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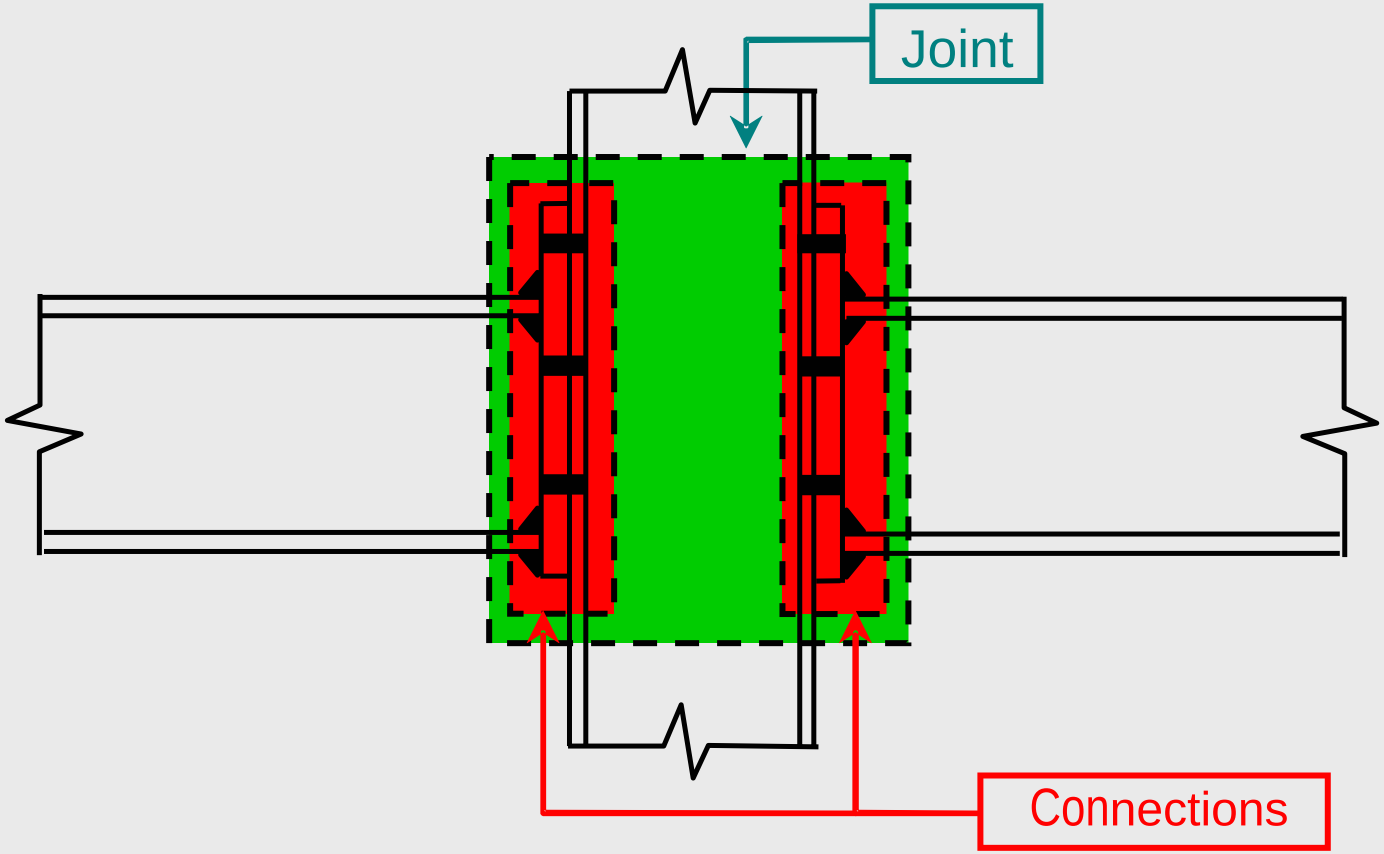
Connection Modelling in Fire

Ian Burgess

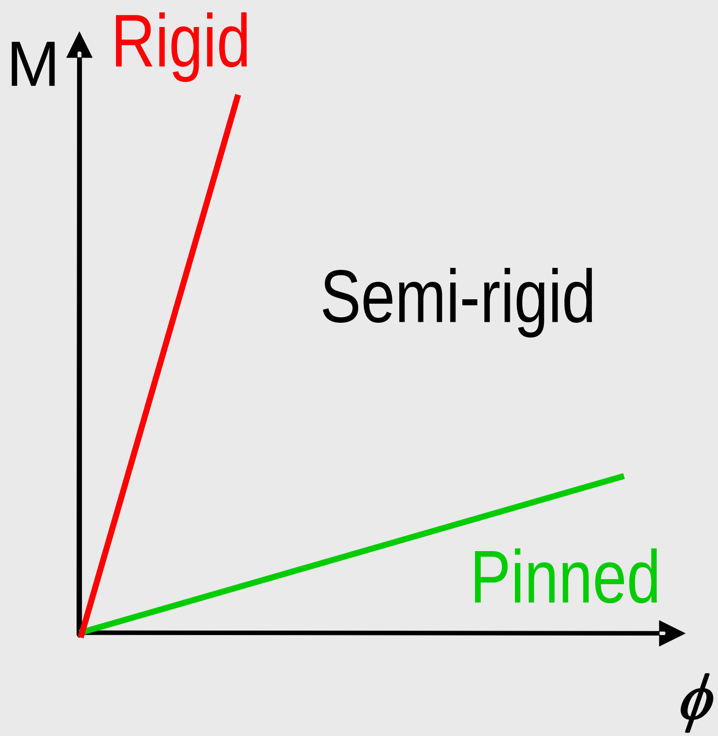
Definition of joint and connection



EC3-1.8 Stiffness classification of joints

$S > k_b EI_b / L_b$

K_b=8 (braced frames)
K_b=25 (other frames)



$S > 0,5 EI_b / L_b$

Other classifications

Strength:

- **“Full-strength”:** Bending strength > Strength of member.
- **“Partial-strength”**
- **“Pinned”:** Bending strength < 0.25 Strength of member.

Ductility:

- **“Ductile/Class 1”:** Sufficient rotation capacity to develop plastic mechanism.
- **“Semi-ductile”**
- **“Brittle/Class 3”:** Can only be used in elastic design.

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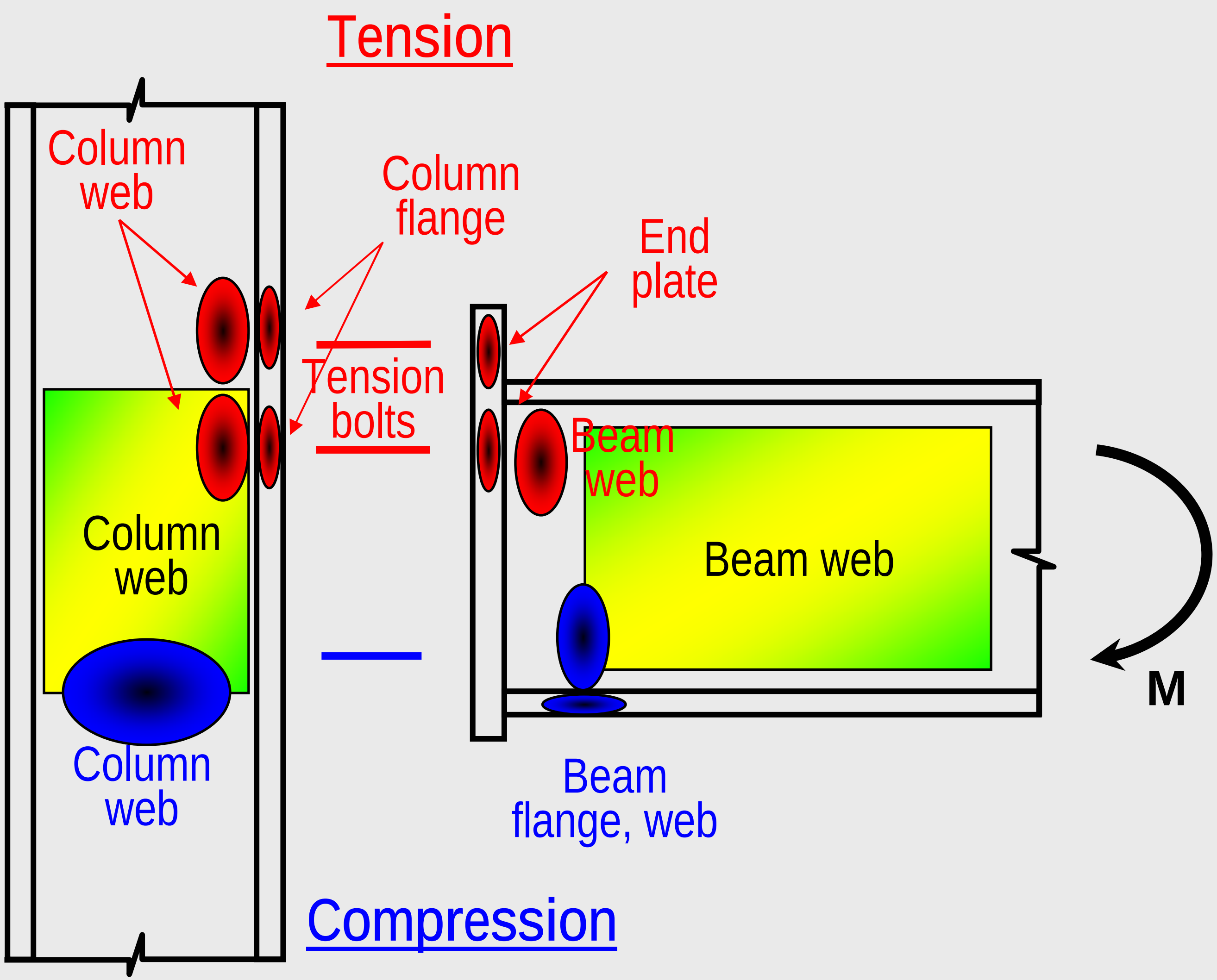
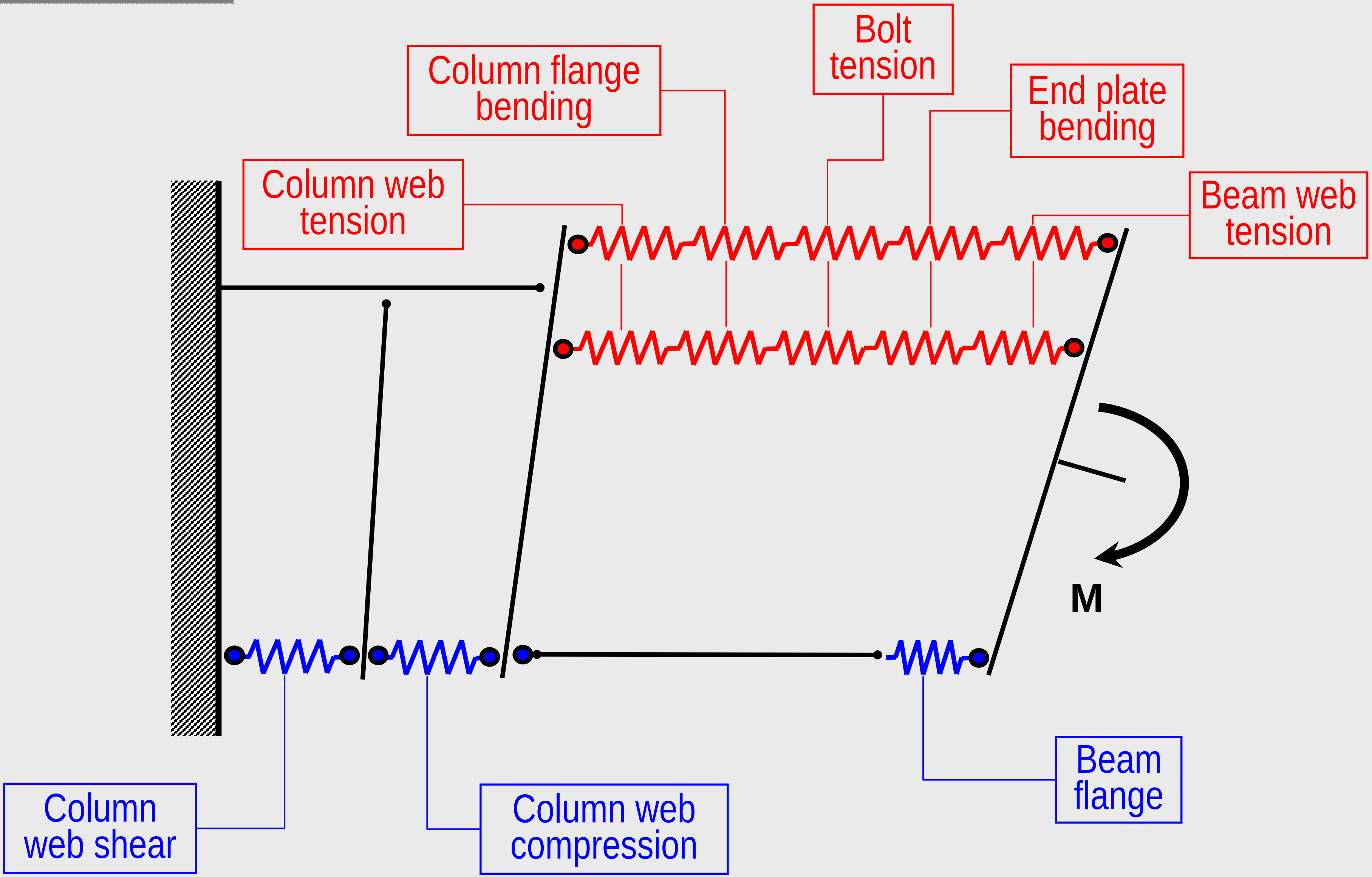
Component Modelling at Ambient Temperature

