Experimental behaviour of reduced web beam section (RWS) connections in fire

A presentation at STIFF

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Overview of presentation

- Background to the collaboration
- Motivation behind this work
- Planning the test
- Test observations, results and a little analysis
- What next…

Background

Brunel University London

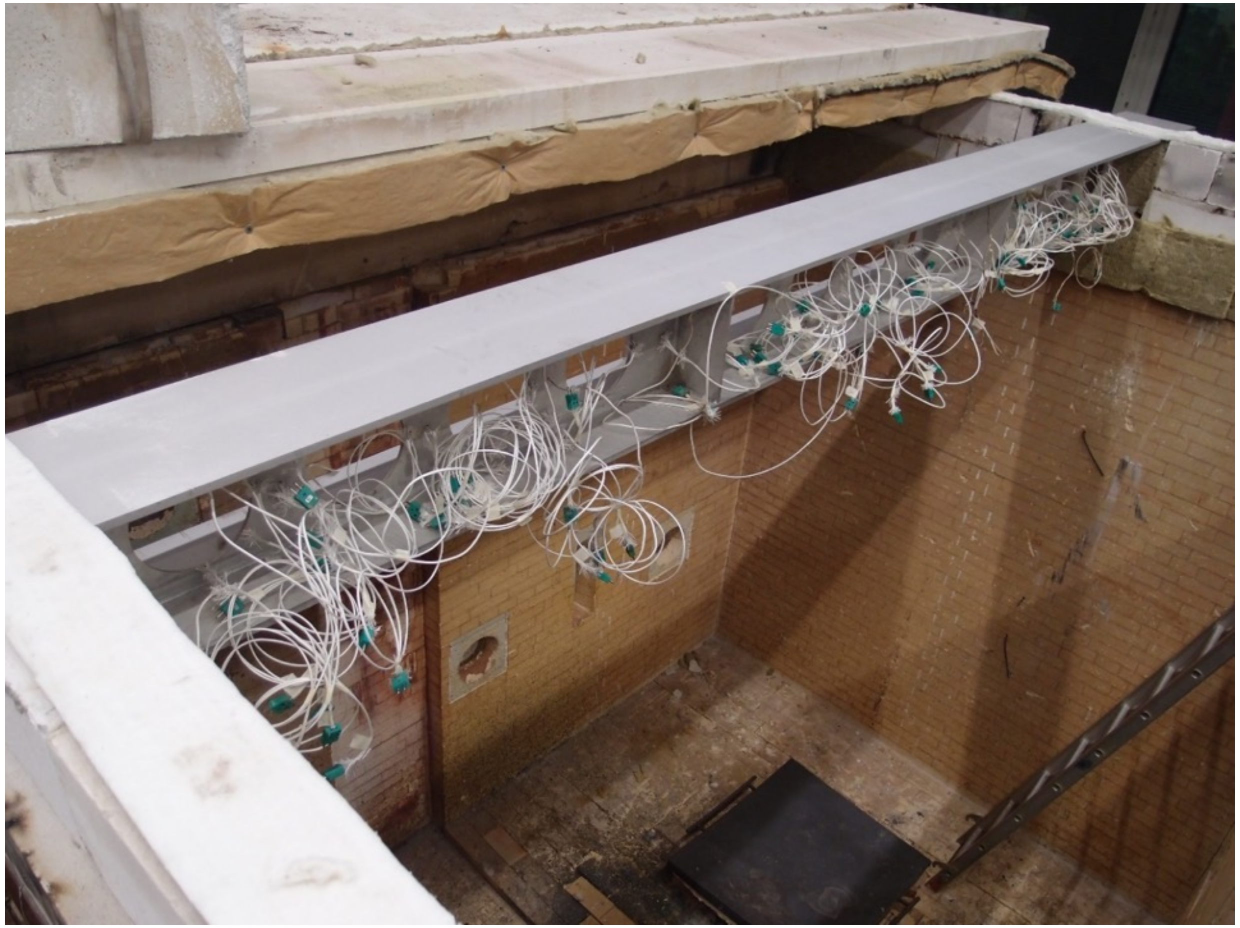
Tampere University

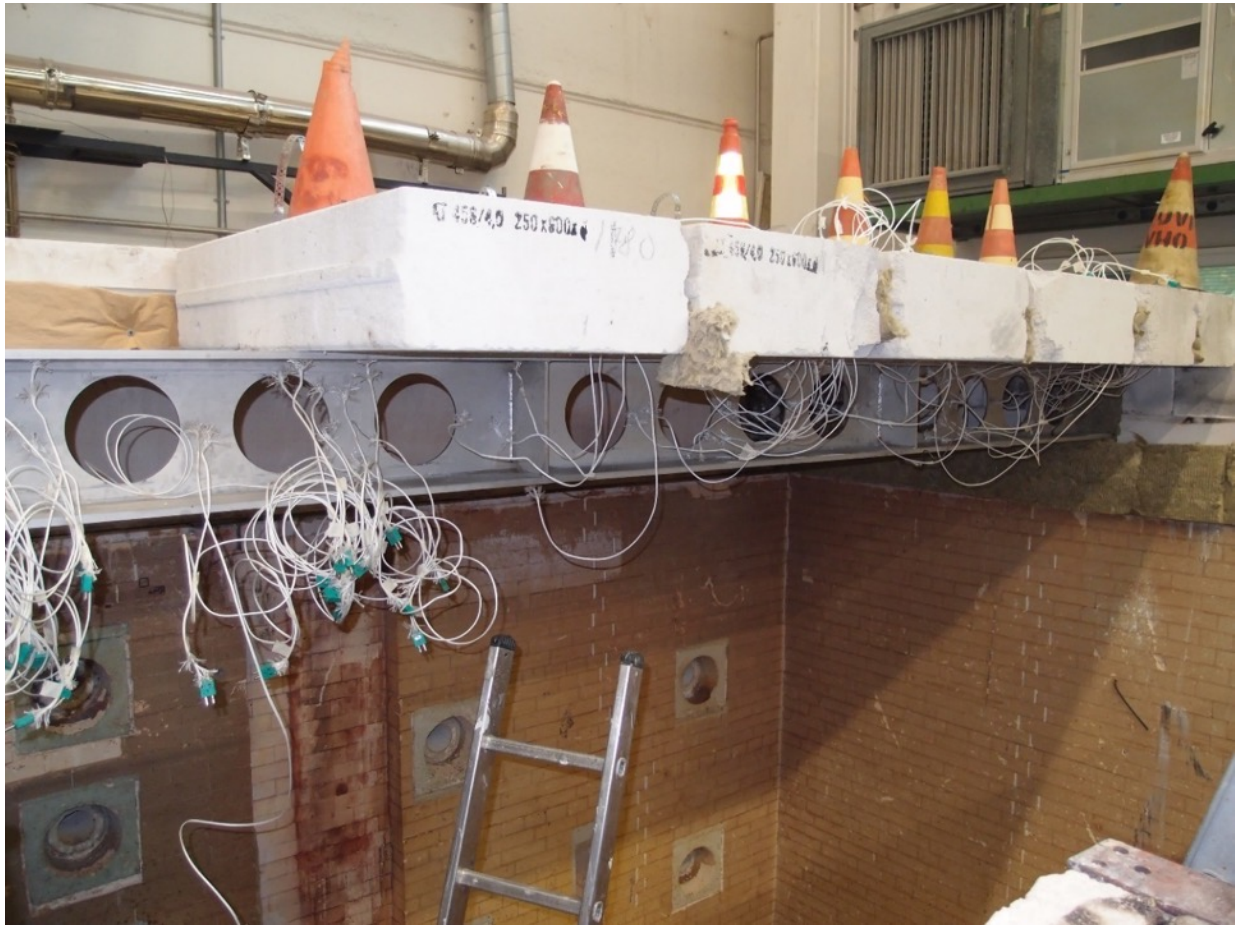
UKRI Research England

I3 grant

2019-24

Previous collaboration





Fire test on a stainless steel cellular beam

Current project: Behaviour of RWS connections, designed for seismic events, in fire

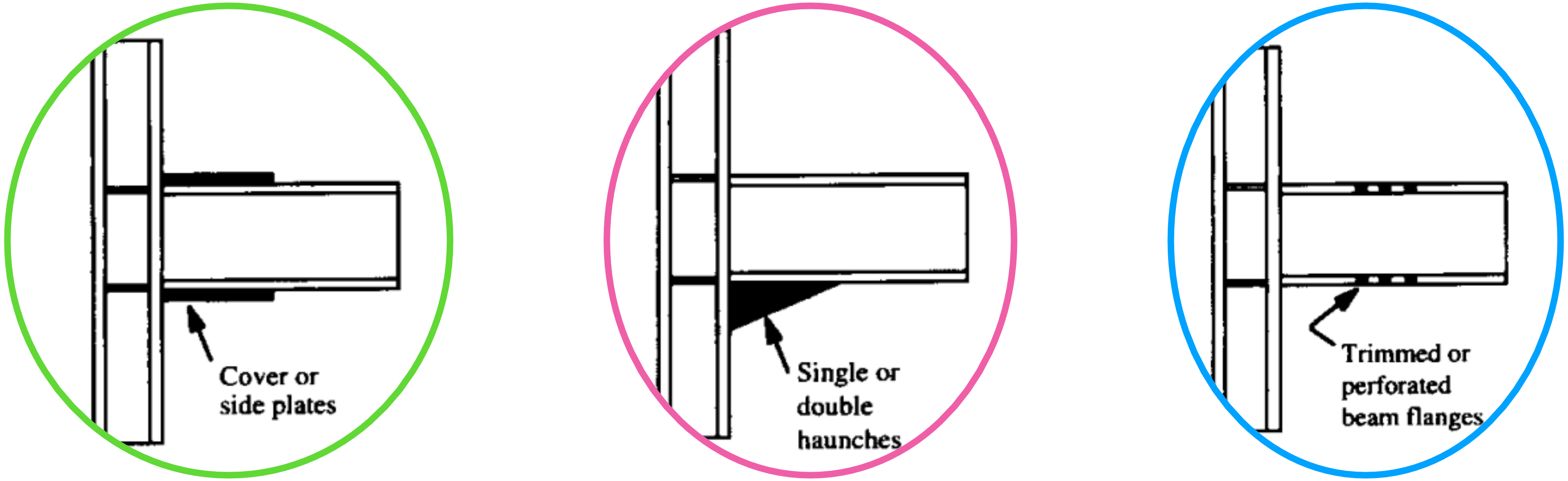
- Why is this important?
- What do we know already?
- What is the behaviour?
- How can engineers analyse the RWS connections under fire?

