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Load Resistance of 3-Side PFP Beams & Means of Achieving Requirement

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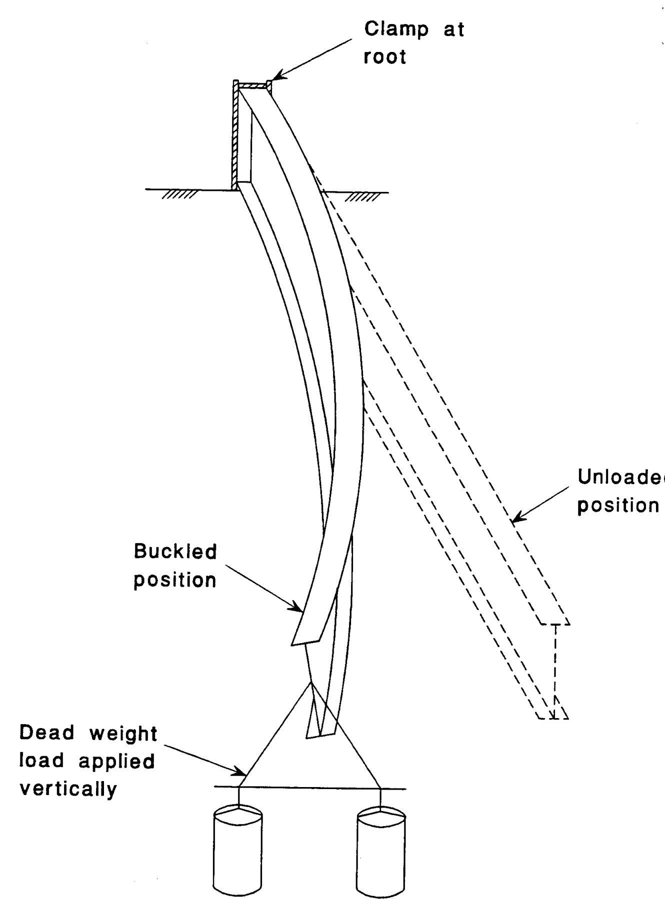
Outline of contents

- Introduction to a few specialist terms: plastic bending resistance, lateral torsional buckling (LTB), effective lateral restraint & key questions for 3 side PFP beams
- Findings of PFPnet scoping study
- Study cases
- Narrow beams: without/with lateral restraints
- Long deep beam: without/with lateral restraints
- Requirements for effective lateral restraints
- Important conclusions & way forward

Specialist terms: plastic bending resistance, LTB, lateral restraint

- Plastic bending resistance: materials reach maximum stresses
- LTB: Out-of-plane movement & twist under in-plane loading
- Longer buckling length = lower resistance
- Worse for deeper/narrower beams



Key questions for 3 side PFP beams

- If lateral restraints are assumed in cold design, so that the structure can reach plastic bending resistance, but they are lost due to fire, what are the implications?
- If lateral restraints can be maintained in fire, would the plastic bending resistance be sufficient in fire?

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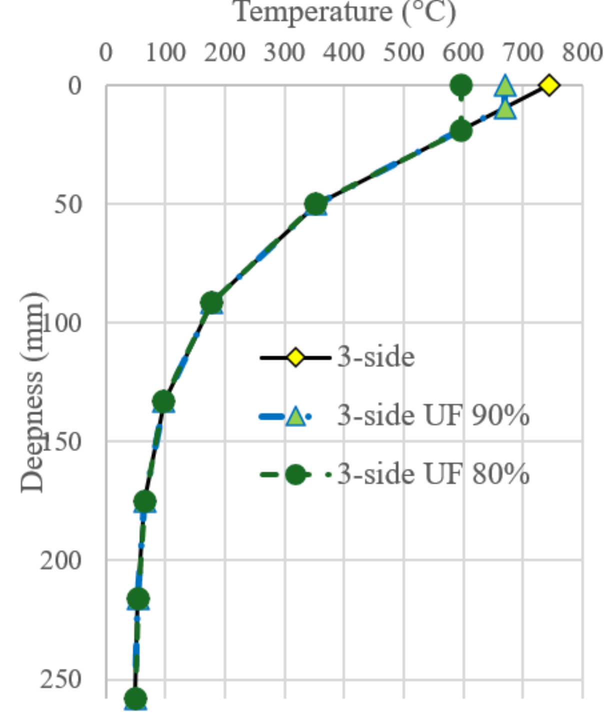
Results of PFPnet Scoping Study