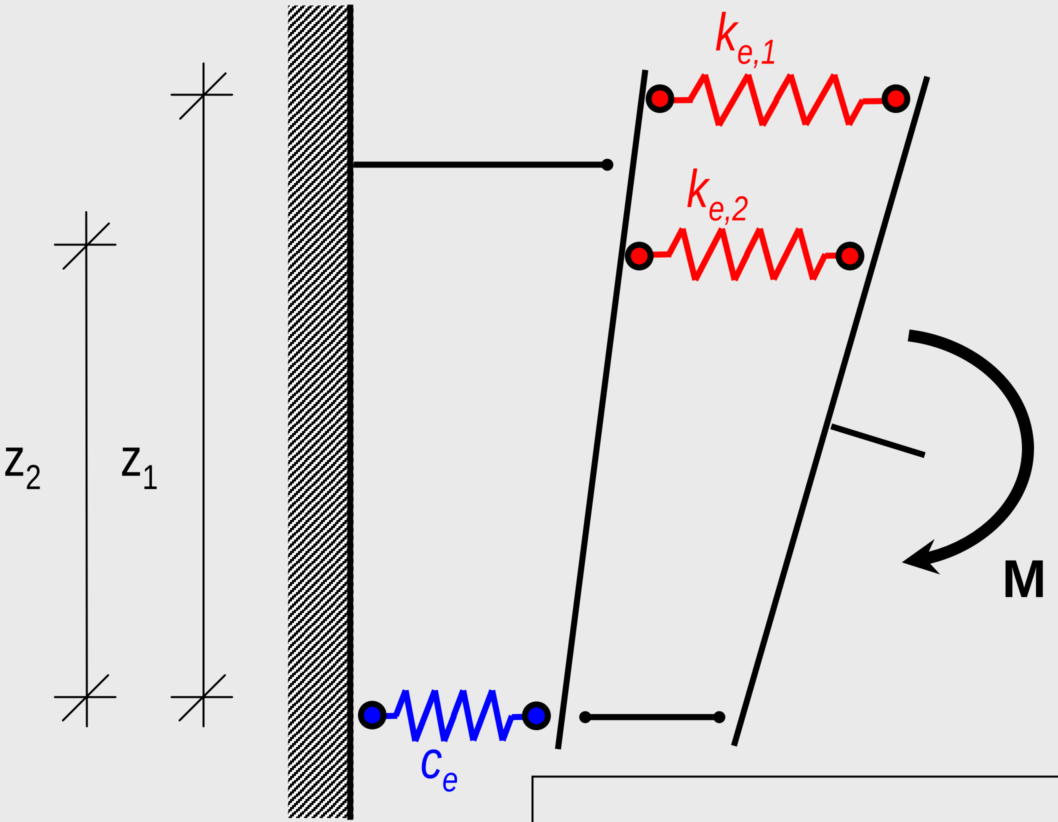
Principal component zones of end-plate



EC3-1.8 extended end-plate joint model

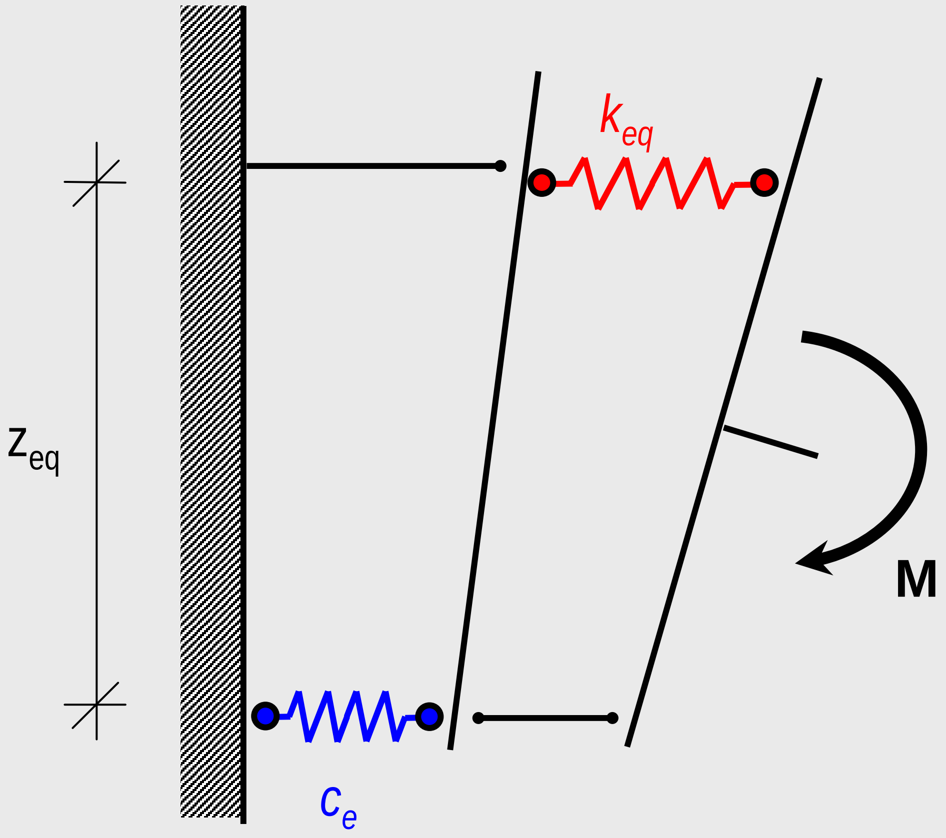


Equivalent spring model



$$k_{et,i} = \frac{1}{\frac{1}{k_{cwt,i}} + \frac{1}{k_{cfb,i}} + \frac{1}{k_{bt,i}} + \frac{1}{k_{epb,i}} + \frac{1}{k_{bwt,i}}}$$

Simplified spring model



Moment-rotation behaviour in fire

Semi-rigid behaviour of connections in fire: original work

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Late 80s – early 90s

- **Design opportunity?** Interest particularly based on using connection residual stiffness and strength to enhance the fire resistance of "simple" steel beams.
- **Analytical studies** to assess the likely advantages/problems.

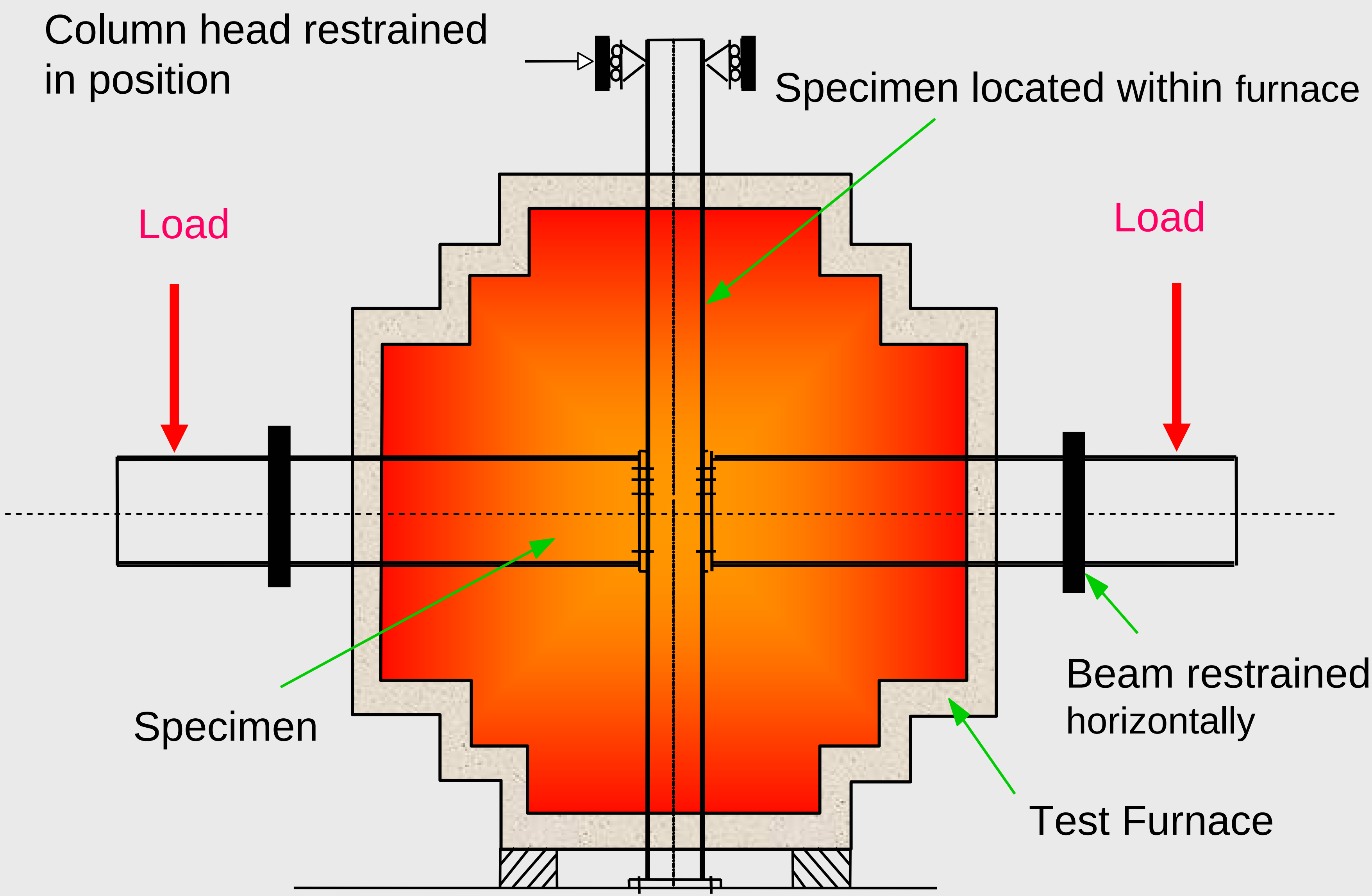
Semi-rigid behaviour of connections in fire: cruciform tests

Mid – 1990s

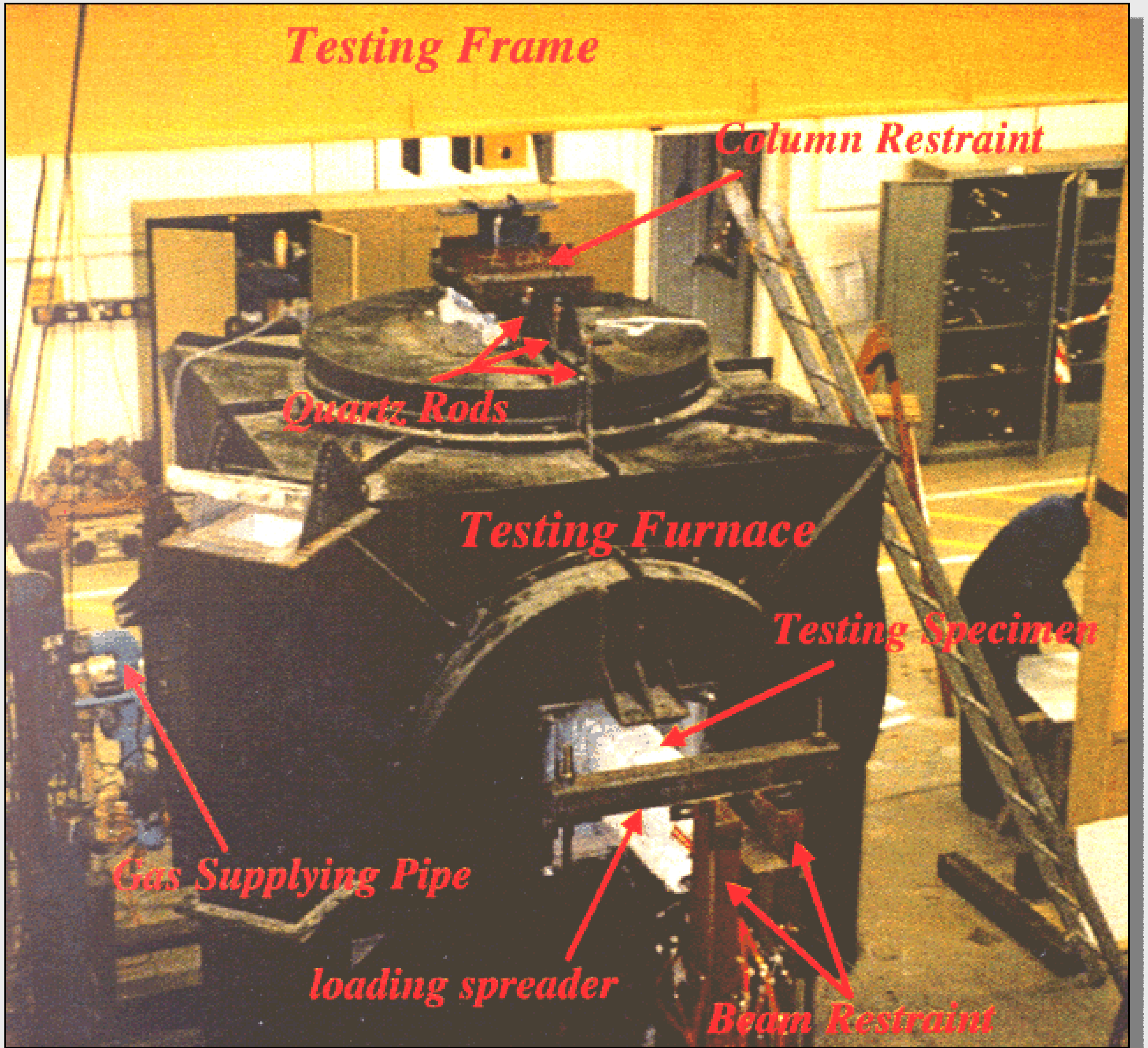
- **Cruciform tests** to create small database of $M\text{-}\phi$ curves. Semi-empirical models to rationalise results.
- 2 successive experimental projects at BRE Garston (Lennon) in “portable” furnace.

  1. **First series** (Leston-Jones) tested a limited range of small non-composite flush-endplate connections.
  2. **Second series** (Al-Jabri) tested flush and extended endplate connections in composite and non-composite arrangements, including some Cardington connections.

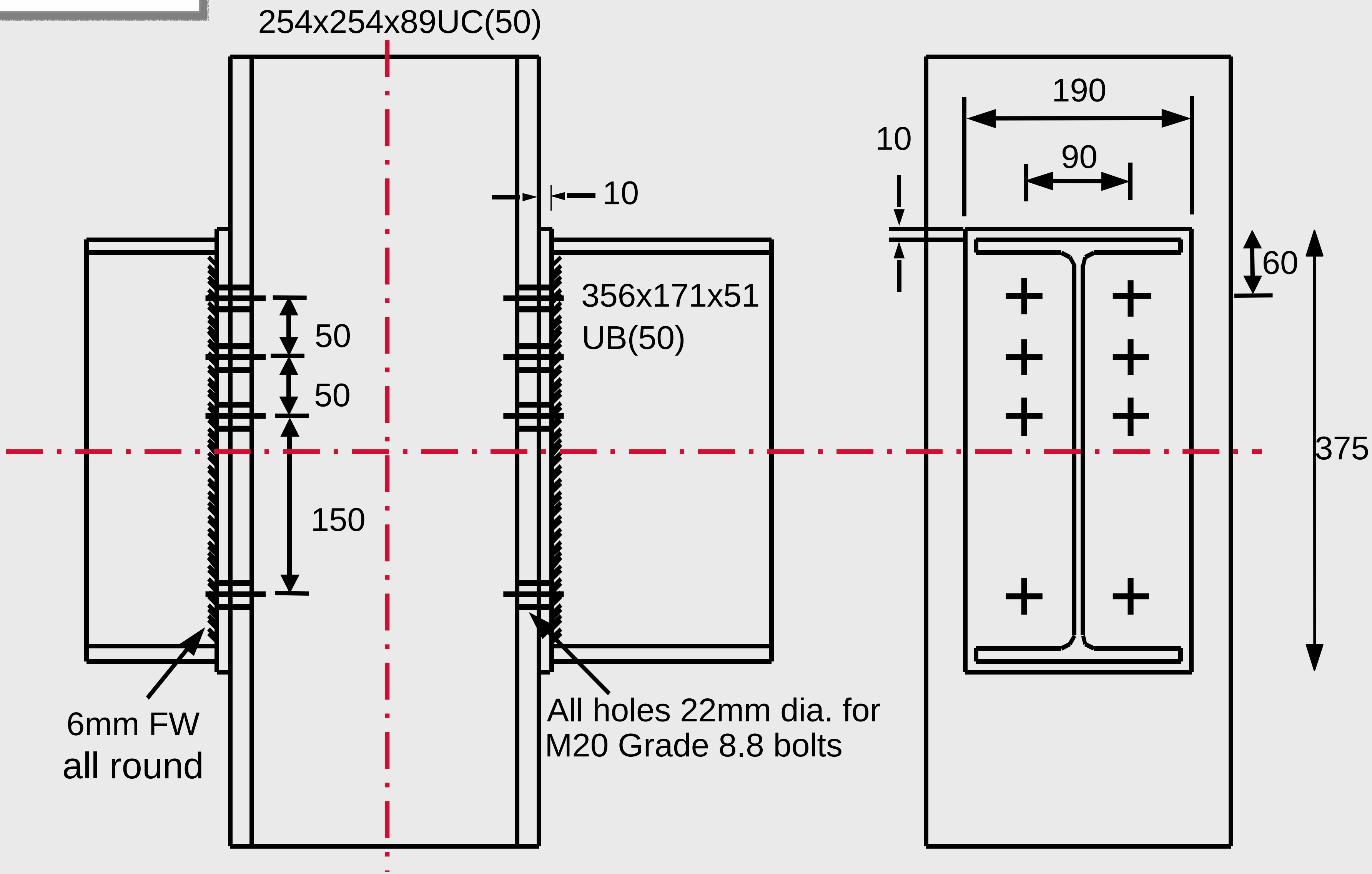
Garston cruciform tests: test arrangement