RWS connections – what and why…

The 1994 Northridge (California, USA) earthquake
The 1995 Kobe (Japan) earthquake

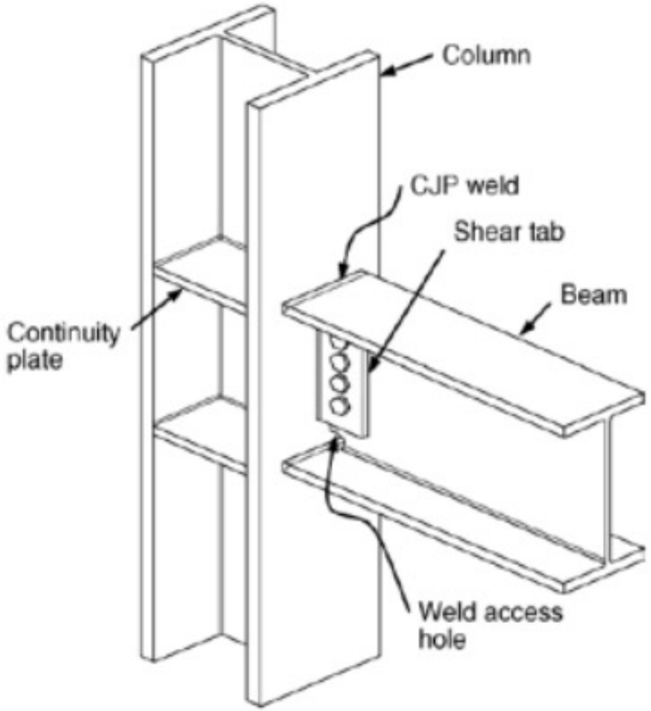
Failures observed in steel moment connections

Strengthening fixed connections

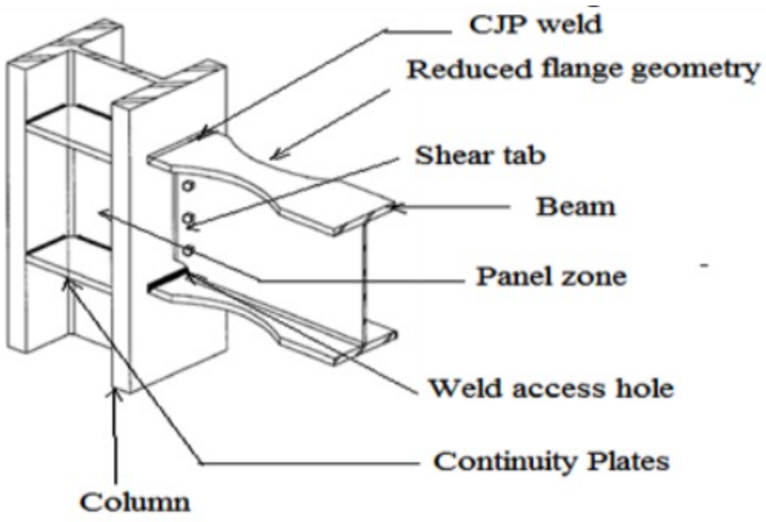


Typical approaches for modifying connections to steel plate move plastic hinge away from the column face

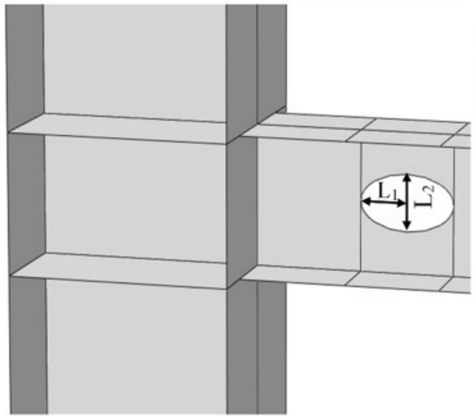
What are RWS connections?



Typical pre-Northridge beam-to-column moment connection



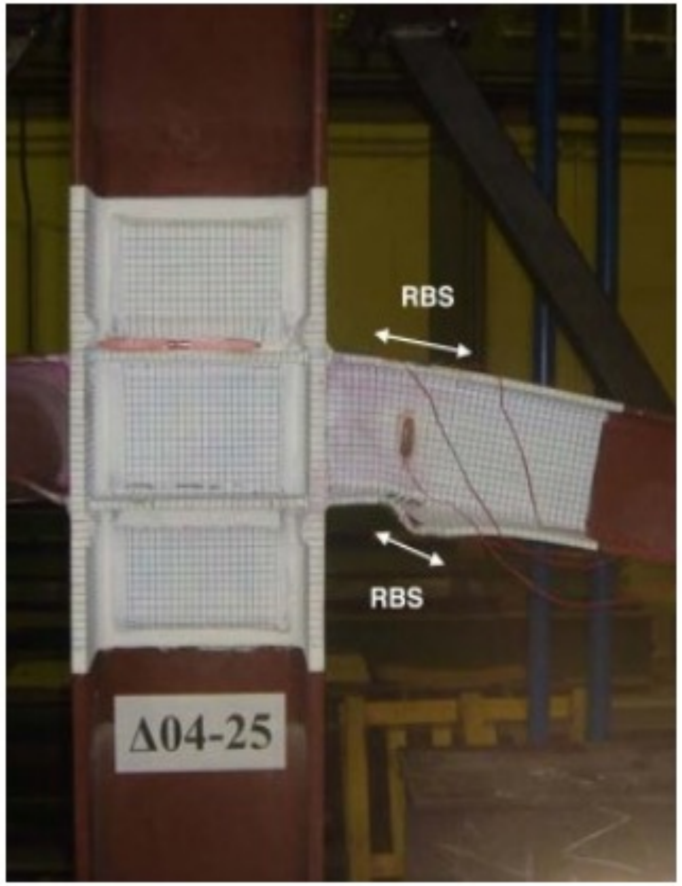
Typical reduced beam section (RBS) connection

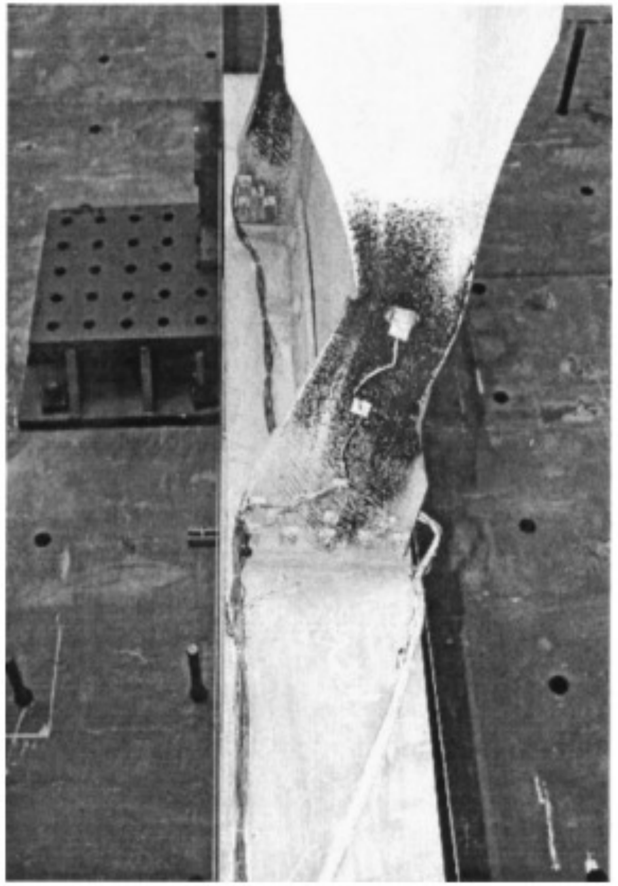


Typical reduced web section connection

Disadvantages of RBS connections?

- Susceptibility of the beam to LTB which ultimately leads to extensive strength degradation in the joint.
- Inability of the reduced portion of the flange to support the web can result in local web buckling.
- Column twisting in deep column connections as a result of lateral torsional buckling of the beam.





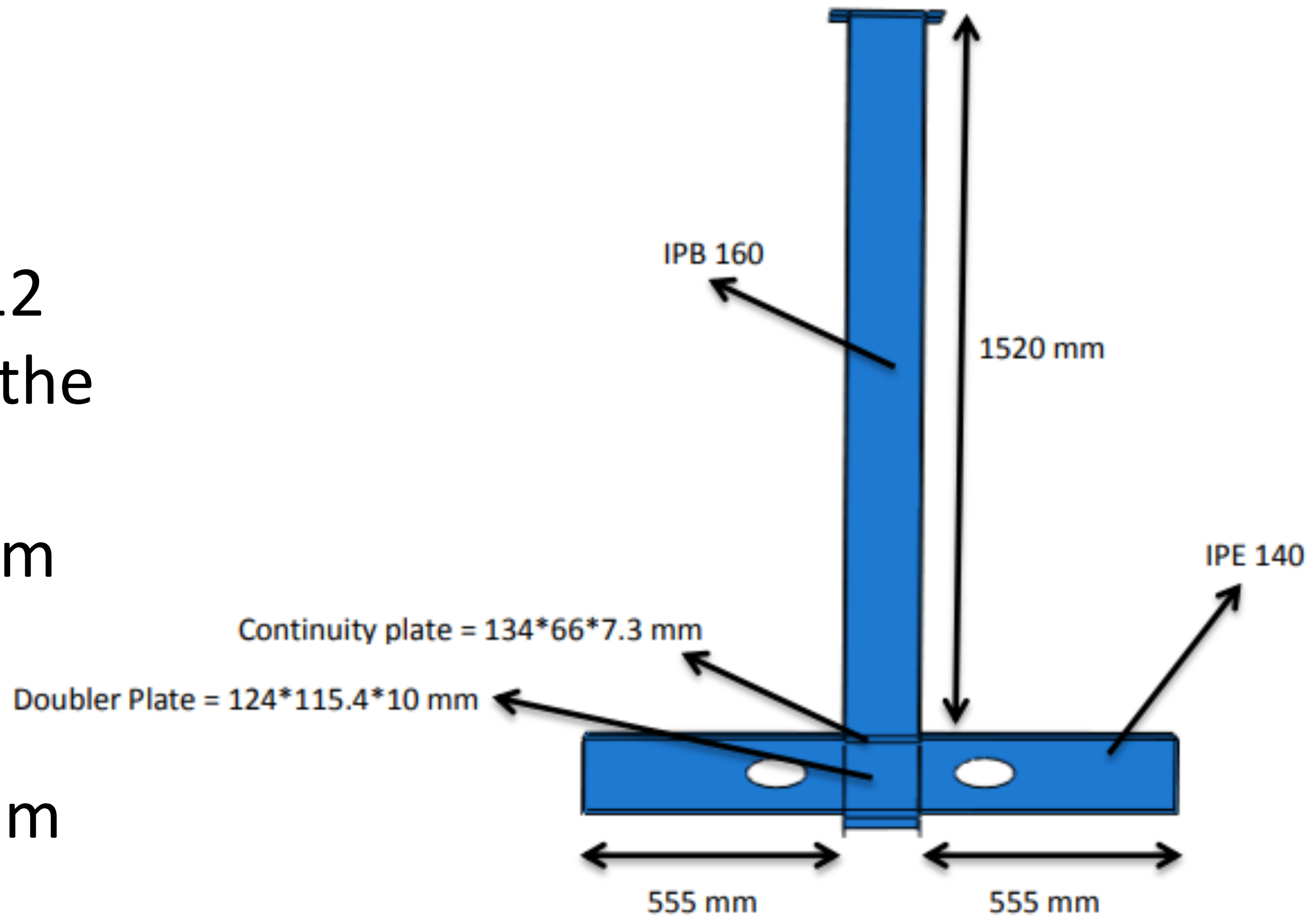
Buckling of Beam Bottom Flange (Pachoumis et al, 2010), Lateral Torsional Buckling of the Beam (Chi and Uang, 2002)