Scoping Study Cases

Structural data

- 30m PG1500x400x40x60, 5m W10x22, 5m W10x49. Span/depth = 20.
- Point loads @2.5m.
- Simply supported ends. No axial restraint, but with warping restraint.
- Lateral restraint conditions:

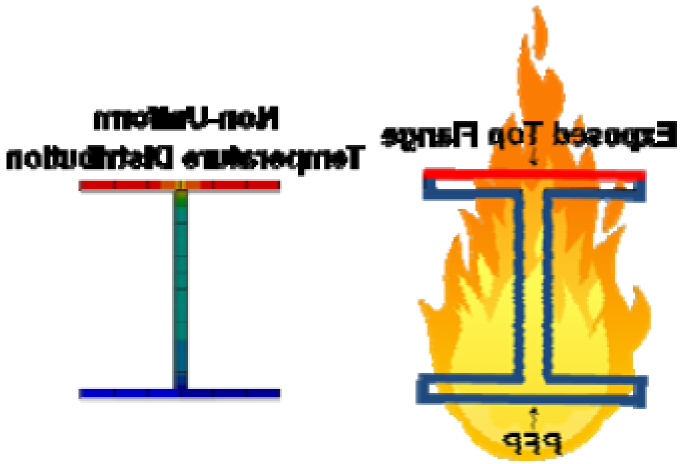
- No
- @2.5m for all beams
- @5m for 30m long beam



Temperature data

- Use PFP thicknesses for 4-side PFP reaching CCT=400^{o}C and 538^{o}C @H60 & H120.
- Equivalent thermal properties of typical PFP materials.
- 10%/20% reduction of top temperature for deep beams.

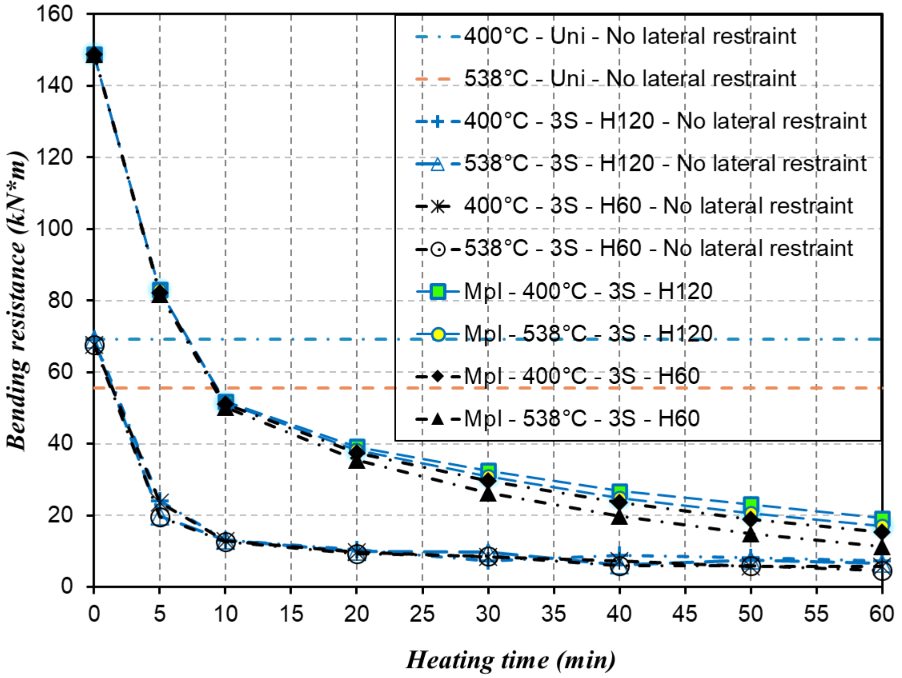
Difference in temperature distributions in shallow and deep beams



