



# FISHWALL

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



UNIVERSITY  
OF TRENTO

## SESSION: Numerical modelling and parametric analyses

- Seismic performance assessment of steel structures associate with partition fire wall using “fusible” links
- Sara Pasquali | Nicola Tondini | Gabriele Zanon
- UNITN

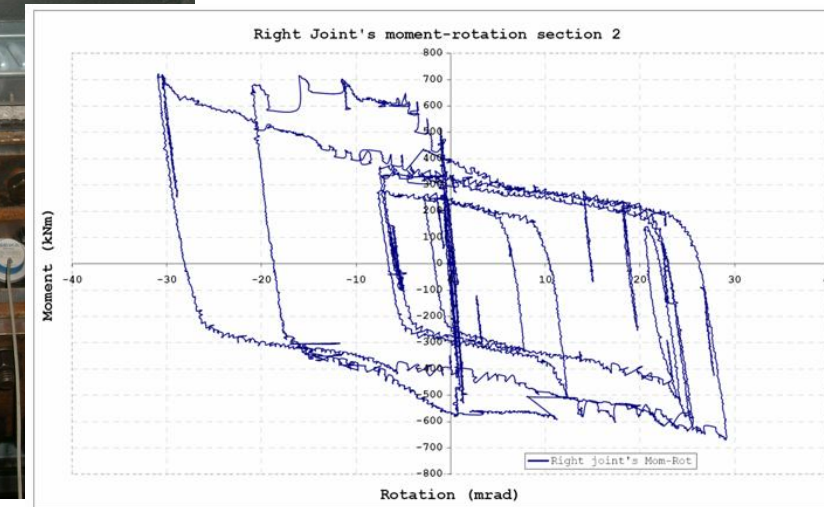
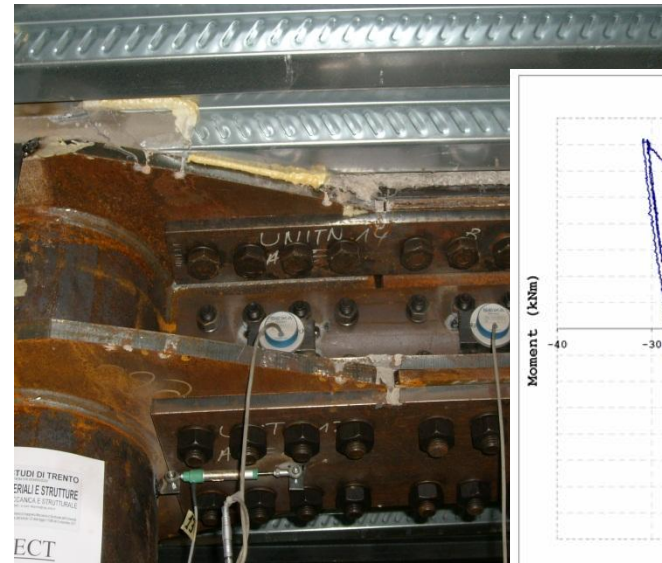
# Presentation outline

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- Introduction on the design philosophy of the fusible link
- 3D global numerical models of selected case studies
- Spectrum-compatible accelerograms selection
- Results of the time-history parametric analyses
- Development of the fragility functions

# Design philosophy of the fusible link

- Correlation between fire and seismic actions:
  - ✓ Follow-up actions: seismic + fire.
  - ✓ **Separated actions.**
- Seismic behaviour is important, especially in the case of industrial buildings to limit downtime and economic losses
- Limitation of the damage in particular in the case of low and moderate seismicity.
- Fusible link characterized from very limited energy dissipation – brittle behaviour

