Research Fund for Coal & Steel

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FISHWALL

FIre and Seismic performances of Hybrid fire WALLs in case of single-storey industrial and commercial steel buildings

SESSION: Experimental campaign – Results and exploitation of seismic tests

- **Fusible links**
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- **UNITN**

Introduction

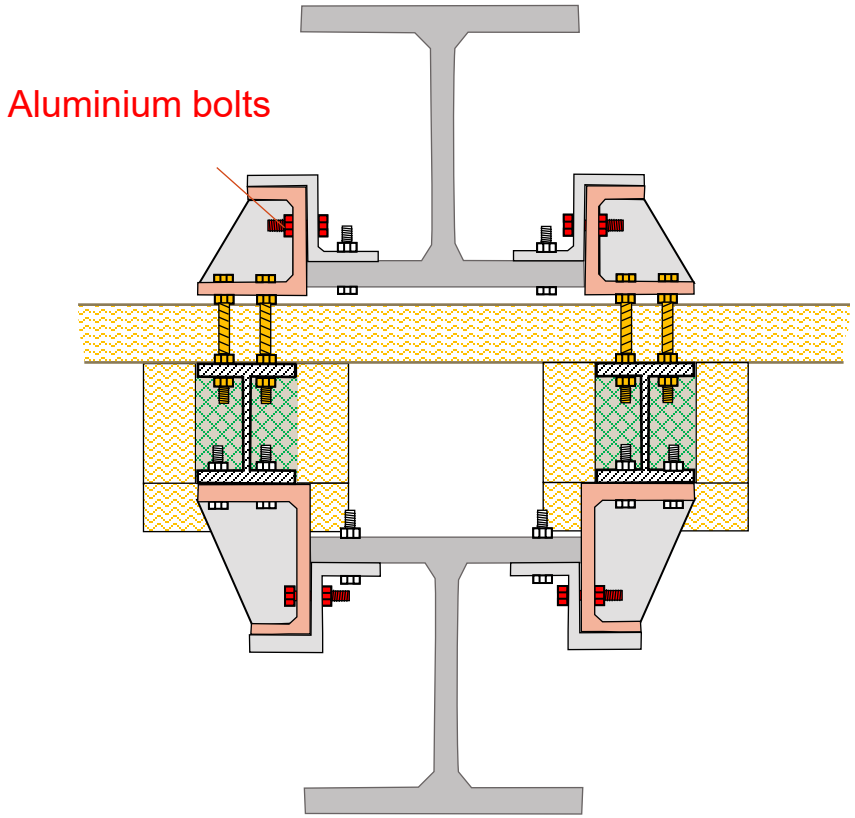
- **The fusible links** considered are links which must adequately **break in the fire situation**
- However, **they are not deemed to be dissipative elements** in the event of a seismic situation because failure of the aluminium bolts constitutes a brittle mechanism
- Therefore, when designing the fusible link system, the **structural engineer must follow the design rules provided by the current standards** (i.e. EN 1993, EN 1998 and EN 1999), ensuring that failure of the components does not occur at low to moderate seismic intensities
- The **fusible link system experiences low forces because it is not designed to resist lateral loads**, and its stiffness is low compared to the main lateral-resisting systems, such as portal frames and vertical bracing systems

Presentation outline

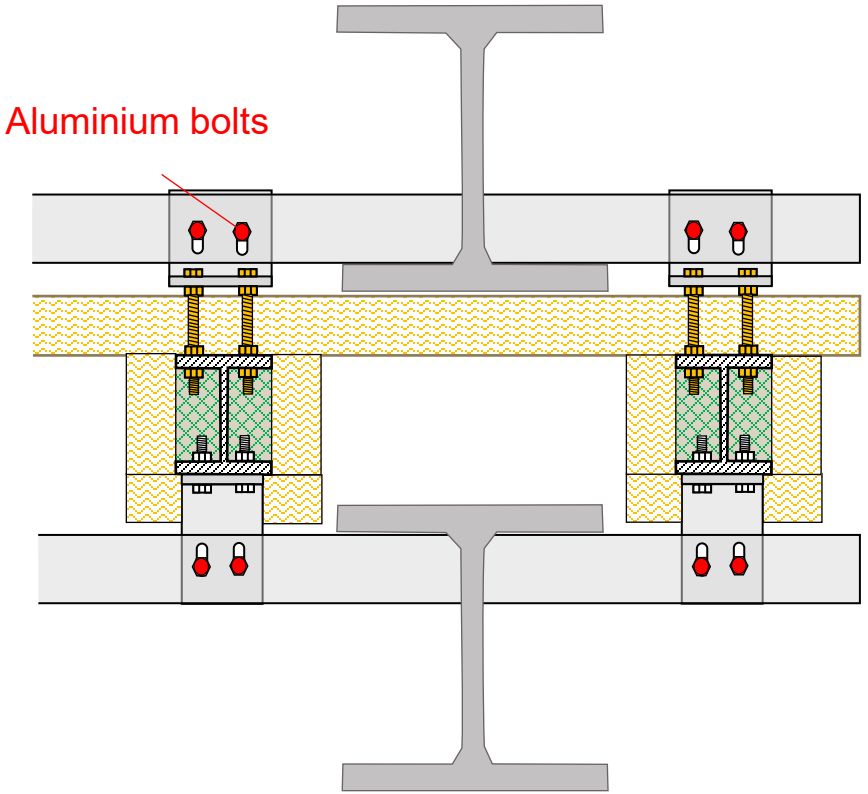
- Analysis of the seismic behaviour of typical single-storey buildings
- Design of specimens
- Results of the experimental campaign
- Calibration and validation of non-linear spring elements able to reproduce the experimental behaviour of the fusible links to be used in global numerical analyses

Seismic details

Reference detail 1



Reference detail 2

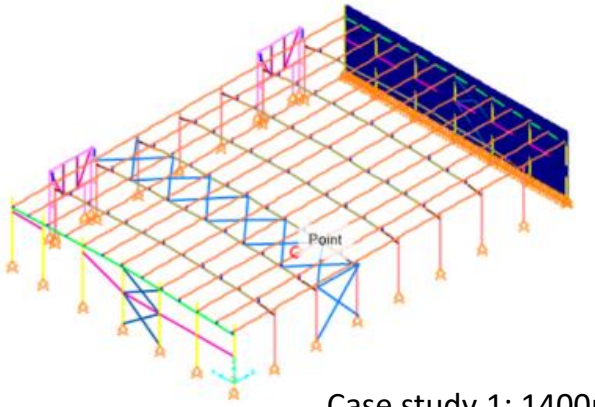


Analysis of seismic behaviour of typical single-storey buildings

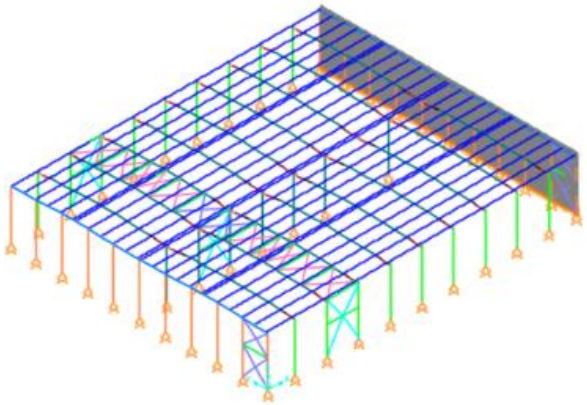
- **Four case studies**:

  2 steel buildings made of hot-rolled sections

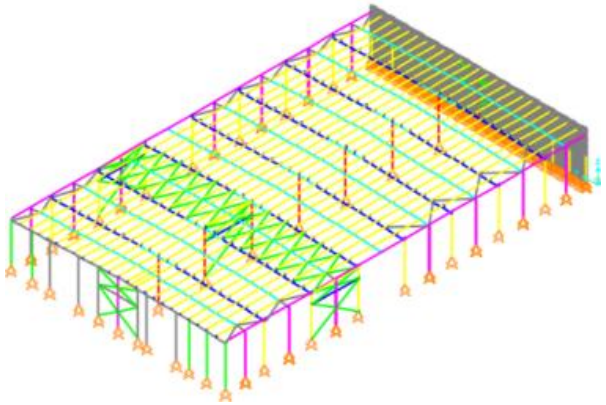
  2 steel buildings made of welded sections



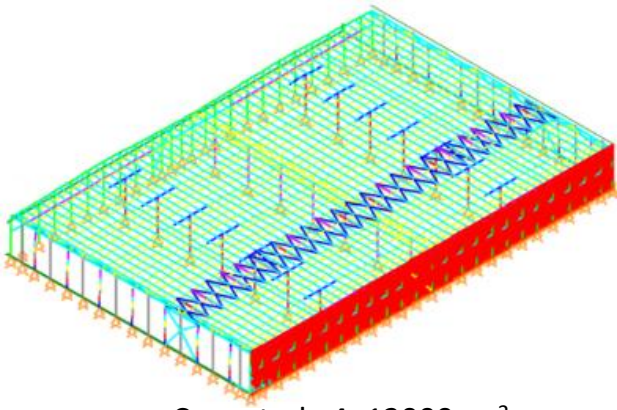
Case study 1: 1400m^2



Case study 2: 3100 m^2



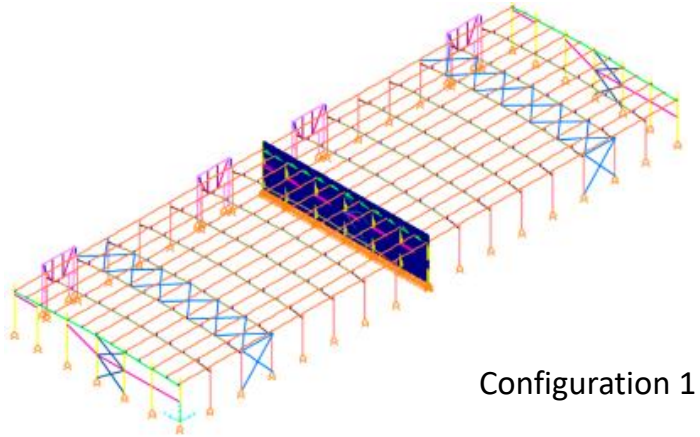
Case study 3: 6000 m^2



Case study 4: 12000 m^2

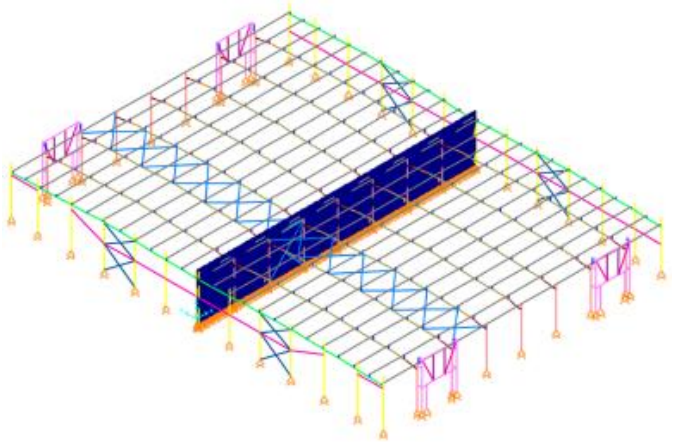
- **Two wall configurations:**

  Wall parallel to the steel portal frames



Configuration 1

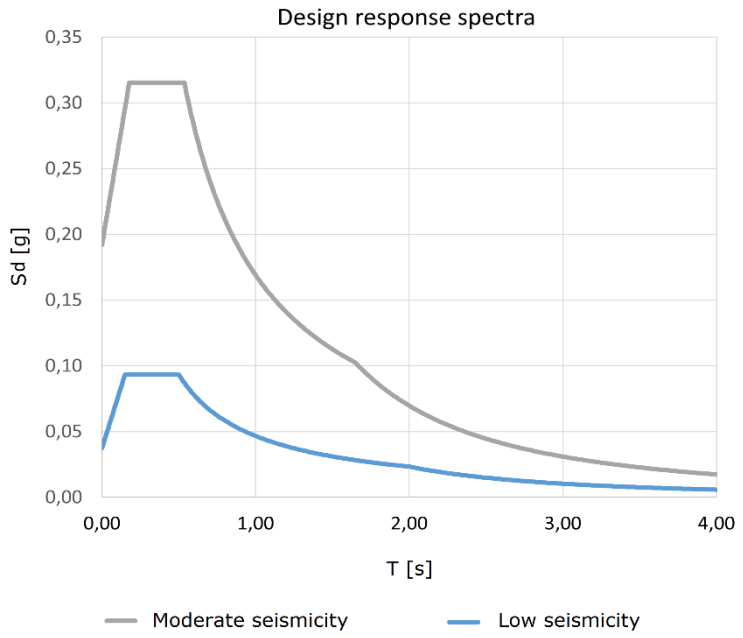
  Wall orthogonal to the steel portal frames



Configuration 2

Analysis of seismic behaviour of typical single-storey buildings

- **Two levels of seismicity**:
  - Low seismicity: 0.04 g
  - Moderate seismicity: 0.12 g
  - Soil type: E
  - q factor: 1.5



- **Modelling assumptions of finite elements models**:
  - Linear dynamic analysis with response spectrum
  - Portal frames, columns and bracing system were modelled as frame elements
  - The bracing system was considered both in compression and in tension
  - Fire wall and roof were modelled with shell elements
  - Each fire wall was connected to the main structure by means of *fusible links* at the roof level
  - *Fusible links* were modelled as elastic frame elements representing M16 aluminium bolts

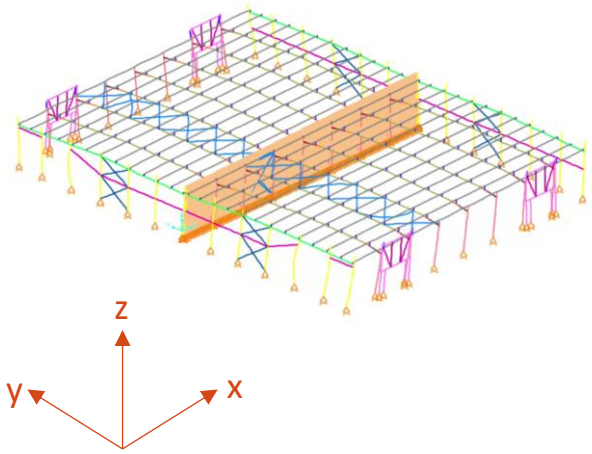
Analysis of seismic behaviour of typical single-storey buildings

Case study 1 - orthogonal			
Period [s]	Ux [%]	Uy [%]	Rz [%]
0.58	0.00	0.84	0.00
0.55	0.00	0.00	0.94
0.28	0.73	0.00	0.00