So, RWS connections…

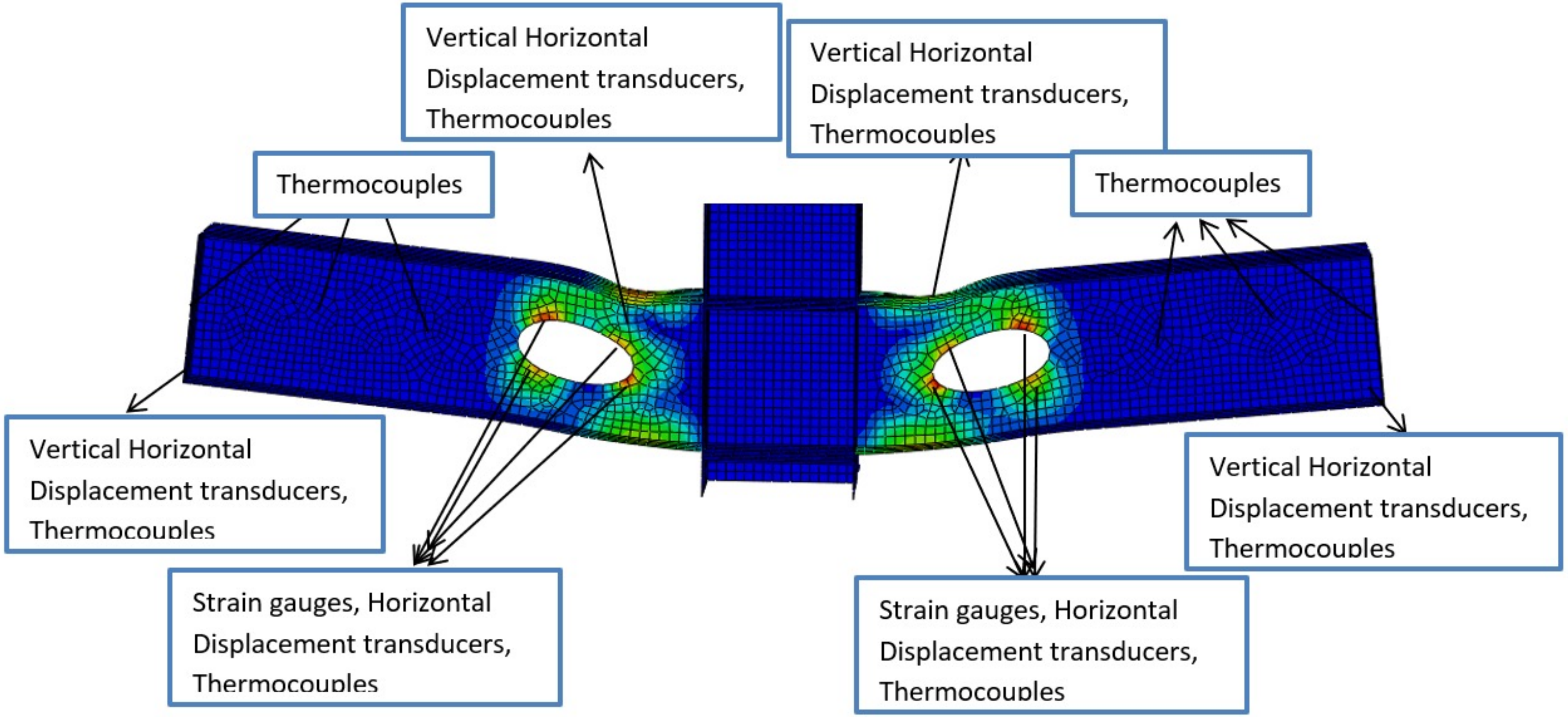
- Came about owing to the increased popularity of cellular beams
- Different web openings have been proposed
- All of the solutions proposed with openings:
    - Reduce stress concentrations at the connection;
    - Result in more ductile behaviour; and
    - Result in greater distance between the location of the plastic hinge, in the beam, and column face.
- But – how do they behave in a fire??

Experimental set-up

- S355 steel
- Column: HEB160
- Beam : IPE140
- Opening: height 56 mm, length 112 mm and horizontal distance from the face of beam end plate 70 mm
- Continuity plate: 134 × 66 × 7.3 mm (*4) to reinforce the web of the vertical post
- Doubler Plate: 124 × 115.4 × 10 mm



Experimental set-up - Instrumentation



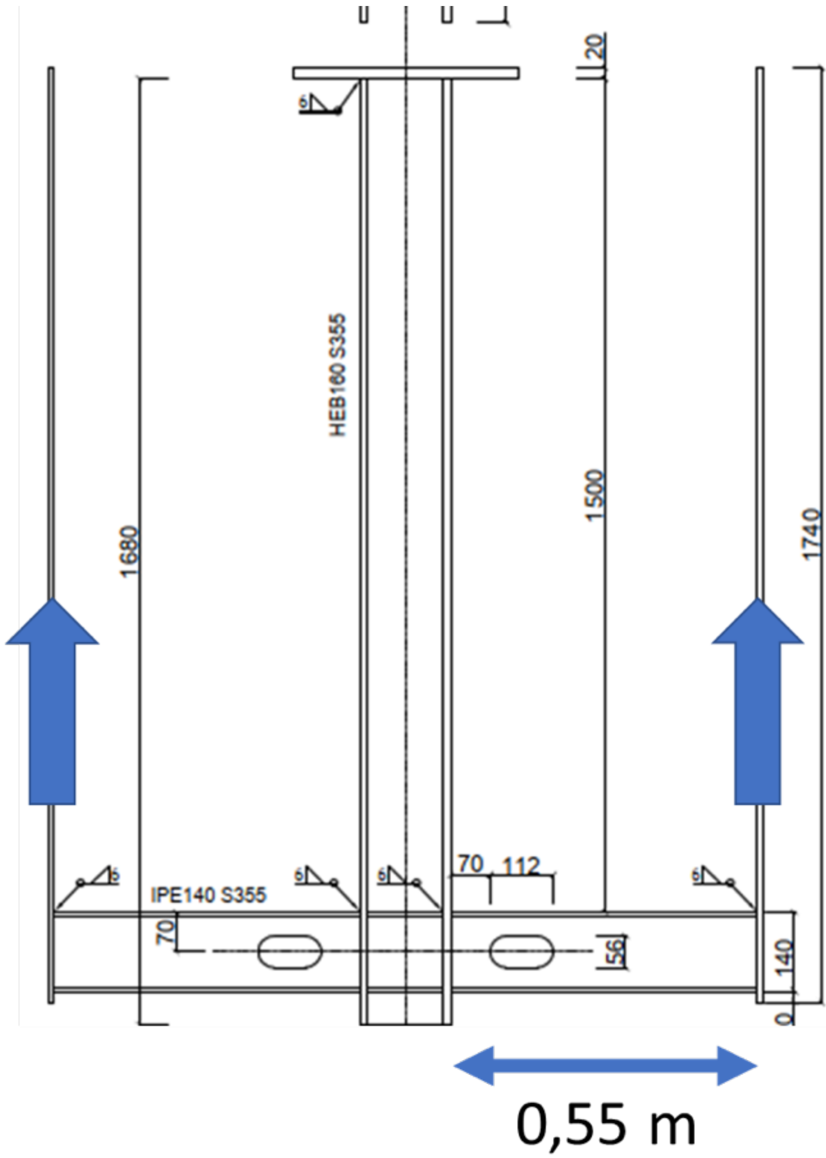
Material properties of the steel sections and plates