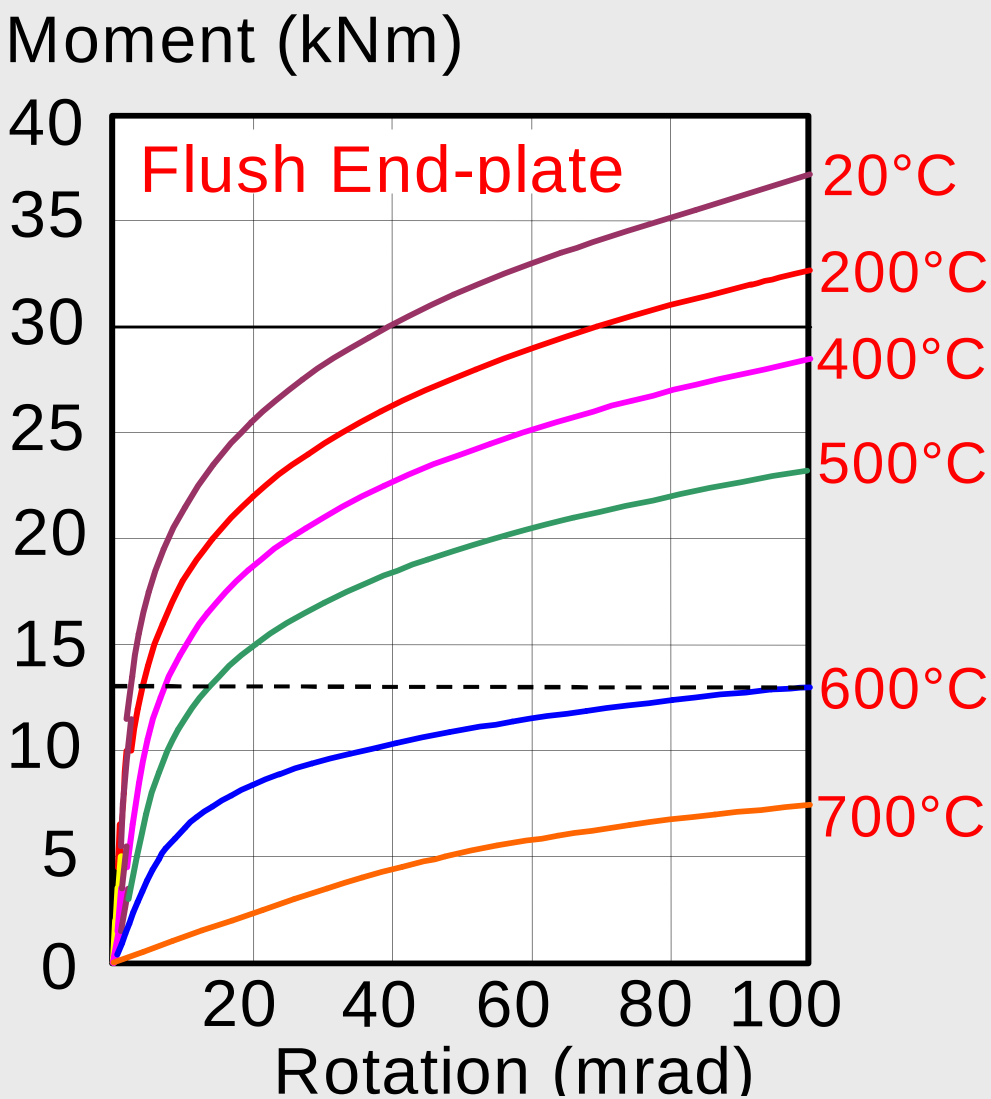
Garston cruciform tests: “portable” furnace