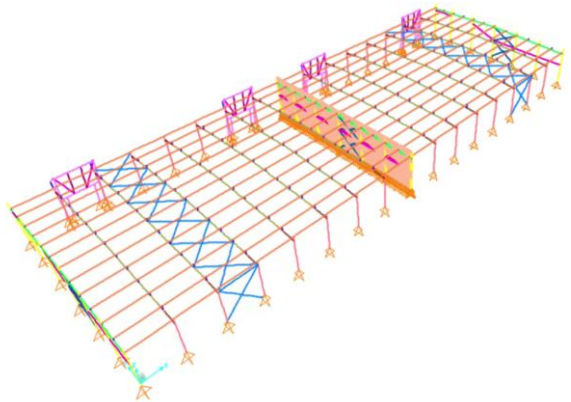
Case study 1 - parallel			
Period [s]	Ux [%]	Uy [%]	Rz [%]
1.22	0.94	0.00	0.00
0.47	0.00	0.00	0.94
0.20	0.00	0.76	0.00

Case study 3 - orthogonal			
Period [s]	Ux [%]	Uy [%]	Rz [%]
0.82	0.00	0.92	0.00
0.71	0.00	0.00	0.96
0.28	0.33	0.00	0.00

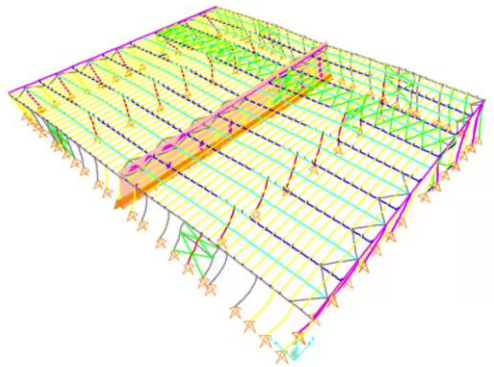
Case study 3 - parallel			
Period [s]	Ux [%]	Uy [%]	Rz [%]
1.10	0.93	0.00	0.00
0.63	0.00	0.00	0.96
0.52	0.00	0.44	0.00



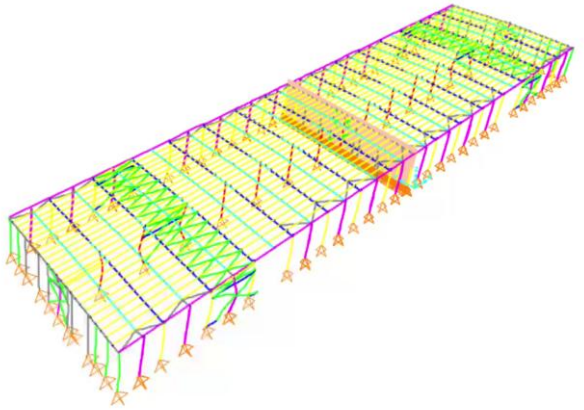
Case study 1 – orthogonal model
2nd mode of vibration, T = 0.55s



Case study 1 – parallel model
1st mode of vibration, T = 1.22s



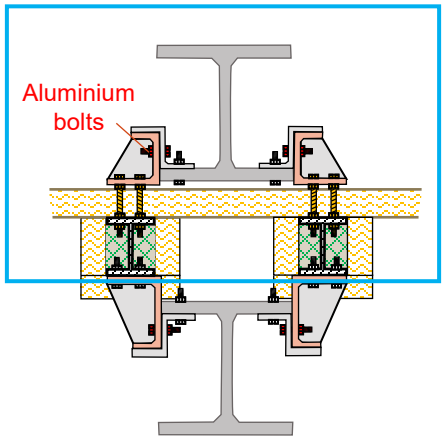
Case study 3 – orthogonal model
2nd mode of vibration, T = 0.82s



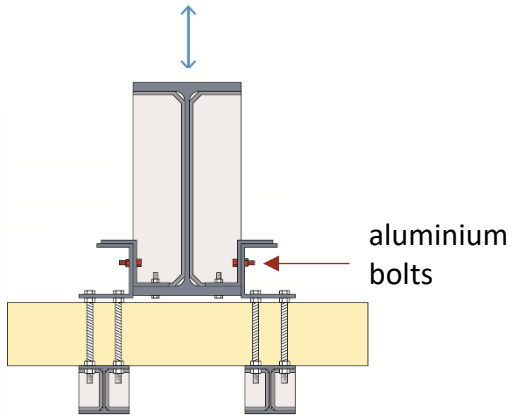
Case study 3 – parallel model
1st mode of vibration, T = 1.10s

Seismic details

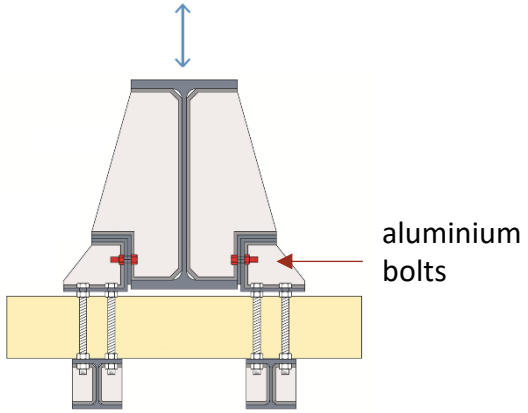
Reference detail 1



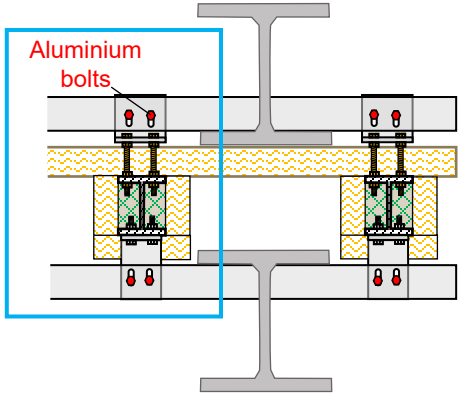
Detail 1



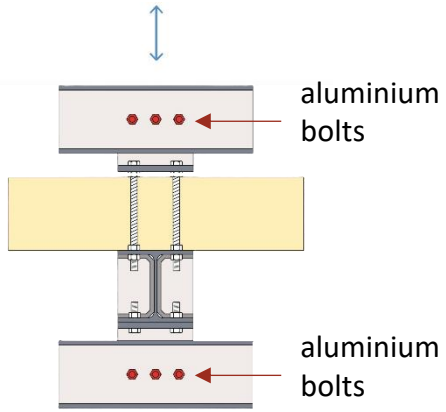
Detail 2



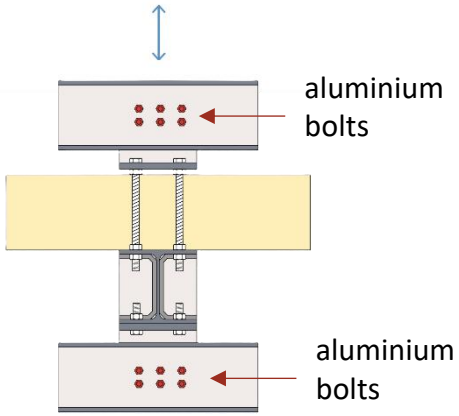
Reference detail 2



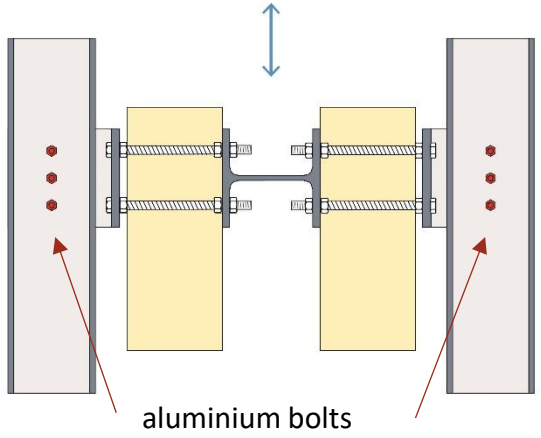
Detail 3.1



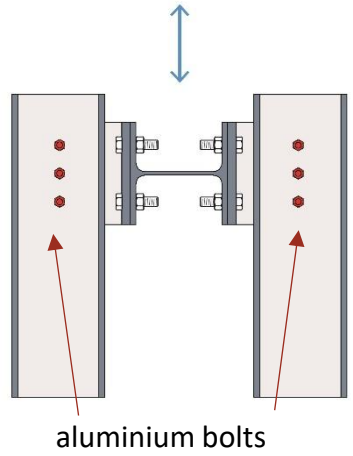
Detail 3.2



Detail 4



Detail 5



Laboratory program

	Seismicity level	Bolts	Tests
Detail 1	Low (V_{Ed} = 80 kN)	M12	2 monotonic tests 2 cyclic tests
Detail 2	Moderate (V_{Ed} = 180 kN)	M16	2 monotonic tests 2 cyclic tests
Detail 3.1	Moderate (V_{Ed} = 180 kN)	M16	2 monotonic tests 2 cyclic tests
Detail 3.2	Moderate (V_{Ed} = 180 kN)	M12	2 monotonic tests 2 cyclic tests
Detail 4	Moderate (V_{Ed} = 180 kN)	M12	2 monotonic tests 2 cyclic tests
Detail 5	Moderate (V_{Ed} = 180 kN)	M12	2 monotonic tests 2 cyclic tests

Design of the seismic tests

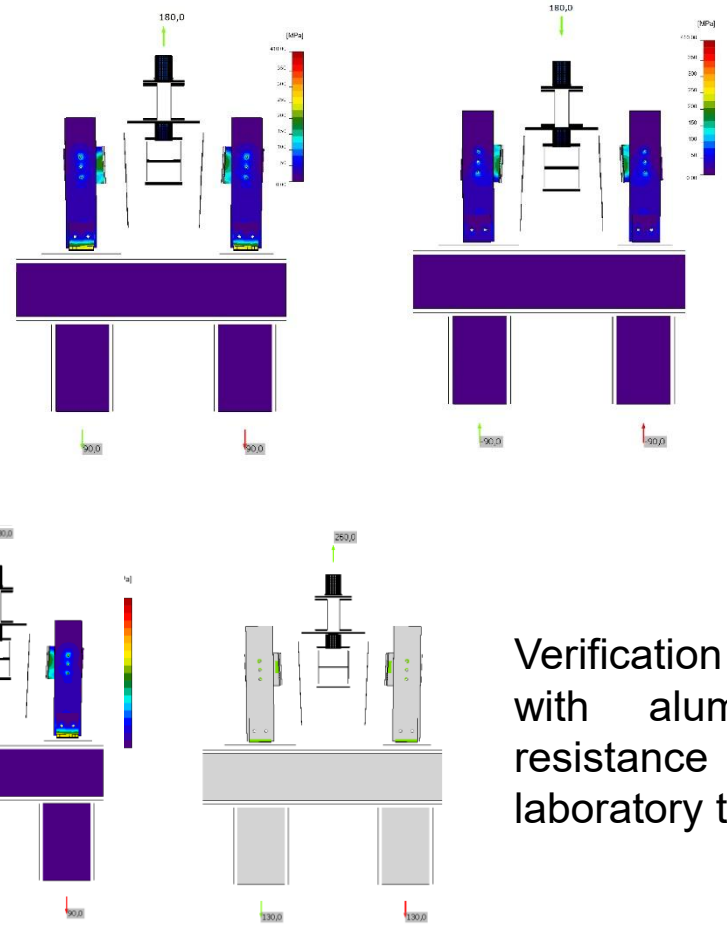
- The details were conceived with the aluminium bolts working in shear.

Seismicity level	Moderate	Low
Max shear value	**179.4 kN**	**80.04 kN**

- Verification of the aluminium bolts according to EN 1999-1-1:2007.

Shear resistance – EN 1999						**Lab tests**
Bolt size	α_v	f_{ub}	A	γ_{M2}	$F_{v,Rd}$	$F_{v,EXP}$
-	-	MPa	[mm^2]	-	[kN]	[kN]
M12	0.5	490	84.3	1.25	16.52	36.59
M16	0.5	490	157	1.25	30.77	79.30

- CBFEM models developed with IdeaStatica software to analyse the behaviour of the specimens under seismic actions with monotonic tests.



Verification of the detail with aluminium bolts resistance according to laboratory tests.

Laboratory equipment

Test set-up

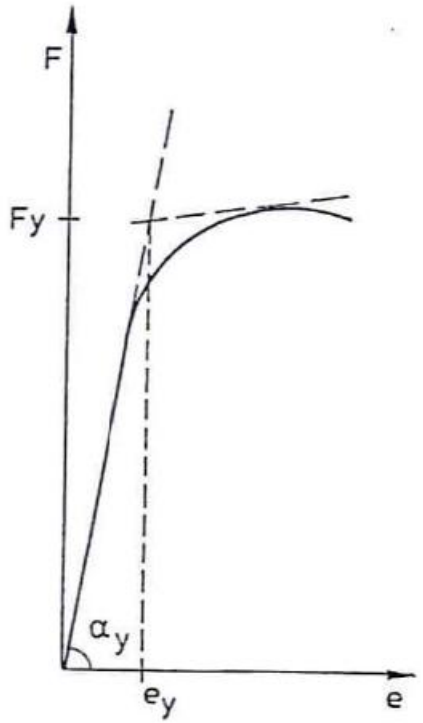
- Hydraulic actuator of 1000 kN capacity and ± 250 mm of stroke
- Strain-gauges, inclinometers and displacement transducers.
- Tests performed in displacement control

inclinometers

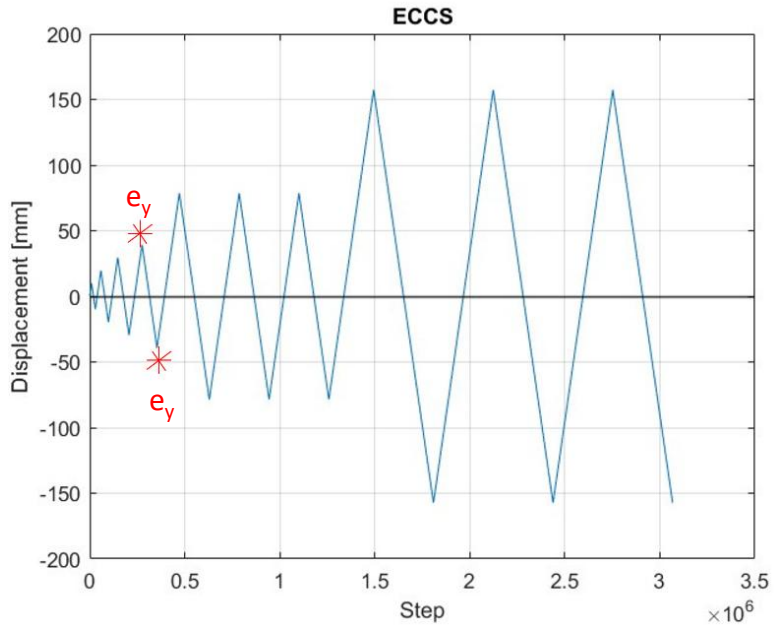
Strain-gauges and displacement transducers