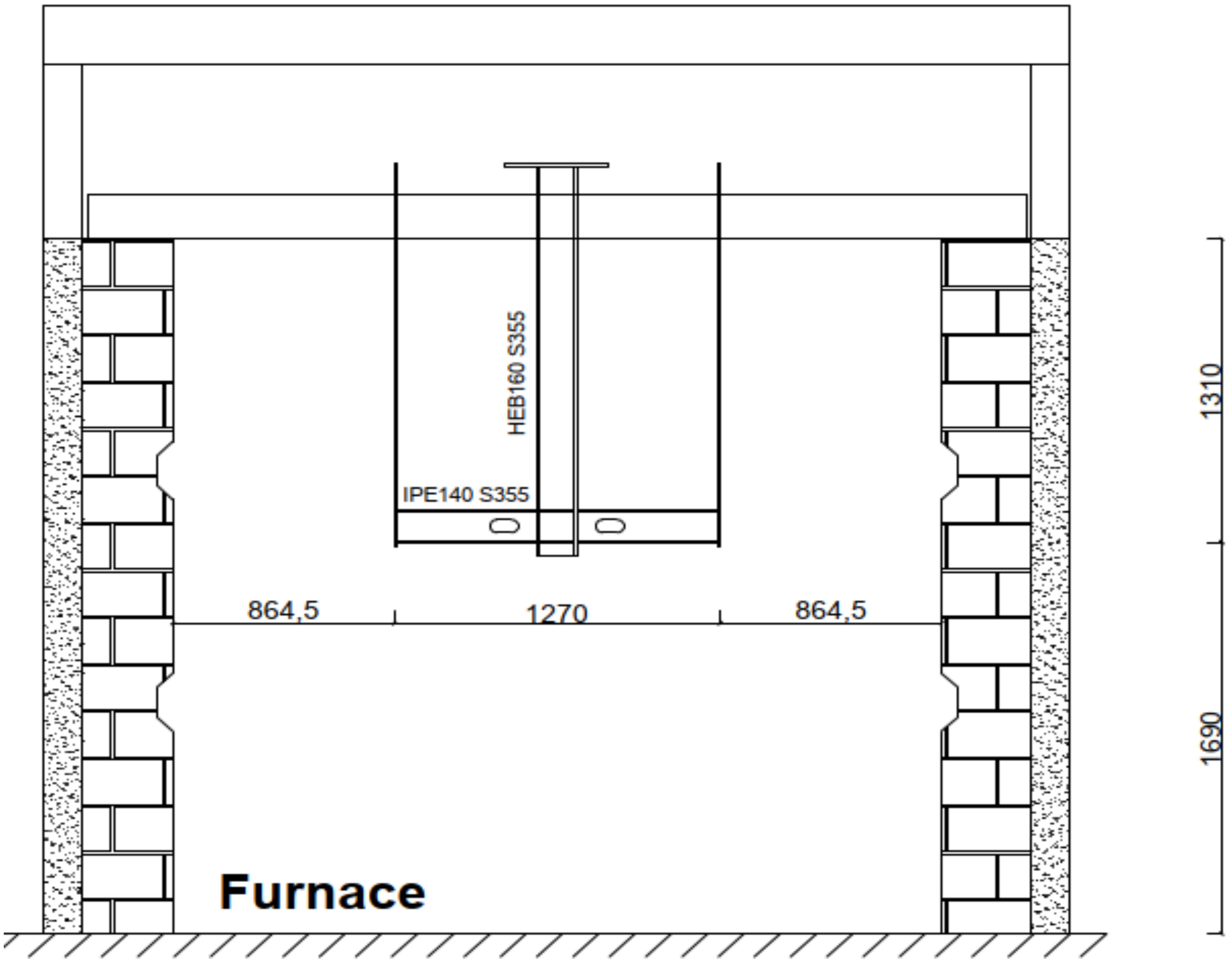
Profile		Test coupon	ε_u (%)	f_y (N/mm^2)	f_y Mean	E (N/mm^2) x 10^5	E Mean	f_u (N/mm^2)	f_u Mean
IPE140	Web	1	22.9	484	458	2.08	2.08	543	538
		2	25.3	454		2.09		537	
		3	24.5	437		2.08		533	
	Flange	1	25.3	435	401	2.07	2.06	547	540
		2	22.2	382		2.07		535	
		3	23.4	385		2.03		538	
HEB160	Flange	1	23.4	446	446	2.07	2.06	535	538
		2	24.8	454		2.05		537	
		3	23.3	437		2.05		543	
	Web	1	20.9	475	462	2.04	2.07	552	555
		2	18.3	464		2.06		557	
		3	23.3	446		2.12		556	
10 mm plate		1	22.0	553	553	2.04	2.03	585	584
		2	20.9	552		2.05		584	
		3	24.3	553		2.0		582	
8 mm plate		1	18.0	469	467	2.2	2.27	548	546
		2	18.6	468		2.3		548	
		3	20.8	465		2.3		543	

1. IPE 140
2. Plate with 8mm thickness
3. IPB160
4. Plate with 10 mm thickness

Experimental process

- Top of HEB160 post is fixed to the loading rig above the furnace
- Then, pull from the cantilever ends of the IPE140 beams.
- Loading: 30% of ambient temperature capacity
- Constant test load of 24 kN per beam end
- Test load is always a “best guess” as do not have ambient test data – used FE model as well as hand calculations
- Fire load – ISO 834 design fire

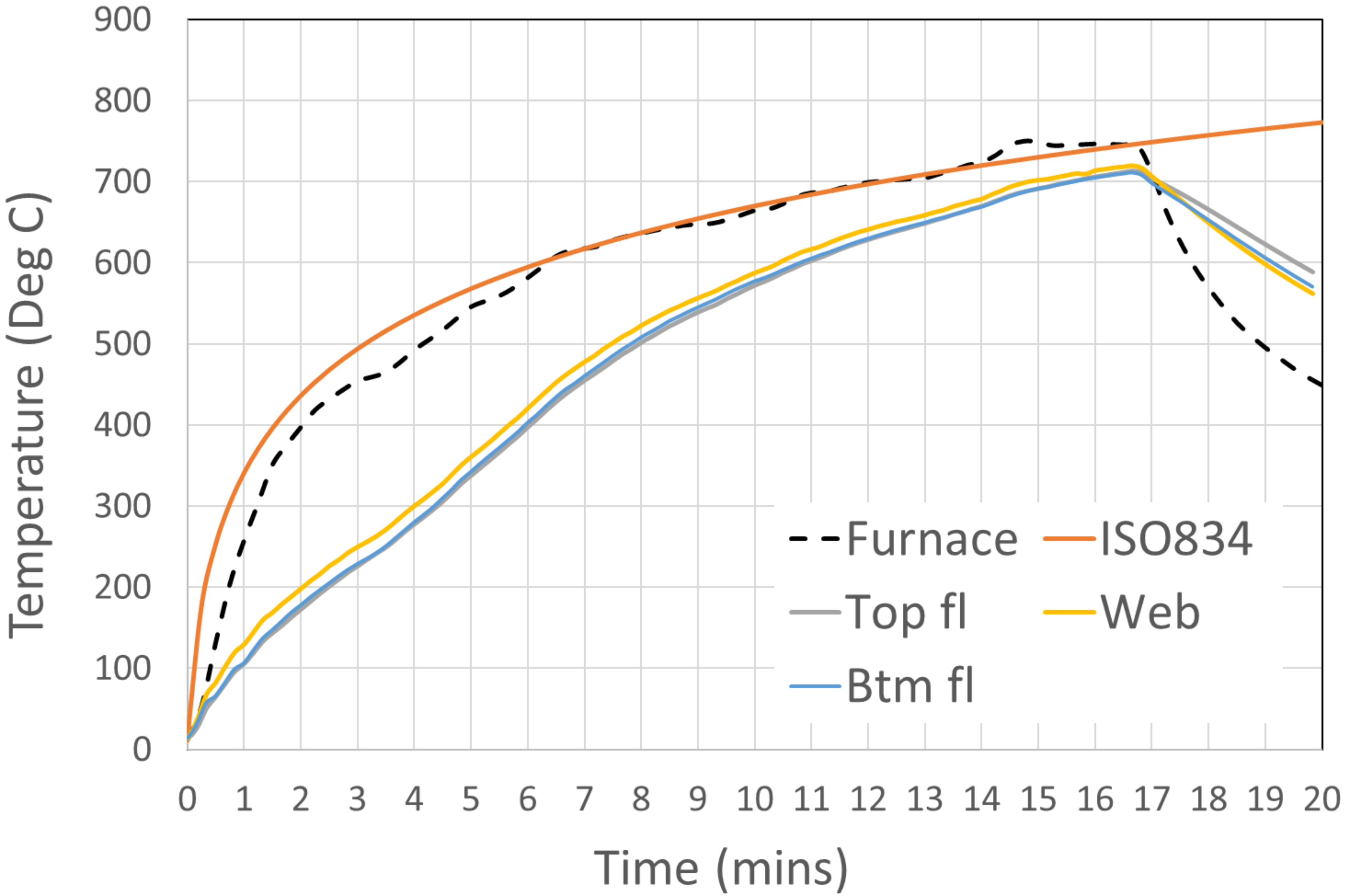




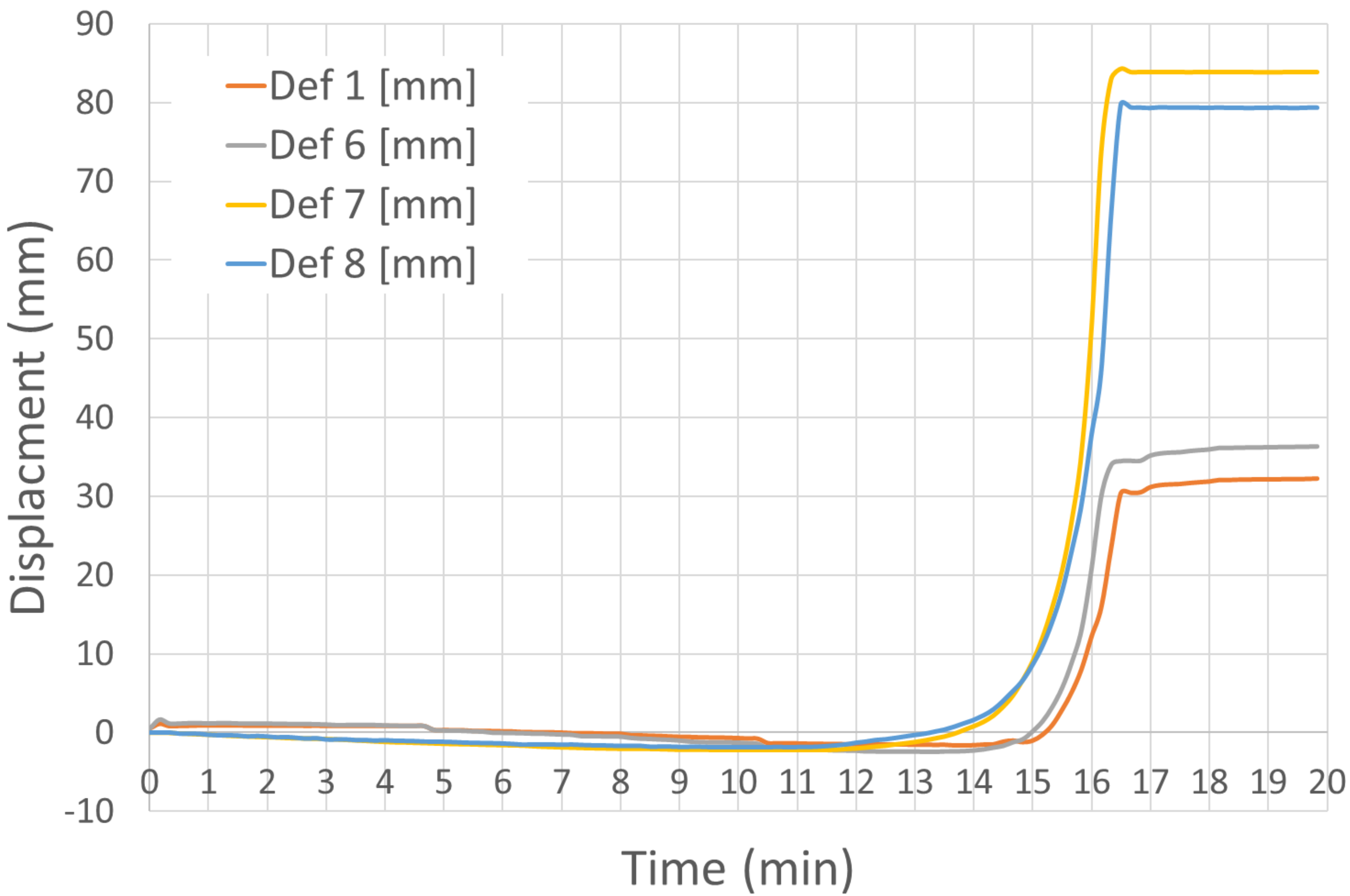
HEB160 S355
IPE140 S355
864,5
1270
864,5
1310
1690
Furnace


