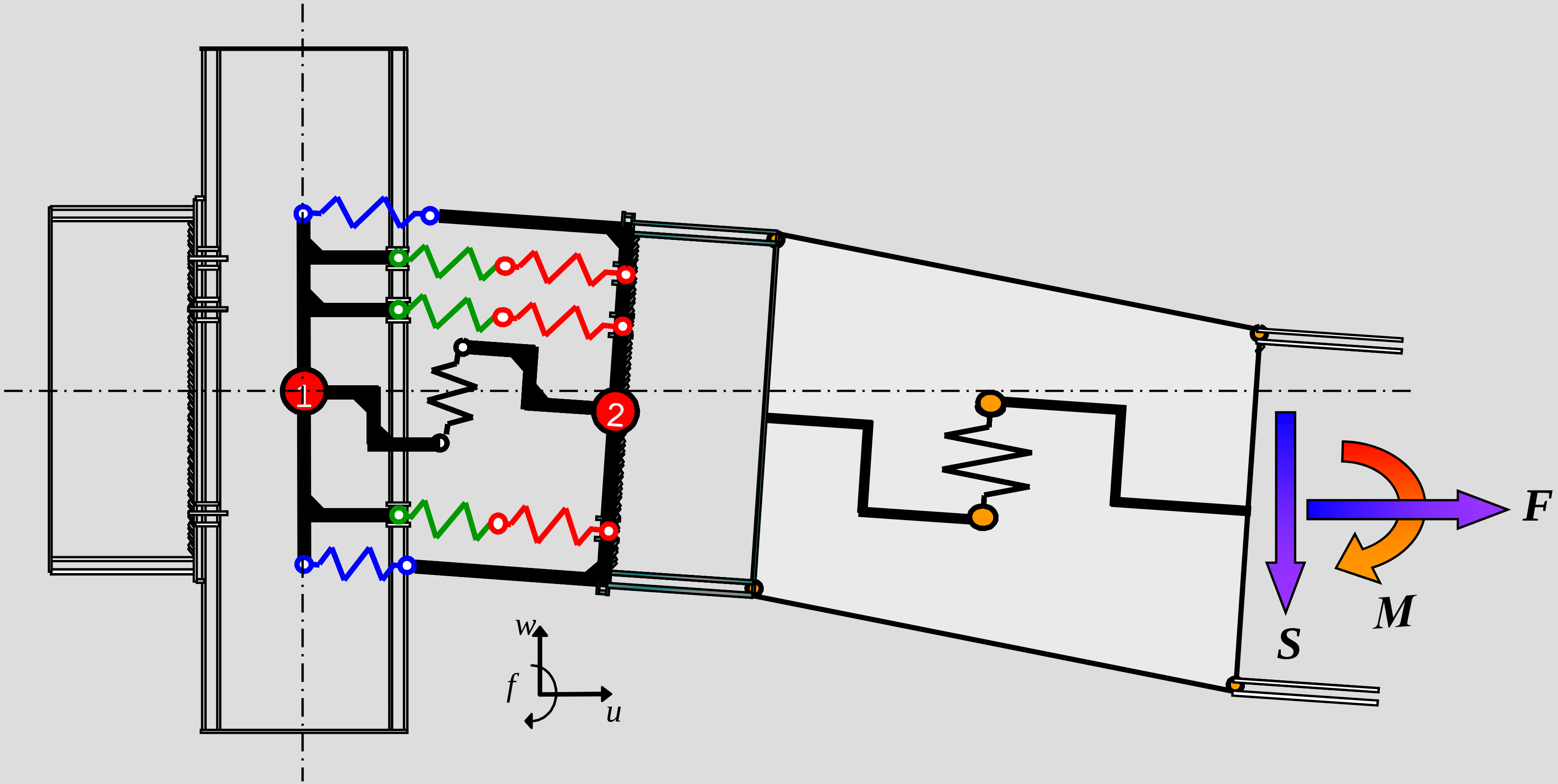
Compression Spring
- Column Web

Shear Spring
- Bolts

