

The 9th International Conference on Coupled Instabilities in Metal Structures

Application of Spot-Welded Built-up Cold-Formed Steel Beams with Corrugated Webs in Frame Structures - Parametric FE Study

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Motivation

COLD-FORMED STEEL SECTIONS

ADVANTAGES

- high strength
- lightweight
- excellent corrosion resistance
- material savings
- structural efficiency ...

Not so advantageous

- local, distortional, global buckling and their interaction
- singly-, point-, or non-symmetric open sections – low torsional rigidity (eccentricity between shear and gravity centers)

- **Built-up CFS members** → improved torsional stiffness, higher load-bearing capacity, doubly symmetric and more favorable structural behavior compared to individual open CFS sections → **Application as primary elements with greater spans**



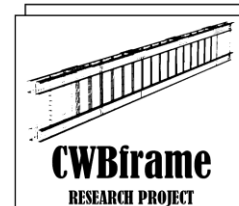
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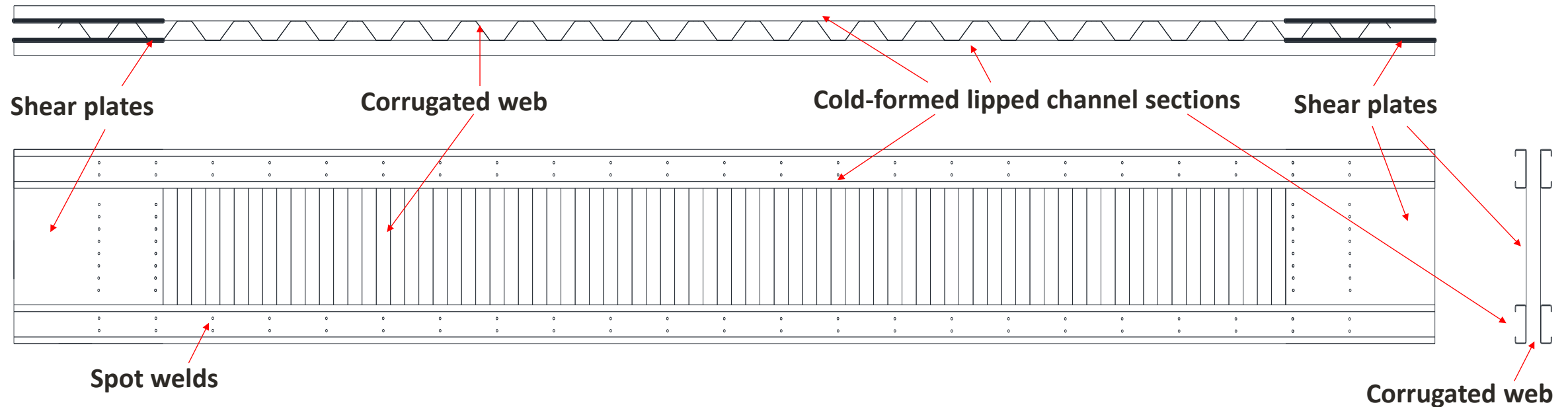


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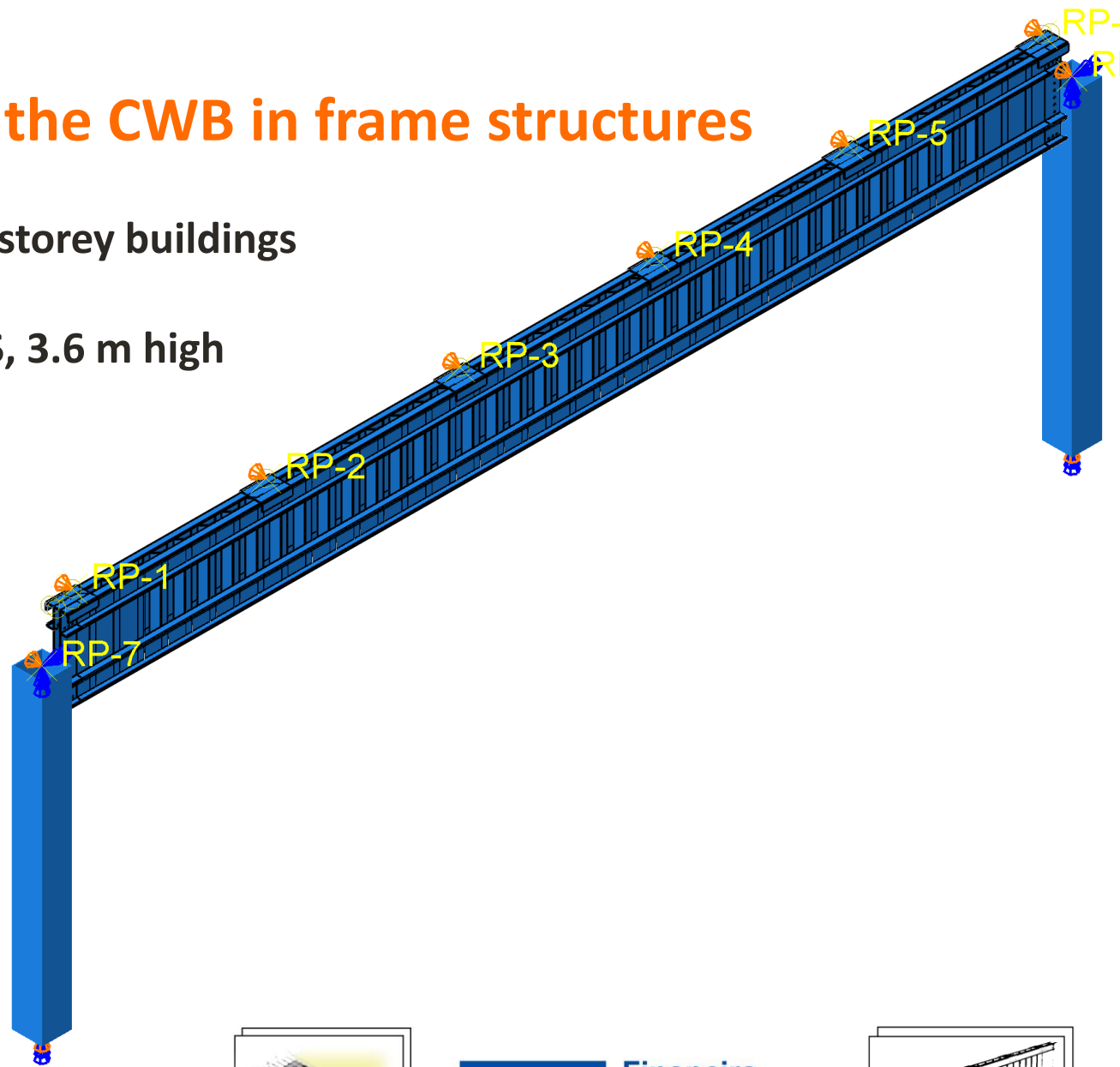
CWB – Corrugated web beam