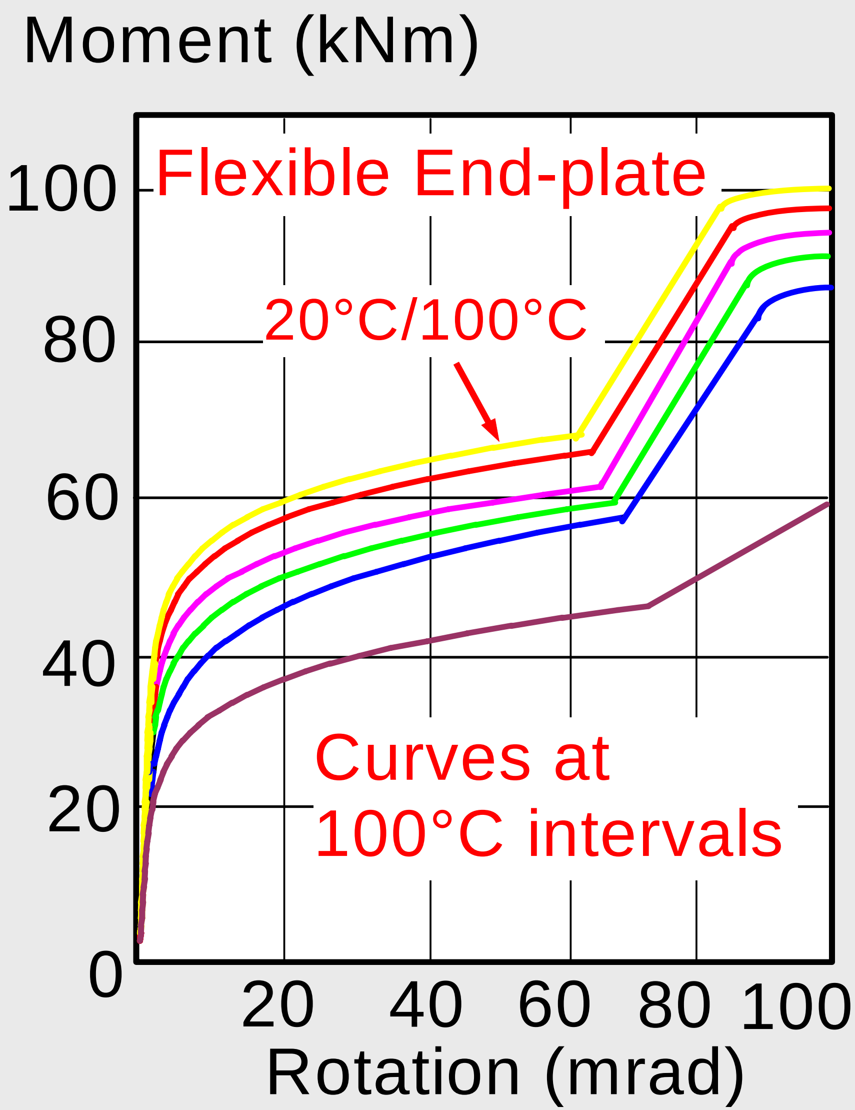


Garston cruciform tests: End-plate Type 2

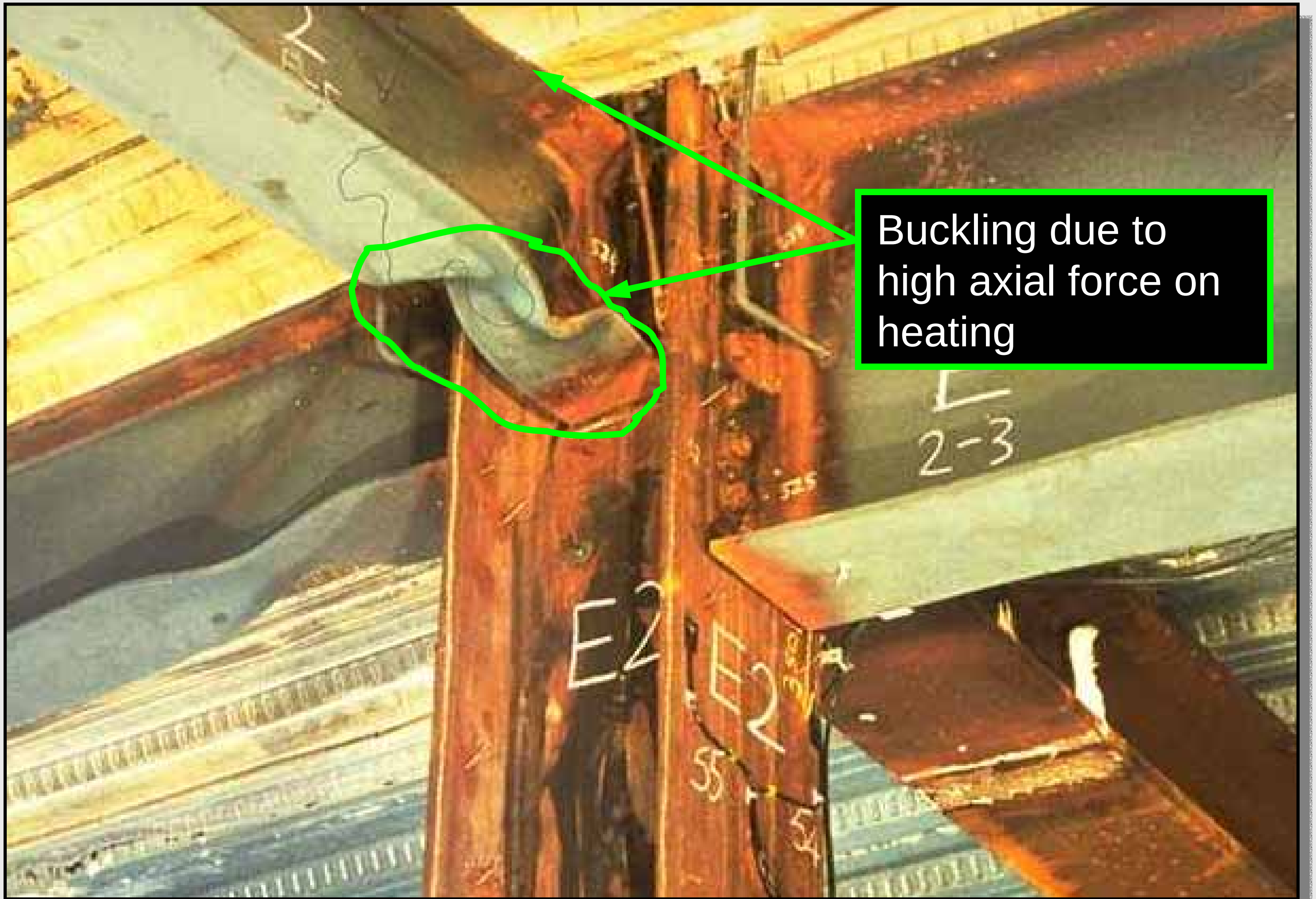


High-temperature M-ϕ-θ characteristics of endplate joints

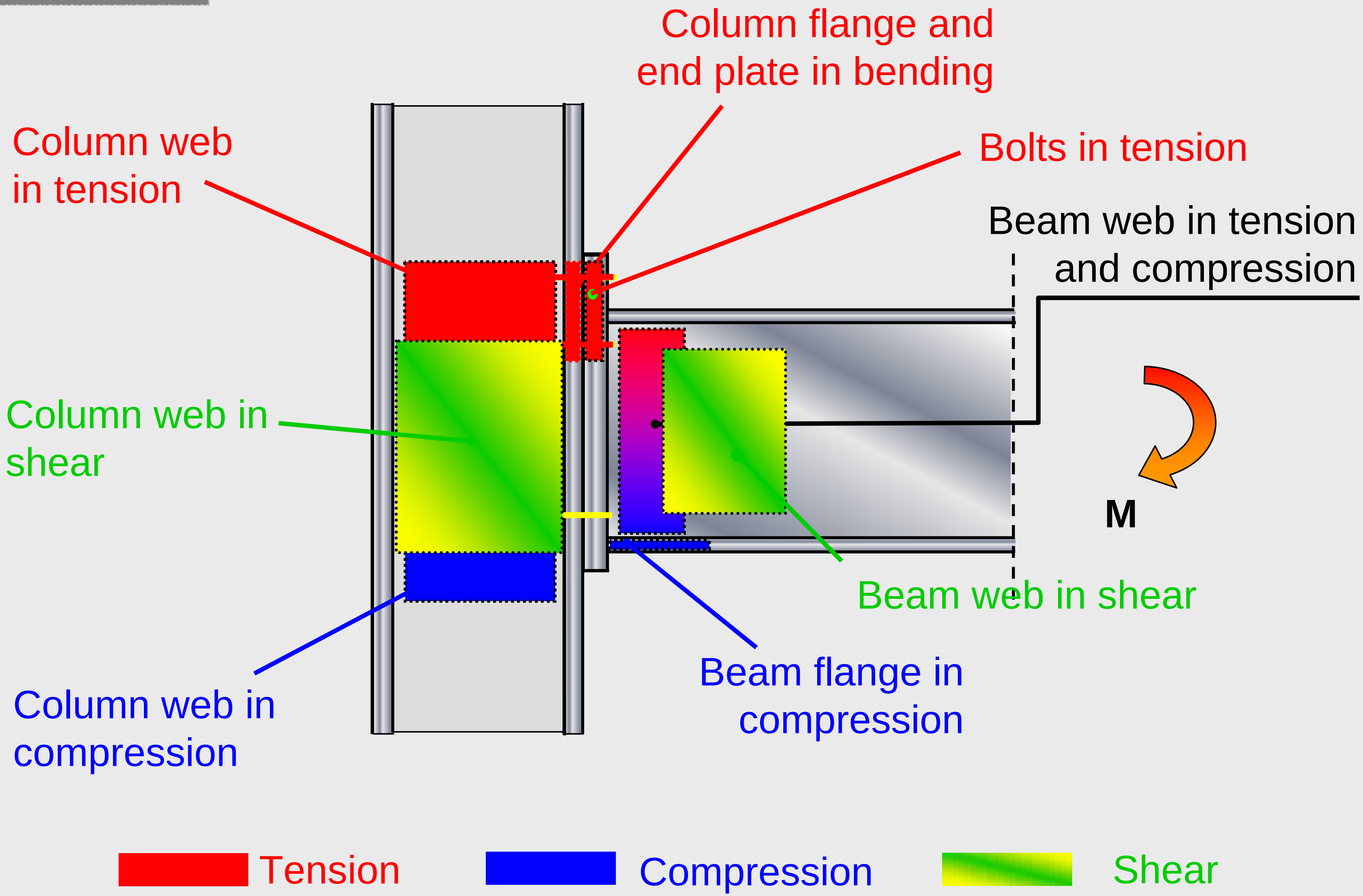




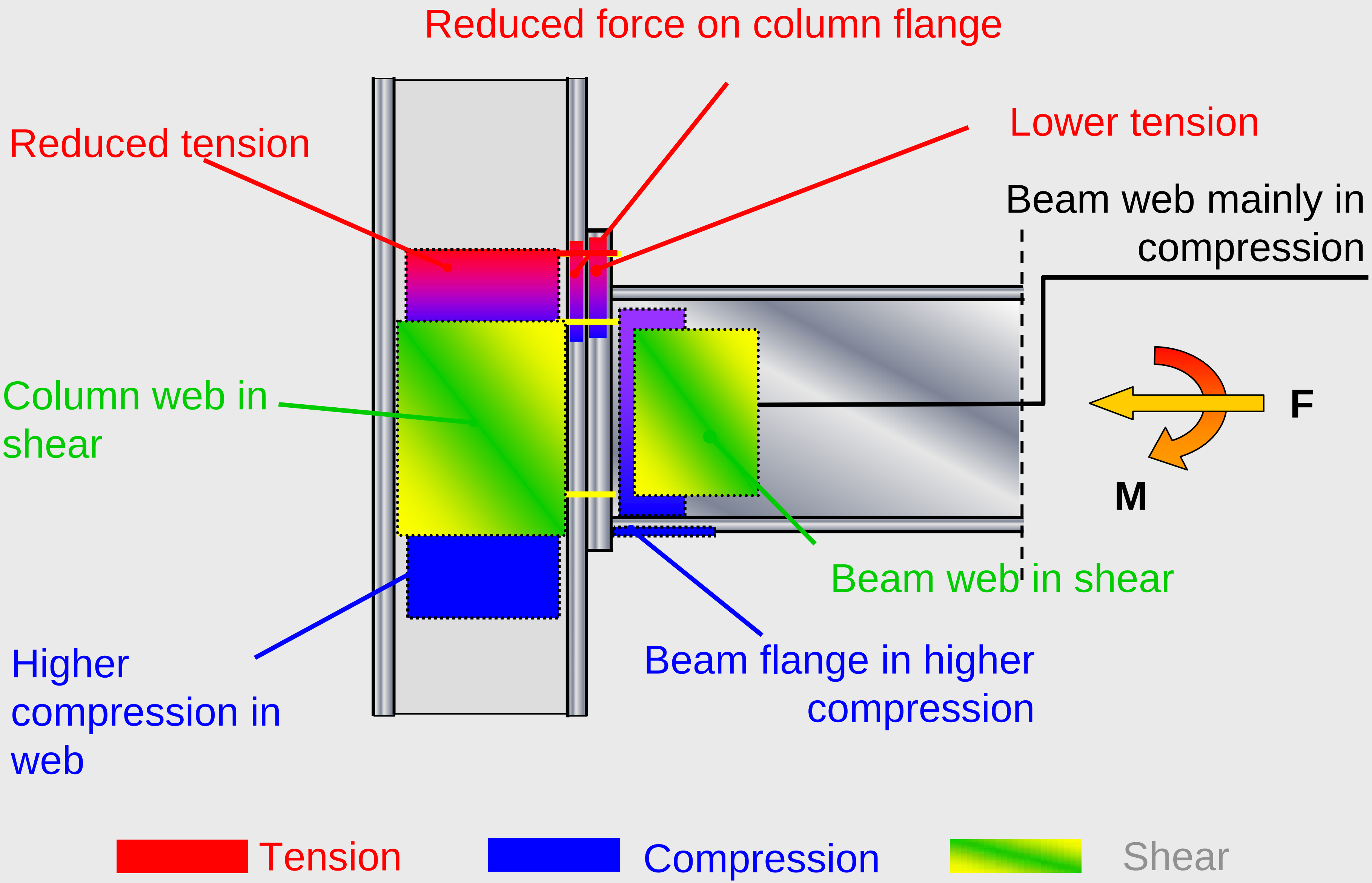
Cardington beam-column joint after fire test



Component zones in end-plate joint



Component zones in end-plate joint with axial thrust



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Component Behaviour at High Temperatures

Spyrou Component testing 1998-2001: Objectives

Tension Zone

- Do experiments on T-stubs at high temperatures.
- Develop simplified/semi-empirical model of tension component behaviour for end-plate joints.
- Check both against finite element modelling.

Compression Zone

- Examine experimentally the effect of elevated temperatures on column web buckling.
- Develop simplified/semi-empirical model of column web compression component behaviour for end-plate joints.
- Check both against finite element modelling.

Generally

- Check flush endplate moment-rotation predictions against previous cruciform furnace tests.

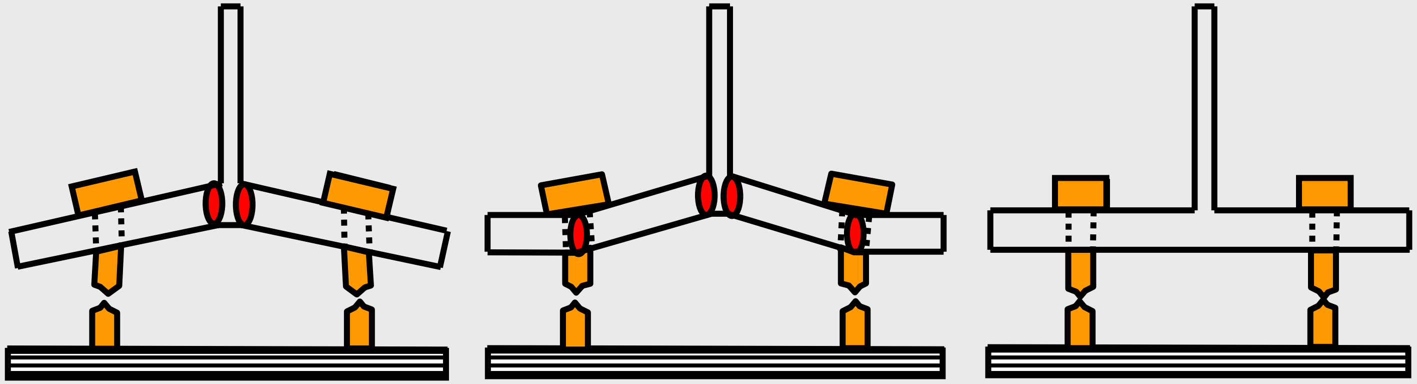
Spyrou furnace and control apparatus

View ports for cameras

Loading actuator

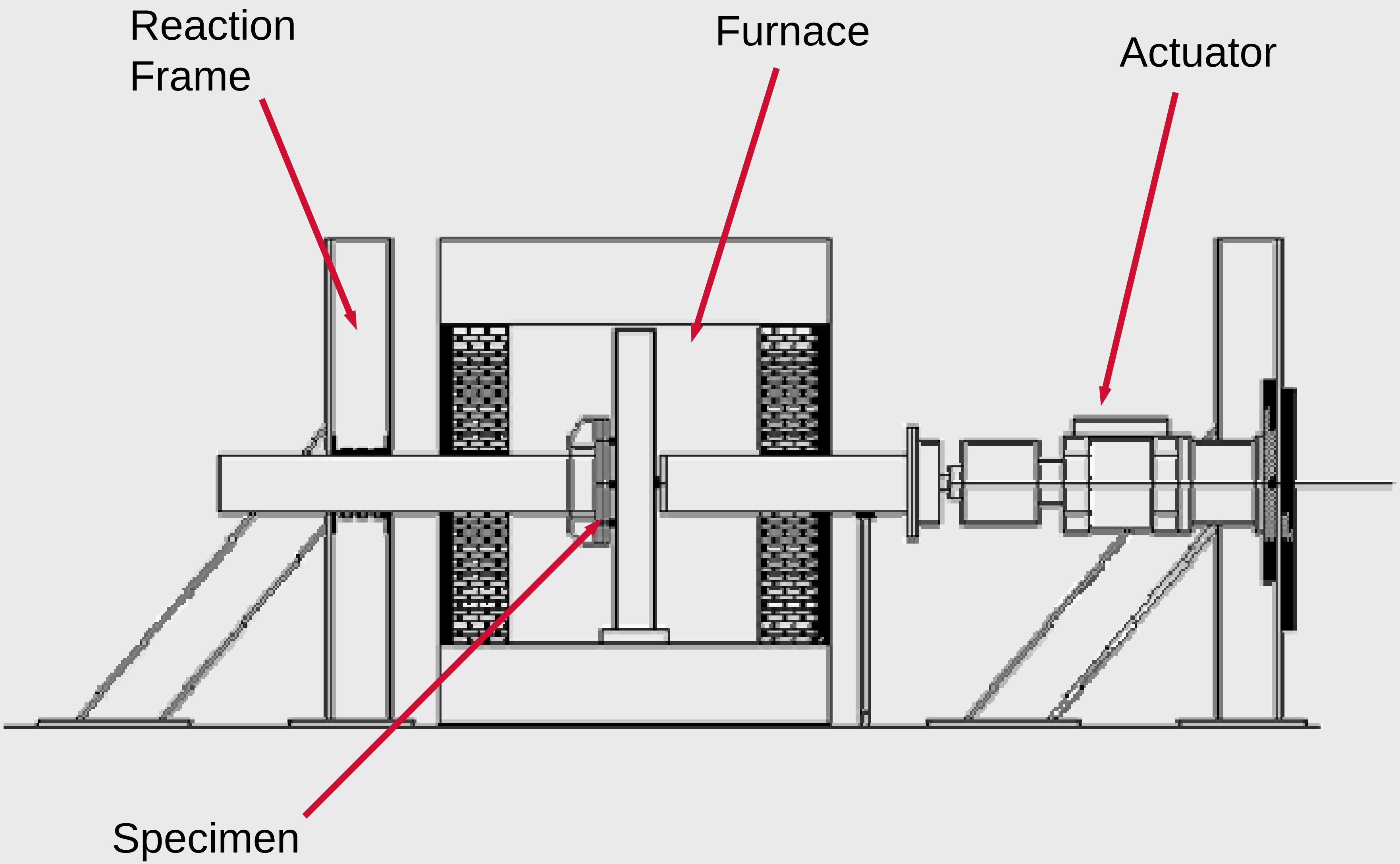
Control panel

Failure modes for tension T-stubs

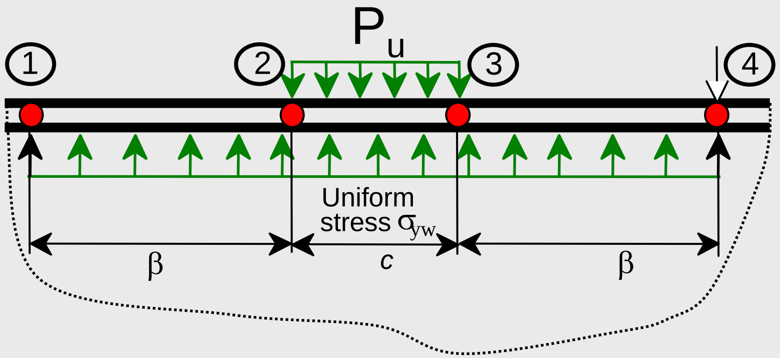


Failure Mode 1　　Failure Mode 2　　Failure Mode 3

Spyrou compression zone test arrangement

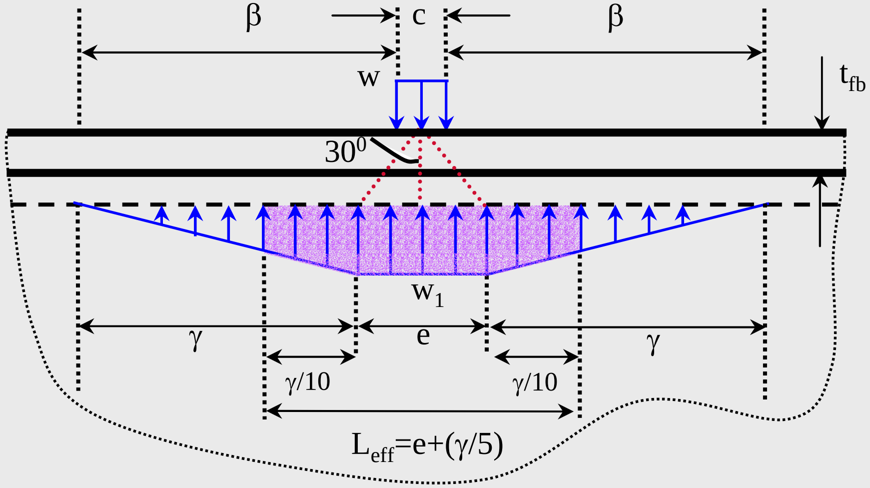


Simplified model of compression zone

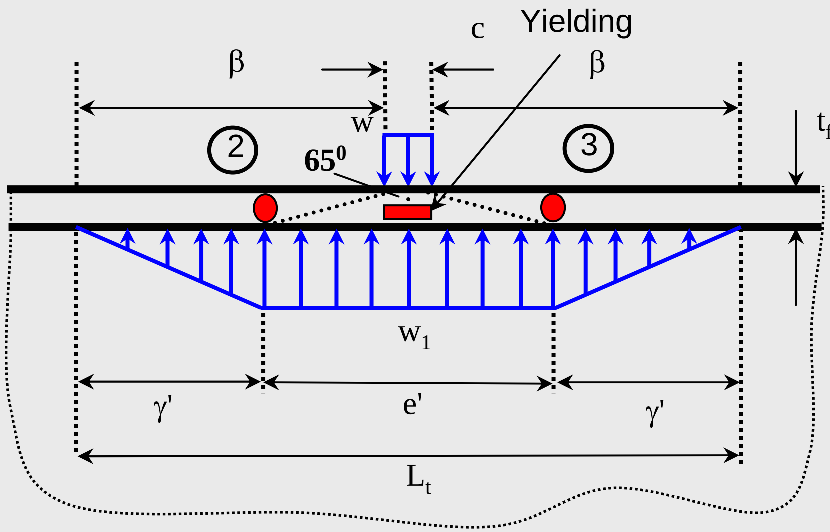


Roberts' model for ultimate strength of stocky webs

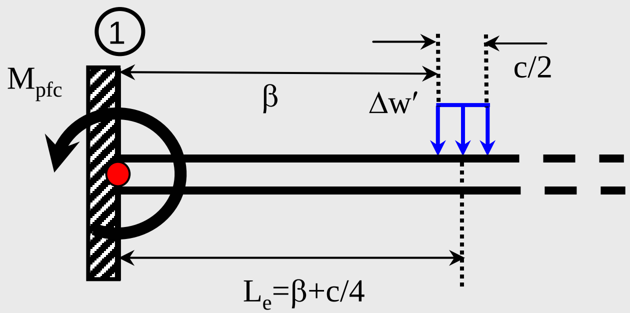
Principles of simple compression zone model