Experimental loading protocol: ECCS

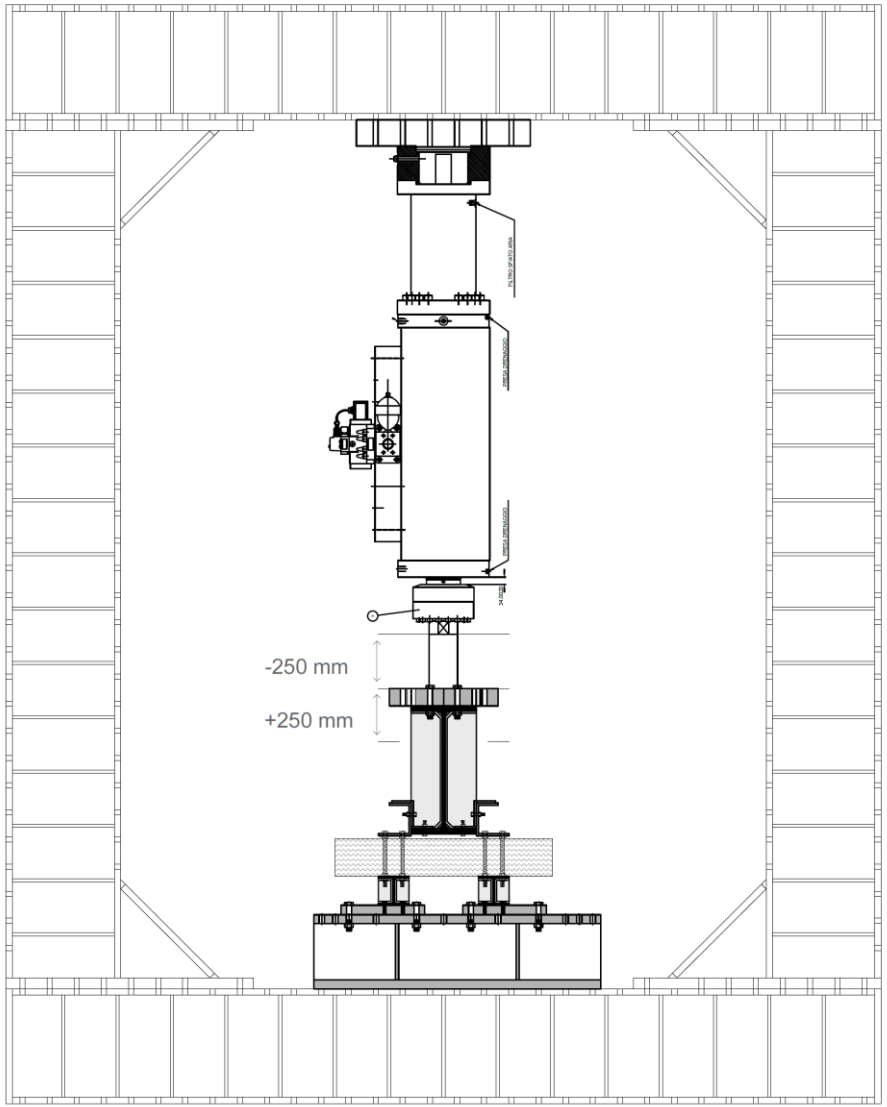
Monotonic tests

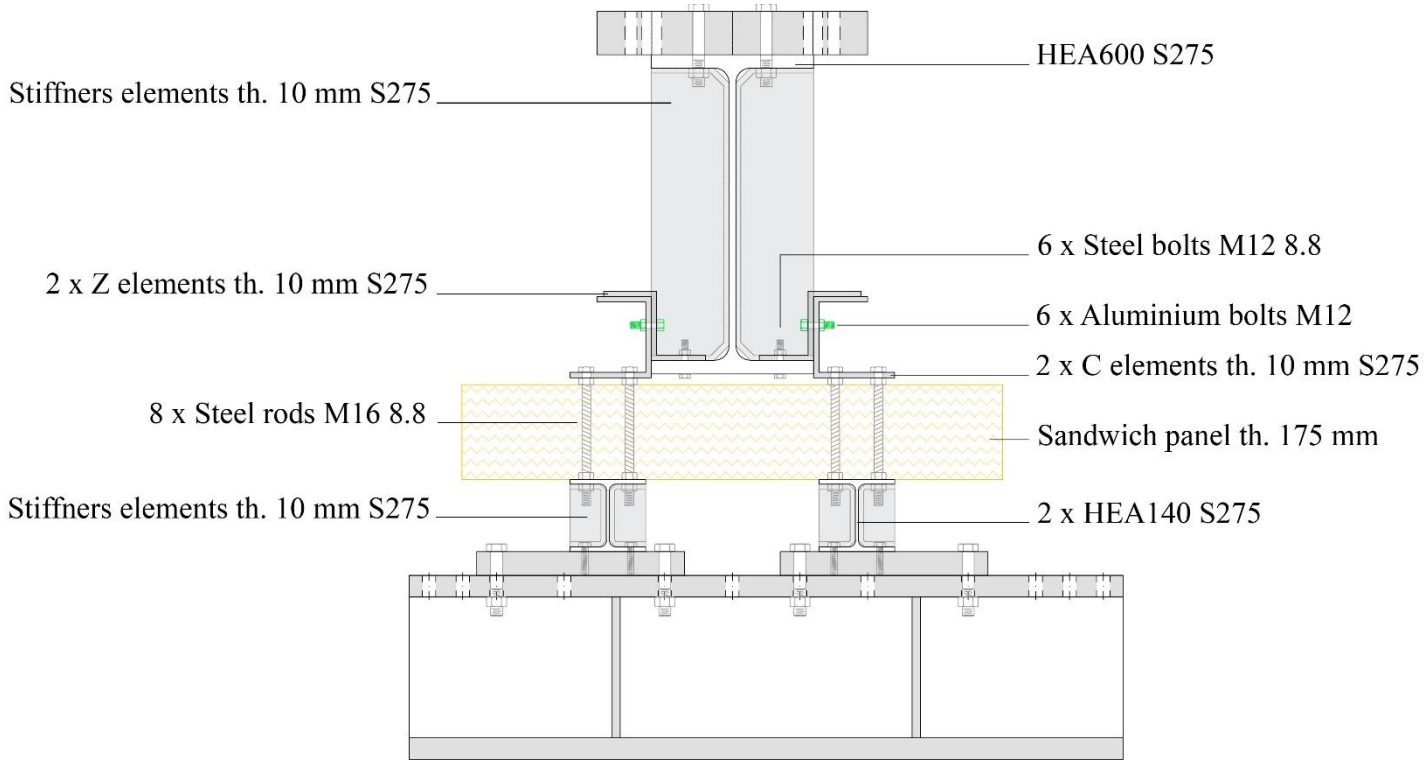


ECCS displacement history



Detail 1 geometry





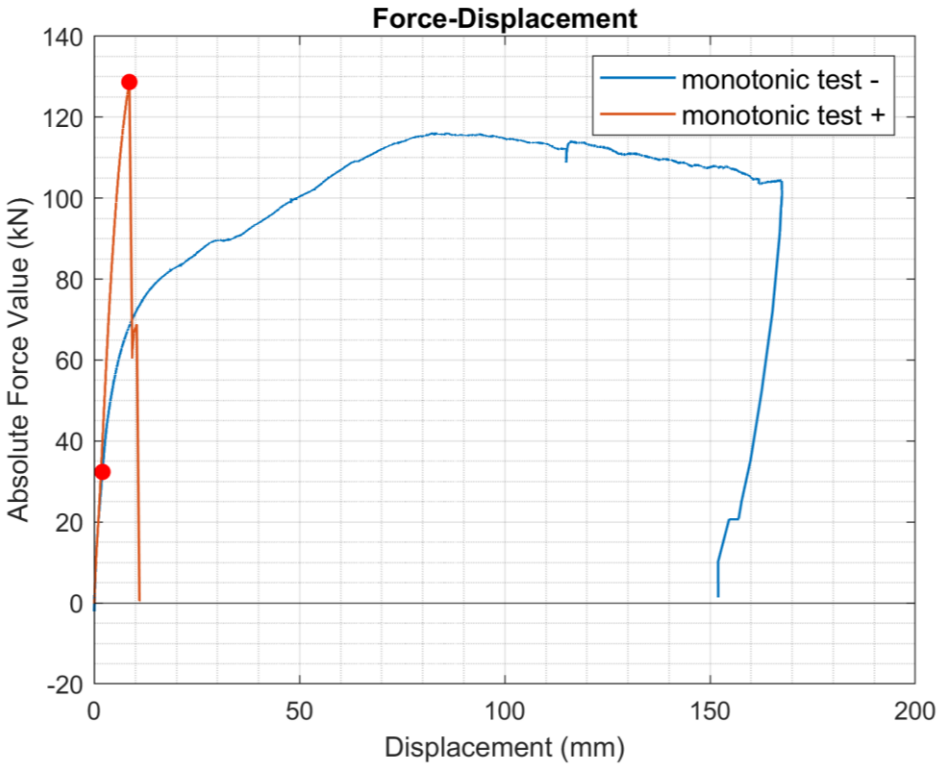
Tests on Detail 1

- Design force of 80 kN
- 6 M12 aluminium bolts

Tension test – max force reached: 128.8 kN

Compression test - max force reached: 116.0 kN*

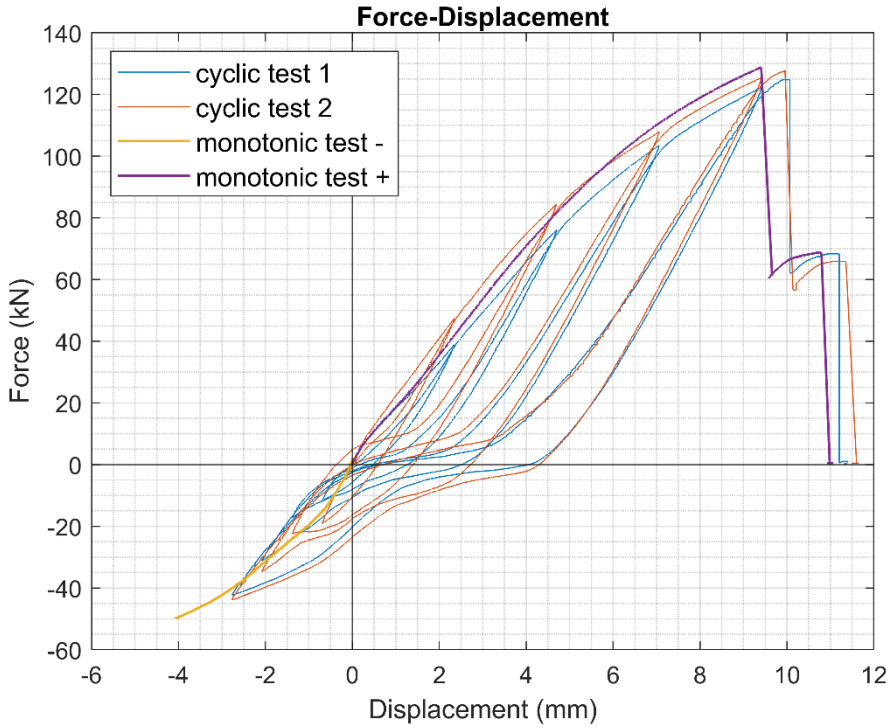
Monotonic tests results



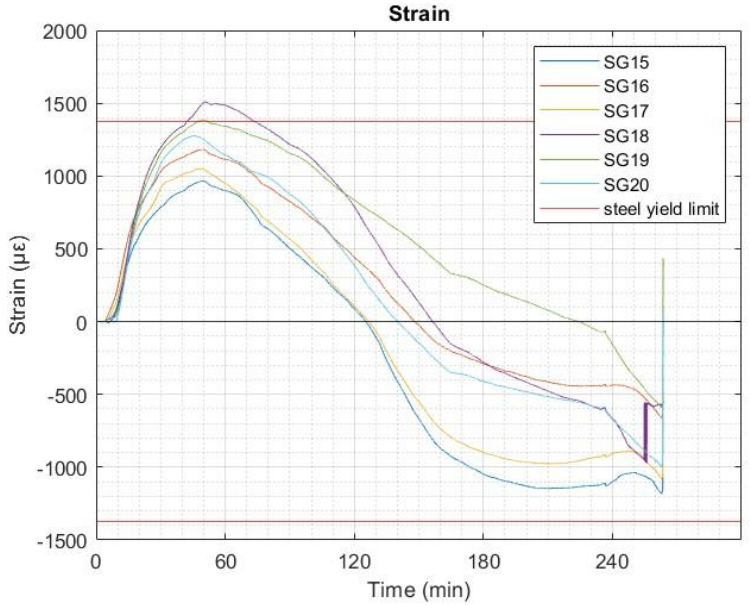
*Steel inelastic behaviour and no failure of the aluminium bolts