SARLIN
Furnaces

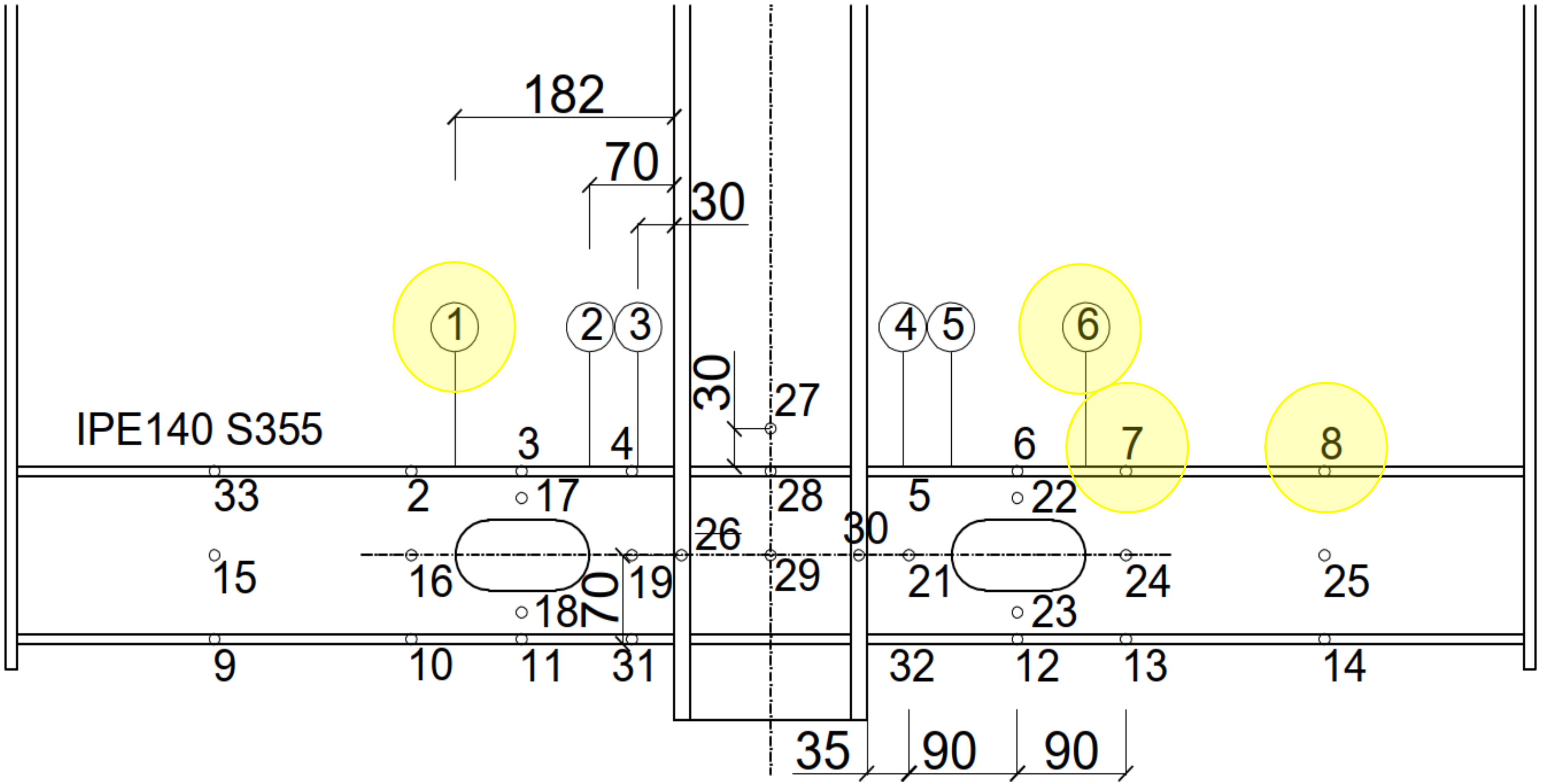
Temperature development



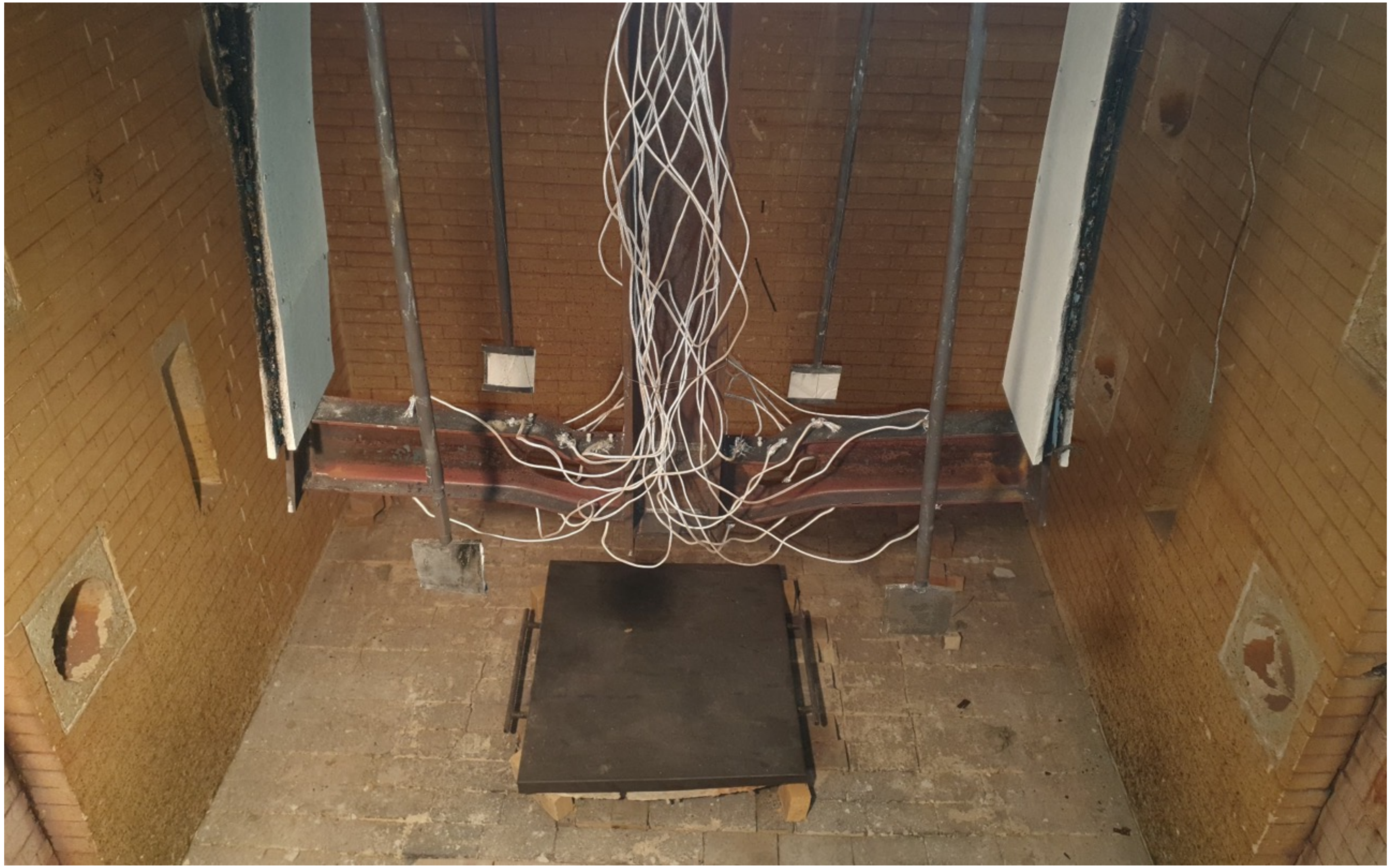
Displacement-time



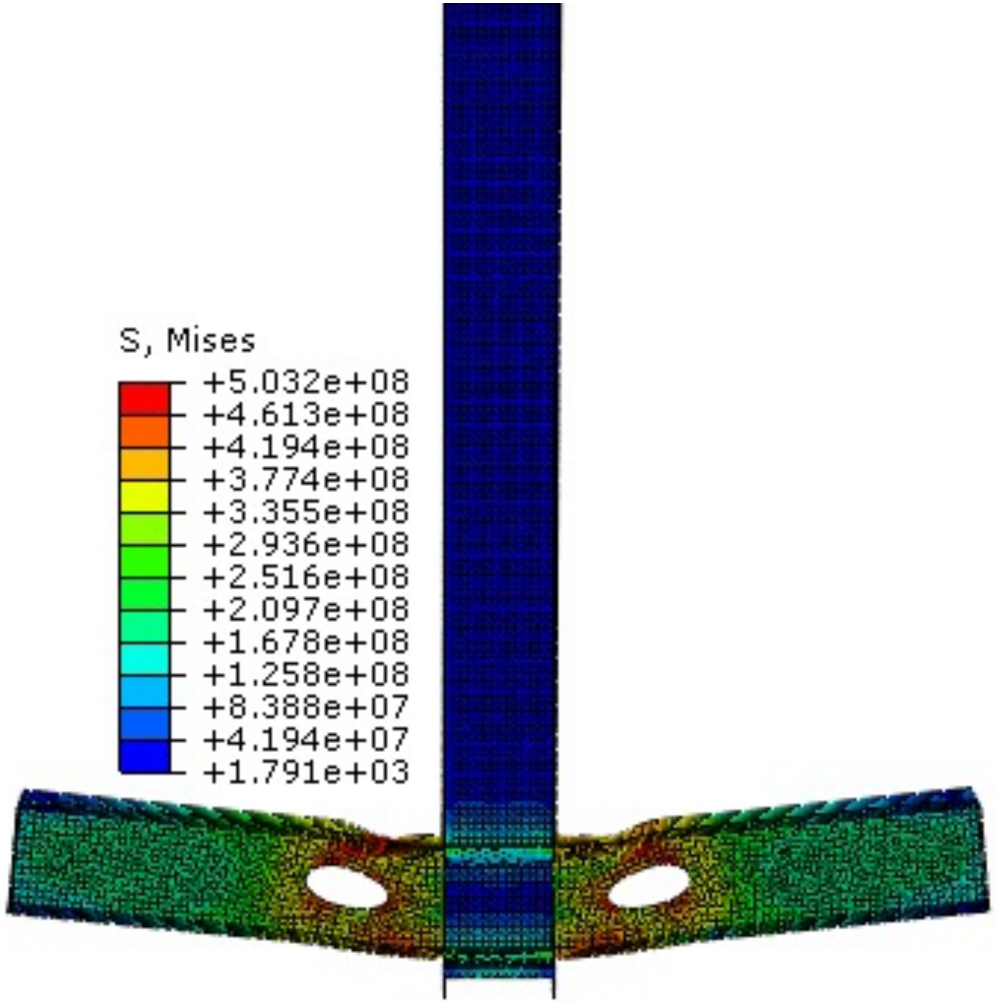
LVDT locations



Specimen after testing



Specimen after testing



Specimen after testing

Temperature after 15 minutes

@ opening at 15 mins:
Web = 703°C, Flange = 692°C

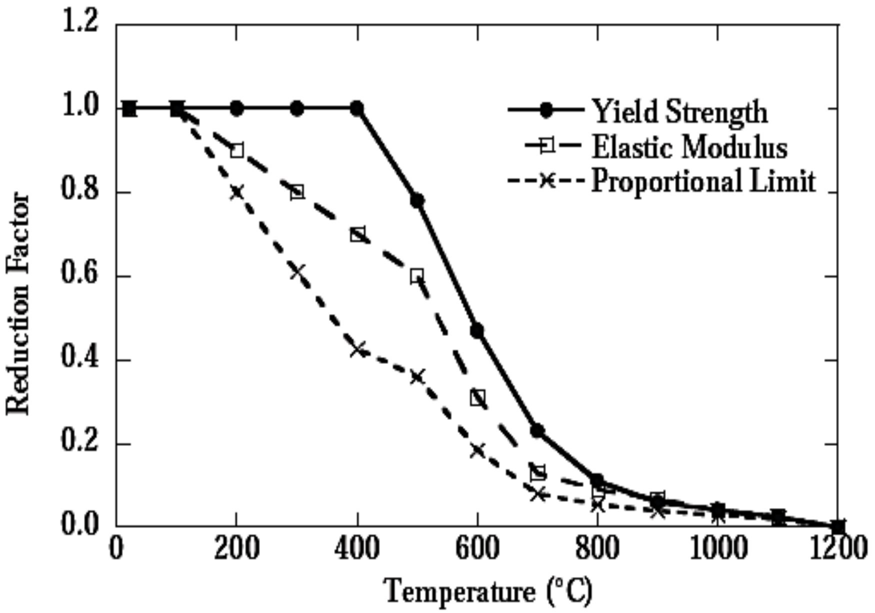
EN1993-1-2: @ 700°C,
$k_y = 0.23$ and $k_E = 0.13$

MP	Location	Temp. at 15 minutes °c	Average °c
2	Top flange	694	
3	Top flange	684	
6	Top flange	692	692
7	Top flange	699	
8	Top flange	696	
33	Top flange	685	
4	Top flange, near column	605	611
5	Top flange, near column	617	
16	Web at opening	710	
17	Web at opening	694	700
18	Web at opening	697	
22	Web at opening	695	
23	Web at opening	699	703
24	Web at opening	716	
19	Web at opening, near col	632	634
21	Web at opening, near col	635	

MP	Location	Temp. at 15 minutes °c	Average °c
15	Web	701	703