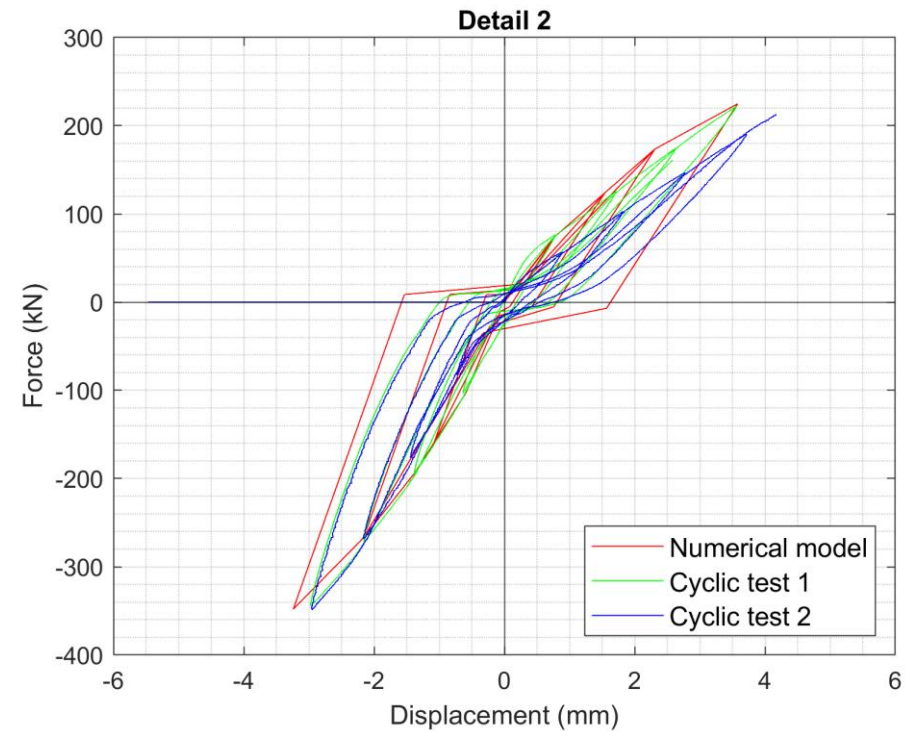


# Numerical models of the details

Experimental campaign



Calibration of the experimental behaviour



**Limited energy dissipation**

# Parametric numerical models

The global numerical models were developed to analyse the response of the fusible links system considering different aspects

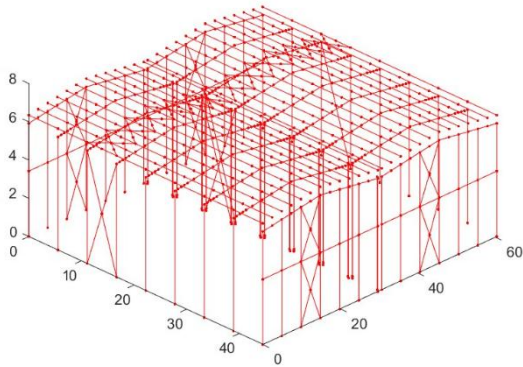
- **Case studies:** different plan dimensions and steel sections;
- **Wall position:** orthogonal or parallel to the portal frames;
- **Structure configuration:** symmetric or asymmetric;
- **Spectrum-compatible accelerograms:** different soil type;
- **Spectrum-compatible accelerograms:** different events distances and magnitudes;