Tests on Detail 1

Cyclic tests



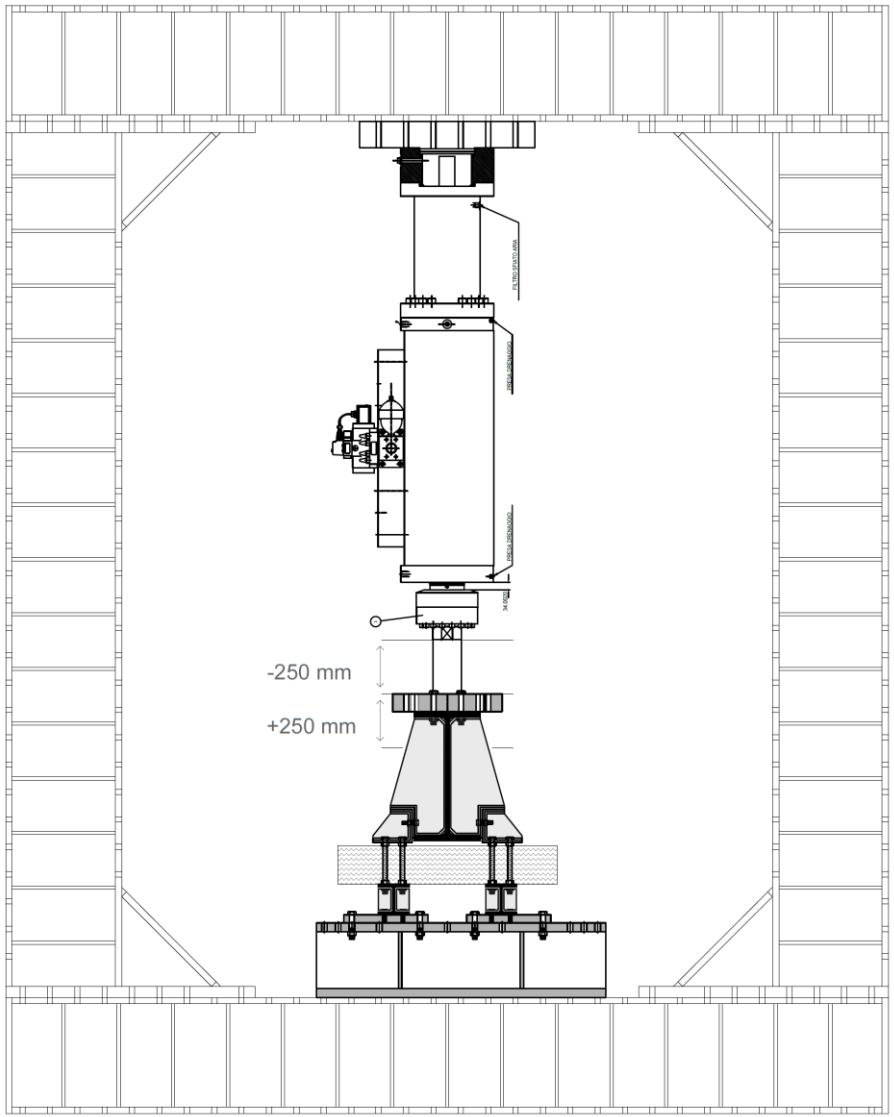
Detail 1 compression test outputs

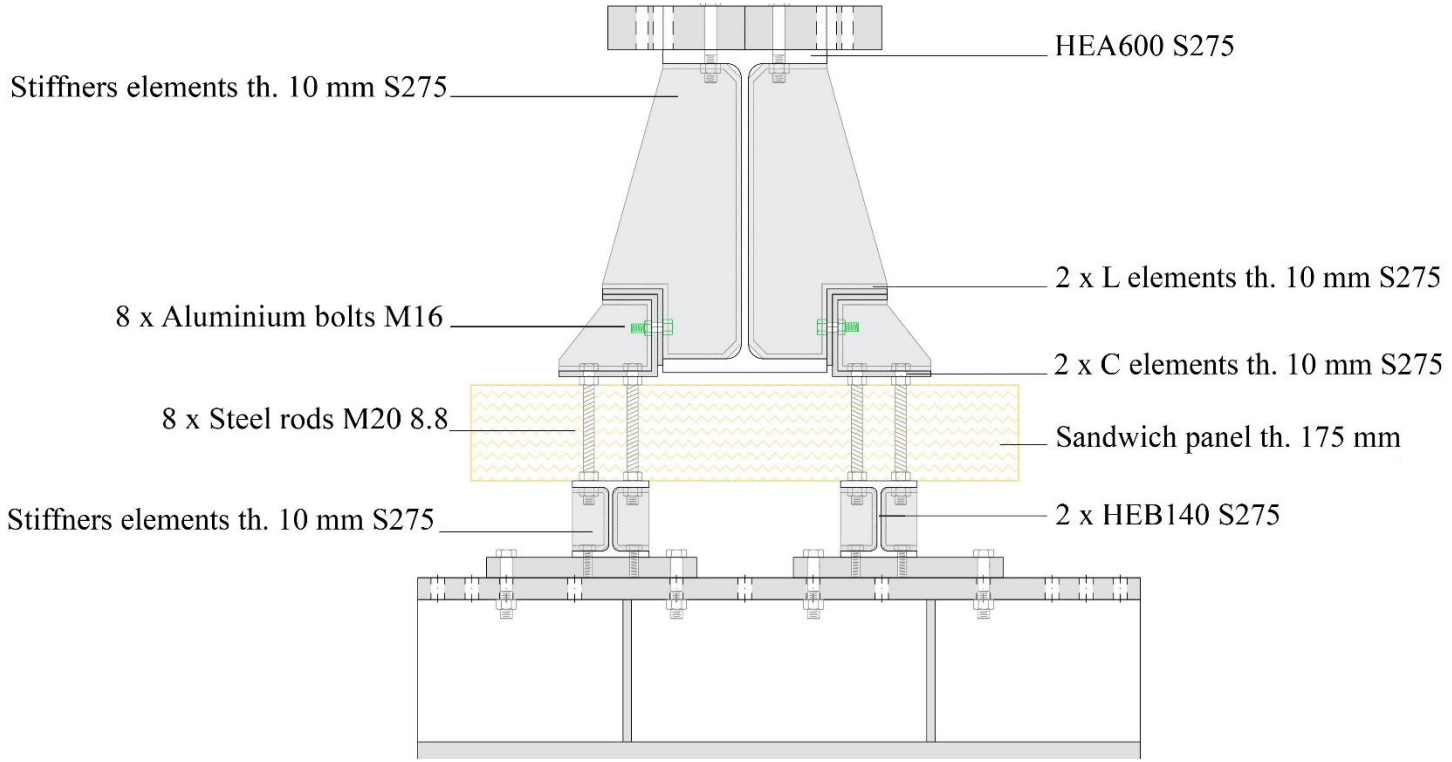


Results comparison:

- Good agreement between the tension test and the relative branch of the cyclic tests;
- Compression part of the cyclic test agrees well in stiffness and strength degradation until the yield displacement;
- Design force of 80 kN reached in all the tests;
- Small hysteretic behaviour was observed.

Detail 2 geometry





Tests on Detail 2

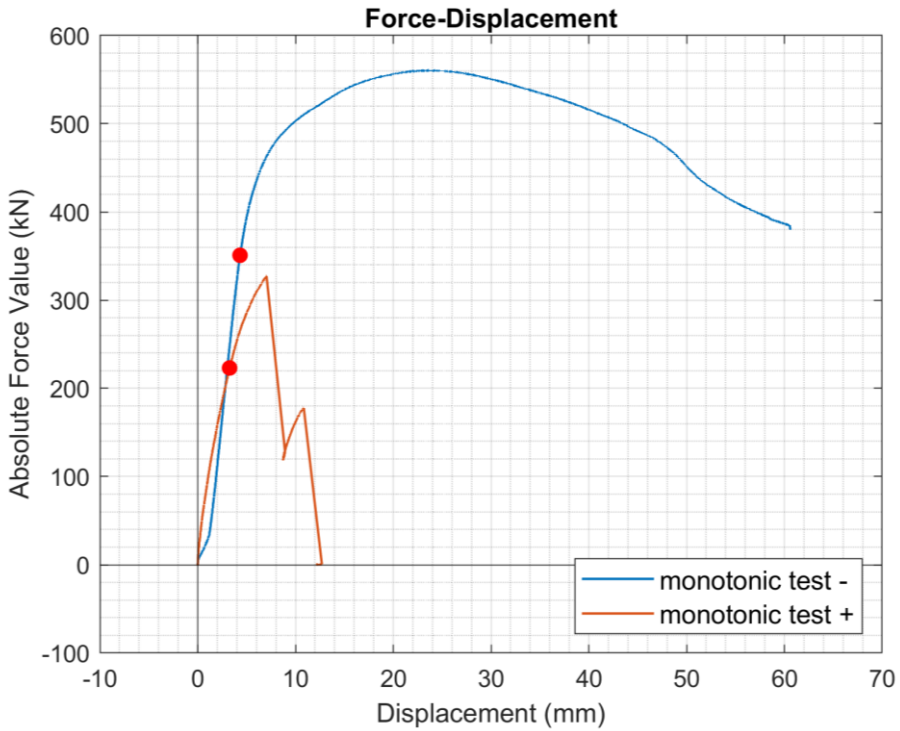
- Design force of 180 kN

Tension test – max force reached: 325.8 kN

- 8 M16 aluminium bolts

Compression test - max force reached: 560.0 kN*

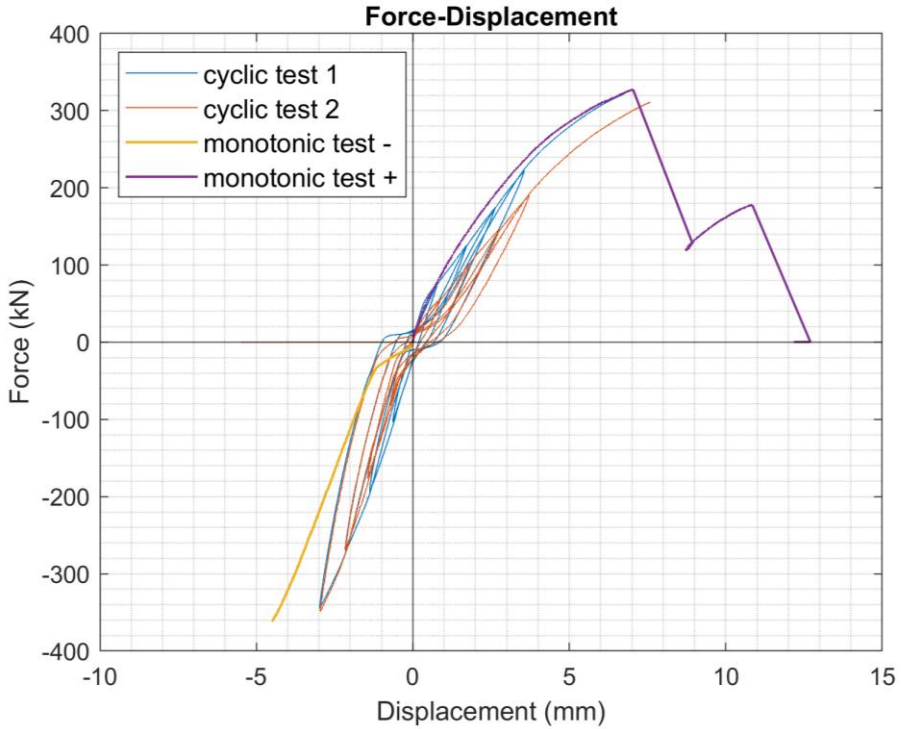
Monotonic tests results



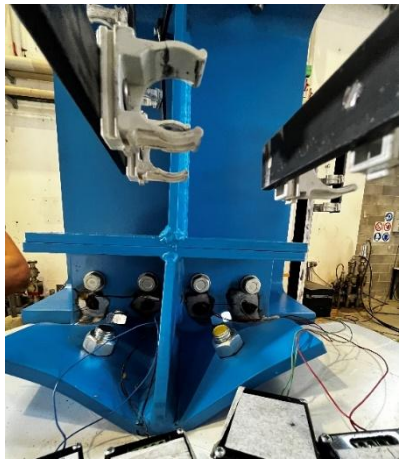
*Steel inelastic behaviour and no failure of the aluminium bolts