- Built-up beam composed of lipped channel sections acting as flanges and a corrugated web
- Connected with spot welds
- Mechanics – analogous to trusses



Application of the CWB in frame structures

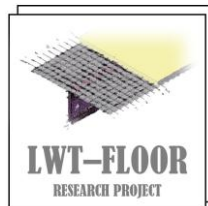
- Variant 1 – multi-storey buildings
- Span – 10 m
- Columns – CF SHS, 3.6 m high



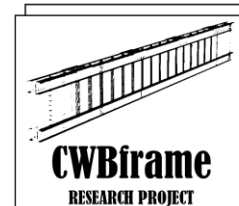
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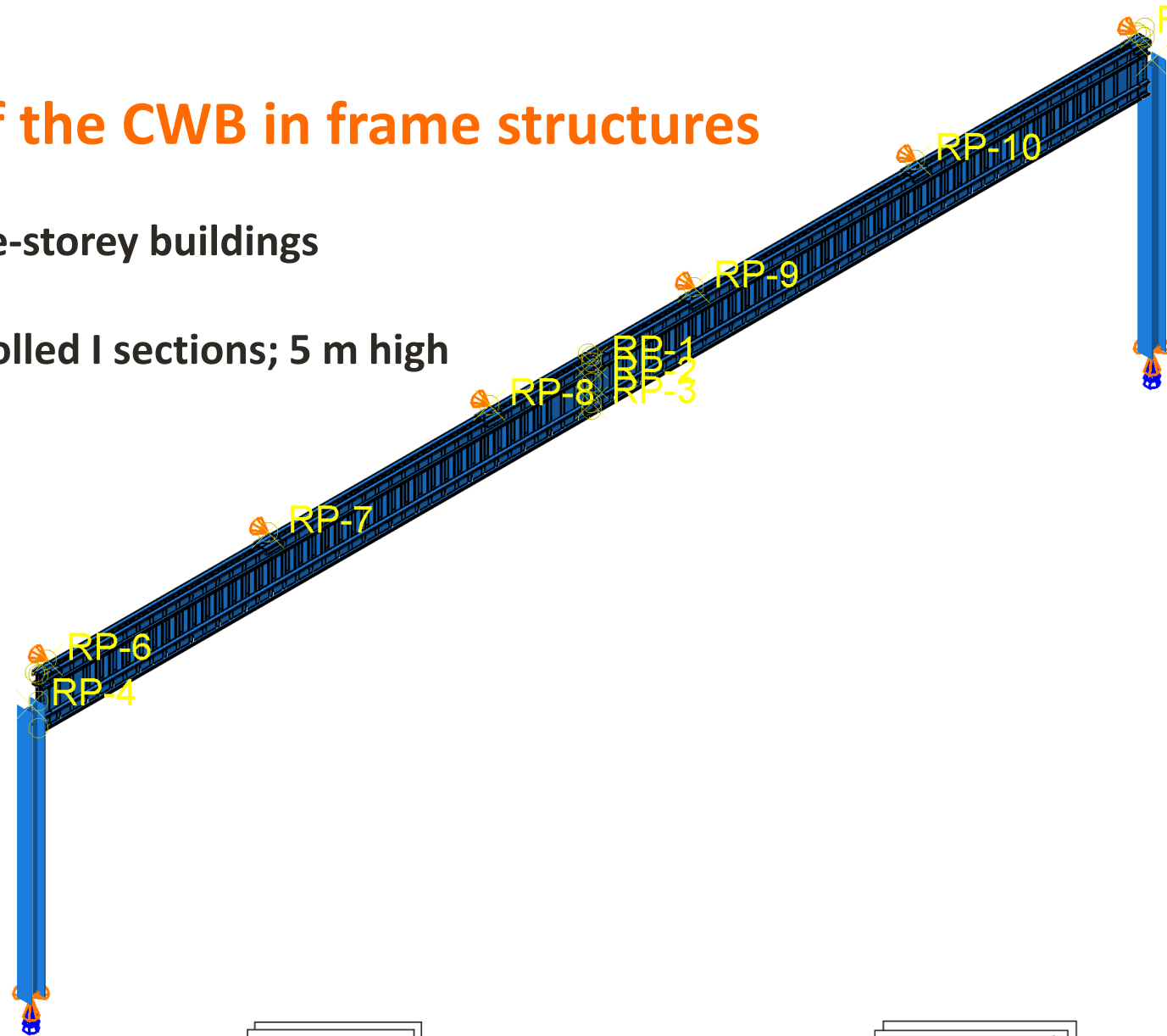


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Application of the CWB in frame structures

- Variant 2 – single-storey buildings
- Span – 20 m
- Columns – hot-rolled I sections; 5 m high



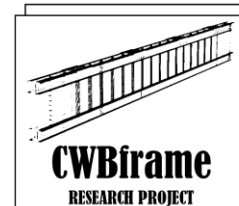
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Preliminary analysis

- **Variant 1**

- 10 m span
- 6 m spacing between frames
- floor system: lightweight composite floor system – LWT-FLOOR - dead load: $1.75 \text{ kN/m}^2 + 1.3 \text{ kN/m}^2$ (floor layers)
- live load : 2.0 kN/m^2

- **Variant 2**

- 20 m span
- 5 m spacing between frames
- dead load: 0.5 kN/m^2
- snow : 2.0 kN/m^2

- **CWB dimensions**

- Height of the CWB and lipped channel sections – in accordance with SLS criteria ($L/250$), only lipped channel sections are considered in calculation of the moment of inertia of the CWB
- Corrugated web thickness – according to EN 1993-1-5, Annex D