25	Web	705	
10	Bottom flange	693	
11	Bottom flange	689	
12	Bottom flange	697	692
13	Bottom flange	696	
14	Bottom flange	685	
31	Bottom flange, near col	624	625
32	Bottom flange, near col	627	
27	Column web	546	546
30	Column flange	545	545
28	Web stiffener	547	547
29	Web doubler	485	485

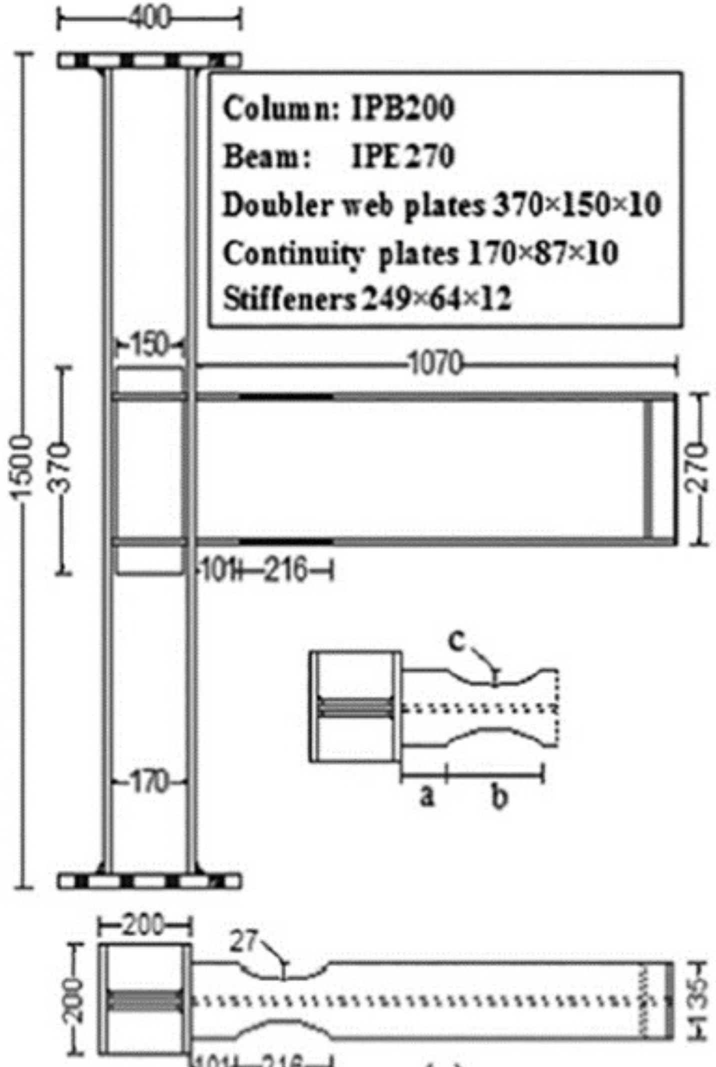
Development of the FE model

- Originally developed to help design the test
- Using ABAQUS
- Validation of the numerical modelling approach was carried out in 2 stages:
    1. Using the tests on RWS (and RBS) connections under cyclic loading tested by Davarpanah et al https://doi.org/10.1016/j.jcsr.2020.106319
    2. Using the tests on steel connections in fire carried out by Lee et al (https://doi.org/10.1016/j.jcsr.2011.02.014)
- At elevated temperature, reduction factors for the change in mechanical properties are taken from EN 1993-1-2

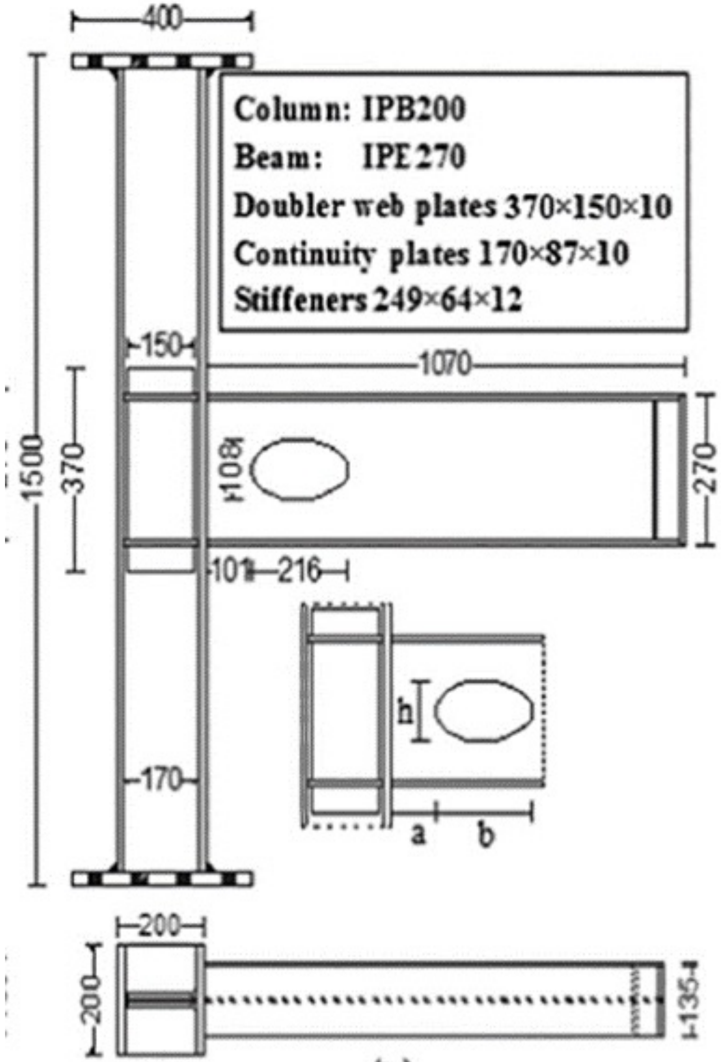


1: Tests on RWS (and RBS)