1.Yield of column web



2. Yield of column flange
(first plastic hinges)



3. Yield of column flange
(final plastic hinges)

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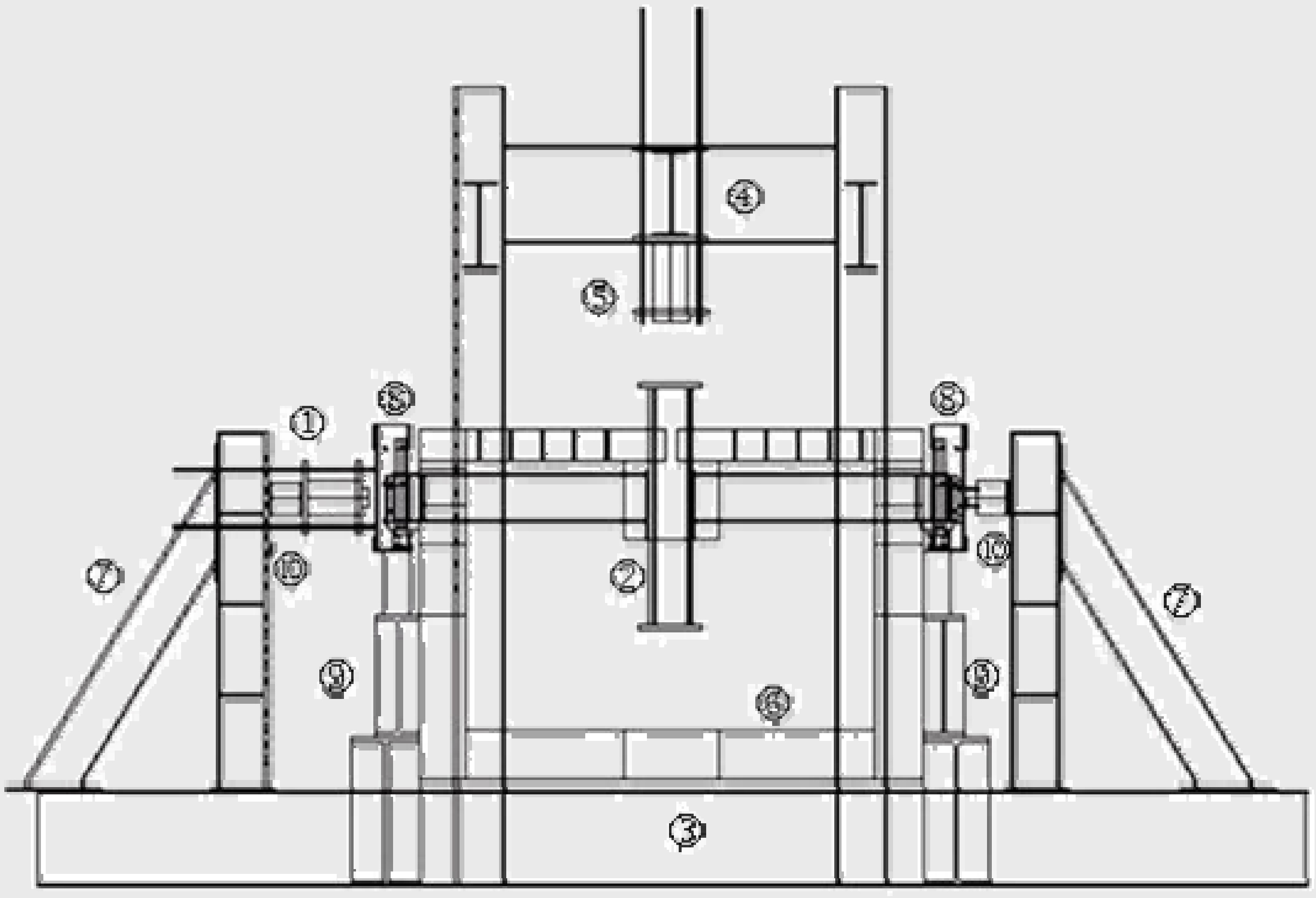
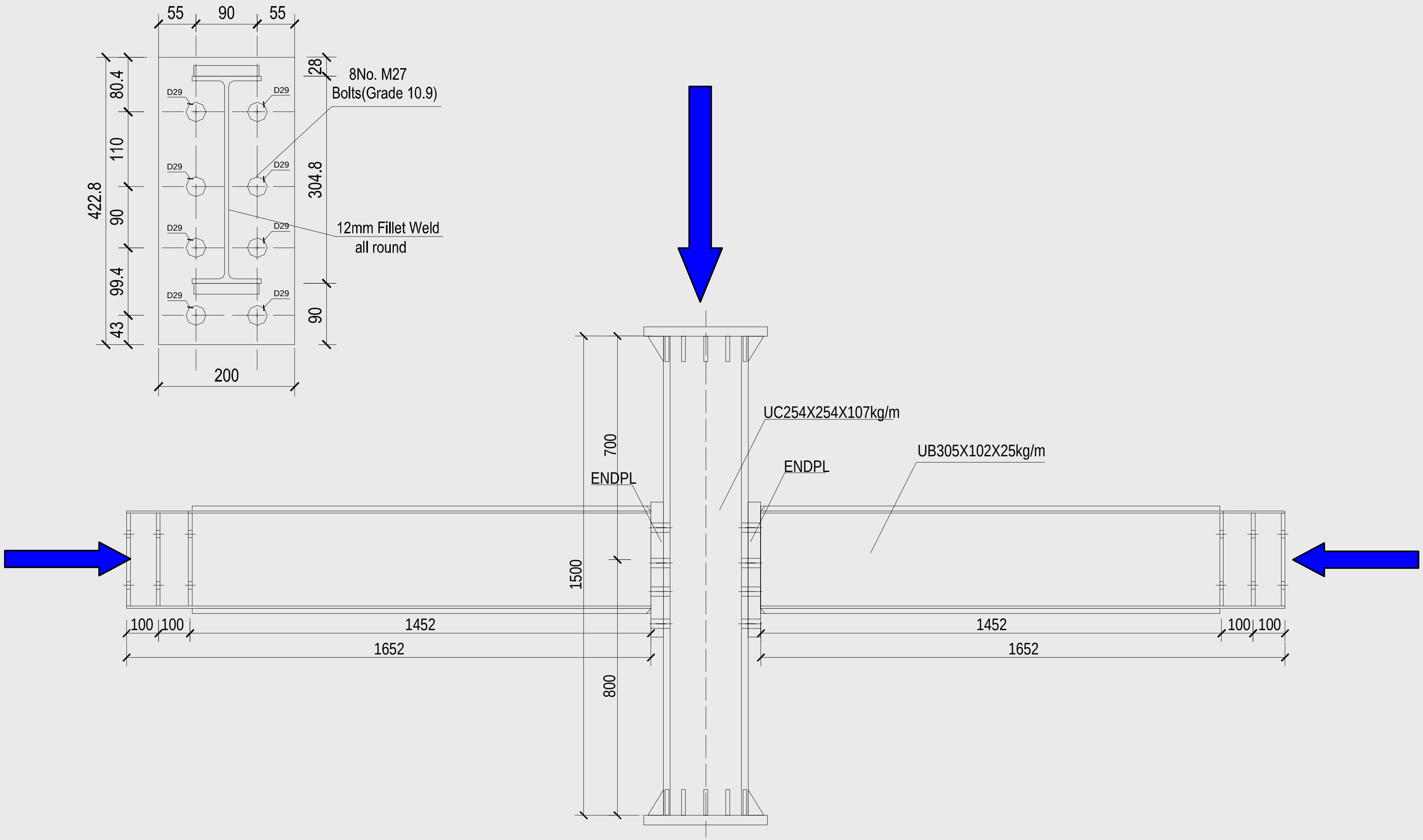
Qian shear panel tests

Restrained high-temperature joint testing

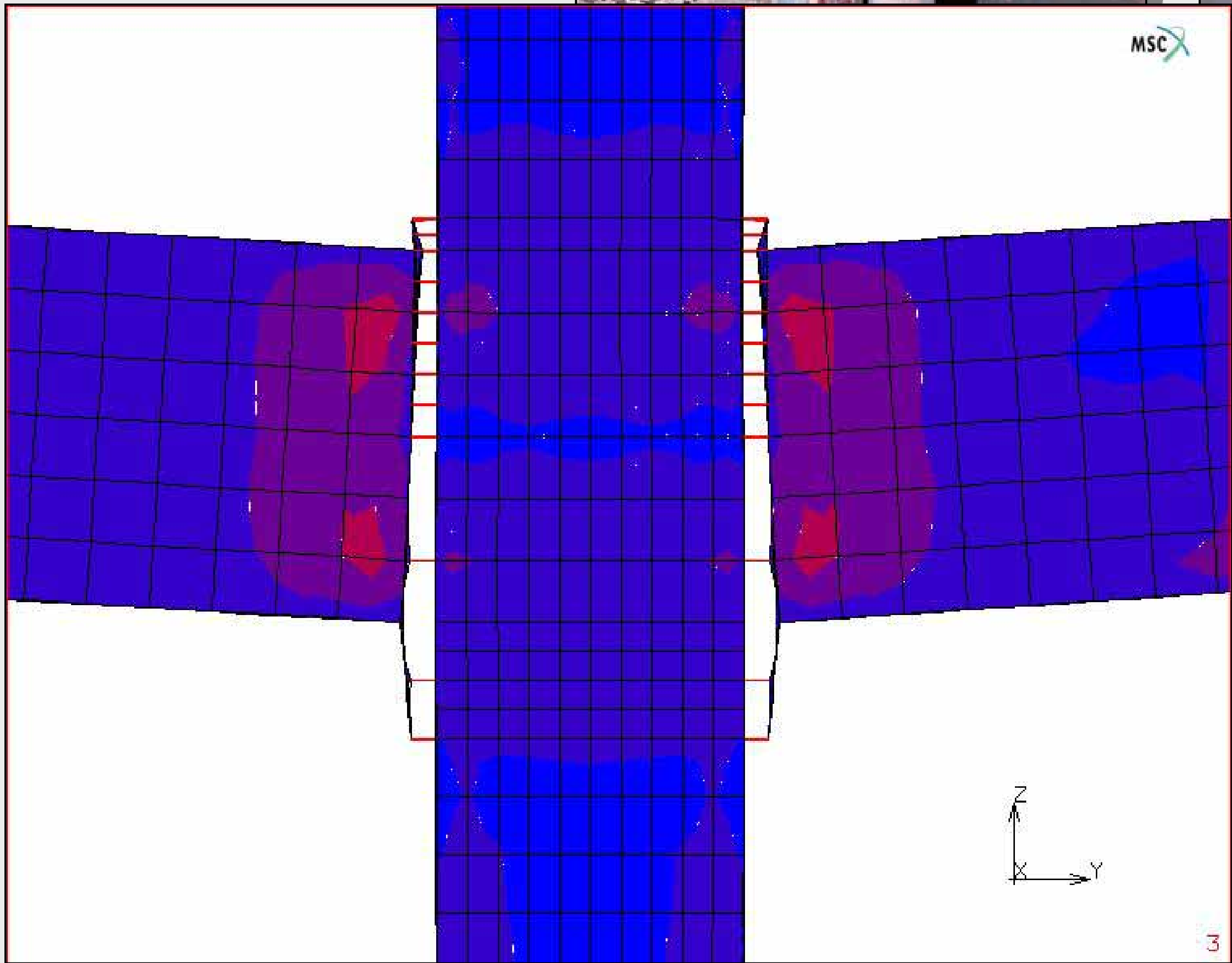
Qian & Tan restrained tests



Qian & Tan restrained specimen



Qian & Tan restrained tests



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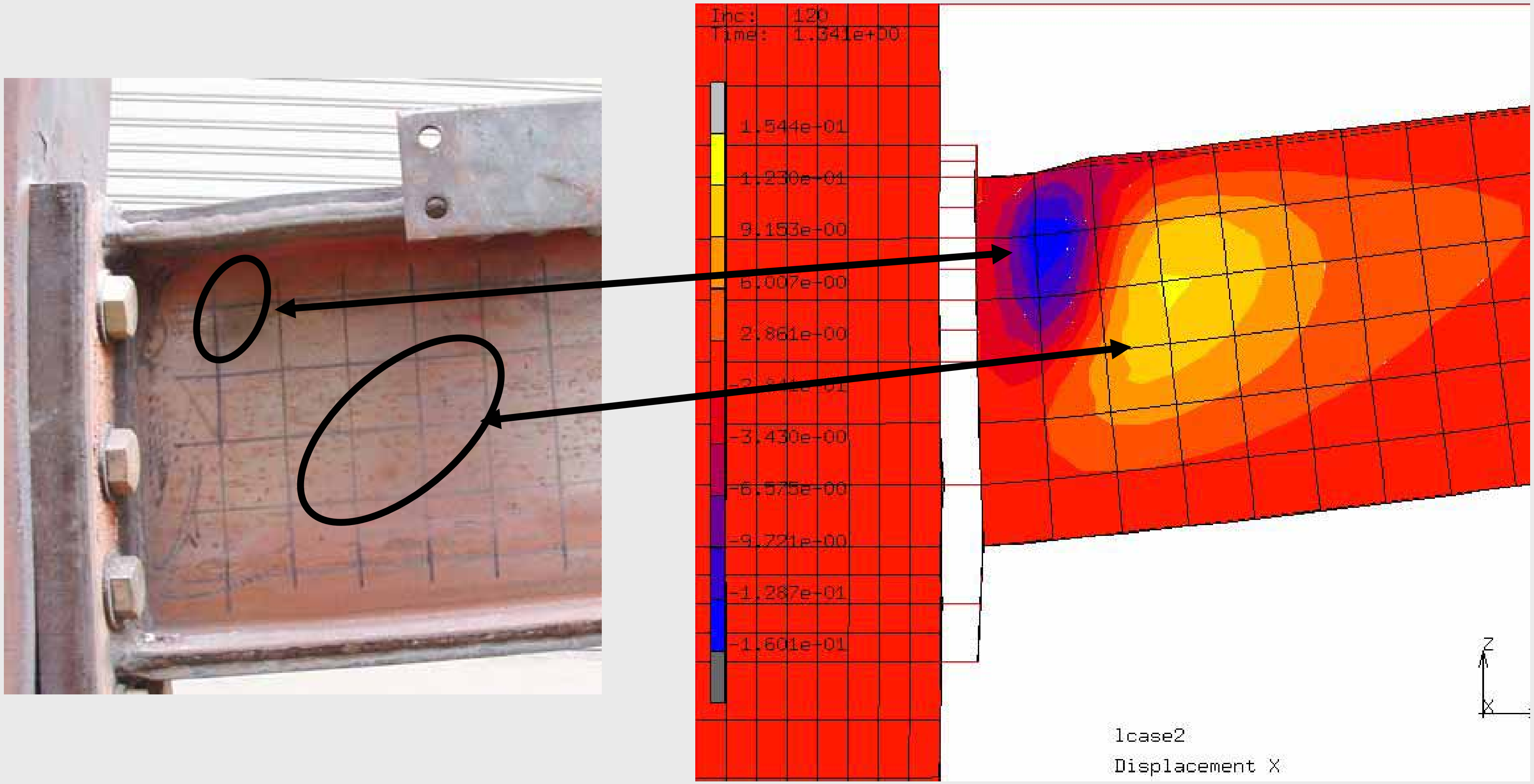
Qian & Tan restrained tests



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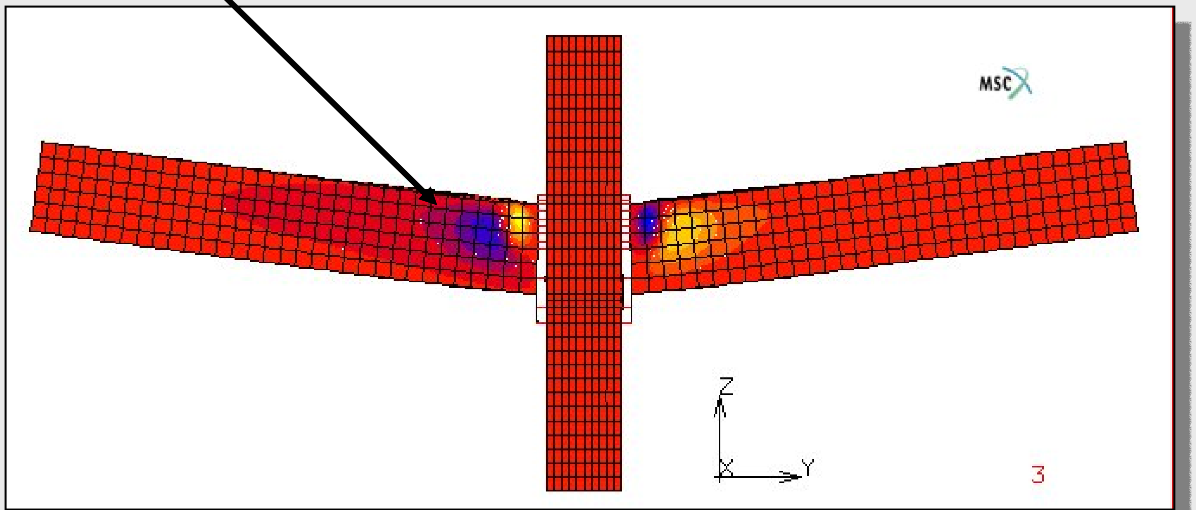
Qian & Tan restrained tests



1. Modified Rotational Models

Simoes da Silva (2001) component approach

- Find ambient-temperature force-displacement response at ambient temperature according to EC3-1-8 component method principles.