- **Adopted height of the CWB for both variants – 840 mm**

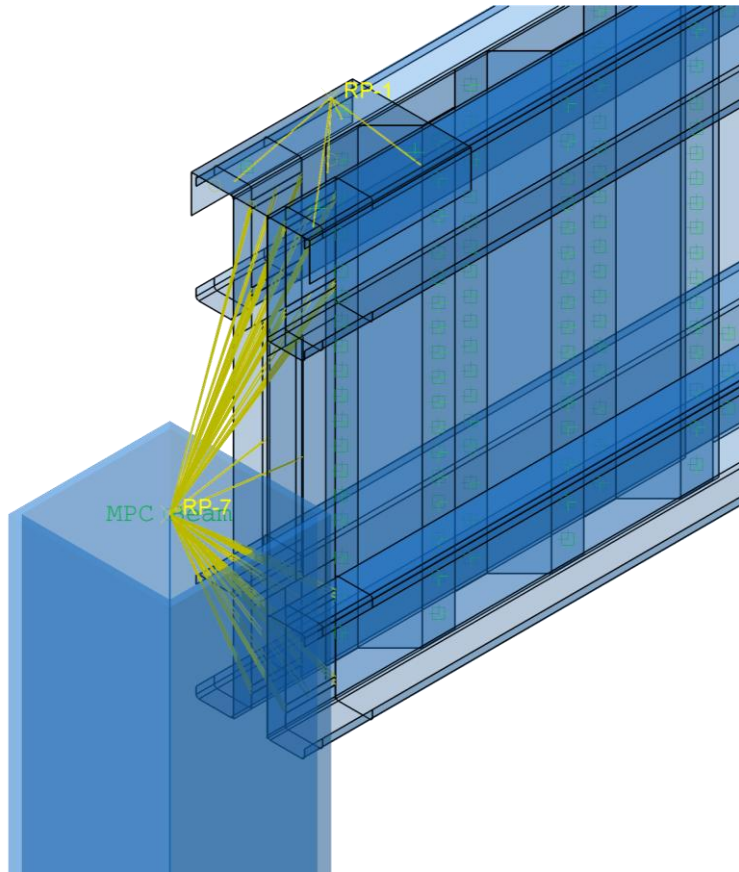
- **Lipped channel sections – C200**

Numerical modelling

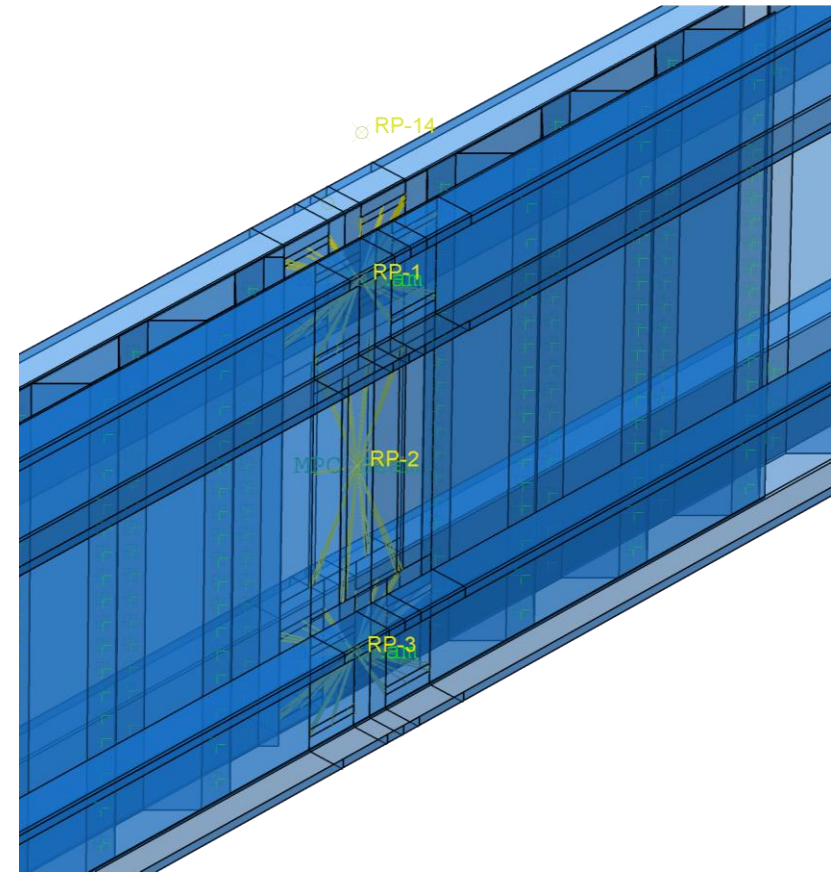
- **ABAQUS/CAE - GMNIA**
- **FEA models of the CWB frame were developed in accordance with model validated against bending test results**
- Mesh sizes (15 mm for all CWB components) – S4R 4-node doubly curved thin or thick shell, reduced integration, hourglass control, and finite membrane strains
- Material characteristics – tensile tests on the coupons – true stress-logarithmic plastic strain curve
- Spot welds – point-based fasteners, bushing type connection defined according to experimental results of the tensile shear test: elastic, plastic, damage and failure characteristics were modelled
- General contact was used with the following parameters: normal direction - hard contact; tangential direction - friction with a coefficient of 0.1; and separation was allowed
- Columns - B31, a 2-node linear beam elements in space
- Column material – $E=210\,000\text{ MPa}$, $\nu = 0.3$, $f_y=350\text{ MPa}$, $f_u=490\text{ MPa}$ ($\epsilon=0.18$)