# Global nonlinear numerical models

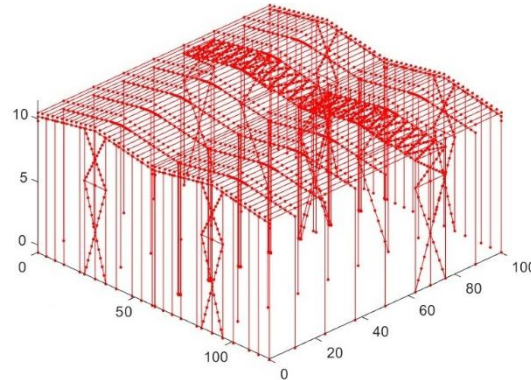
## CASE STUDY 1: CARCASSONE

Case study area: 2800 m<sup>2</sup>



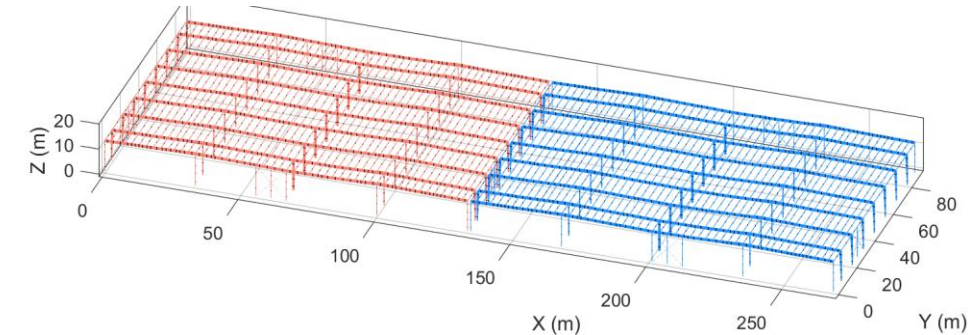
## CASE STUDY 3: PIBRAC

Case study area: 12060 m<sup>2</sup>



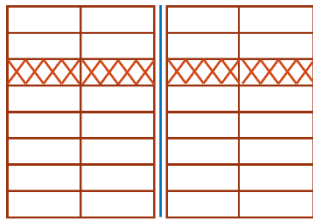
## CASE STUDY 4: BRESSUIRE

Case study area: 24000 m<sup>2</sup>

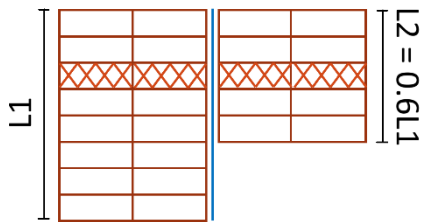


Fire wall **orthogonal** to portal frames

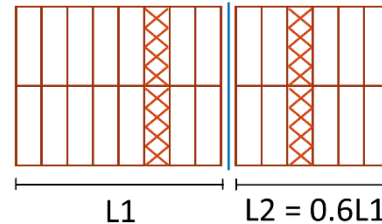
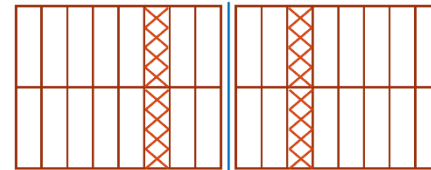
SYMMETRIC



ASYMMETRIC



Fire wall **parallel** to portal frames

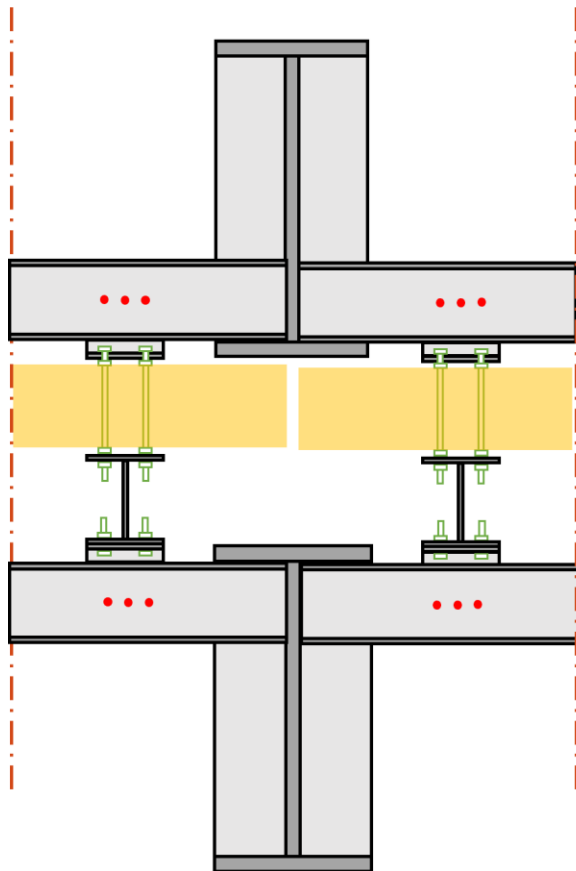


Modelling assumptions:

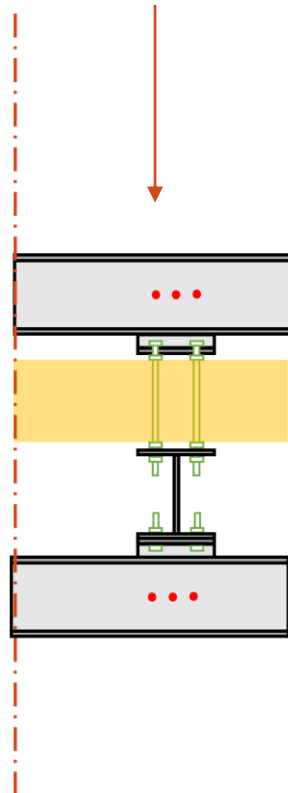
- Columns, beams and bracing systems modelled as nonlinear finite elements with distributed plasticity
- Facades, purlins and support elements modelled as elastic beams elements
- Development of the models in the OpenSees software

# Details building configuration

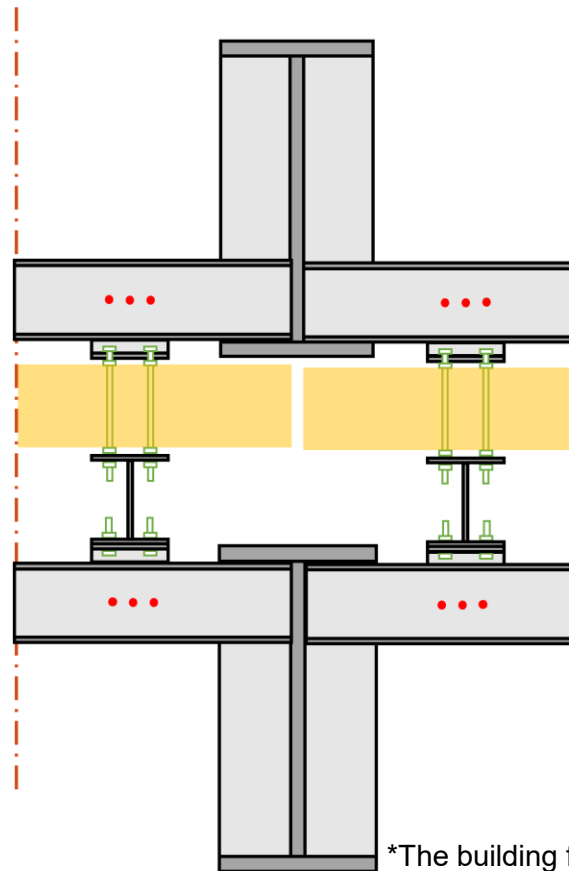
Each portal frame column configuration with the fusible links system, regardless of the details considered



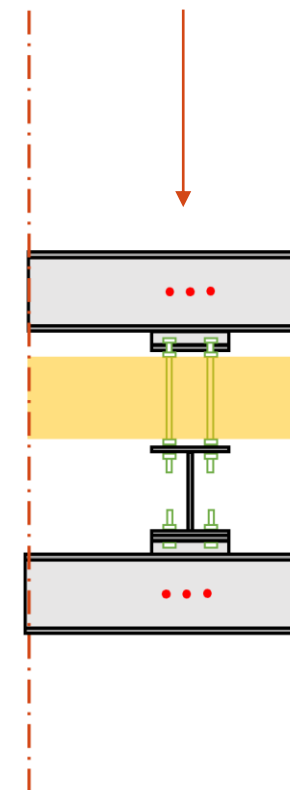
Additional column and fusible link system at each 5 m between the portal frames columns