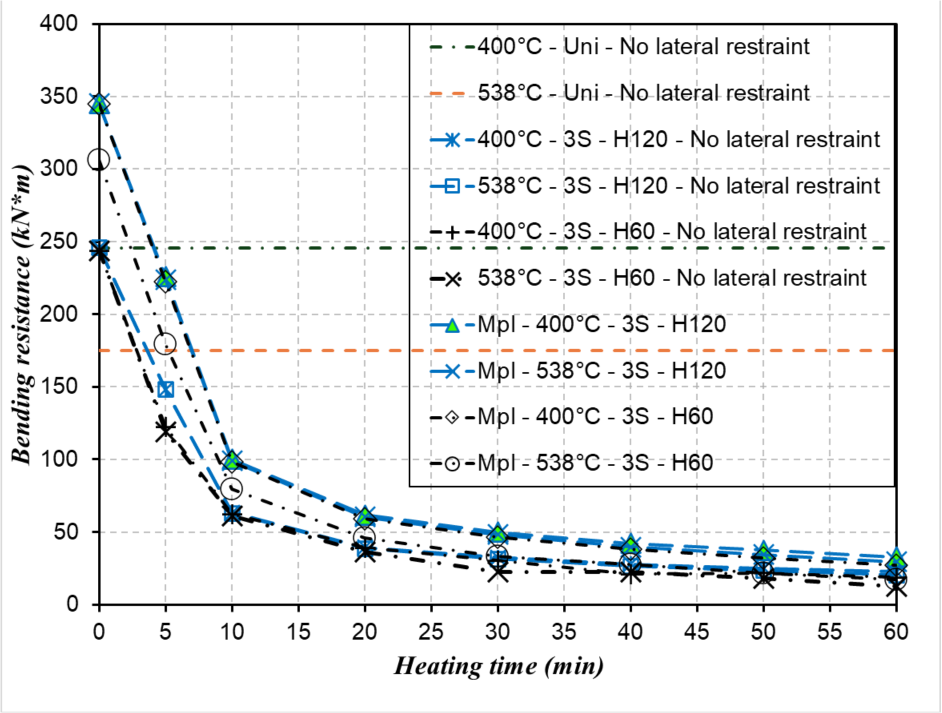
Results for shallow beams

Without effective lateral restraint

W10x22



W10x49



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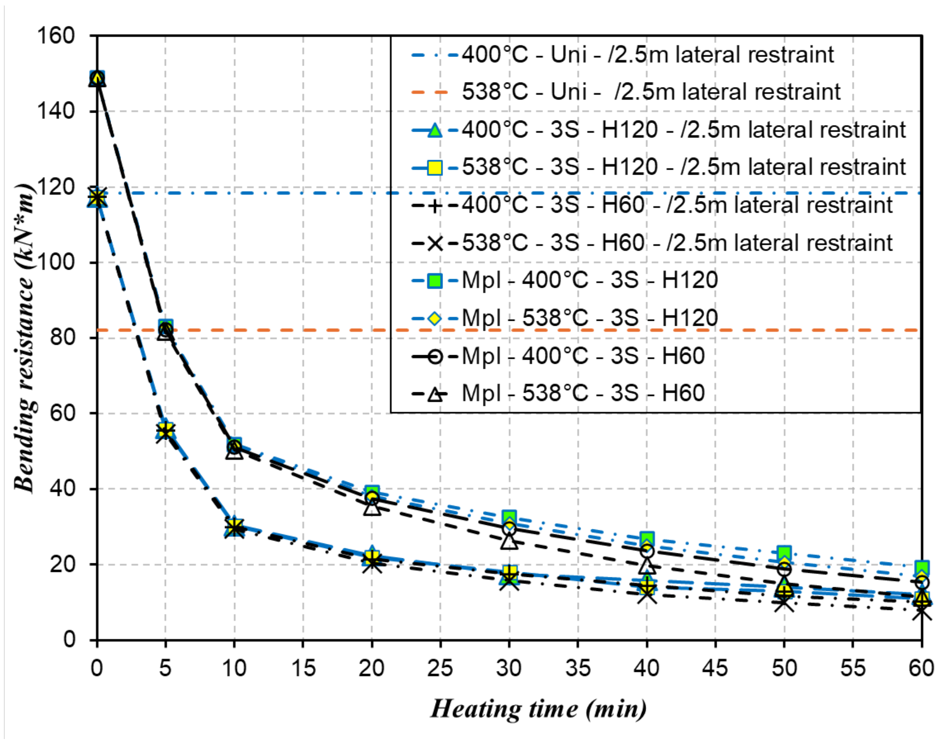
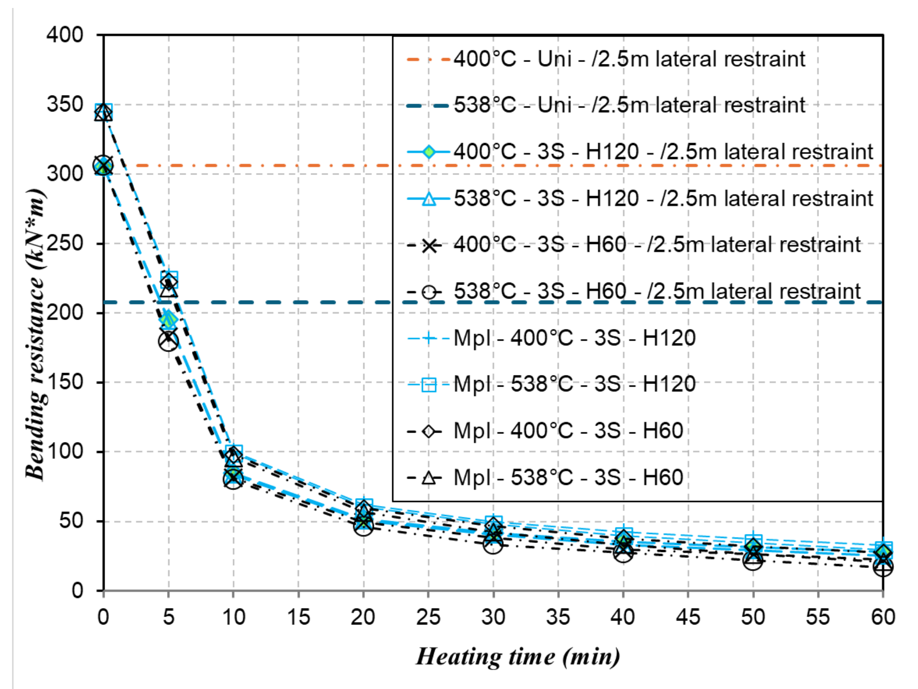
With effective lateral restraint