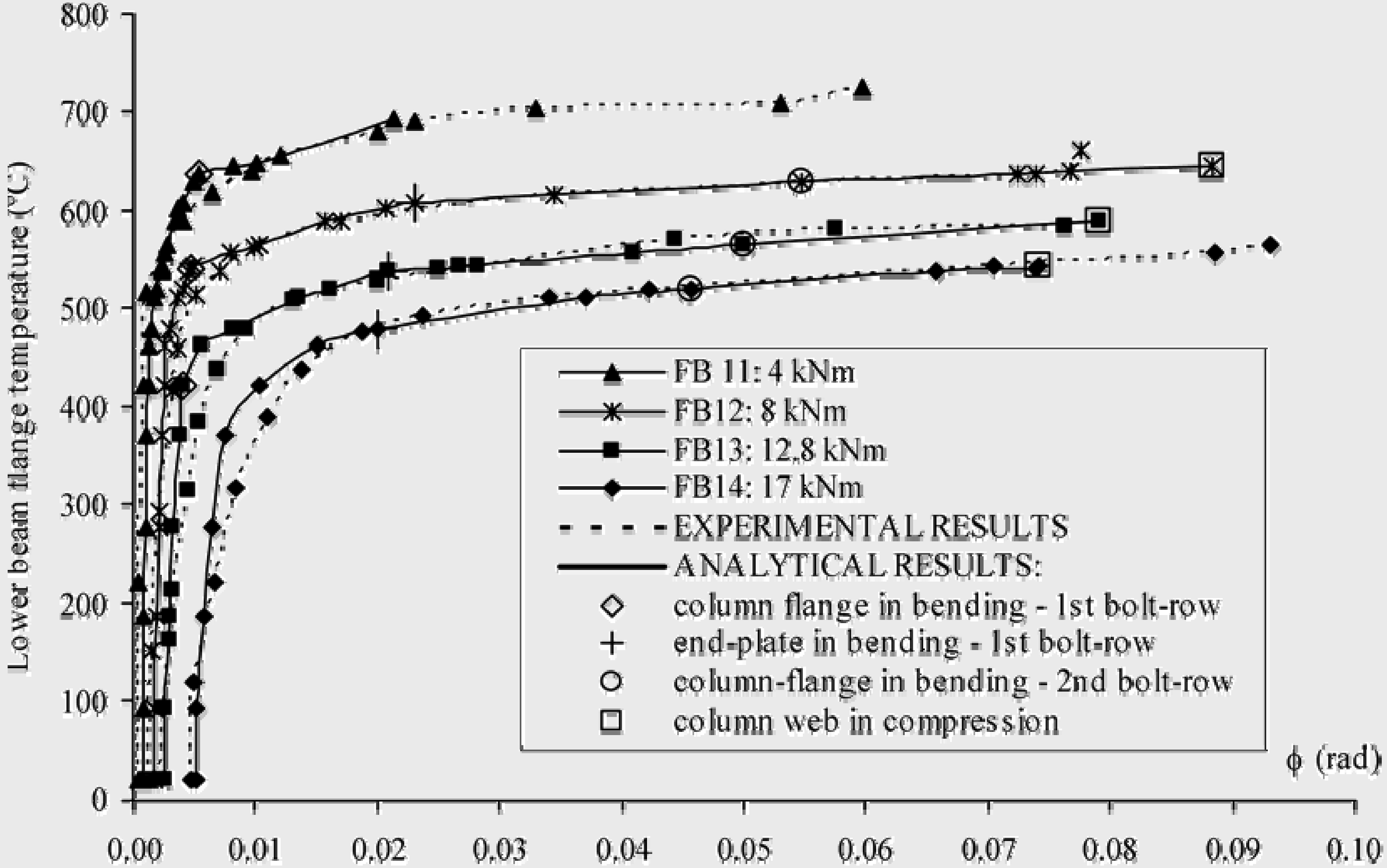
- Apply high-temperature material reduction factors for stiffness and strength to produce high-temperature equivalents.

$$F^{y}_{i,\theta} = k_{y,\theta} \times F^{y}_{i,20°C}$$

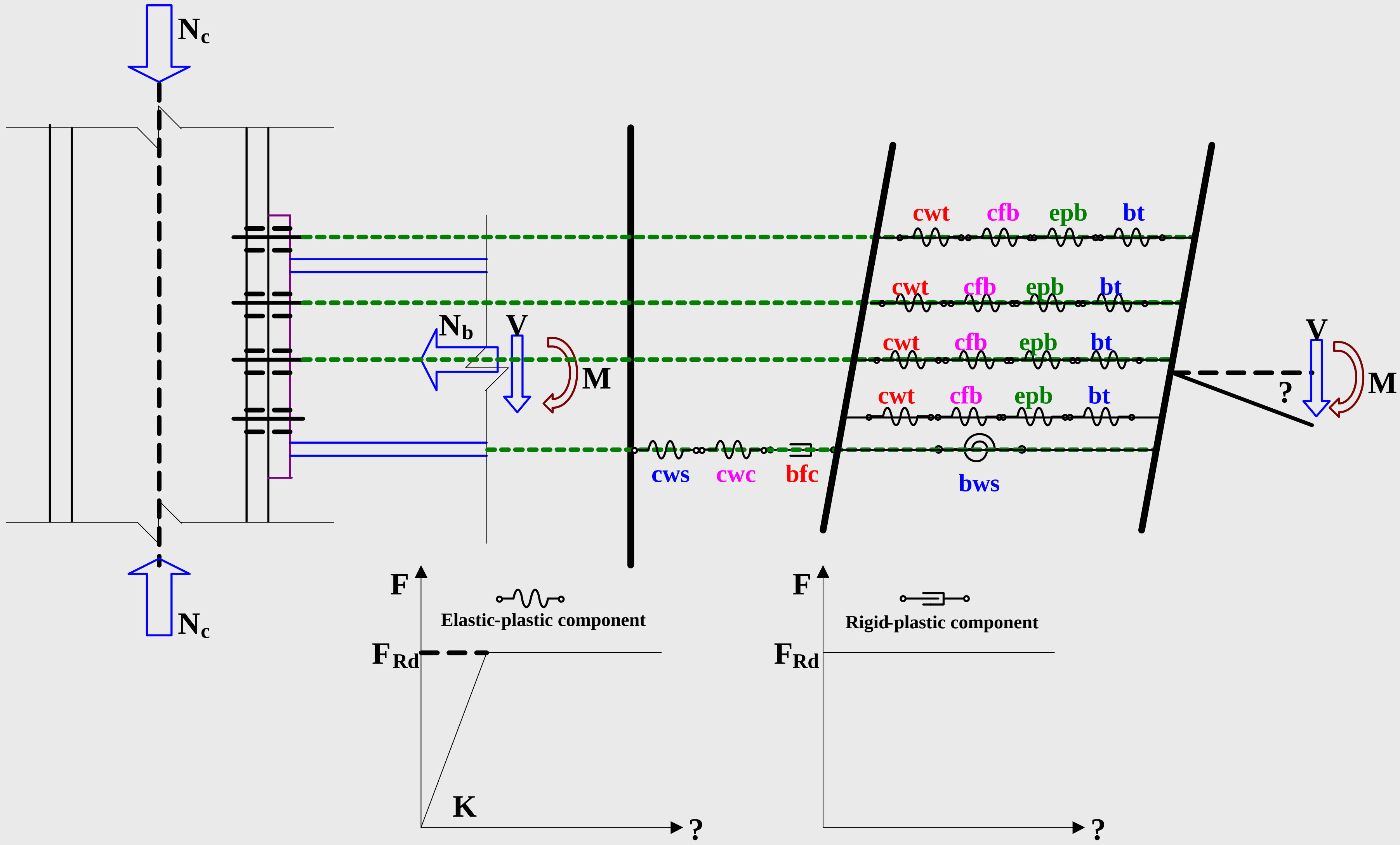
$$K^{e}_{i,\theta} = k_{E,\theta} \times K^{e}_{i,20°C}$$

$$K^{pl}_{i,\theta} = k_{E,\theta} \times K^{pl}_{i,20°C}$$

Simoes da Silva modelling of Sheffield tests



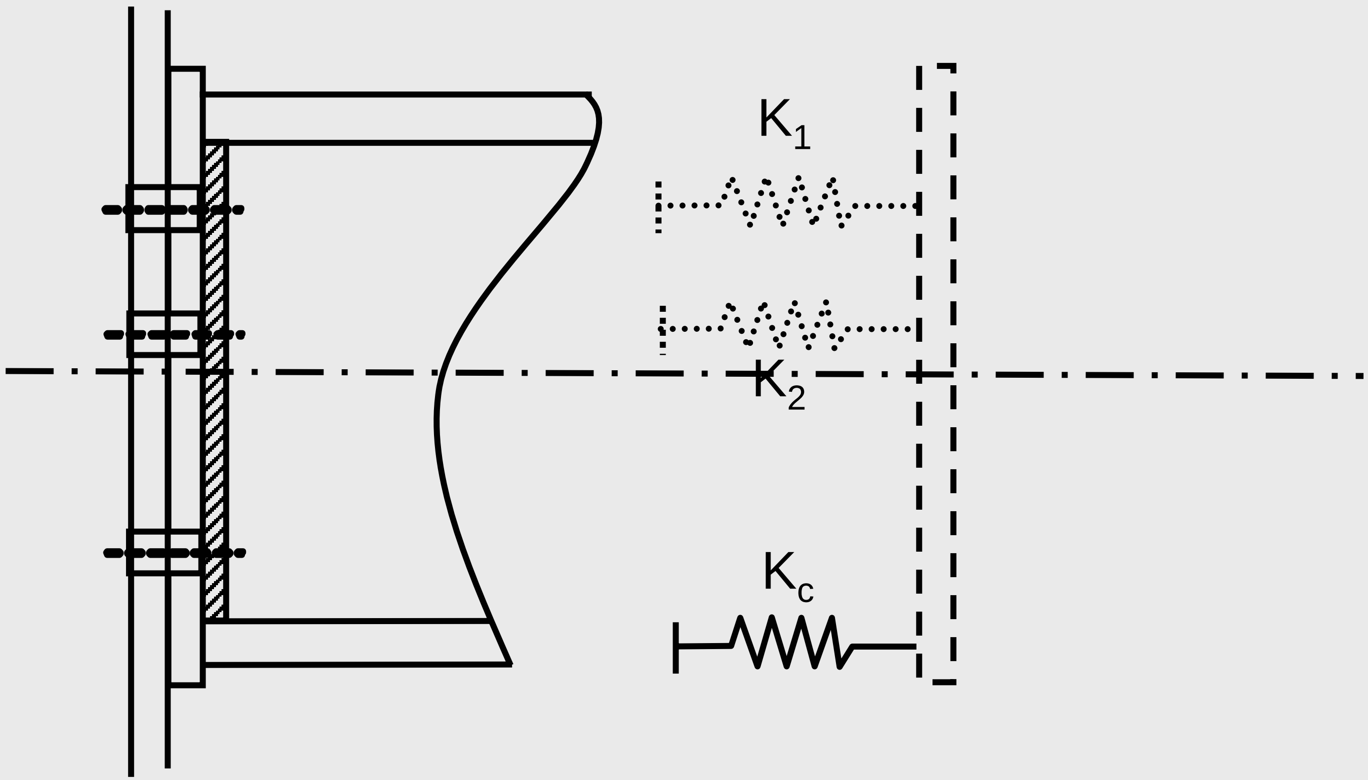
Modified rotational models: Qian & Tan



2. General Connection Elements

The "Component" method with axial force

- In fire axial compression acts together with moment due to restraint to thermal expansion. Component model would deal with this automatically, though M-ϕ curves change due to thrust.



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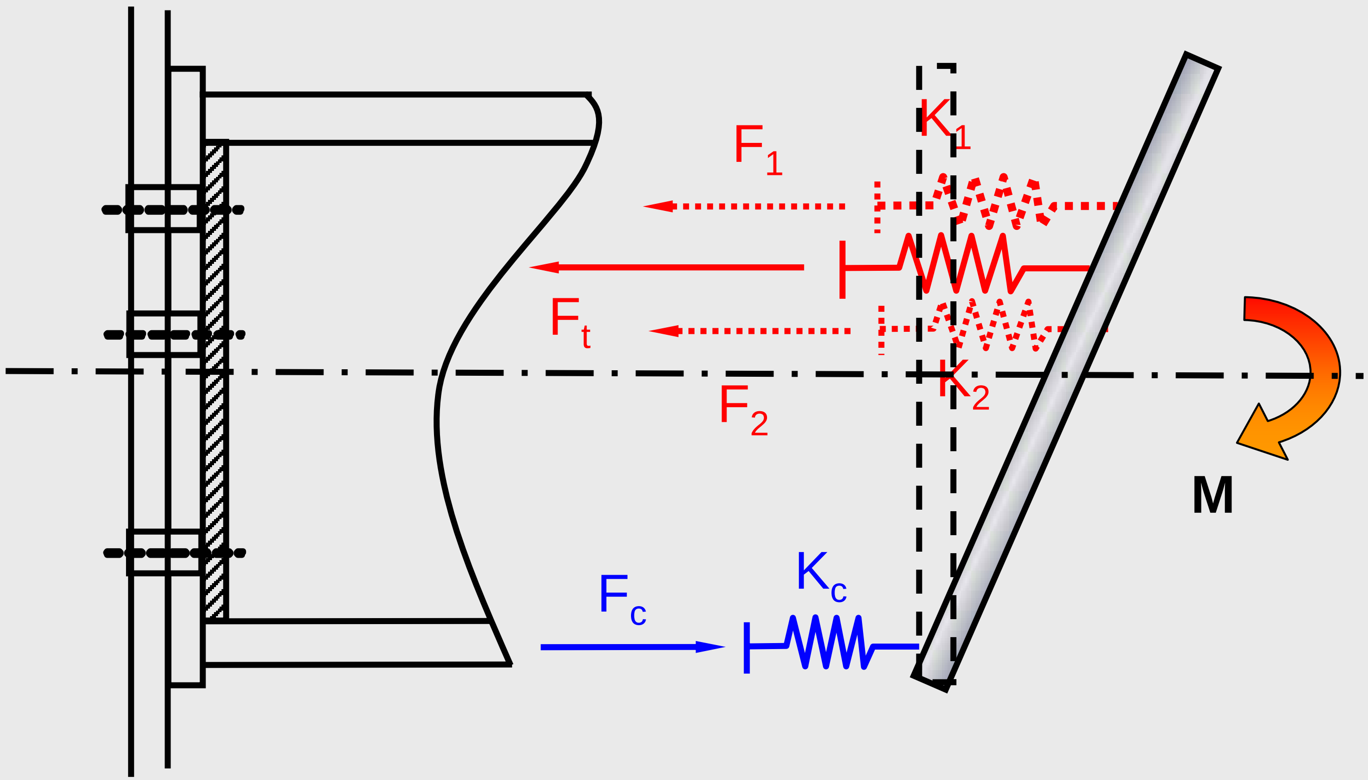