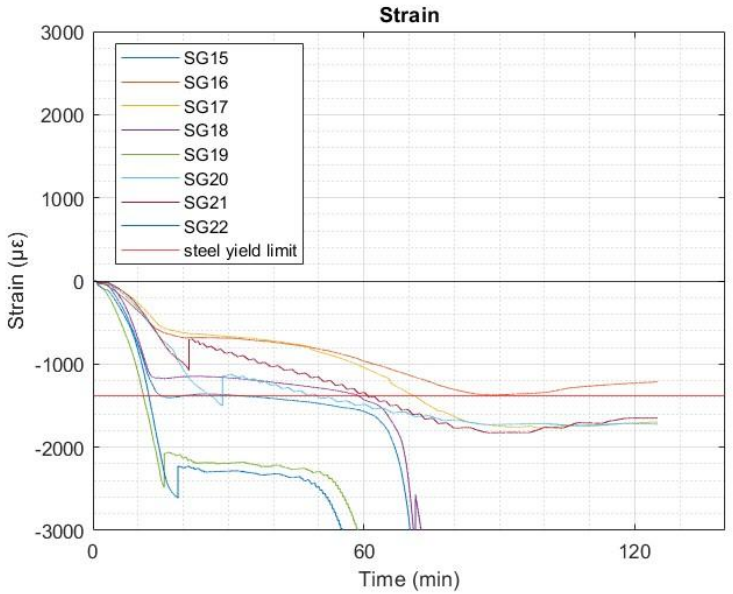
Tests on Detail 2

Cyclic tests



Detail 2 compression test outputs

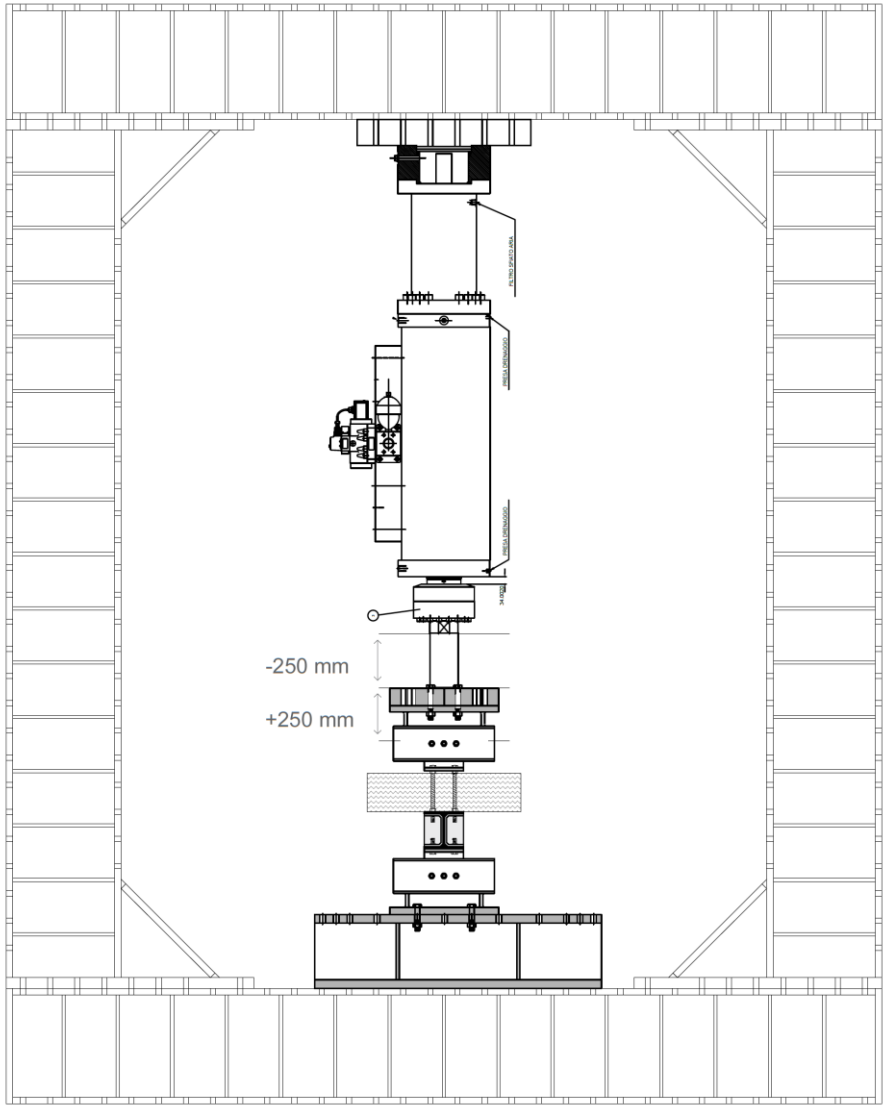


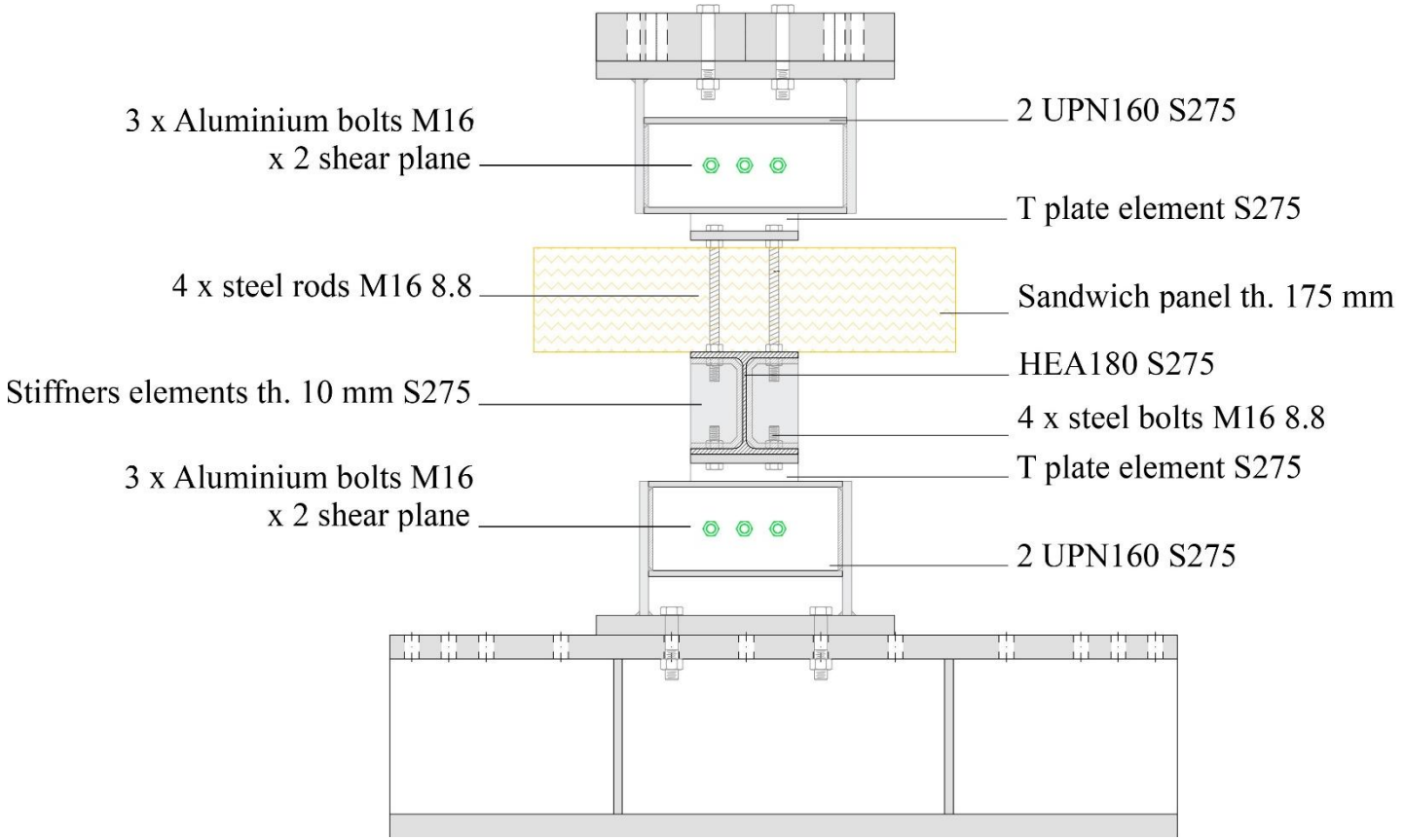


Results comparison:

- Good agreement especially on the tension part;
- Design force of 180 kN reached in all the tests;
- On the tension part, the cycle shape is the same, but the second one experienced higher slip due to specimen imperfections;
- Very small hysteretic behaviour of the detail.

Detail 3.1 geometry





Tests on Detail 3.1

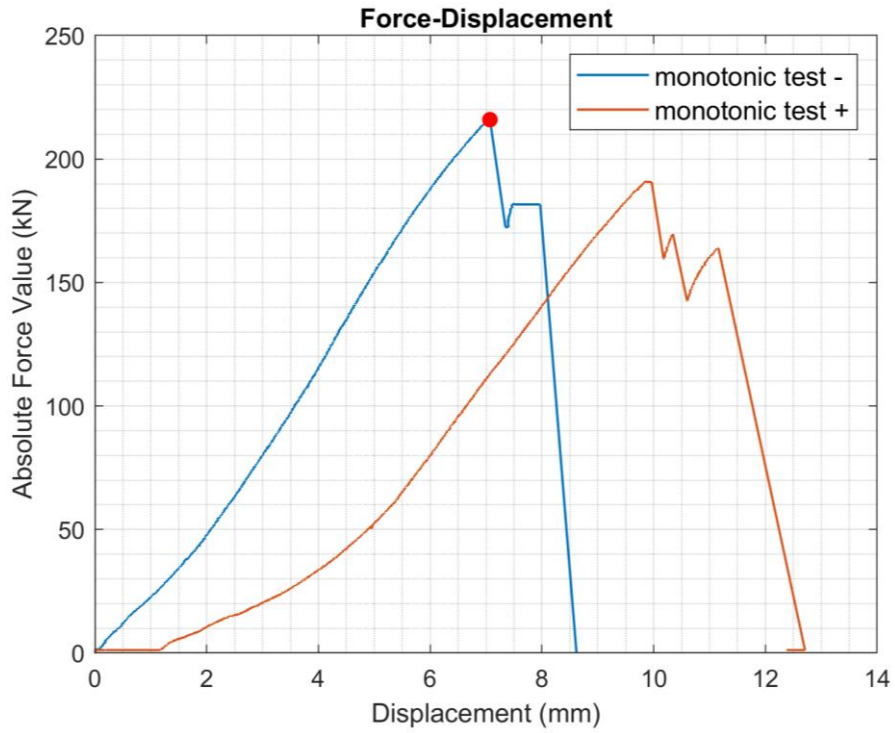
- Design force of 180 kN

Tension test – max force reached: 190.7 kN

- 3 M16 aluminium bolts x 2 shear planes

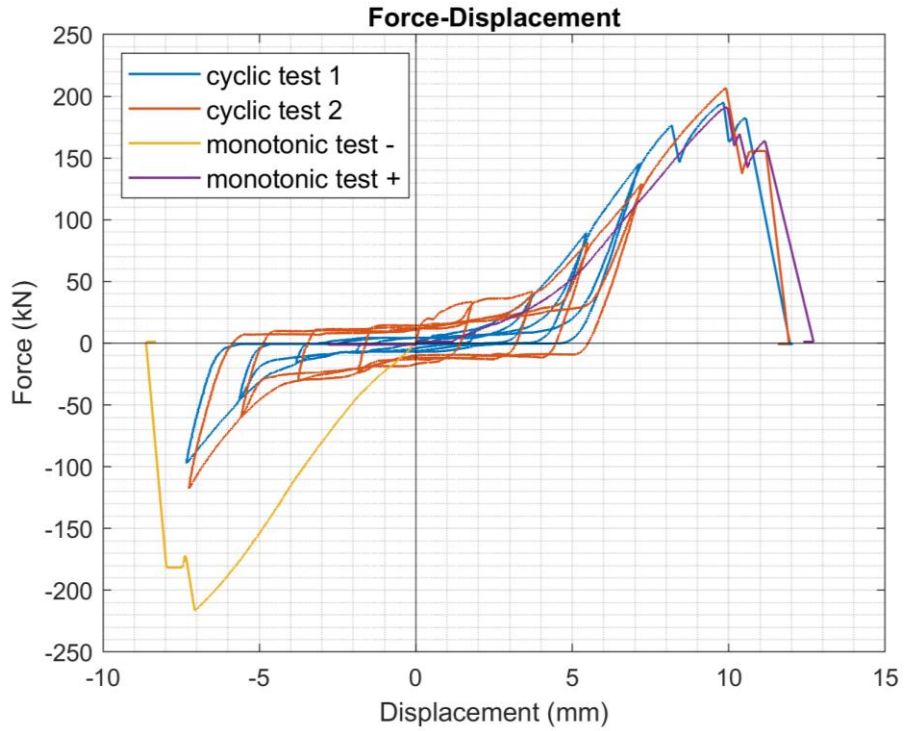
Compression test - max force reached: 215.2 kN

Monotonic tests results



Tests on Detail 3.1

Cyclic tests



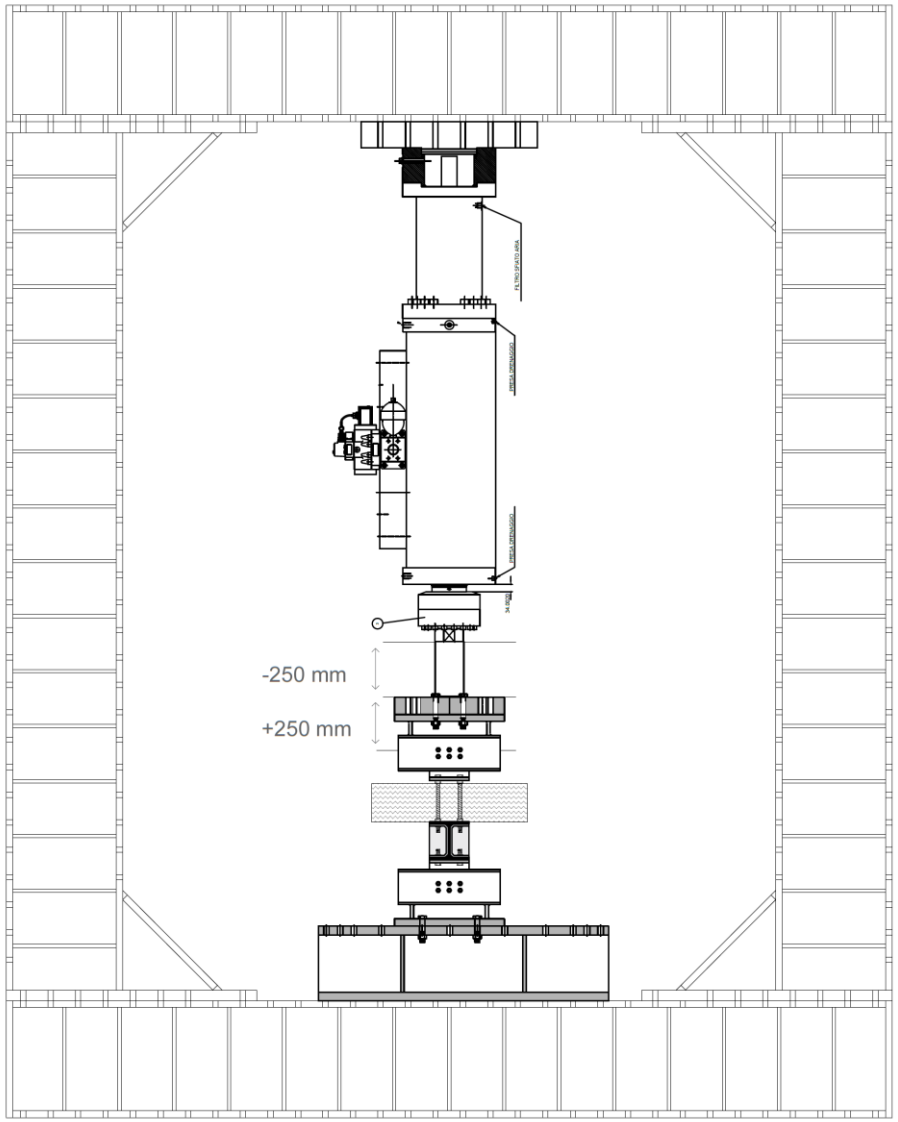
Tension test

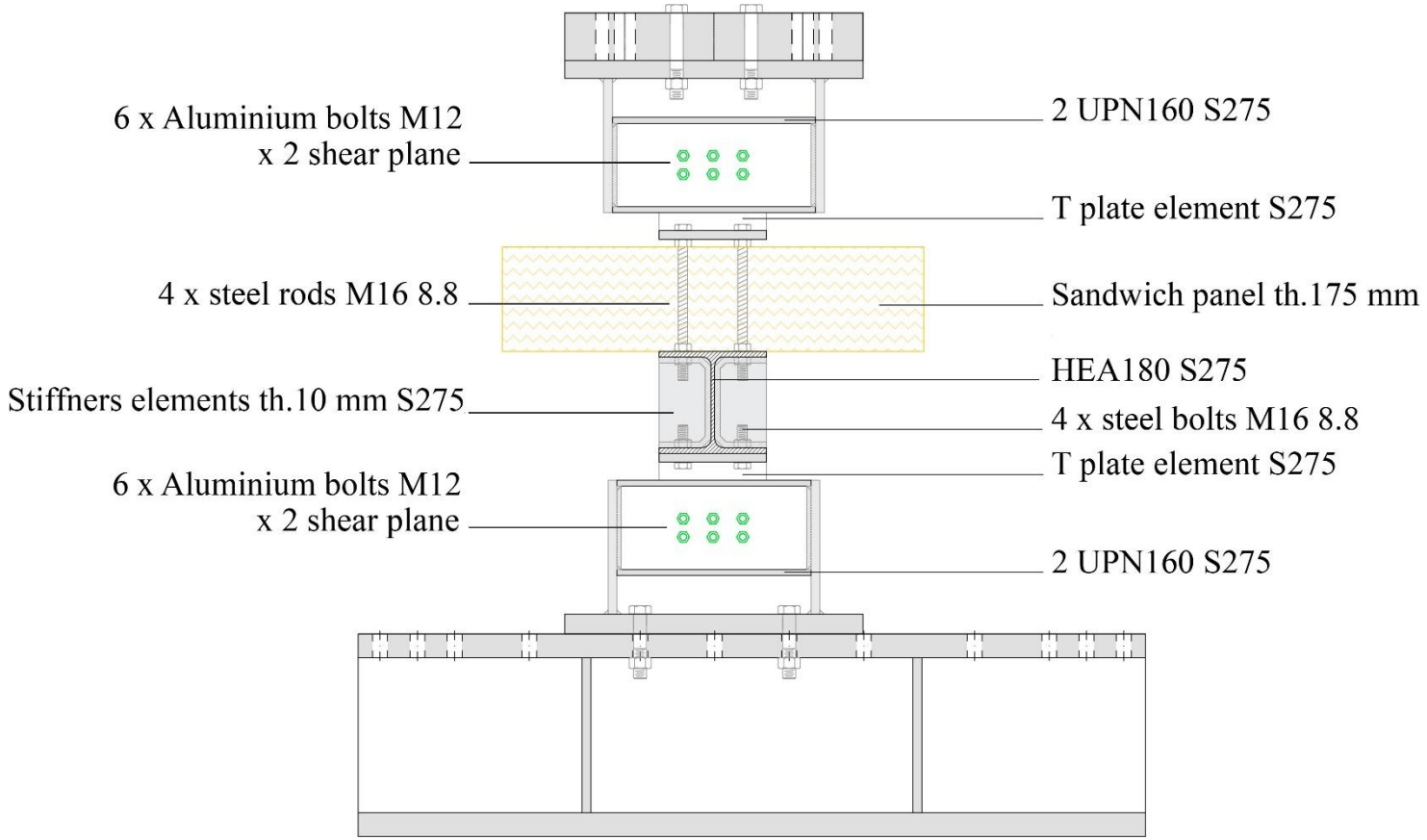
Compression test

Results comparison:

- The two cyclic tests are in a good agreement: indeed, the second cyclic test exhibited wider cycles due to an initial stiffer cycle than the first cycle test;
- Good agreement with the tension test curve;
- Compression branch of the cyclic tests were affected by significant pinching due to bolt-hole clearances
- Very small hysteretic behaviour of the detail

Detail 3.2 geometry





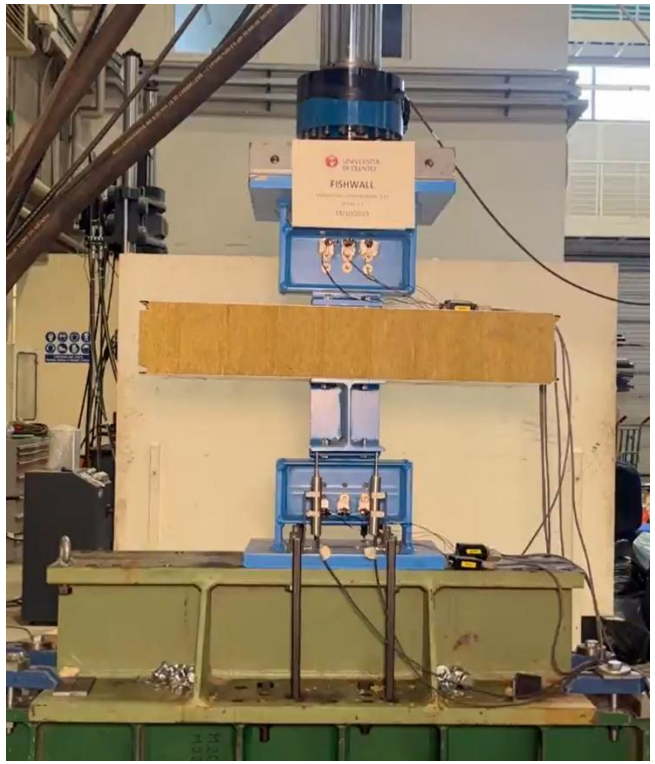
Tests on Detail 3.2

- Design force of 180 kN

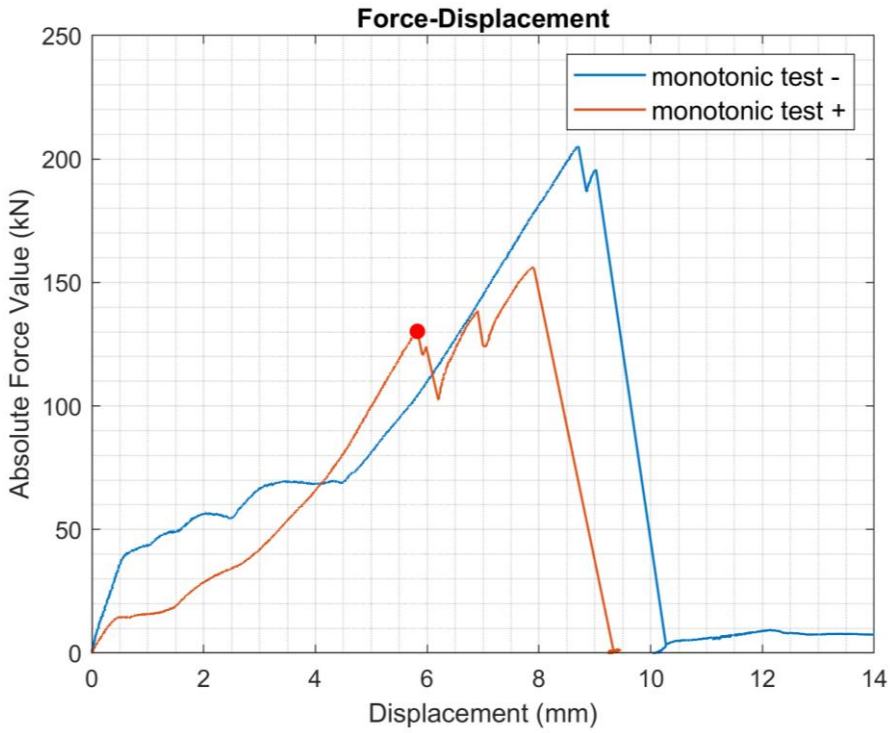
Tension test – max force reached: 130 kN

- 6 M12 aluminium bolts x 2 shear planes

Compression test - max force reached: 205.2 kN

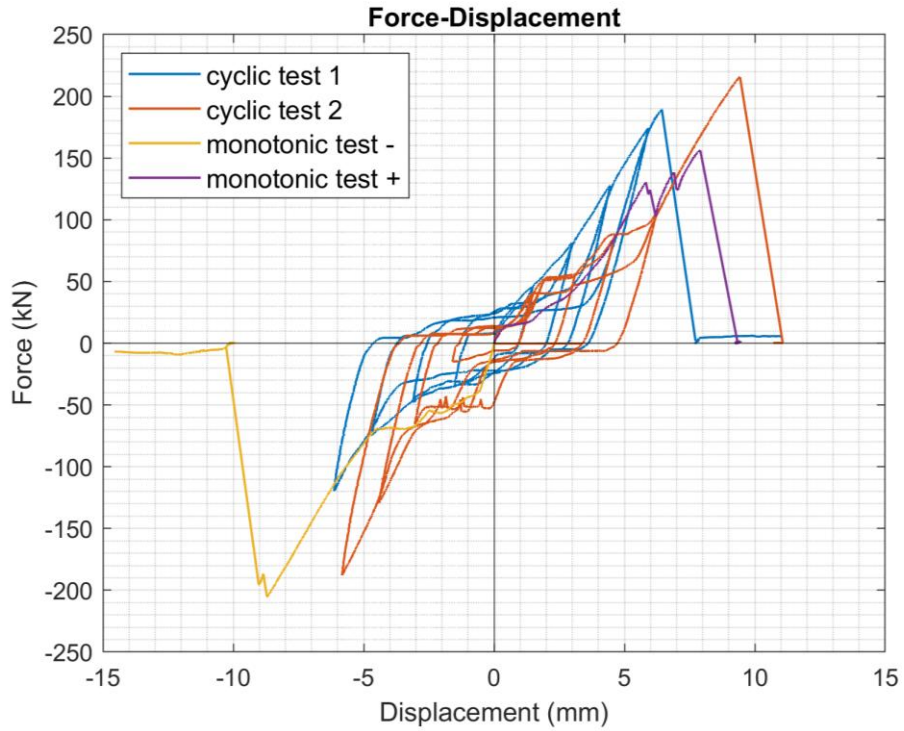


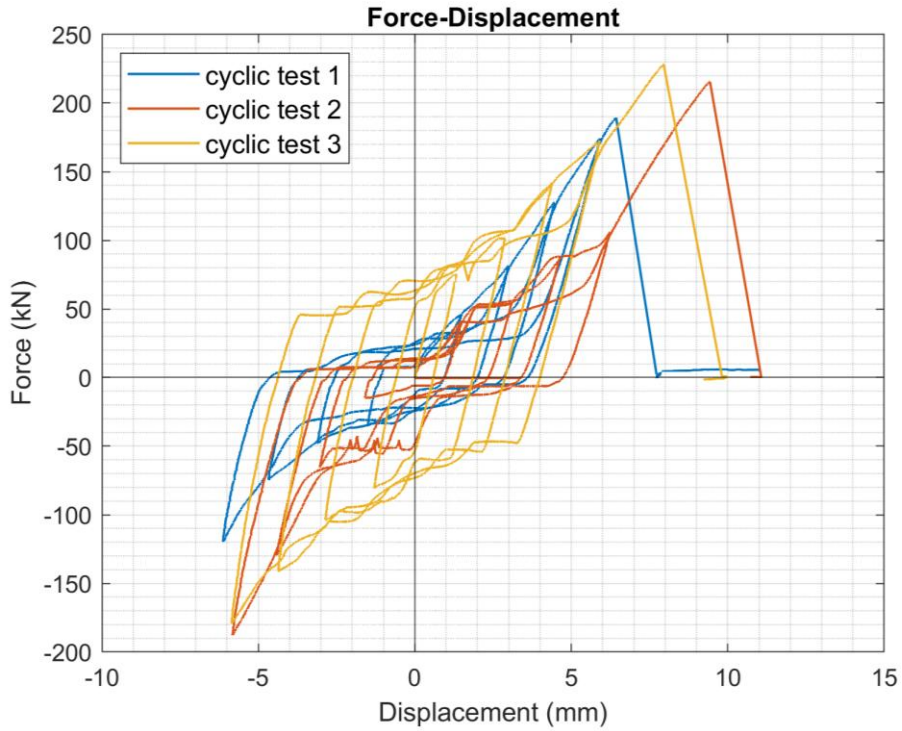
Monotonic tests results



Tests on Detail 3.2

Cyclic tests

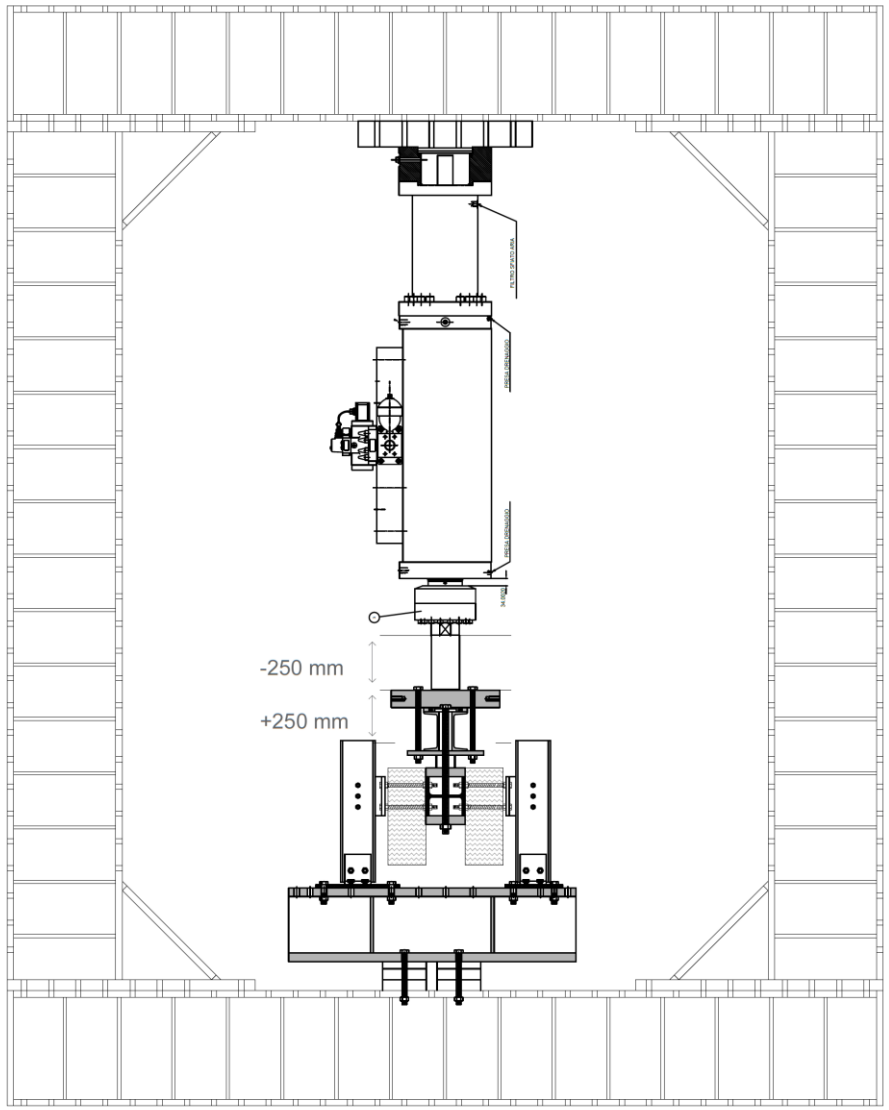


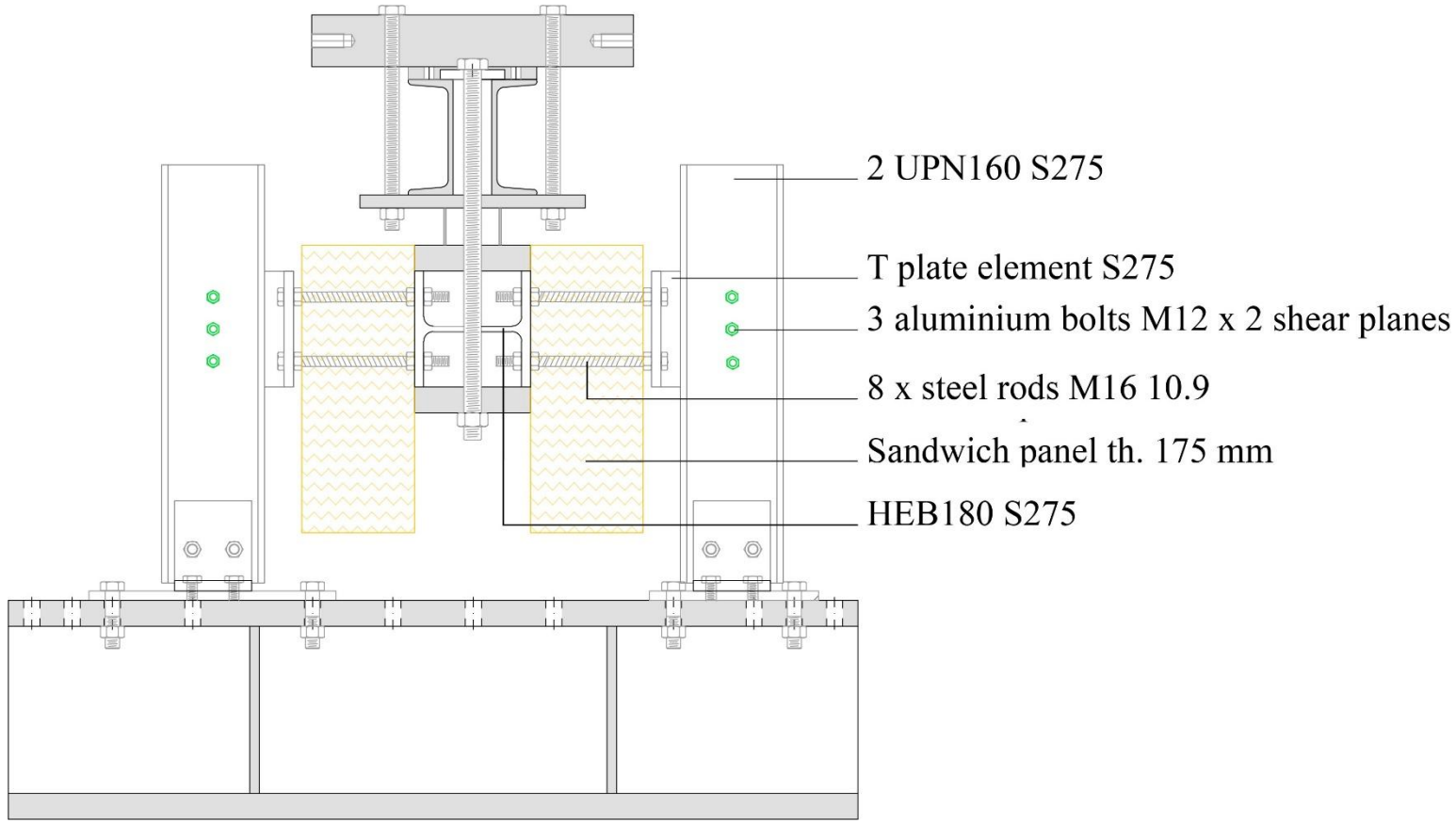


Results comparison:

- With respect to Detail 3.1, Detail 3.2 exhibited more imperfections caused by a higher number of bolts;
- Non-negligible difference between the cyclic tests and the monotonic tests in terms of both force and displacement;
- A third cyclic test was performed with special precautions in the assembling;
- The third cyclic test recorded higher values of force and less pinching effects that the firsts two cyclic tests;
- The design force of 180 kN was reached by all the cyclic tests.

Detail 4 geometry





Tests on Detail 4

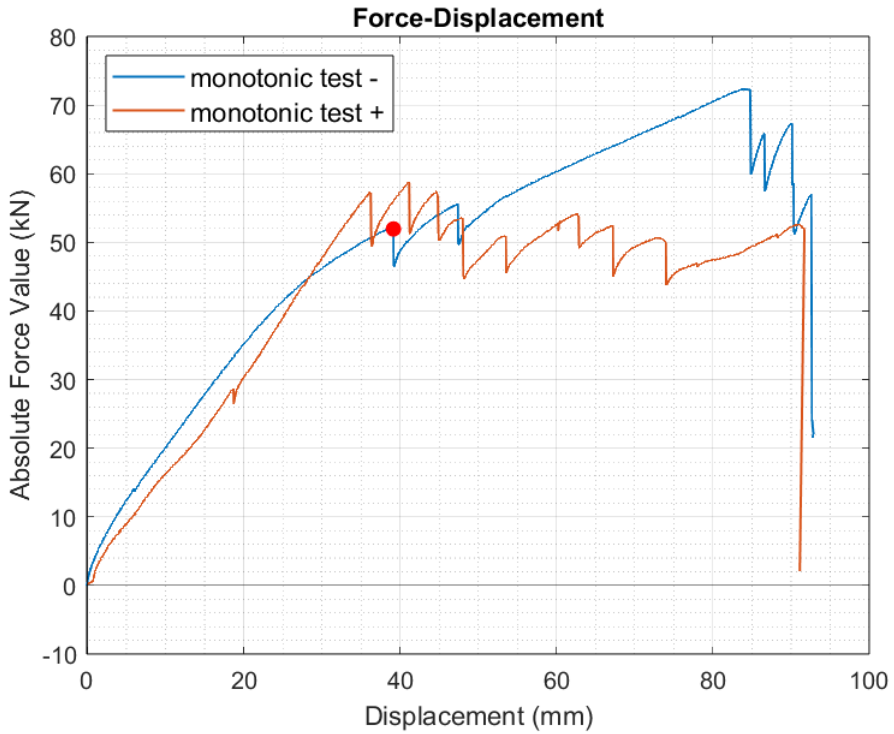
- Design force of 180 kN

Tension test – max force reached: 56.9 kN

- 6 M12 aluminium bolts x 2 shear planes

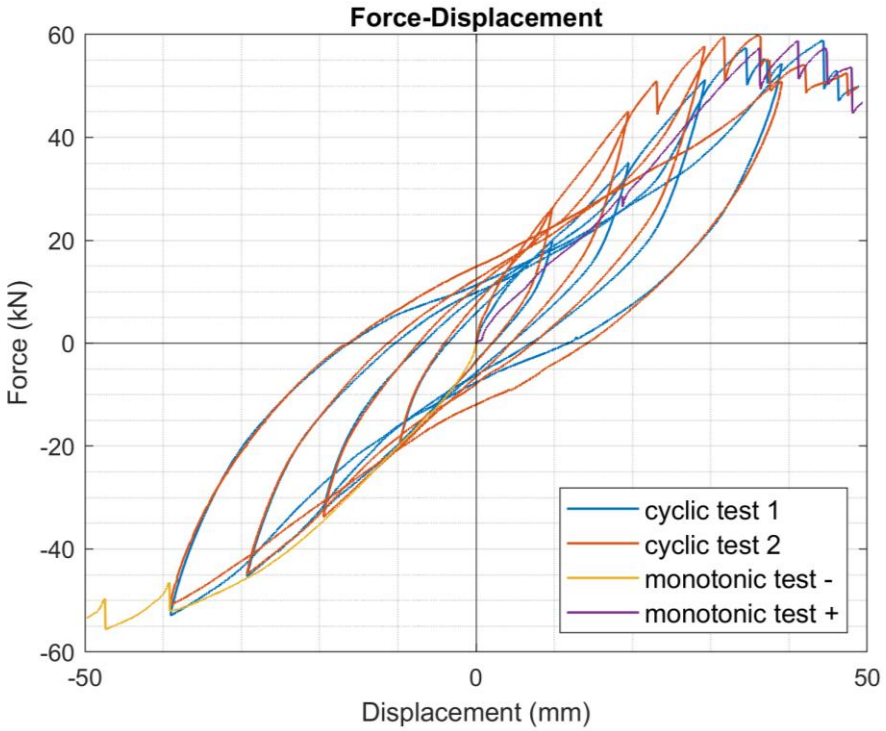
Compression test - max force reached: 52 kN

Monotonic tests results



Tests on Detail 4

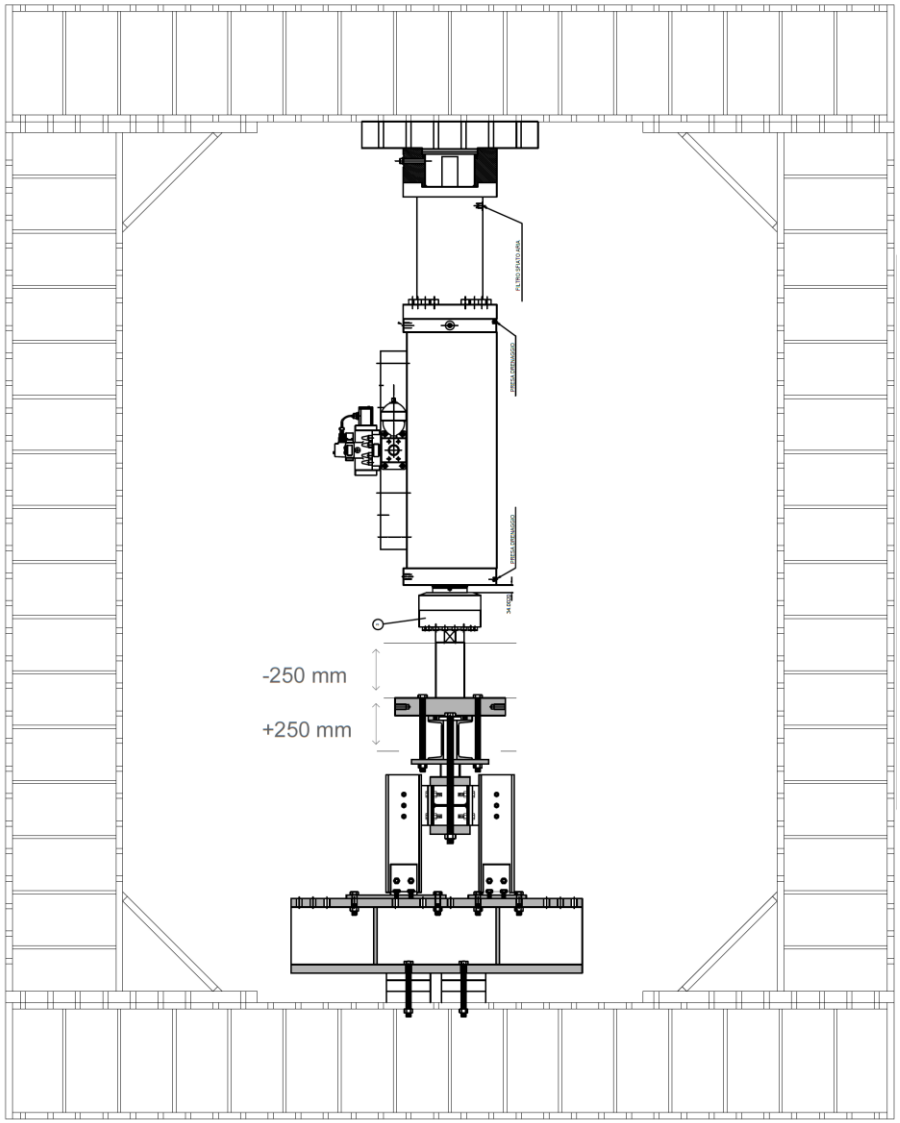
Cyclic tests

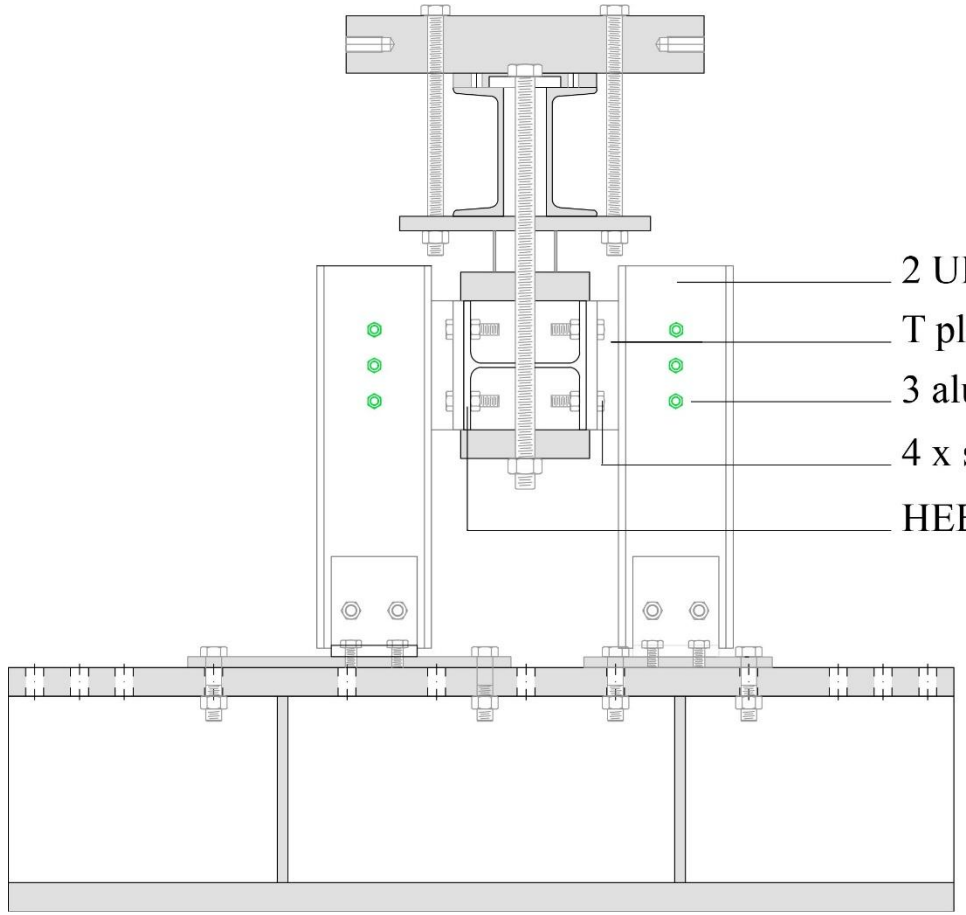


Results comparison:

- The four tests are in a good agreement
- A progressive failure of one or more shear planes occurred
- Design force of 180 kN was not reached in any tests
- Presence of the sandwich panels led to large deformations that induced additional forces on the aluminium bolts