REF:



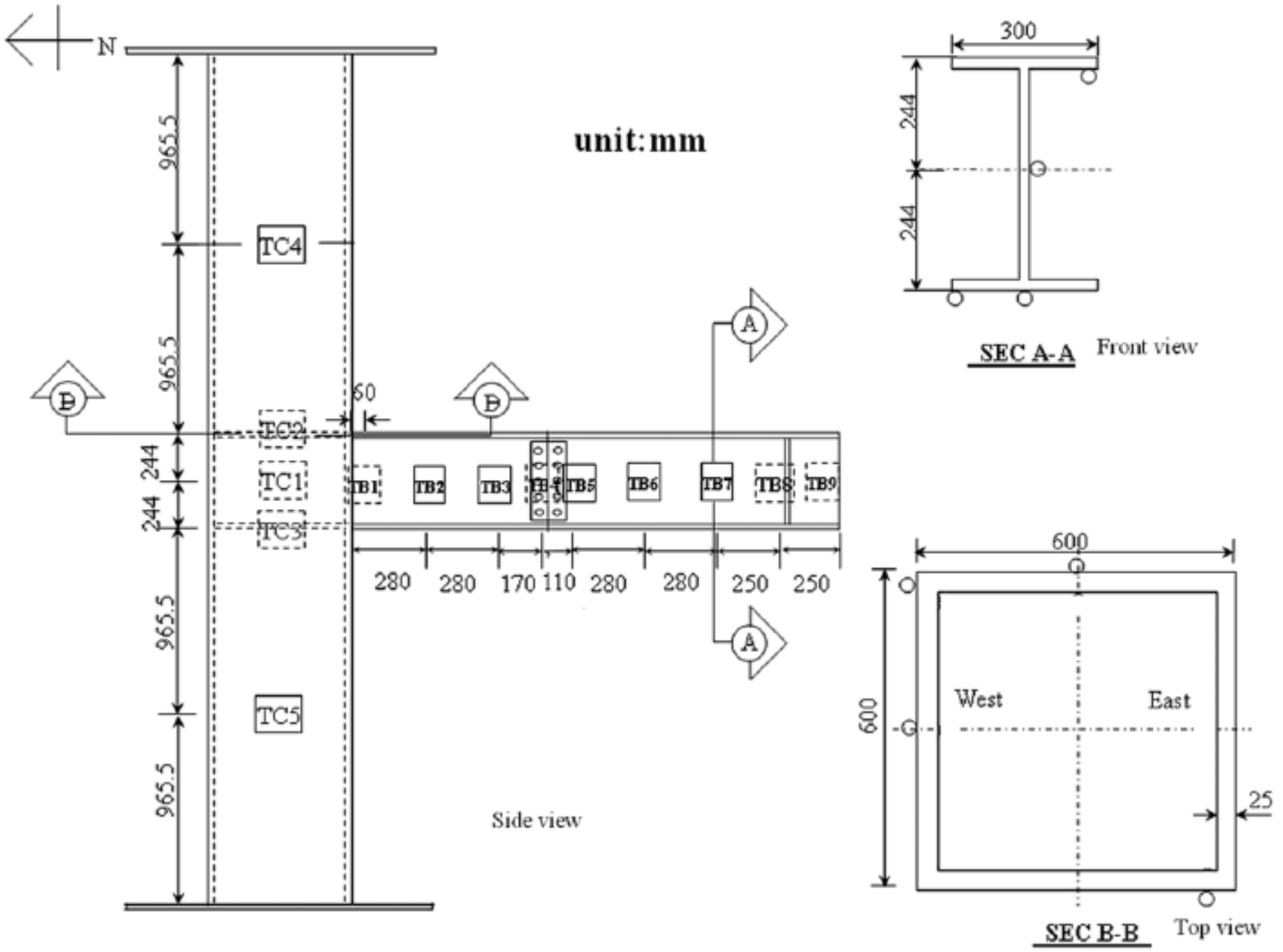
(a)



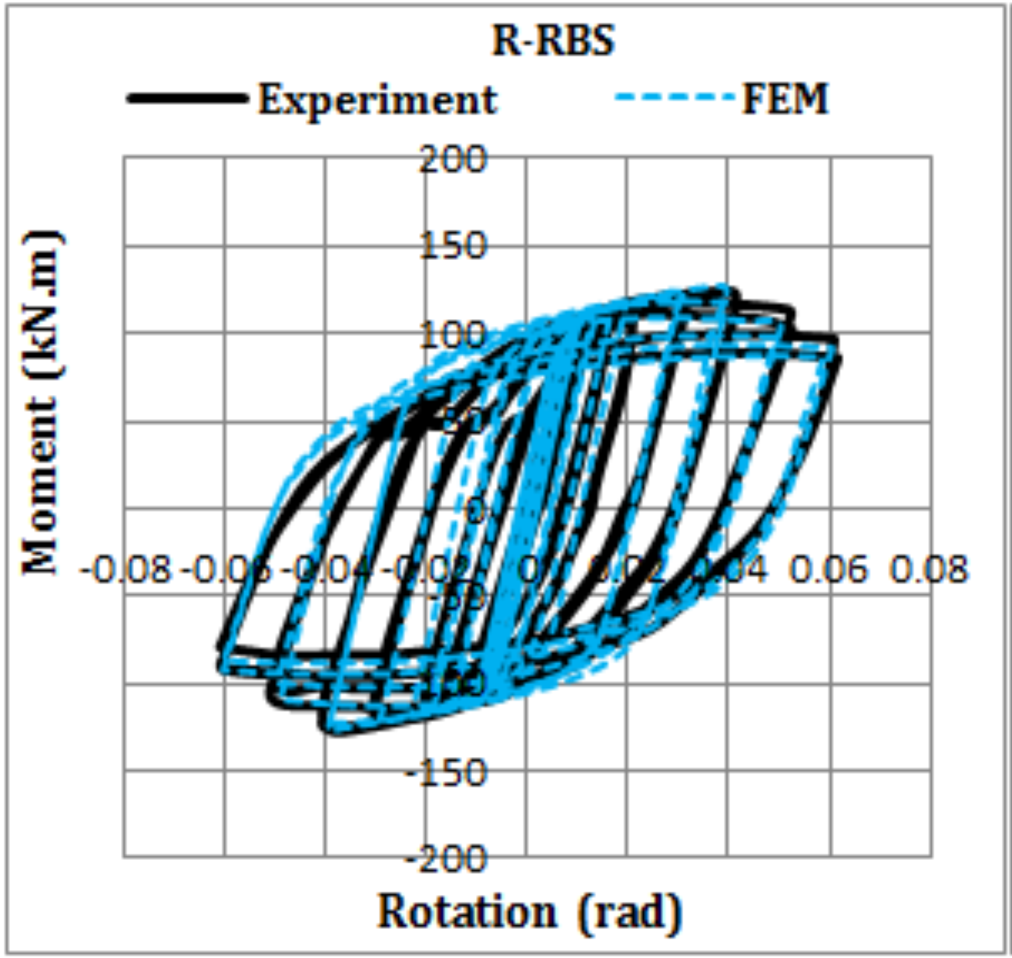
(b)

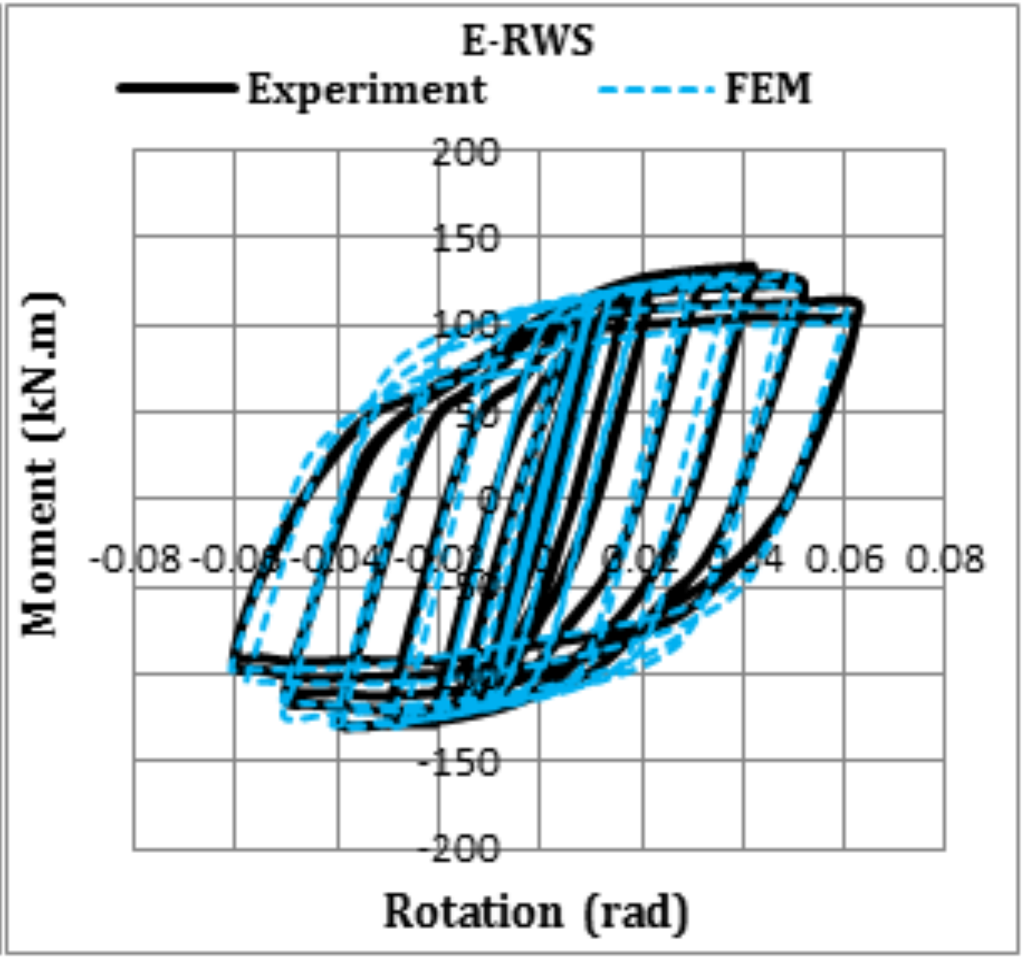
2: Fire test on steel connection

REF:

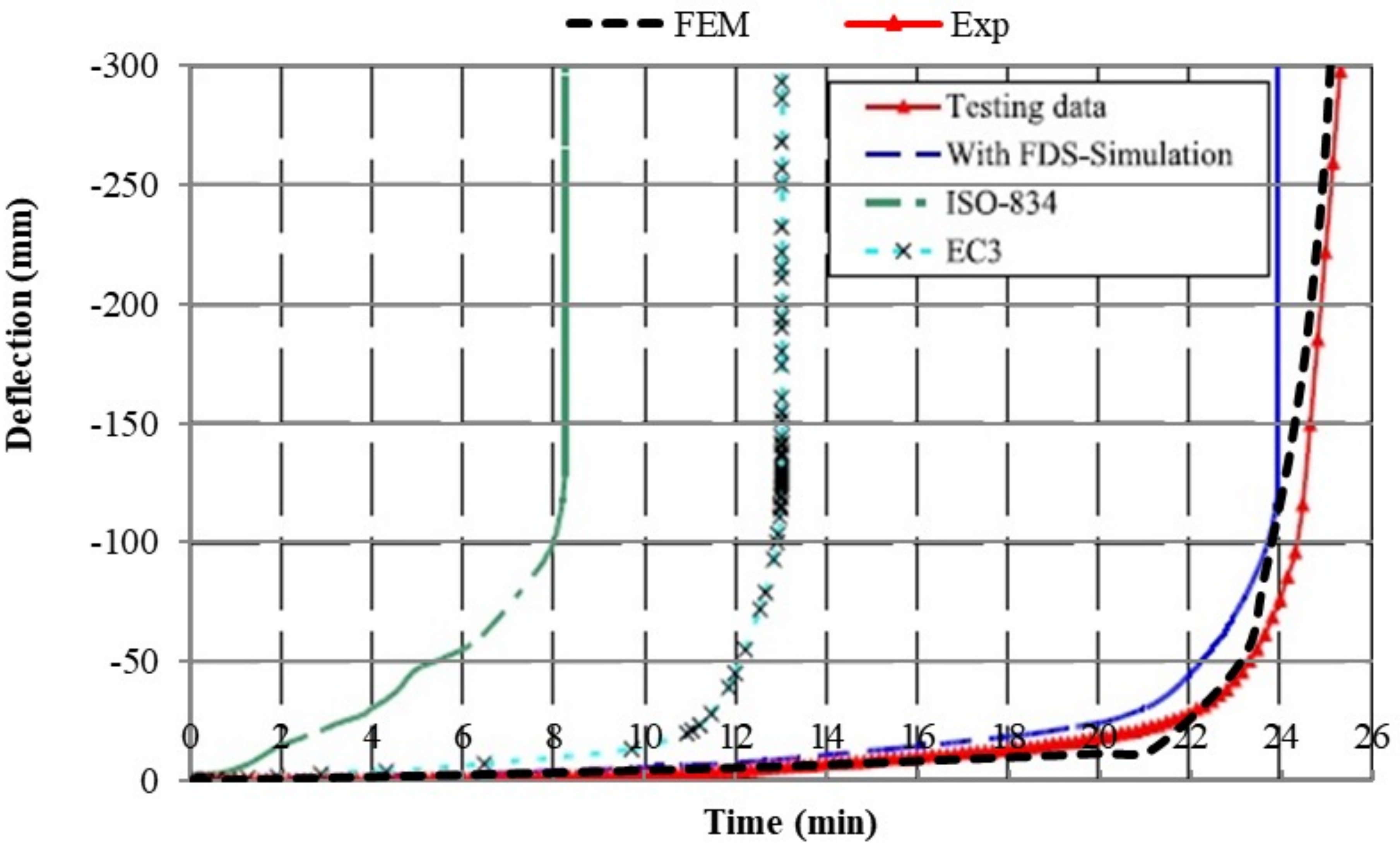


1. Validation of the FE model RBS/RWS (under cyclic loading)

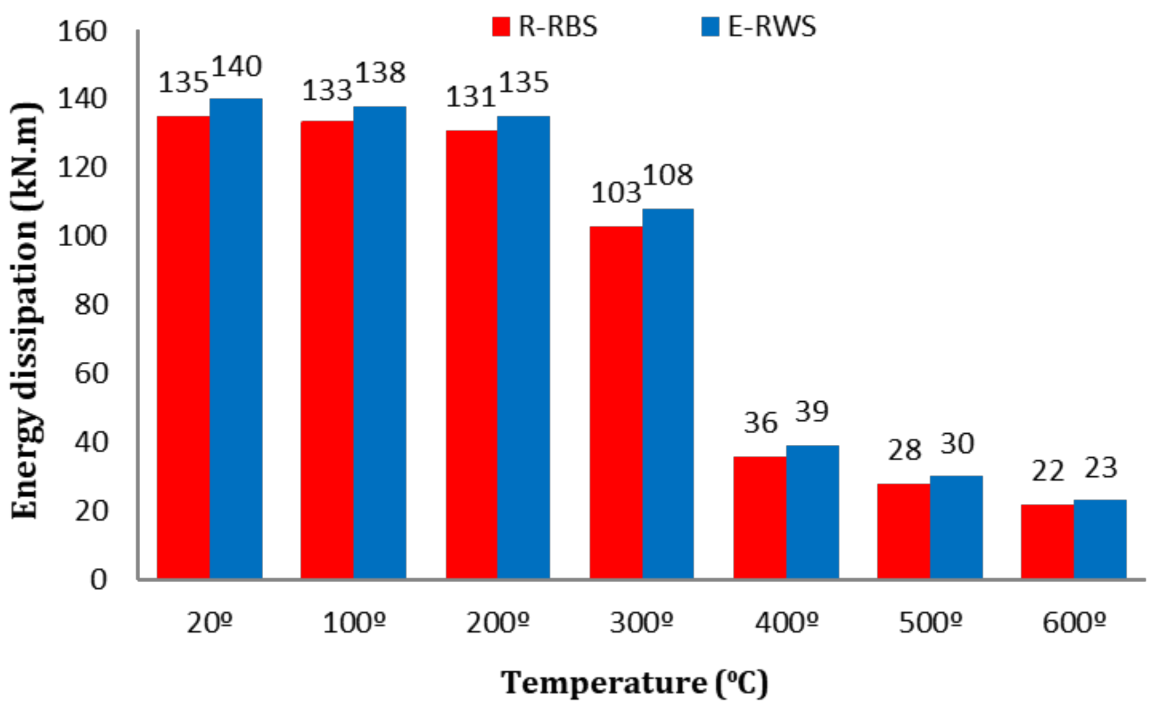


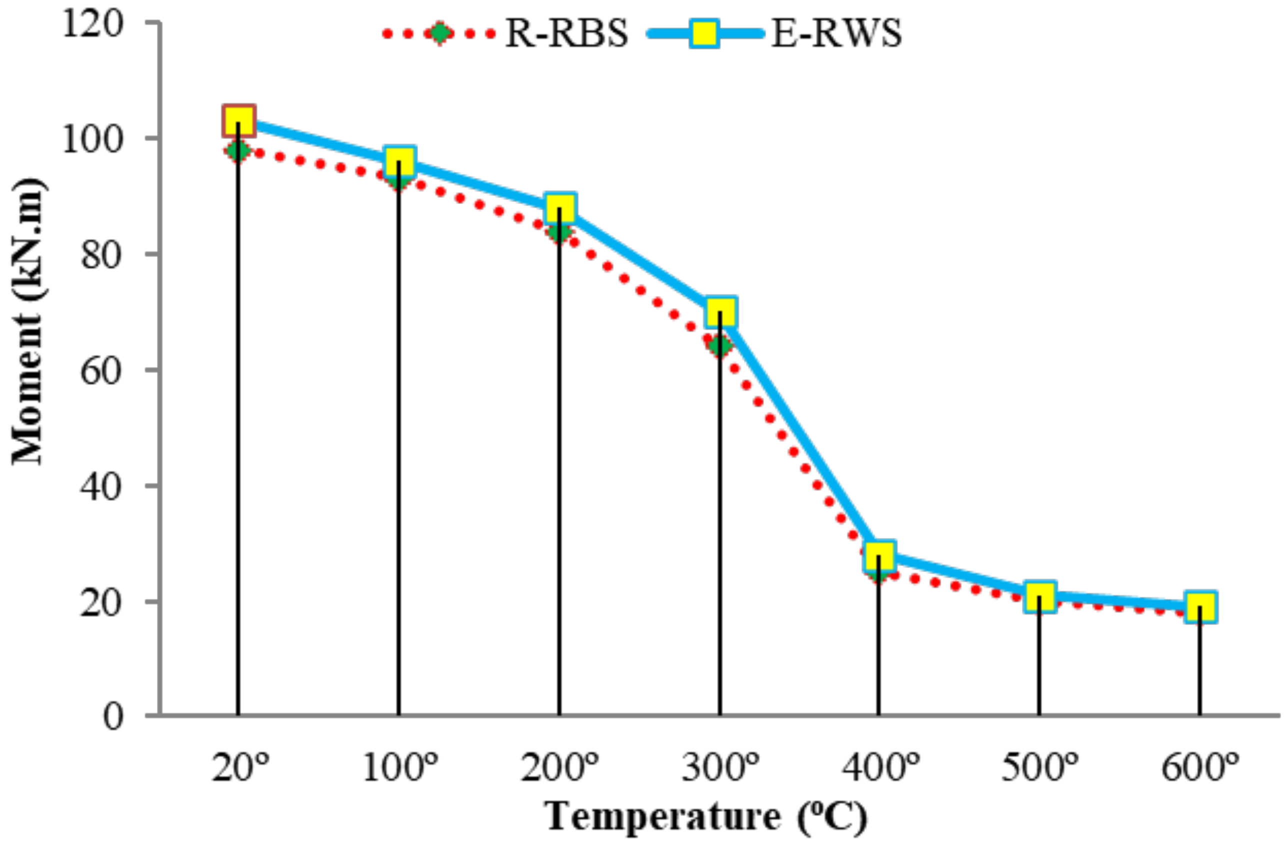


2. Validation of the FE model for elevated temperature



Results & discussion





Thank you – any questions?

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