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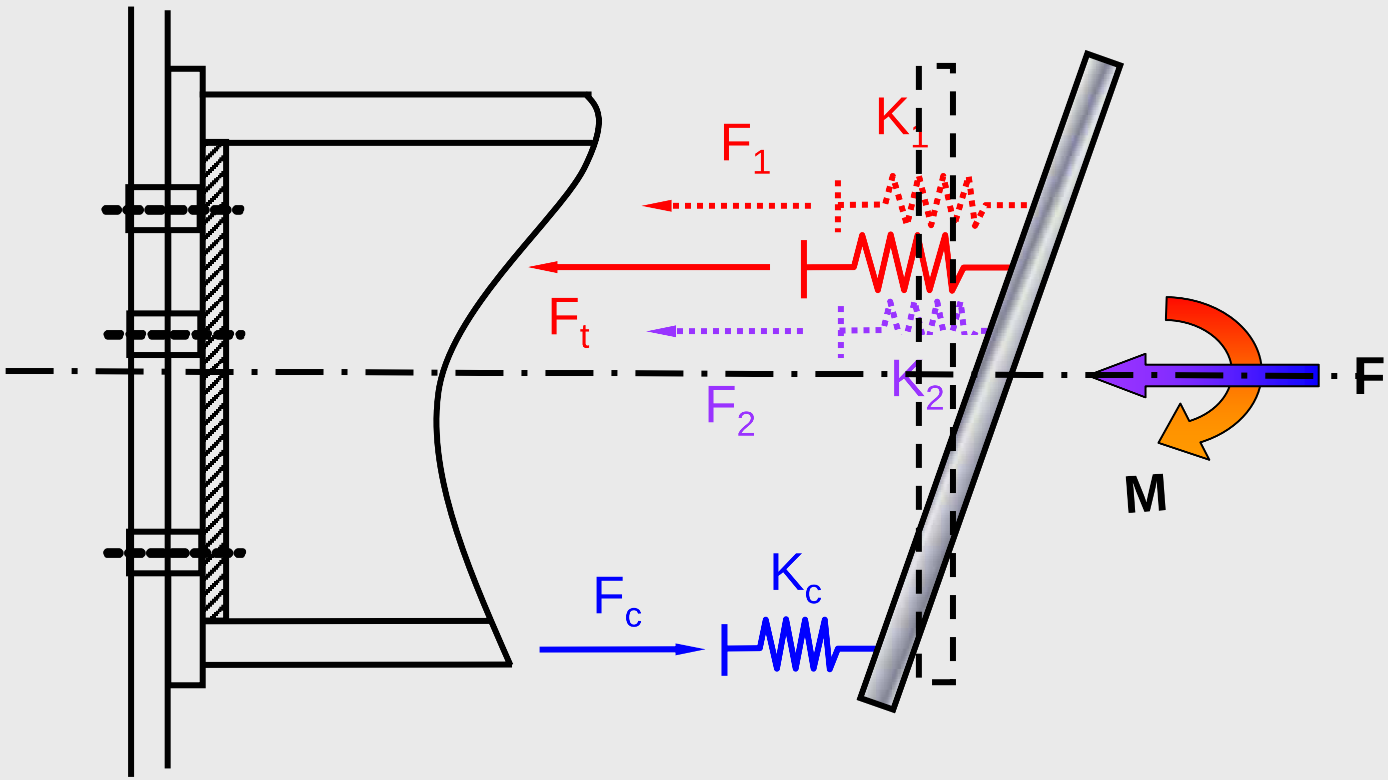
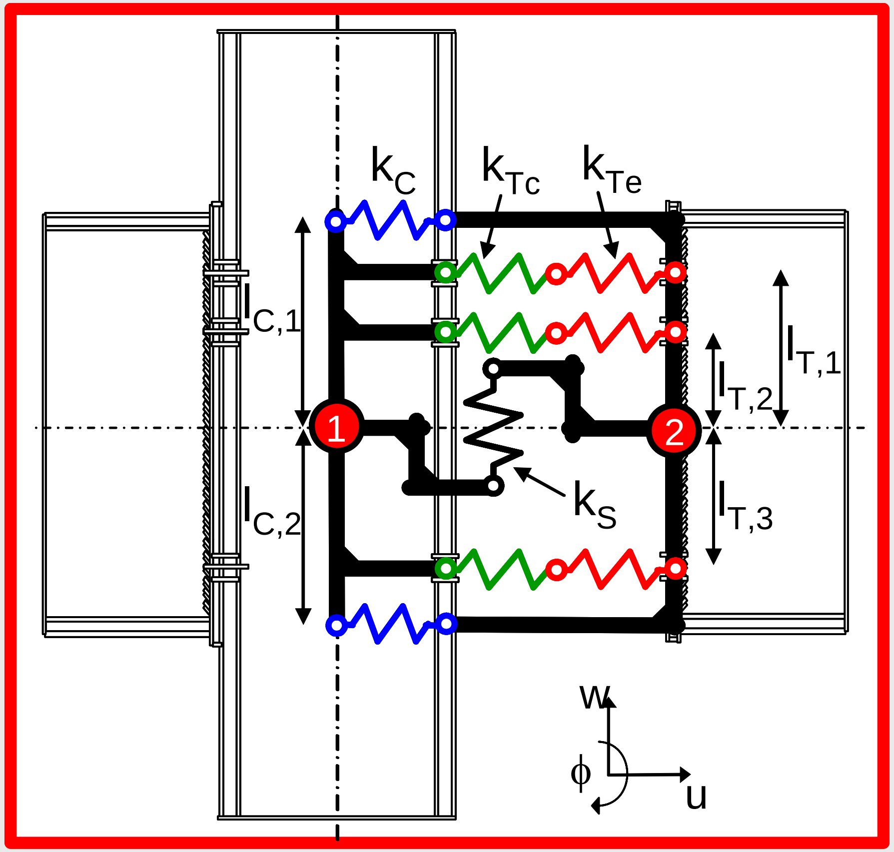
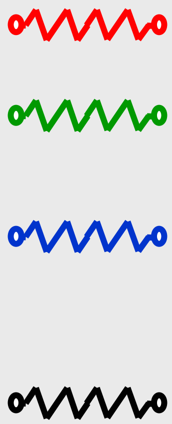


Component-Based Connection Element (Block)





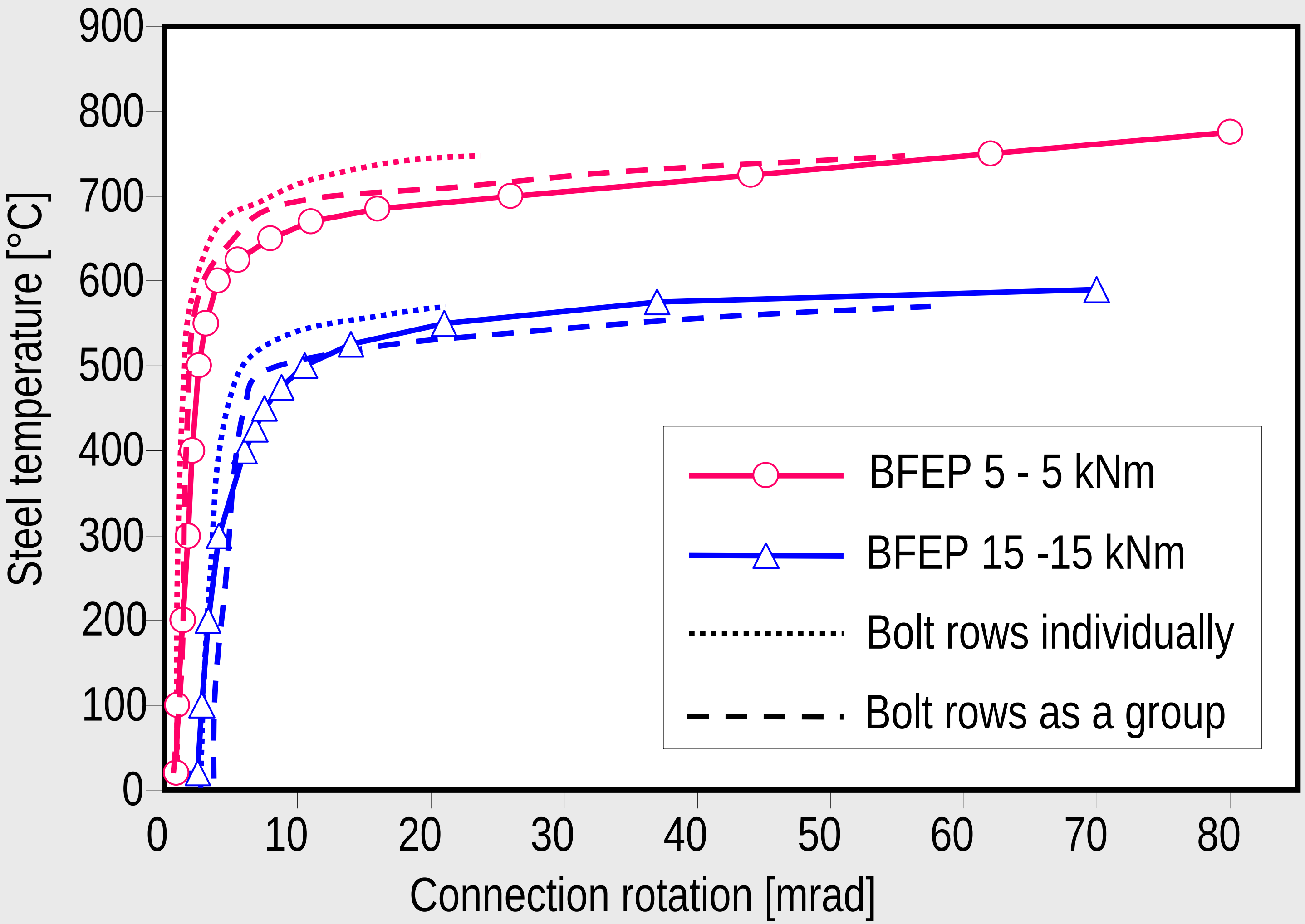
Tension Spring –

T-Stub in End-Plate

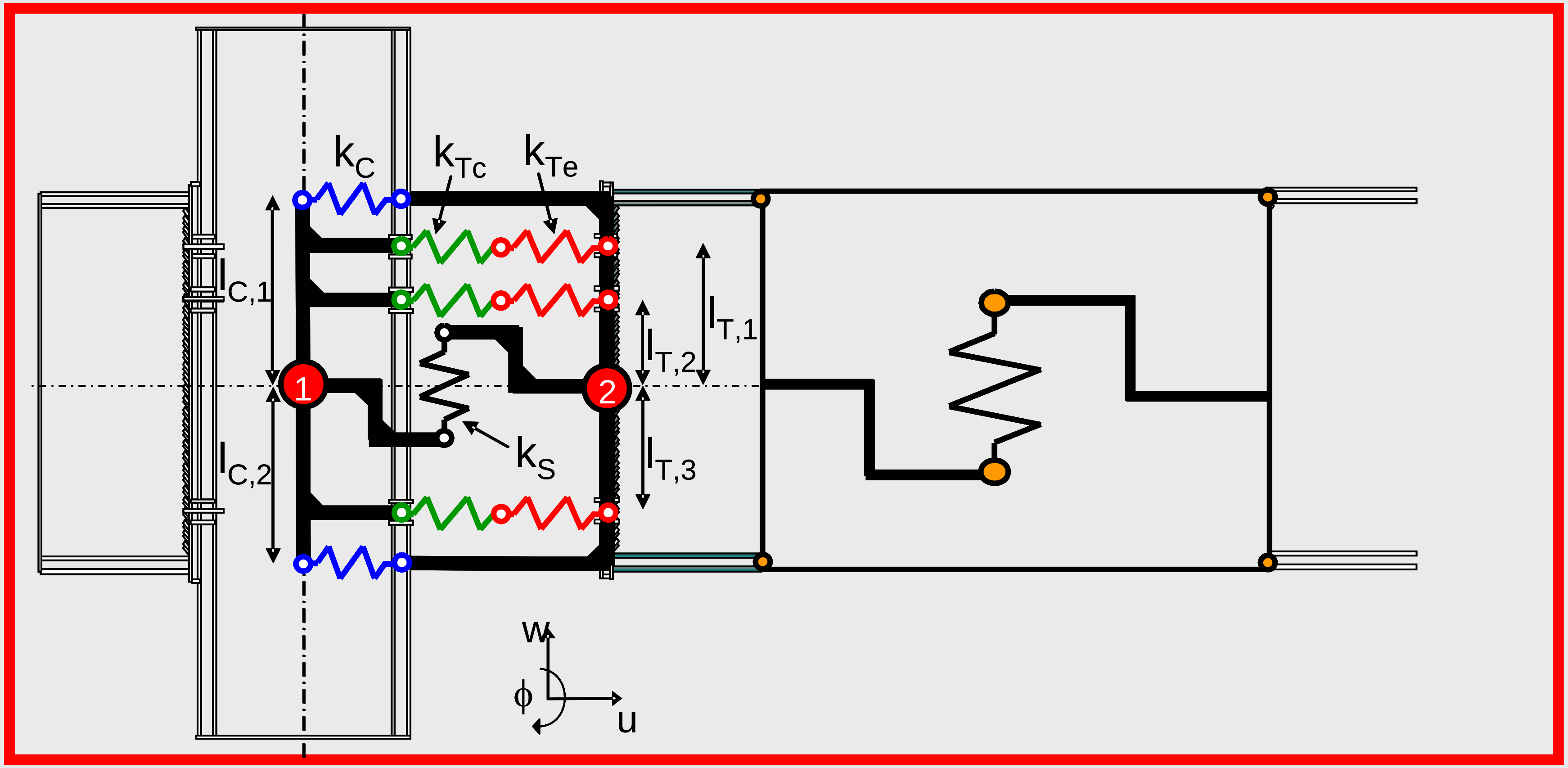
Compression Spring
- Column Web

Shear Spring
- Bolts

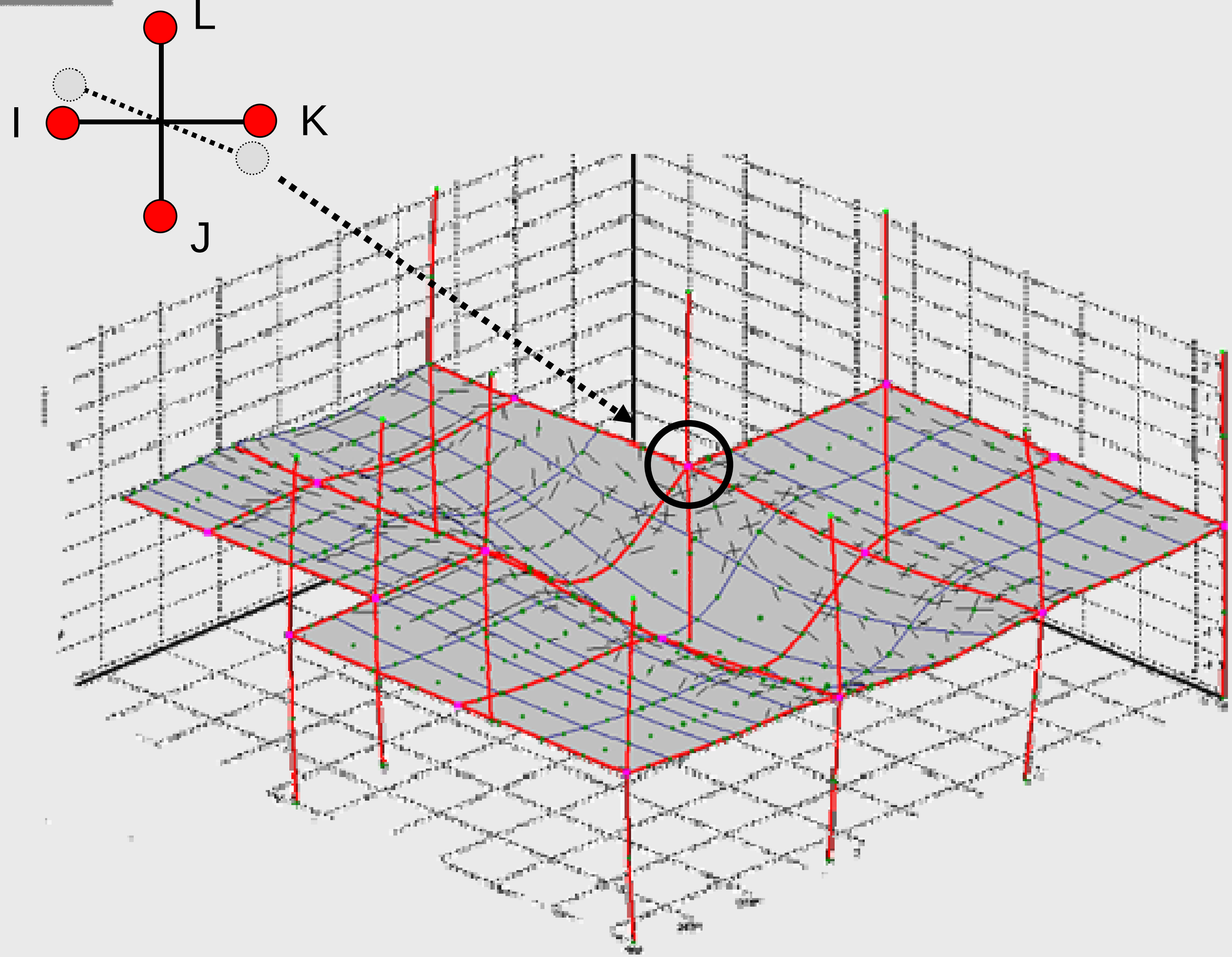
Comparison of joint element with tests by Leston-Jones