W10x22



W10x49



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Main messages

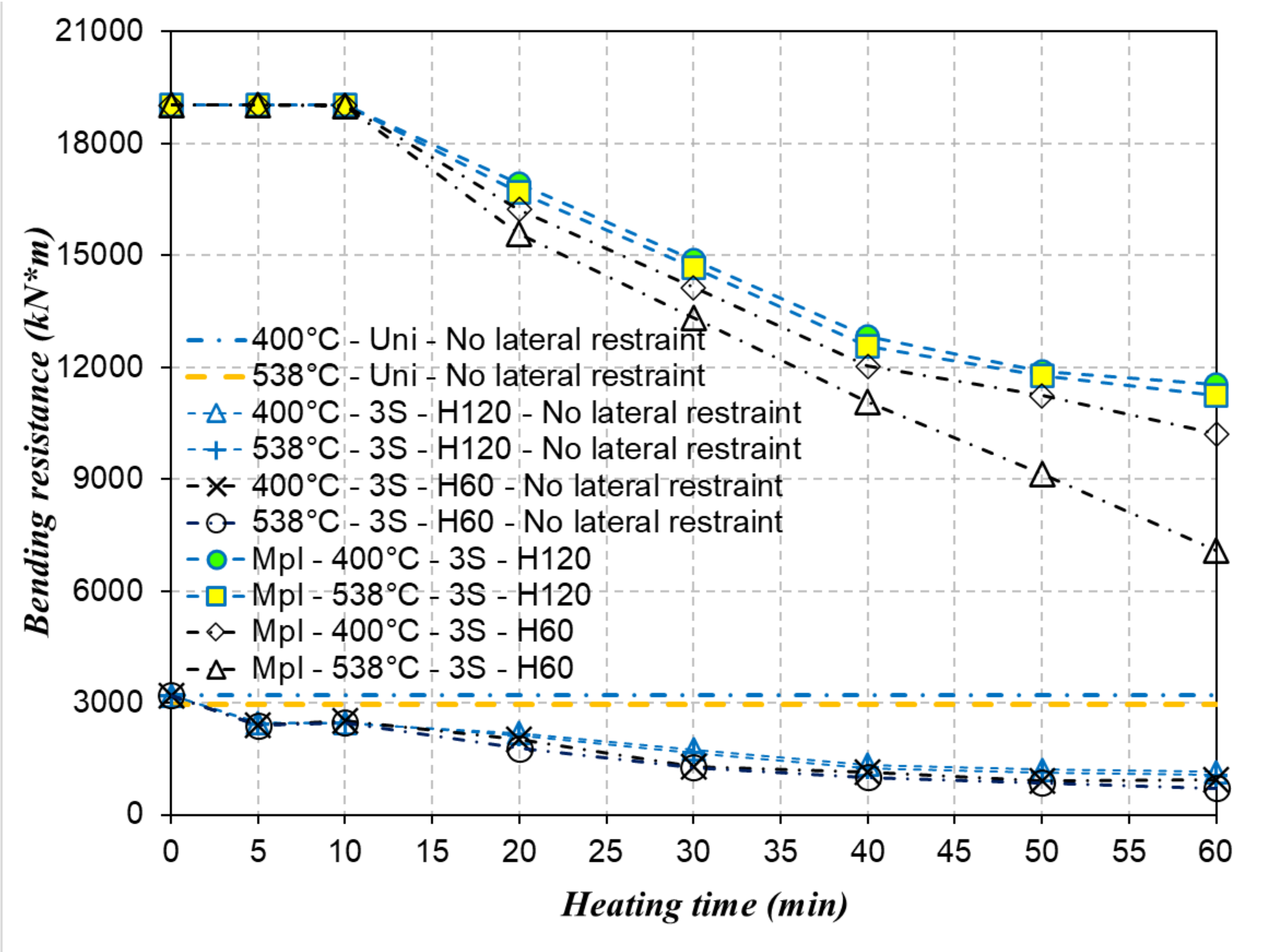
- Beam not able to have meaningful fire resistance in idealised 3-side PFP, due to rapid reduction in plastic bending resistance, <50% of ambient before 5 minutes.
- 3-side PFP beam resistance a fraction of 4-side PFP beam resistance
- LTB resistance of <u>narrow</u> beam without lateral restraint very low, hence benefits more from lateral restraint.
- Almost negligible change in resistance with different coating thicknesses (due to high top flange temperature & rapid heat conduction from inside)