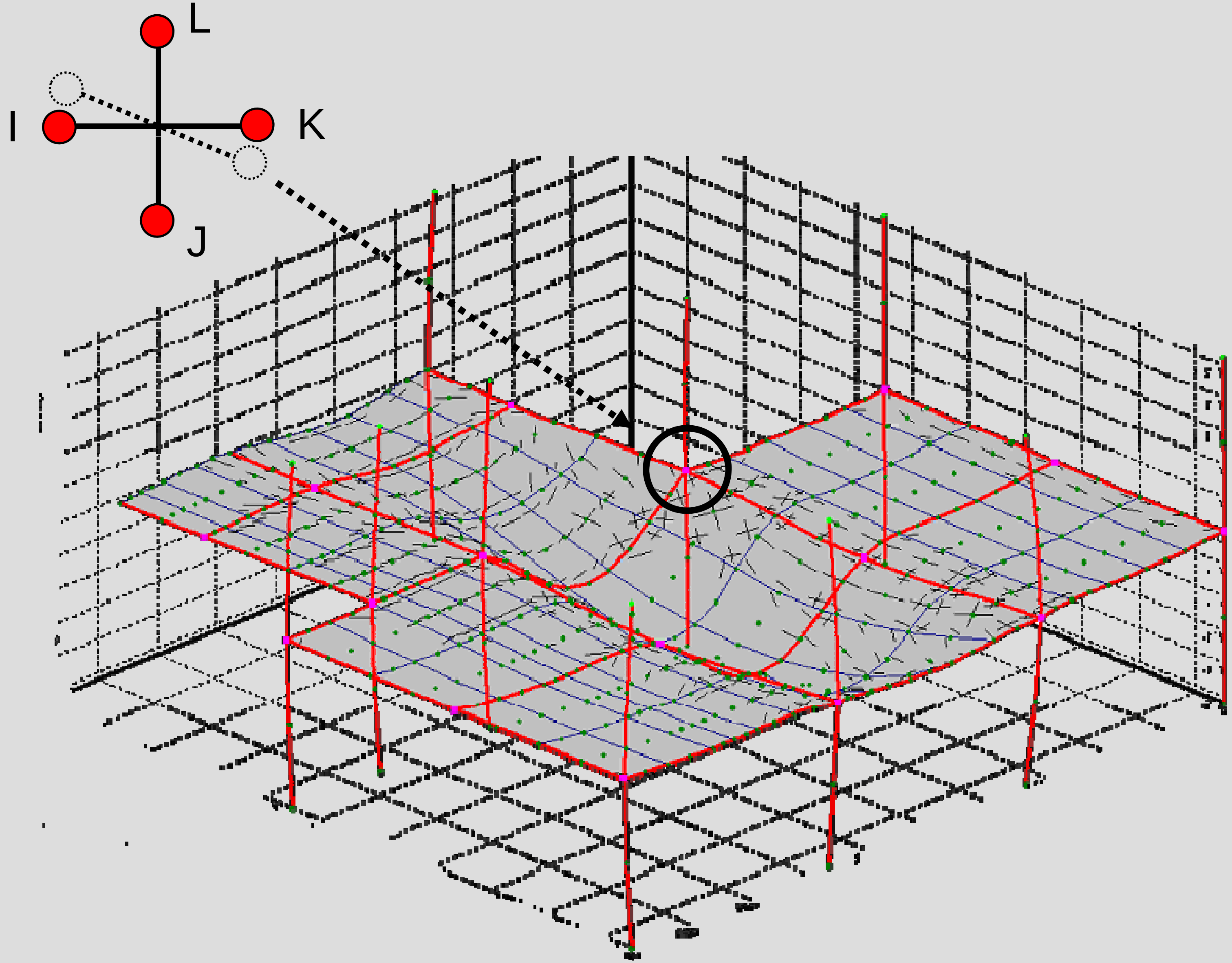
Component-based connection element: beam shear panel