Component-based connection element: beam shear panel



Implementation of joint element in software



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The end …

… nearly …

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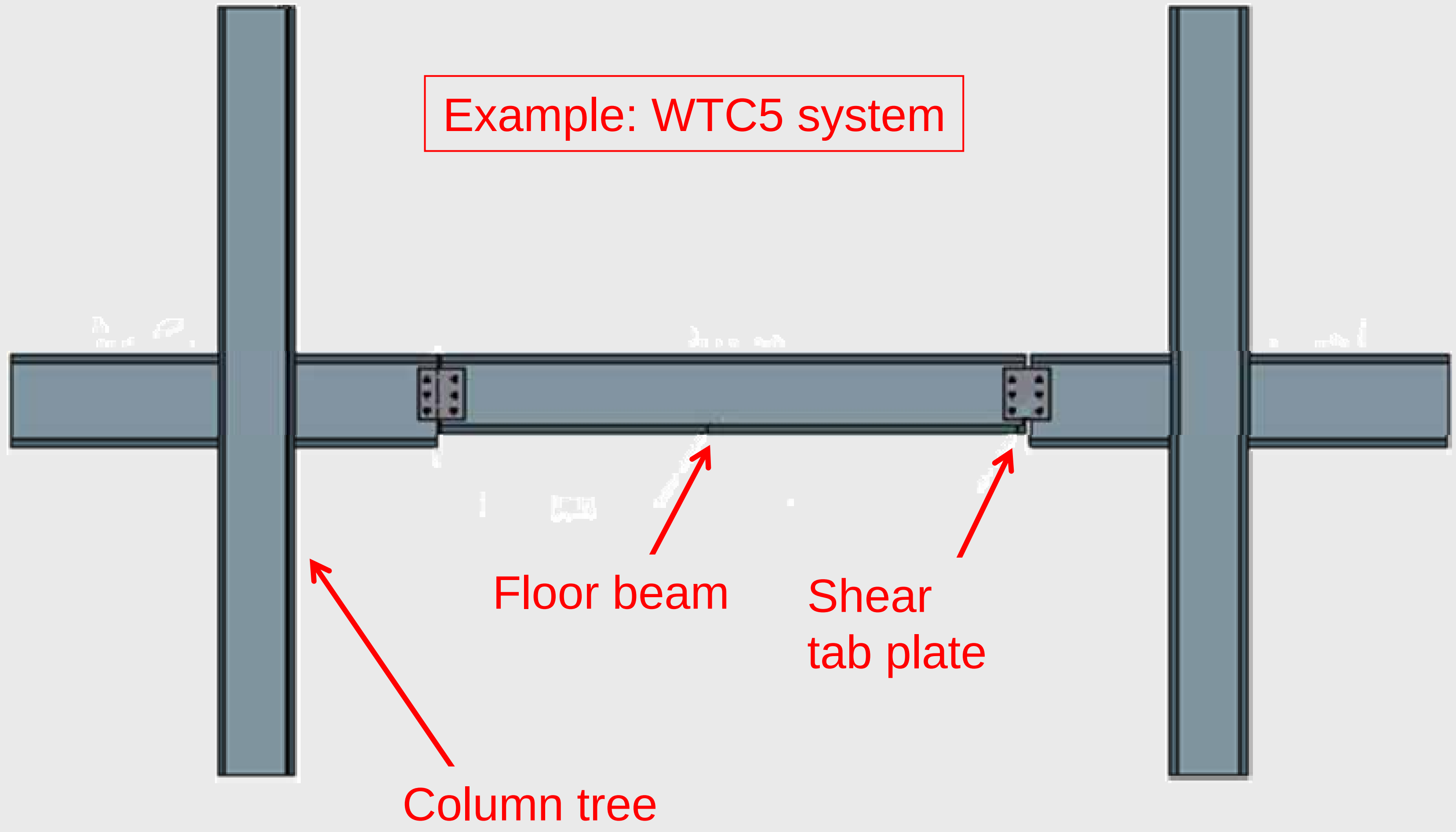
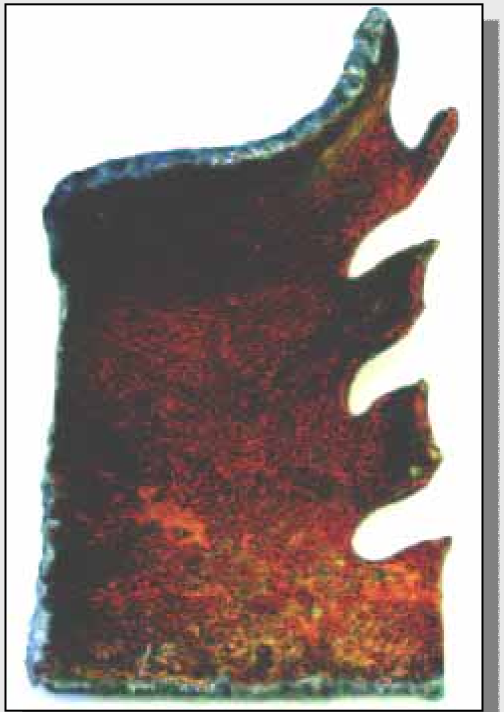
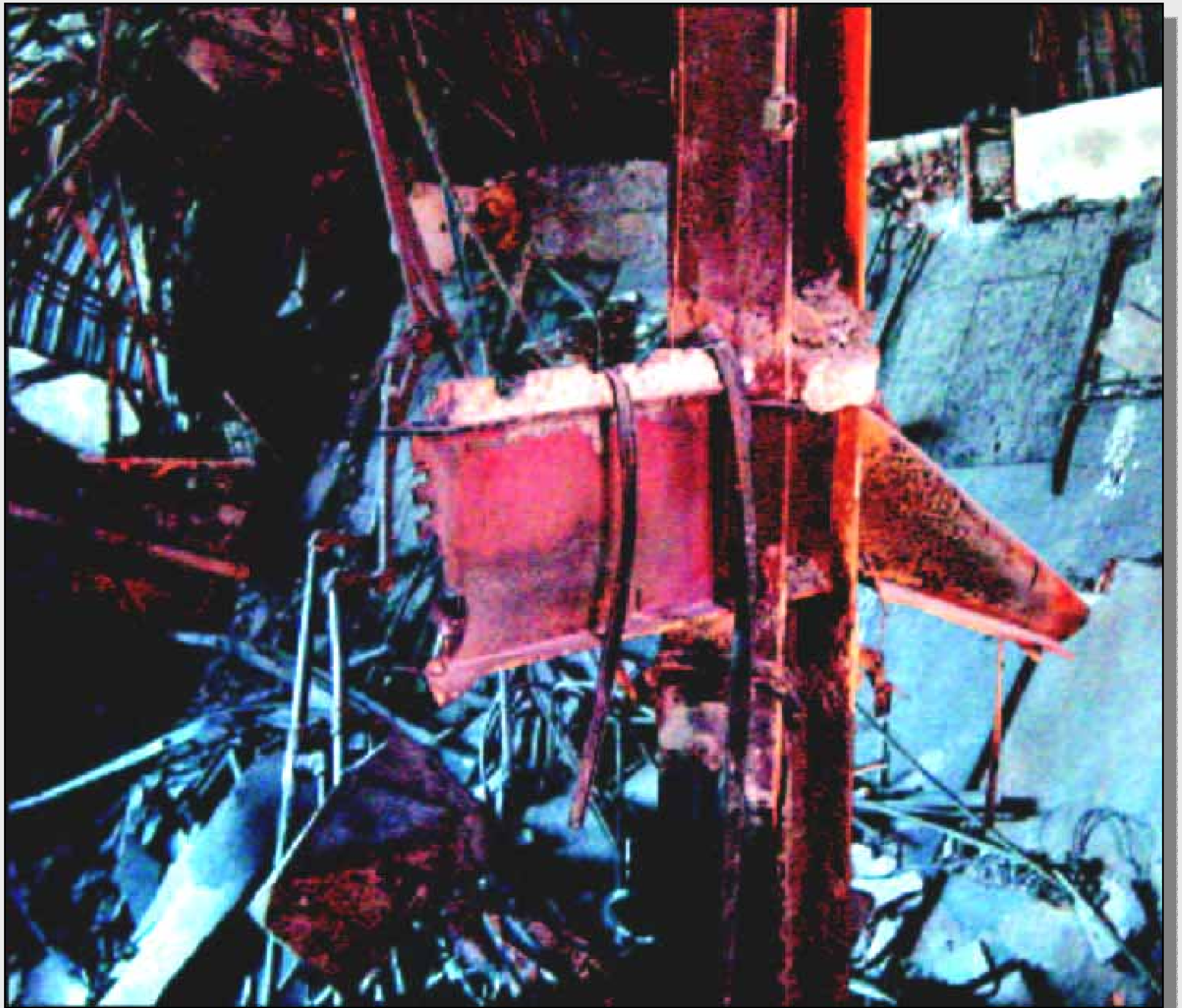
Next emphasis

Robustness in tying (tension) of typical connection details in fire.

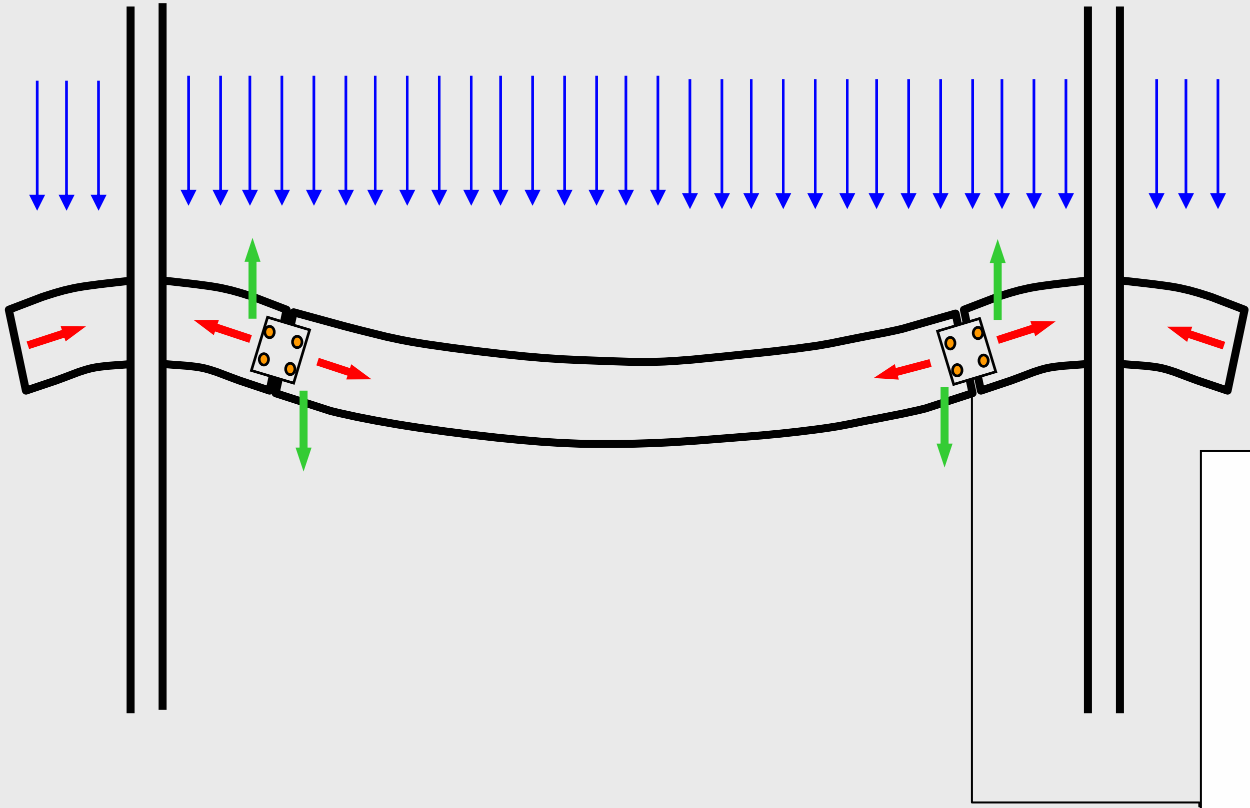


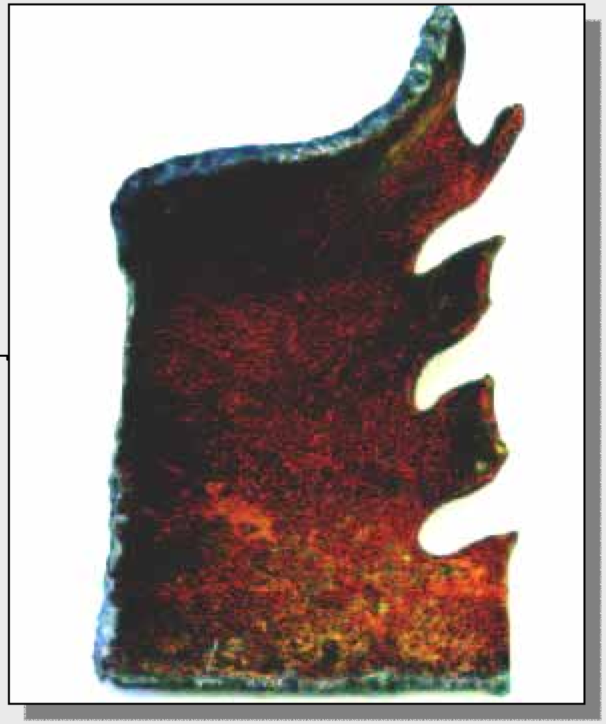
Failure of tab plates in WTC 5 column trees





Combined catenary tension and shear





Current work on robustness

… Thank you