Detail 5 geometry





Tests on Detail 5

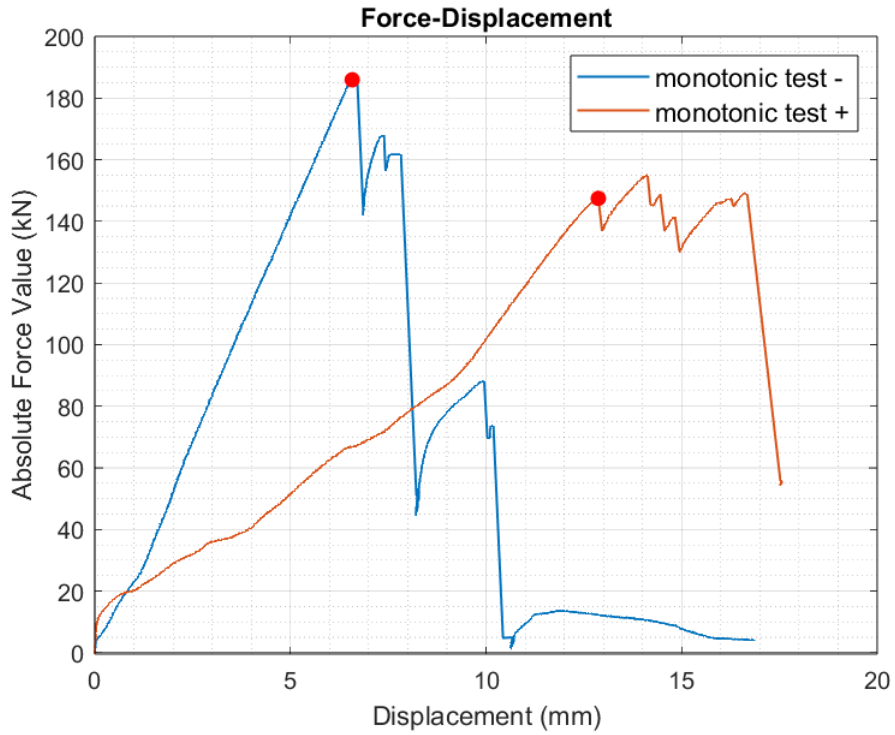
- Design force of 180 kN

Tension test – max force reached: 147.6 kN

- 6 M12 aluminium bolts x 2 shear planes

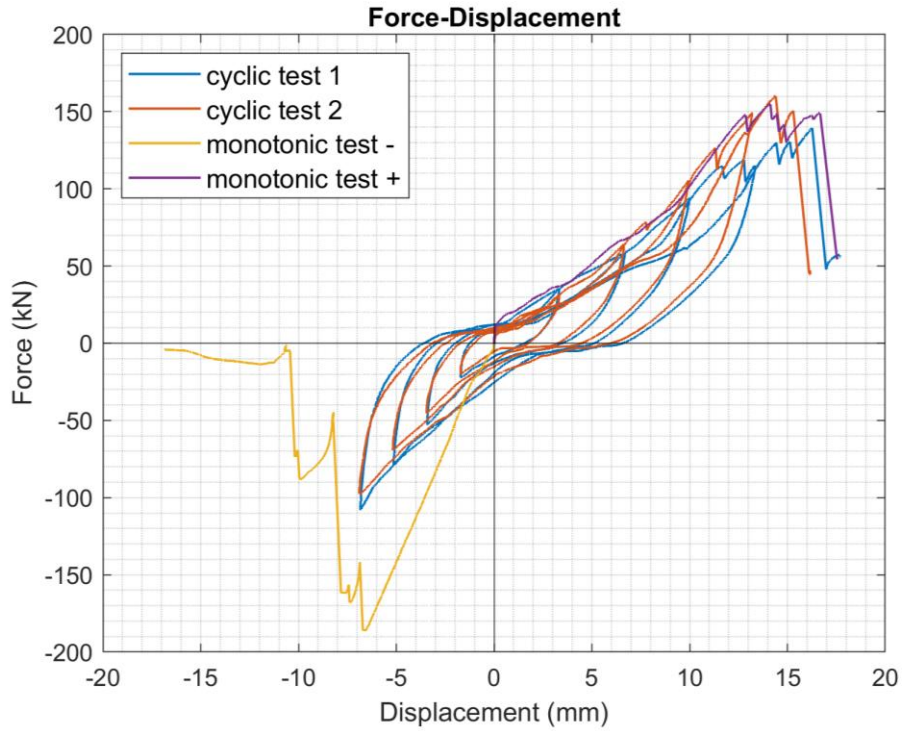
Compression test - max force reached: 185.9 kN

Monotonic tests results

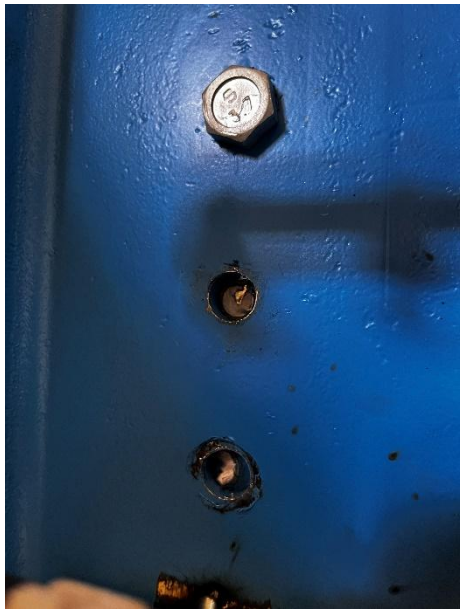


Tests on Detail 5

Cyclic tests



Cyclic tests

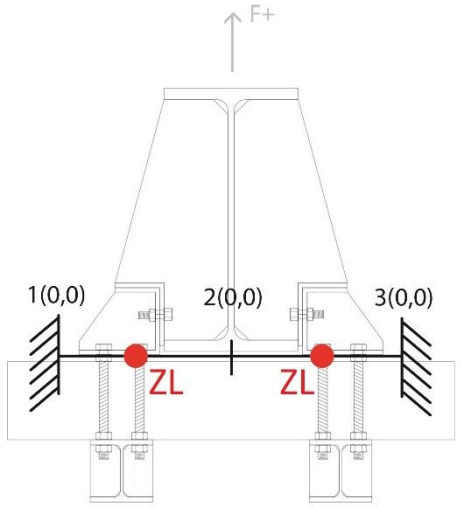


Results comparison:

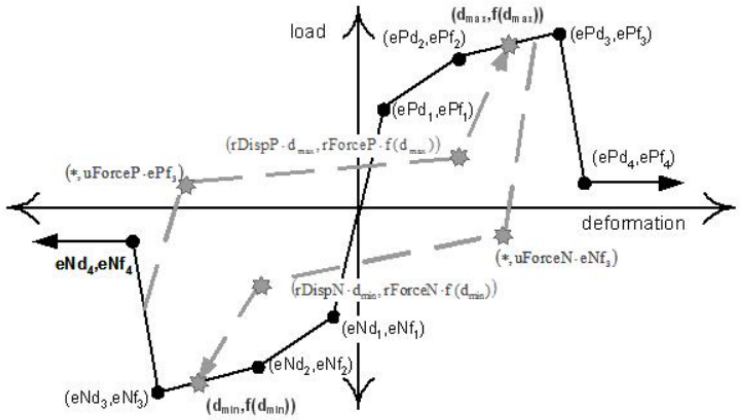
- Cyclic tests are in a good agreement between them
- Progressive failure of one or many shear planes occurred
- Design force of 180 kN was not reached
- Absence of the sandwich panel allowed higher forces to be achieved with respect to Detail 4;
- Higher stiffness was observed in compression due to a different assembly process

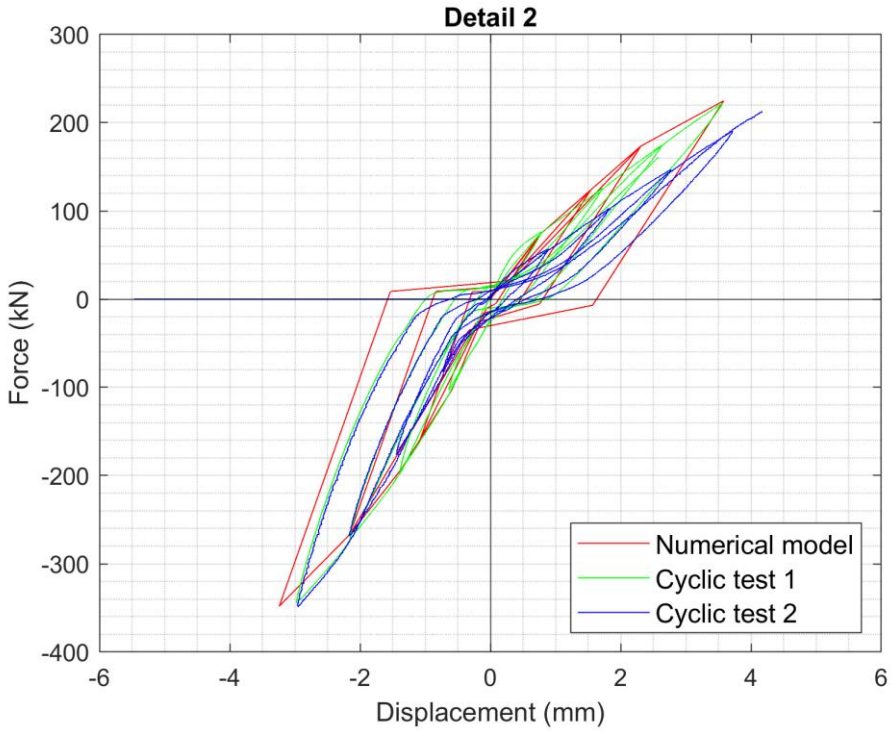
Calibration of the experimental behaviour – Detail 2 example

Fusible link Opensees model



Pinching4 model assigned to ZeroLengthElement [ZL]

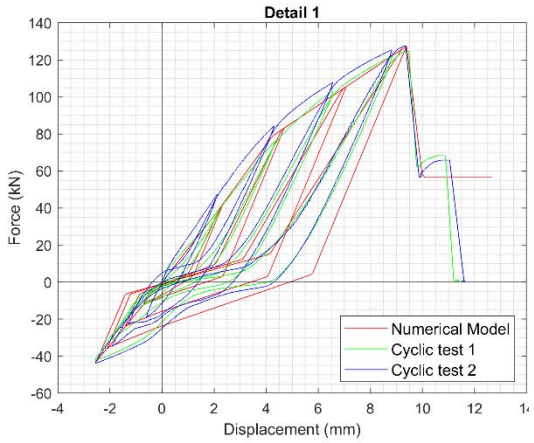




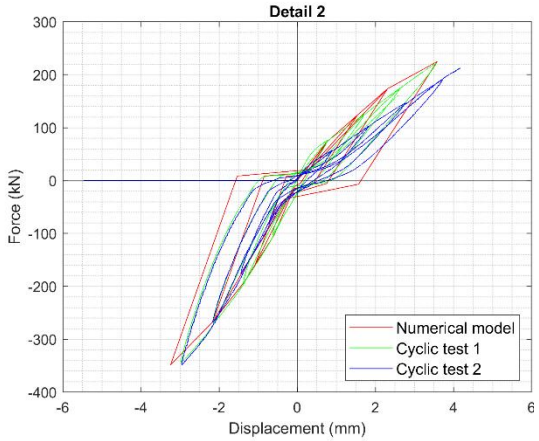
	Max force [kN]	ERROR [%]	Min force [kN]	ERROR [%]
Cyclic Test 1	221.2	-0.5%	-348.6	-0.2%
Cyclic Test 2	212.6	3.5%	-348.5	-0.2%
Calibration	220.0	-	-348.0	-

All details calibration

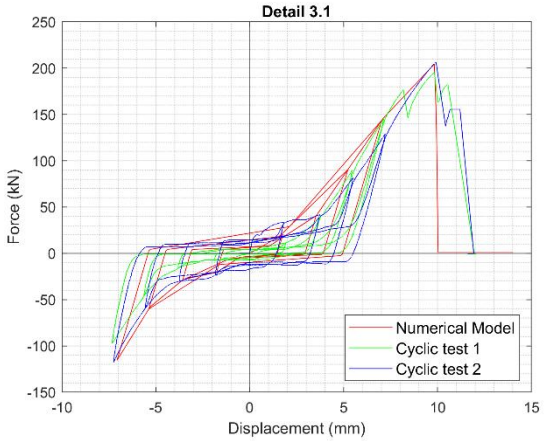
Detail 1



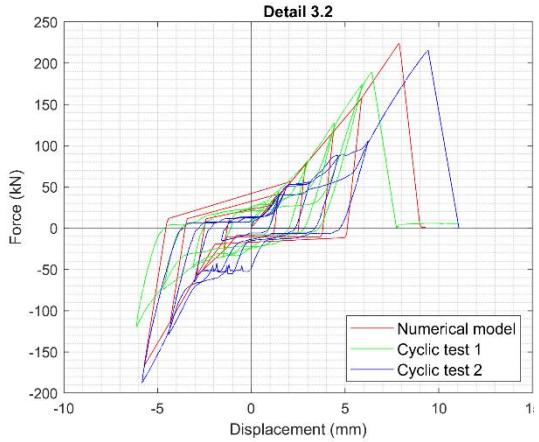
Detail 2



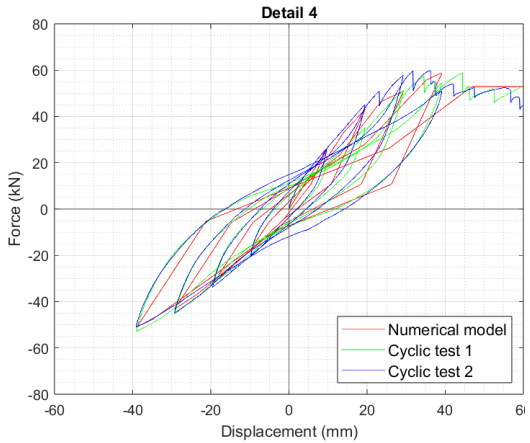
Detail 3.1



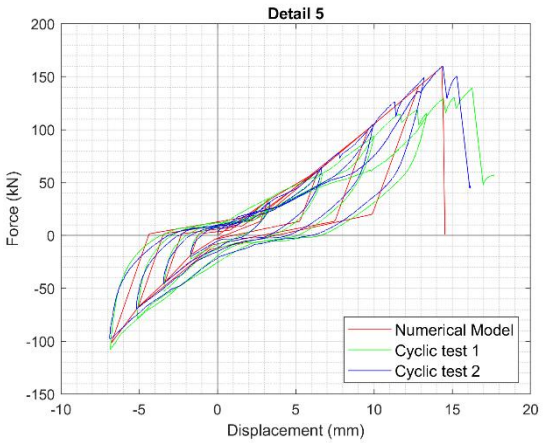
Detail 3.2



Detail 4



Detail 5



		Max force Cyclic Test 1 [kN]	Max force Cyclic Test 2 [kN]	Max force Numerical model [kN]	Max Error [%]
Det 1	Pos	124.7	127.8	127.5	2.2
	Neg	-42.3	-43.8	-44.1	4.1
Det 2	Pos	221.2	212.6	220.0	3.5
	Neg	-348.6	-348.5	-44.1	0.2
Det 3.1	Pos	194.9	206.5	204.5	4.9
	Neg	-97.0	-117.6	-115.0	18.2
Det 3.2	Pos	189.3	215.4	224.4	18.5
	Neg	-119.8	-187.8	-167.0	38.6
Det 4	Pos	50.8	57.4	59.9	16.4
	Neg	-50.9	-52.9	-52.6	3.5
Det 5	Pos	126.9	114.6	136.0	18.7
	Neg	-96.6	-107.9	-101.4	13.2

Conclusions

- Details with a **lower number of aluminium bolts** are preferable because they imply lower imperfections.
- The laboratory tests have shown that **the way of assembling** the fusible links may play a role in the detail response.
- As expected, a **brittle response** with limited hysteretic behaviour was observed.
- The **sandwich panel** allows for large deformations of the details and led to **additional forces.**
- **Detail 1 and Detail 2** represent a good option: fusible links are only loaded in one direction and symmetrically, so the magnitude of secondary forces is negligible.
- A good agreement between the experimental and the numerical curves was obtained, with a maximum error within 20%.

Thank you for your attention!

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