What can be done with shallow beams?

- No more than a few minutes of fire resistance in idealised 3-side PFP conditions.
- Ok to lose them in fire? If so, then nothing need doing.
- Very low applied load (e.g. <10% ambient plastic bending resistance) & short heating duration (e.g. <15 minutes)? – possible to demonstrate adequacy.
- Unaccounted but reliable sources of fire protection to the top flange?

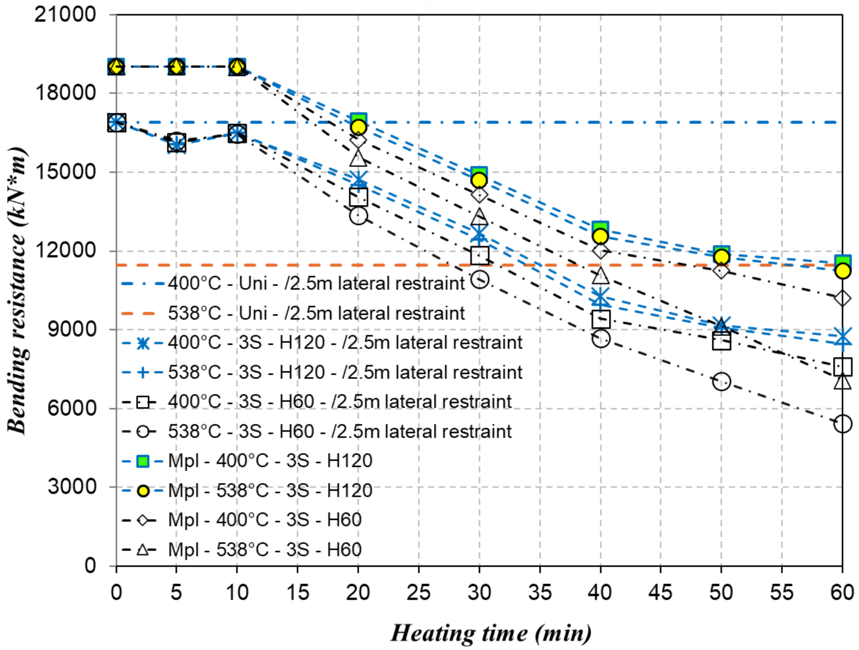
Results for 30m long beam

Without effective lateral restraint

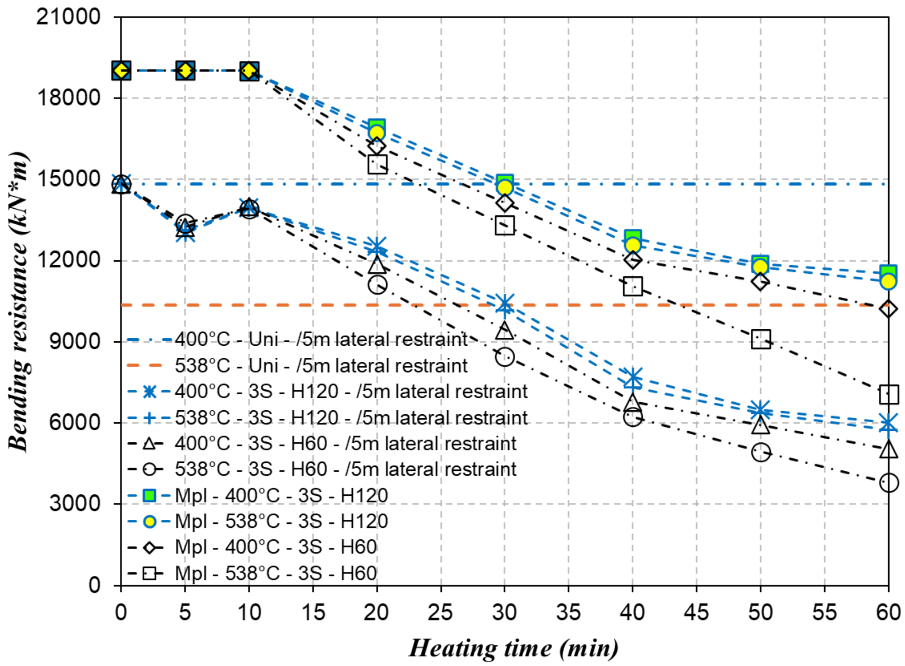


With effective lateral restraints

Restraint @2.5 spacing



Restraint @5m spacing



Main messages

- LTB resistance of unrestrained beam = tiny proportion of plastic bending resistance (10-15%).
- Slow reduction in plastic resistance due to limited heat conduction from inside. Plastic bending resistance ~ 50% ambient @H60.
- Lateral restraints effective: LTB resistance ~60% plastic bending resistance @5m restraint spacing, ~80% @ 2.5m restraint spacing
- Limited enhancement effects of reducing top flange temperature (due to resistance mainly from the lower part of the section)
- Could be engineered to achieve required fire resistance in idealised 3-side PFP
- Possible means of achieving required fire resistance:

- Effective lateral restraints
- Low design loads in fire (e.g. <<40% ambient plastic bending resistance)
- Other benefits: limited length of fire exposure/possible cooling effects at top flange

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Requirements for effective lateral restraint