Numerical modelling

- Beam-to-column connection



- Beam-to-beam connection



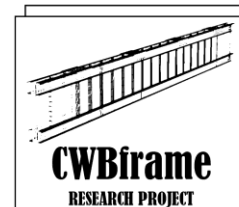
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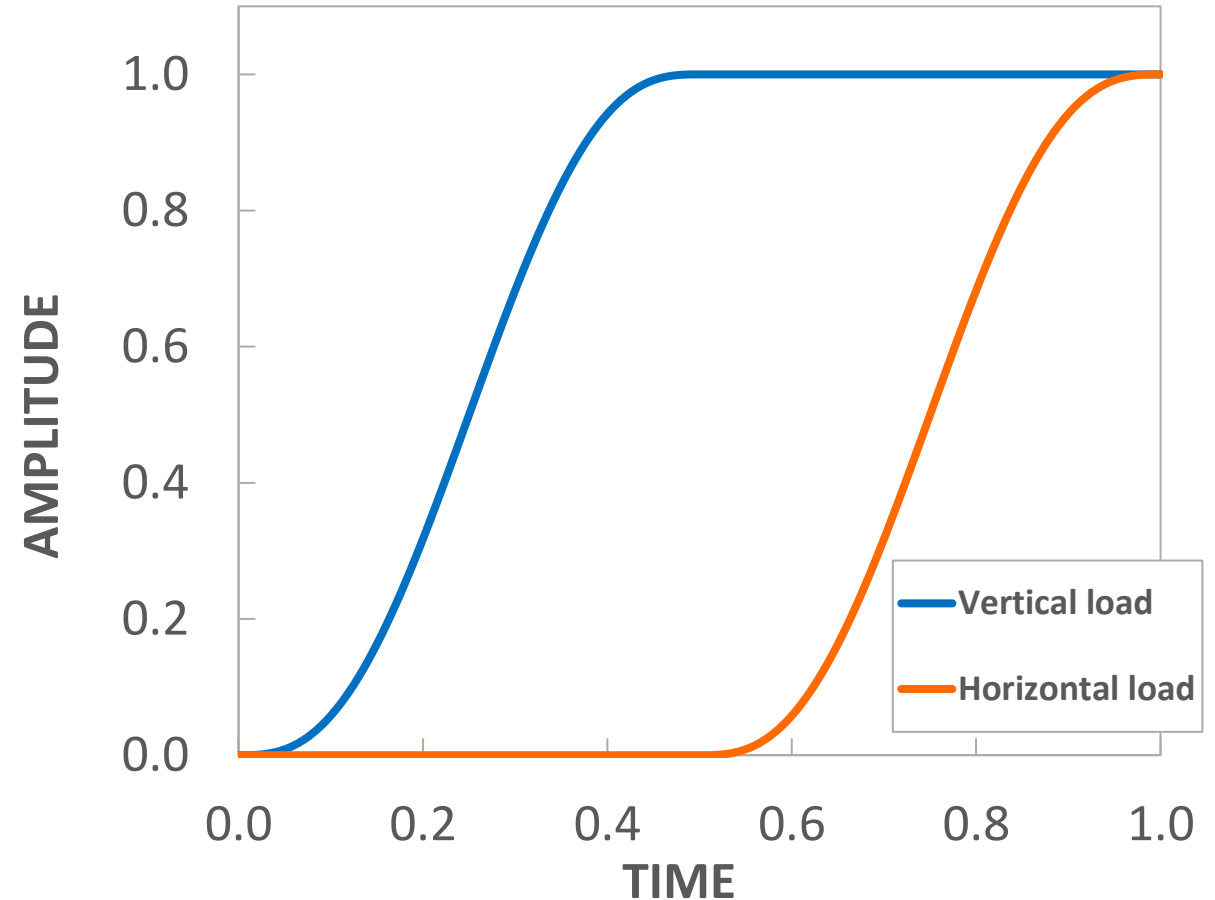


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Numerical modelling

- **Loading**
 - **Vertical load:** defined as a concentrated loads in the reference points at the position of the purlins in the case of the CWB frame intended for single-story buildings or at the position of the beams of the LWT - composite floor system for multistorey applications
 - **Horizontal load:** defined as horizontal displacement
- **Initial imperfections:** out-of-the-plane of the CWB, cross-sectional imperfections, global sway imperfection



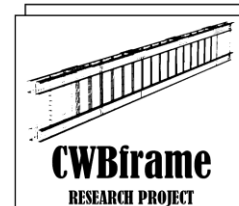
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Parametric analysis

- The study investigates the influence of the following parameters:
 - thickness of the lipped channel section C200 acting as a flange : 2.5 mm and 2.0 mm
 - corrugated web thickness: 0.8 mm, 1.0 mm, and 1.2 mm
 - shear plate thickness : 0.8 mm, 1.0 mm, and 1.2 mm
 - magnitude of the initial imperfections: L/1000 and L/500
 - number of spot welds between the flanges and corrugated web: 2 or 3

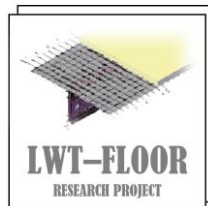
Model name	Column cross-section	Height [m]	Span [m]	Thicknesses of the components [mm]		
				t_{C200}	t_{SP}	t_{CW}
CWB_FRAME 1	SHS 300/12.5	3.6	10	2.5	1.2	1.2
CWB_FRAME 2	SHS 300/12.5	3.6	10	2.5	1.0	1.0
CWB_FRAME 3	SHS 300/12.5	3.6	10	2.5	0.8	0.8
CWB_FRAME 4	SHS 300/12.5	3.6	10	2.0	1.2	1.2
CWB_FRAME 5	HEB 260	5	20	2.5	1.2	1.2
CWB_FRAME 6	HEB 260	5	20	2.5	1.0	1.0
CWB_FRAME 7	HEB 260	5	20	2.5	0.8	0.8
CWB_FRAME 8	HEB 260	5	20	2.0	1.2	1.2