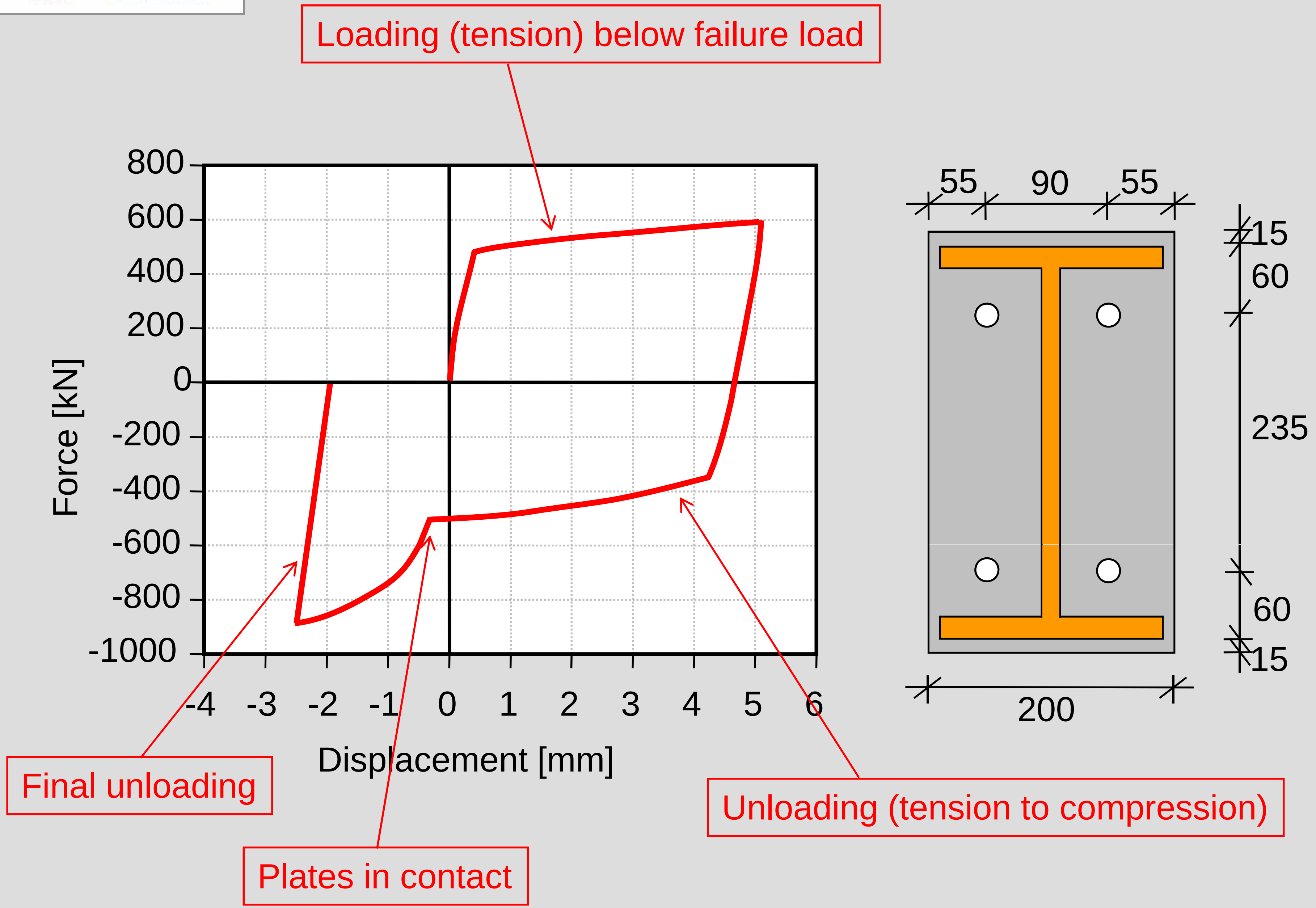
Component-based connection element: beam shear panel



Implementation of joint element in software



How complex? Tension force on end plate



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The End

AGAINST CATASTROPHIC EVENTS