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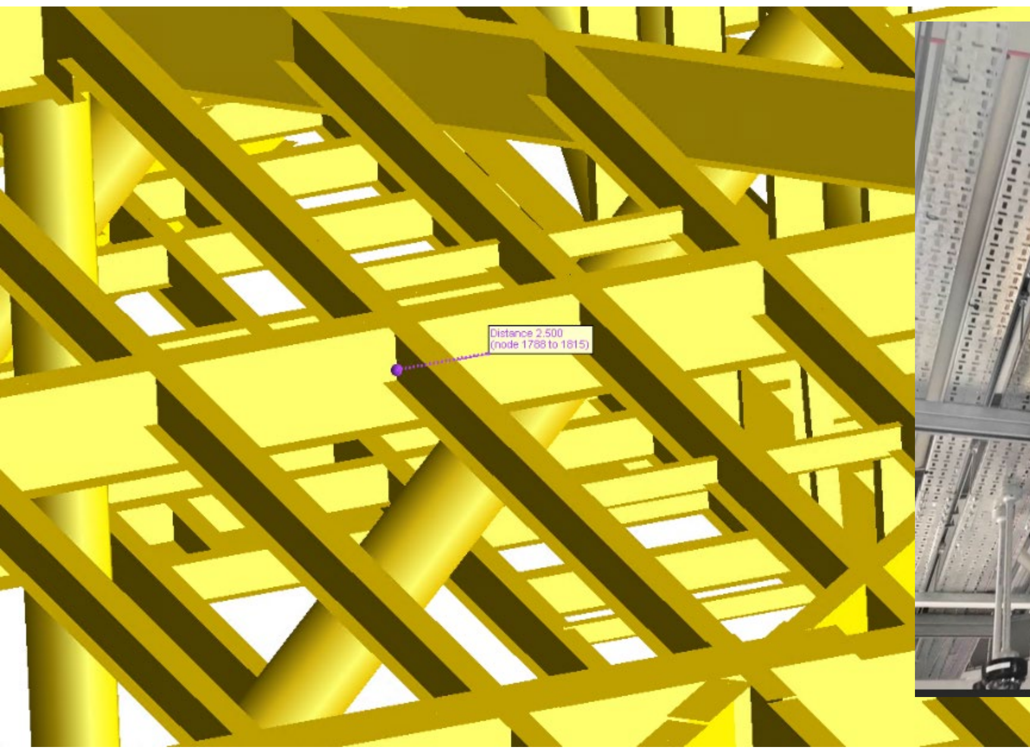
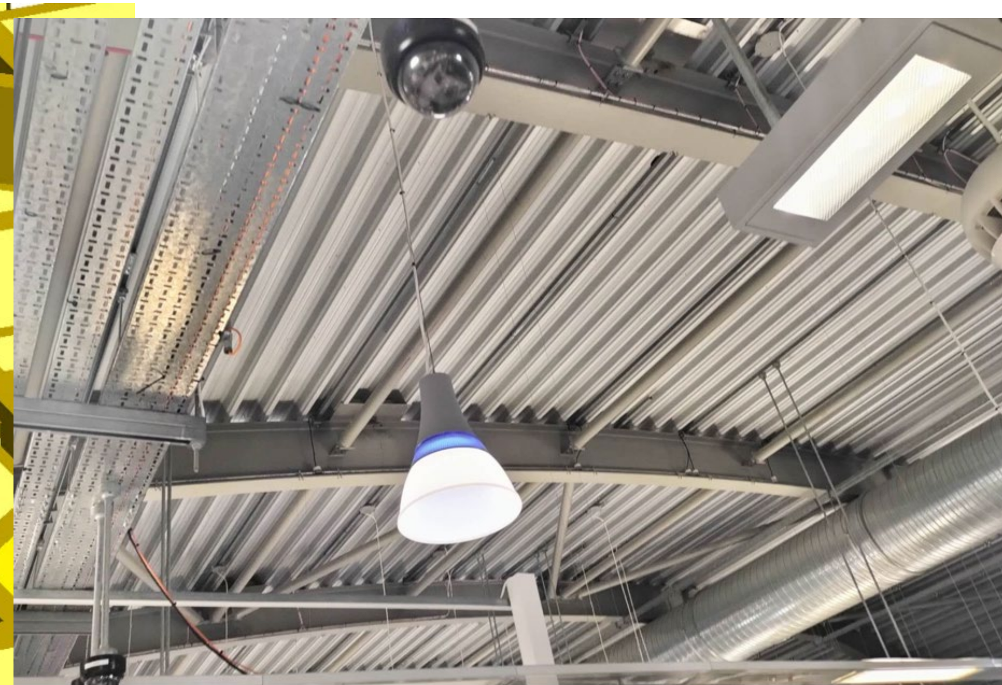