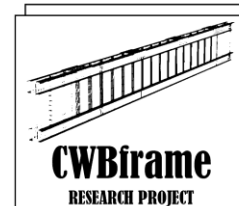
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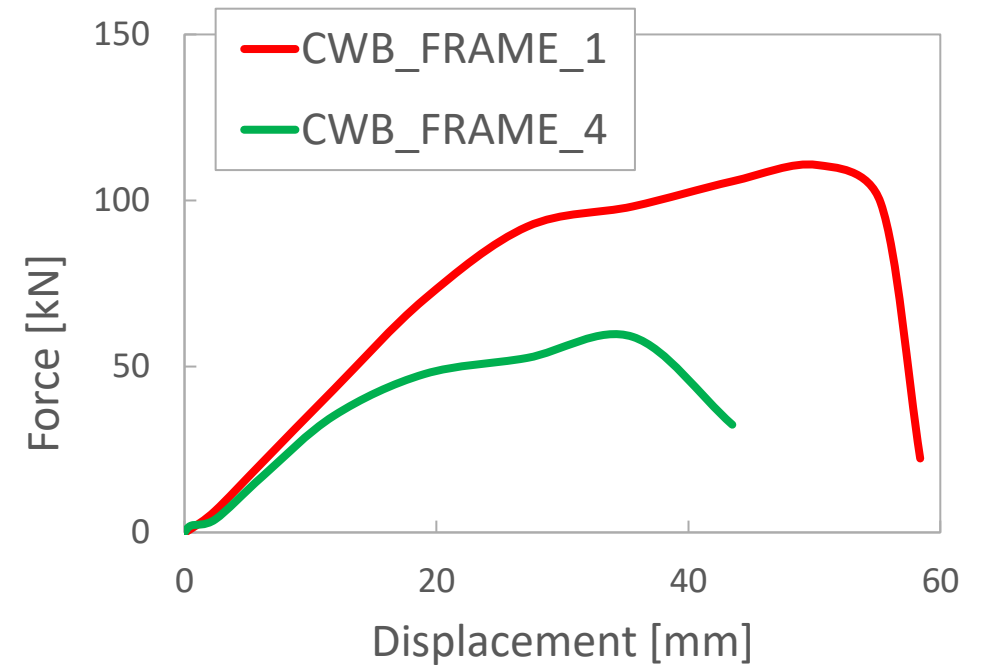
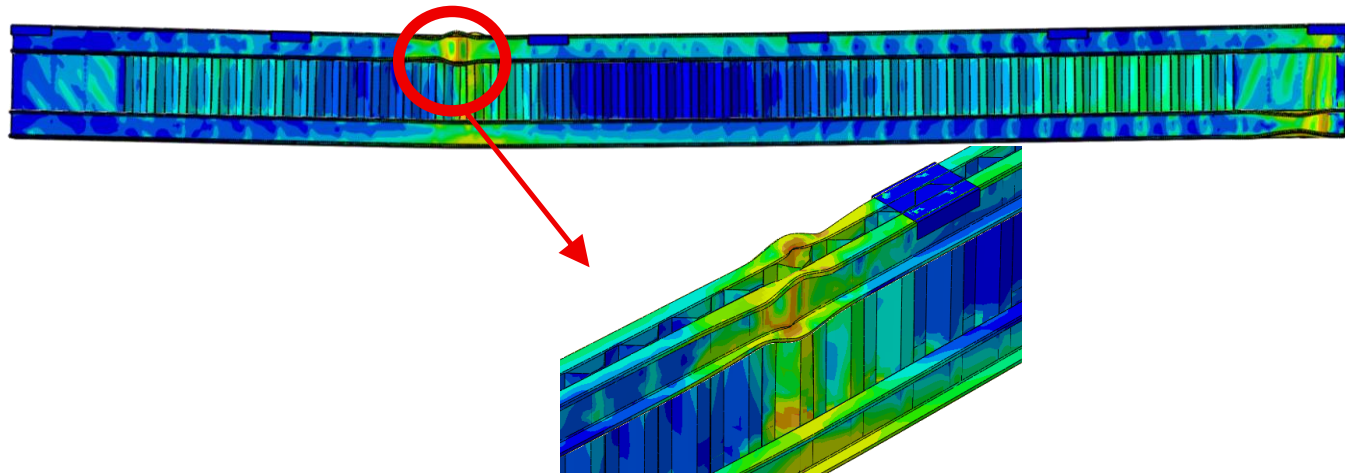


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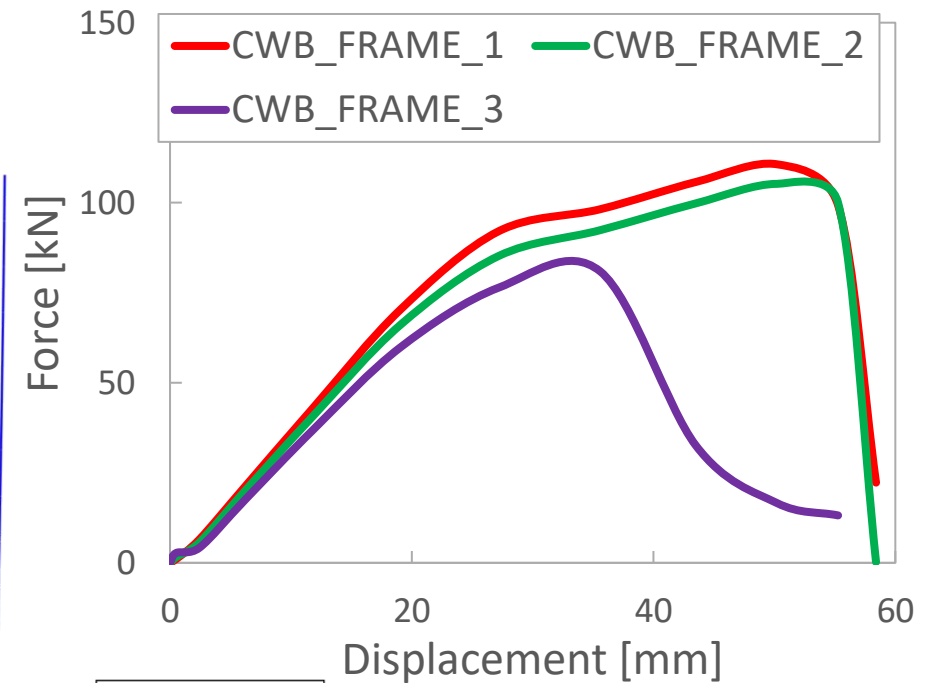
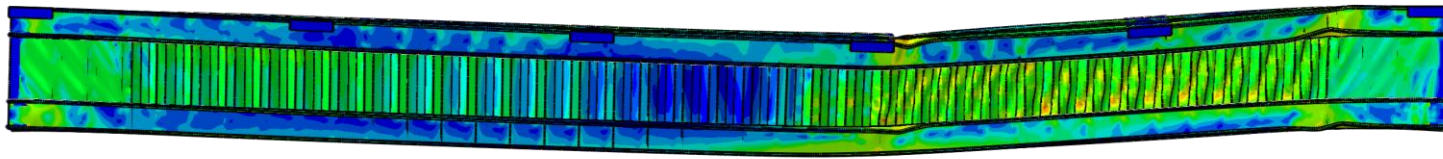
Results – influence of the flange thickness – 10 m span

- The CWB frame with 2.5 mm-thick flanges has higher stiffness and significantly higher capacity than the one with 2 mm-thick flanges
- Failure mode: distortional buckling of the flange (lipped channel section)



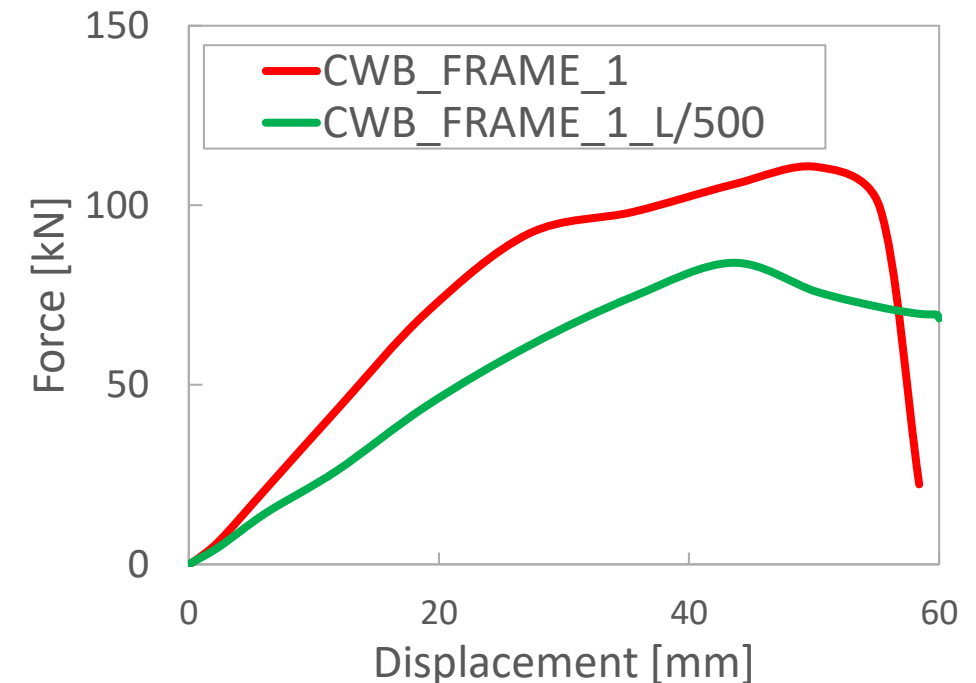
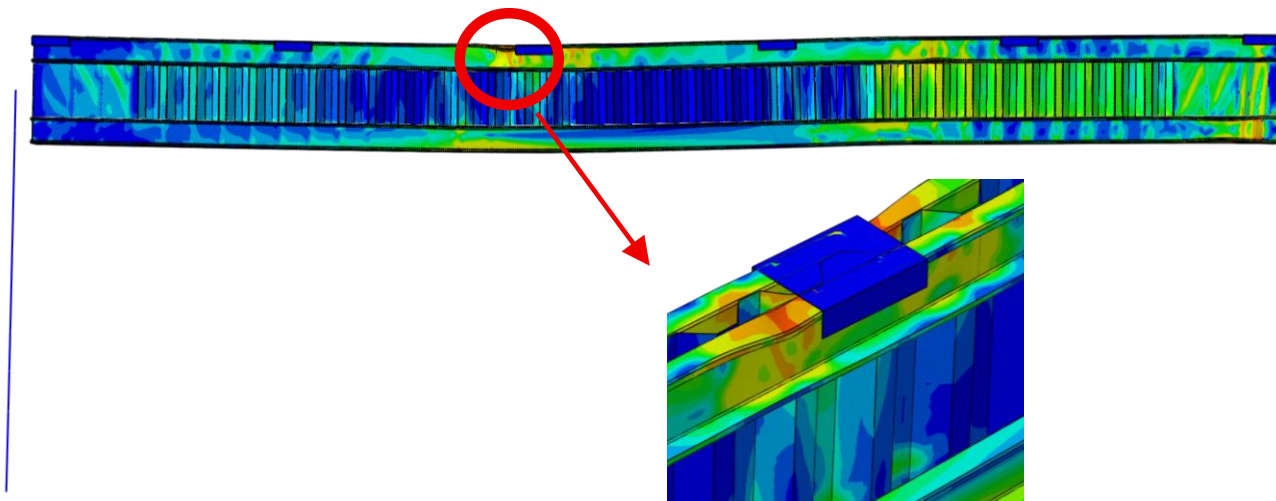
Results – influence of the CW and SP thicknesses – 10 m span

- The CWB with 1.2 mm and 1.0 mm thick CW and SP – minimal reduction in stiffness and capacity
- Failure mode: distortional buckling of the flange (lipped channel section)
- The CWB with 0.8 mm thick CW and SP – moderate reduction in stiffness and significant decrease in capacity
- Failure mode: distortional buckling of the flange + buckling of the CW



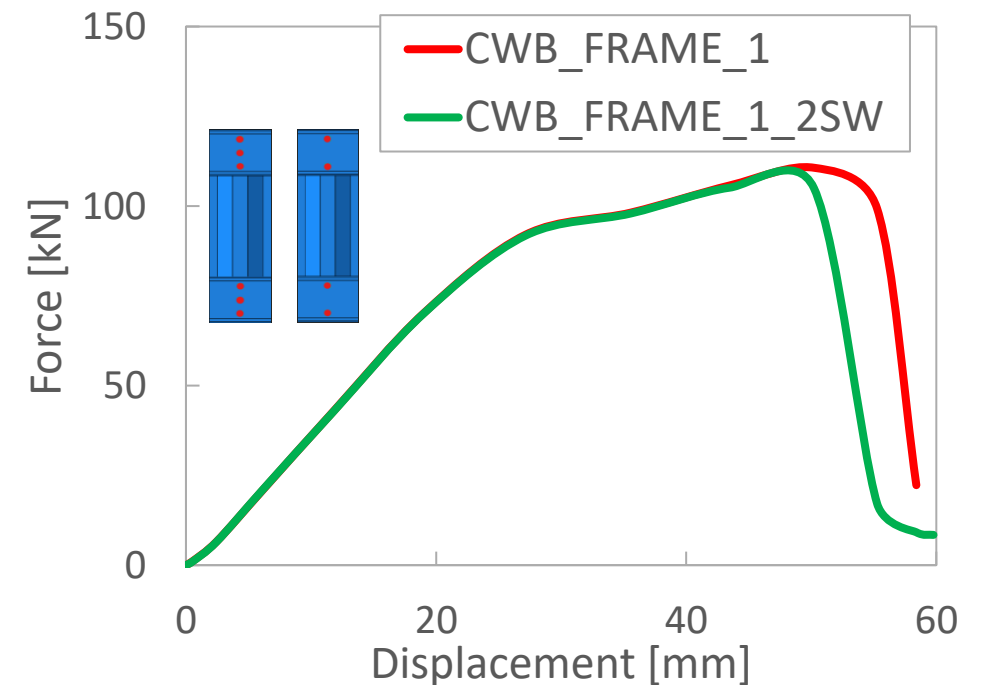
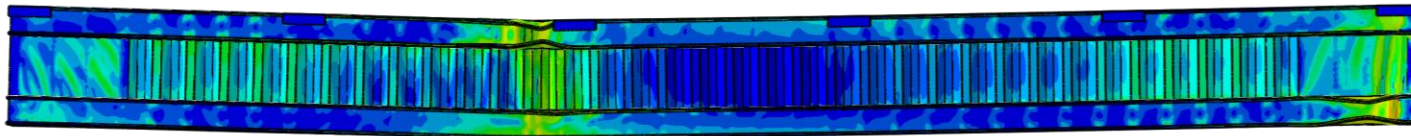
Results – influence of the initial imperfection magnitude - 10 m span