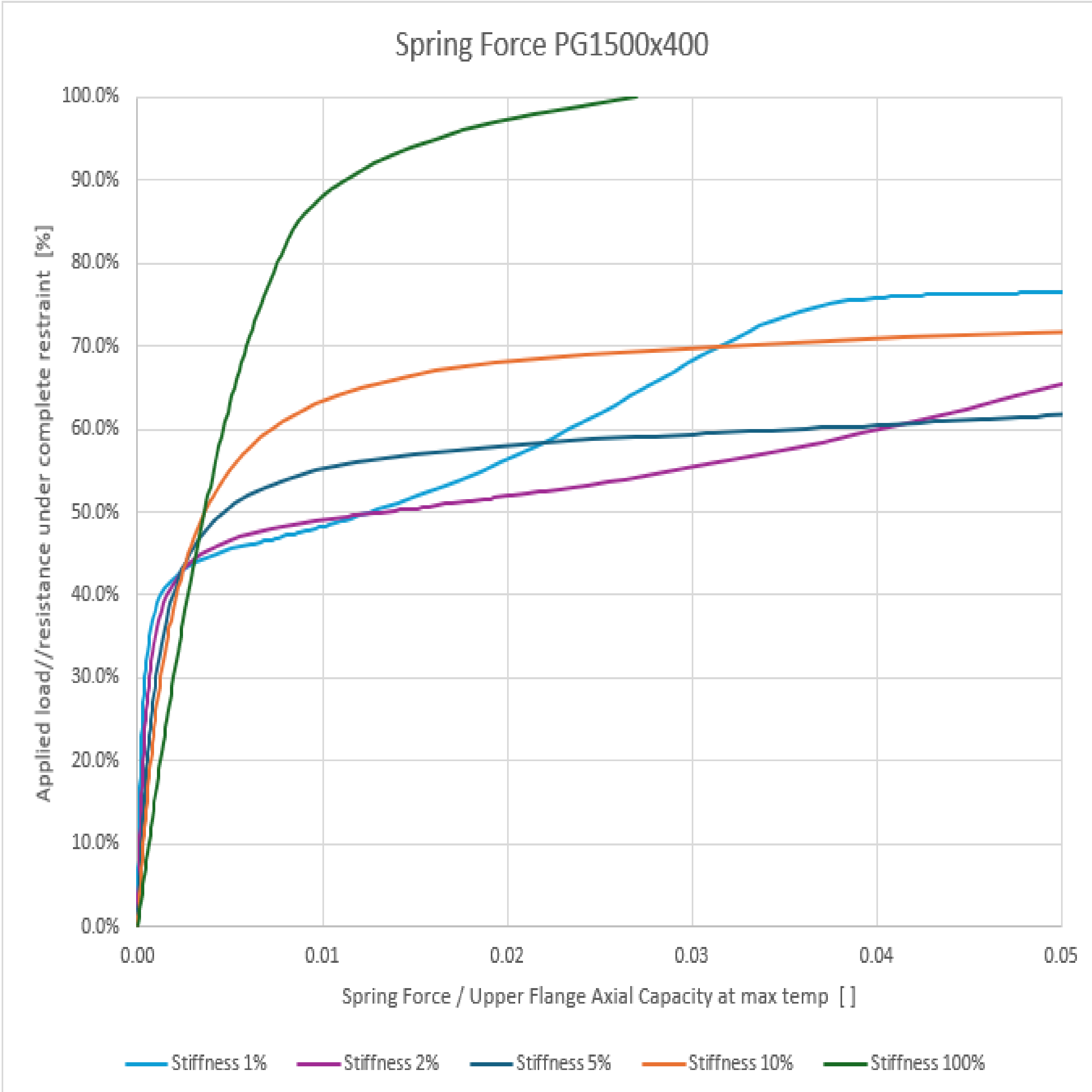
Potential source of lateral restraints – secondary beams