- The CWB with an initial imperfection magnitude of $L/500$ had significant drop in capacity and stiffness
- Failure mode: local buckling of the flange



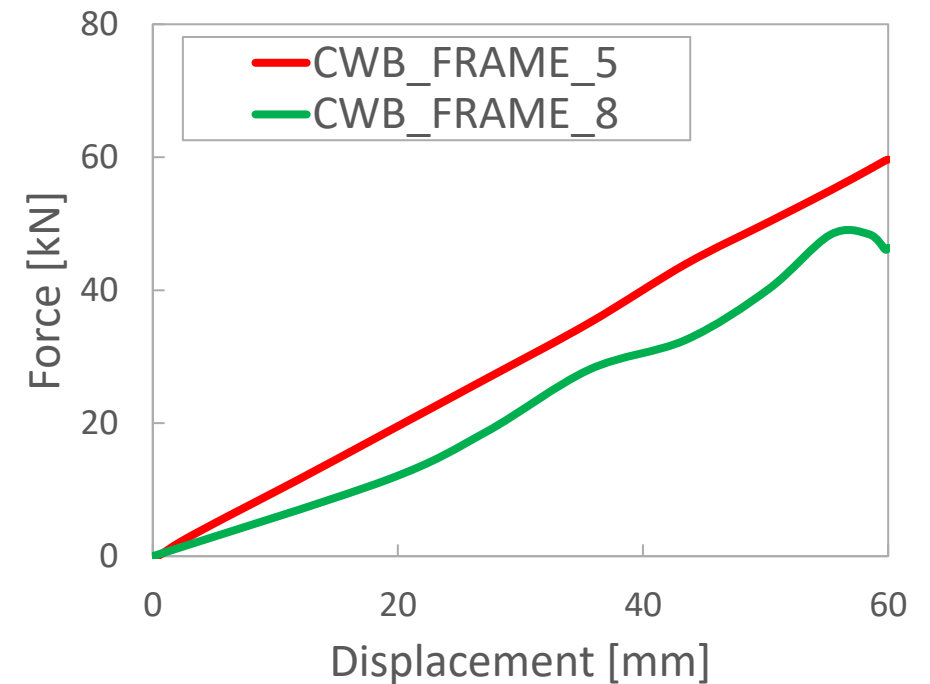
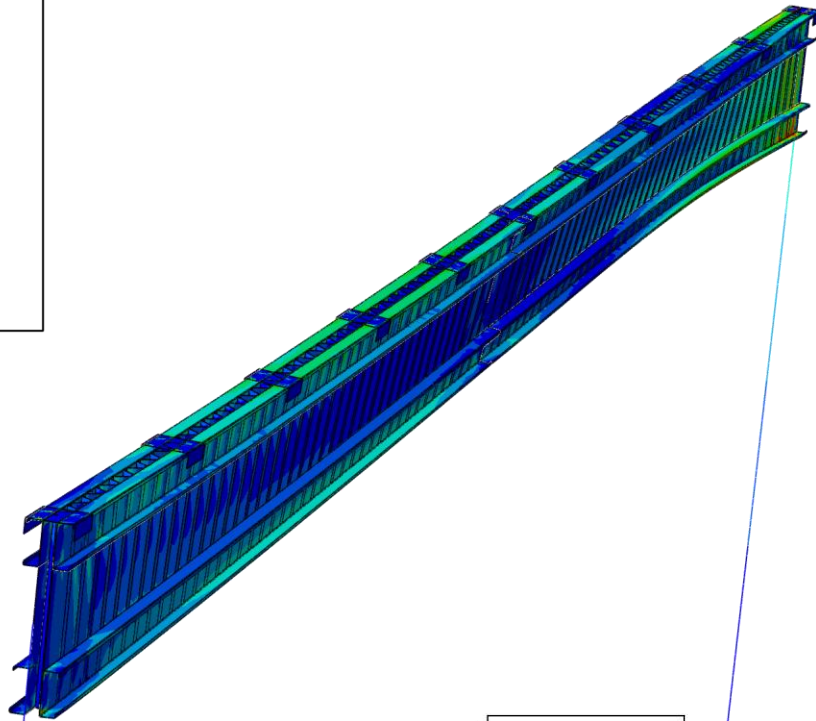
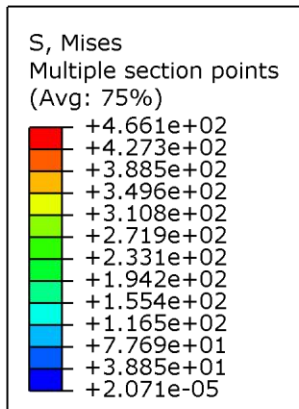
Results – influence of the number of spot welds - 10 m span

- Reducing the number of spot welds from 3 to 2 has a negligible influence on the initial stiffness, but collapse occurs earlier in the case of 2 spot welds
- Failure mode: distortional buckling of the flange



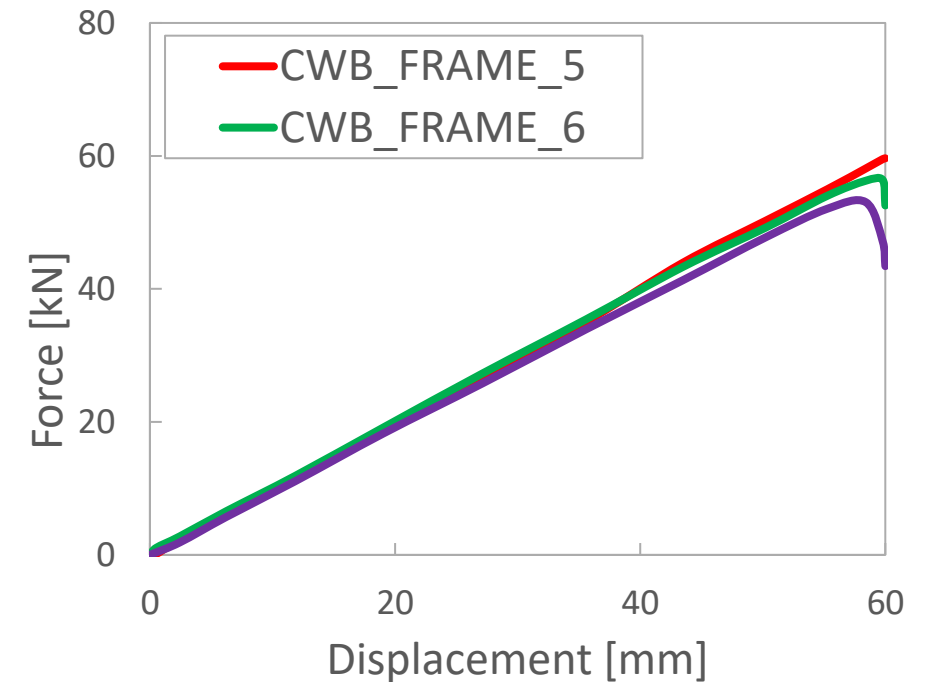
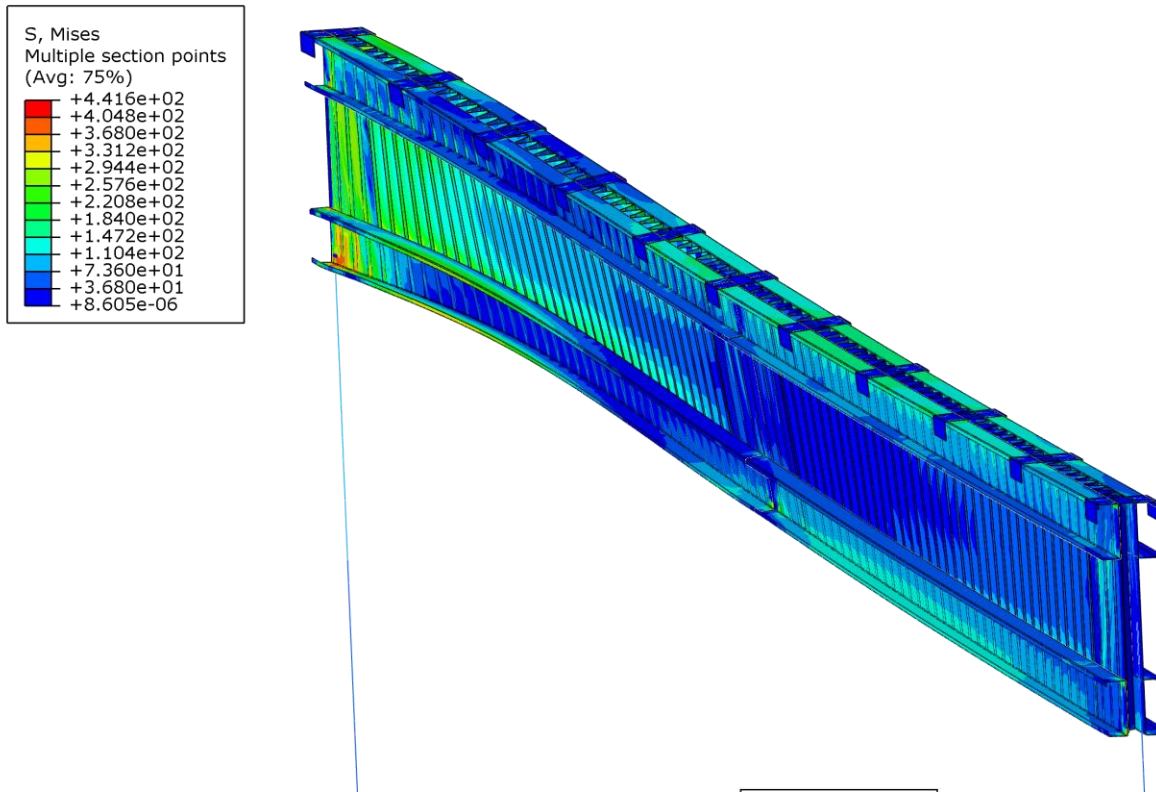
Results – influence of the flange thickness – 20 m span

- The CWB frame with 2.5 mm-thick flanges has higher stiffness and significantly higher capacity than the one with 2 mm-thick flanges
- Failure mode: global buckling of the flange - for 2.0 mm thick flanges



Results – influence of the CW and SP thicknesses – 20 m span

- The CWB with 1.2 mm, 1.0 mm and 0.8 mm thick CW and SP – influence on the stiffness was negligible but the drop in a capacity was observed in the case of 1.0 mm and 0.8 mm thick CW and SP
- Failure mode: global buckling of the flange - for 1.0 and 0.8 mm thick CW and SP



Conclusions

- 10 m span CWB frame - Flange thicknesses below 2.5 mm and CW and SP thicknesses below 1.0 mm – significant reduction in capacity and stiffness
- Number of spot welds – negligible influence on the stiffness, minor reduction in capacity
- L/1000 and L/500 initial imperfections – significant influence on the capacity and stiffness
- 10 m span CWB frame failure modes - distortional buckling of the lipped channel section – flange or corrugated web buckling + distortional buckling (0.8 mm thick CW)
- 20 m span CWB frame – negligible effect on the stiffness between 0.8 mm, 1.0 mm and 1.2 mm thick CW and SP, minor reduction in capacity due to global buckling of the flange (0.8 mm and 1.0 mm CW and SP)
- the CWB with a 2.5 mm thick lipped channel section, 1.2 mm thick SP, and SP, where no forms of instabilities were observed
- For the shorter span, local/distortional buckling modes are predominant, while for the greater span the flexural buckling mode is predominant.

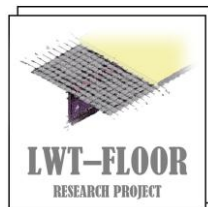
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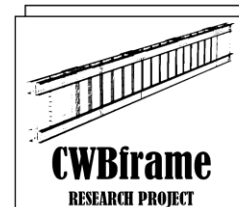
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