Results (Beam load – Spring force relations)



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Summary of results

Beam	Spring Stiffness	Spring Force / Upper Flange Axial Capacity at max temp [%] (normalised by ultimate capacity of the beam) 1%	2%
W10x22	1%	76.5%	79.0%
	2%	77.2%	77.9%
	5%	79.4%	81.0%
	10%	82.9%	83.9%
	100%	93.3%	94.0%
PG1500x400x40x60	1%	48.2%	55.9%
	2%	49.0%	51.9%
	5%	55.0%	58.0%
	10%	63.0%	68.0%
	100%	88.0%	97.0%

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Example from a typical structure

Force resistance

- Required: spring axial resistance (area) > 2% of beam top flange
- Top flange area (PG1500x400x40x60) = 240cm^2
- Provision
- W36x16x245 (H=916.4mm, B=419.4mm, tw=20.3mm, tf=34.3mm)
- A=460cm^2

Spring stiffness

- Required: spring stiffness > EI/L^3 of in-plane bending
- EI/L^3 ((PG1500x400x40x60) 2992 N/mm
- Provision:
- EA/l (W36x16x245)= 707700N/mm @ 20^{o}C
- @1150^{o}C, EA/l>0.01*above=7077N/mm > 2992 N/mm

Conclusions & way forward

- Shallow beams: high top flange temperature & rapid heat conduction from inside = rapid reduction in plastic bending resistance & cannot be engineered to achieve required resistance in idealised 3-side PFP.
- Not needed?/low load & time?/demonstrating effective 4-side PFP
- Deep beams: plastic bending resistance substantial (50%+ ambient) due to large lower part low temperature. LTB resistance tiny fraction of plastic bending resistance without lateral restrain. Lateral restraints (e.g. @2.5m/5m spacing) effective in LTB resistance being high % (~80%/60%) plastic bending resistance. Possible to achieve required fire resistance.
- Effective lateral restraints/modest applied load in fire
- Benefits of fire exposure along not along the entire beam/possible shielding effect (minor)
- Effective lateral restraint: should be able to resist 2% of top flange compression resistance at the maximum temperature – not difficult to provide.