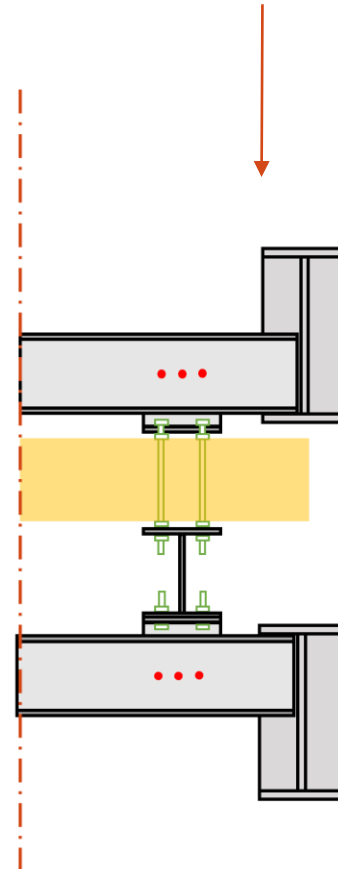
Each portal frame column configuration with the fusible links system, regardless of the details considered



Additional column and fusible links system at each 5 m between the portal frames columns



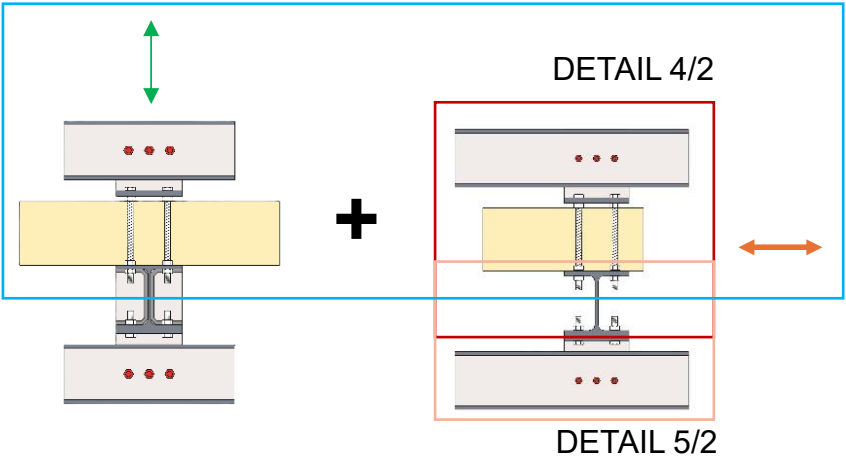
Building façade column\*



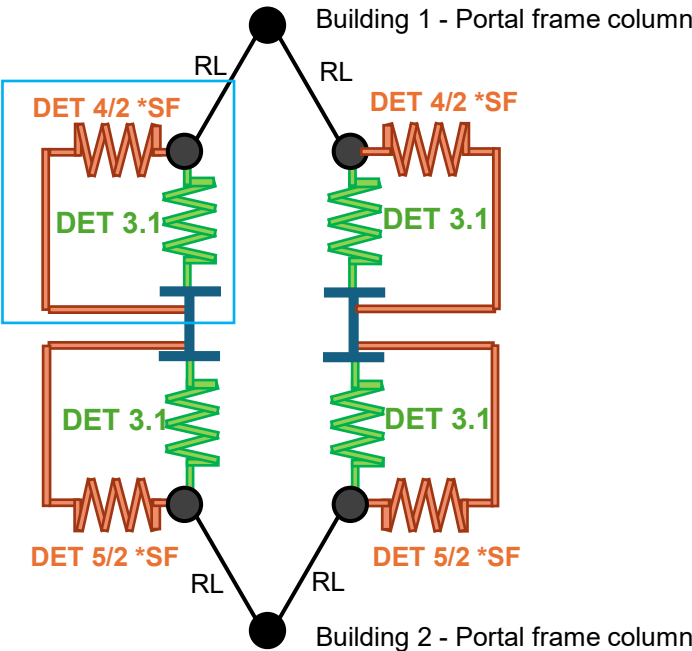
\*The building façade column has a different representation due to its usual smaller section

# Fusible links numerical models

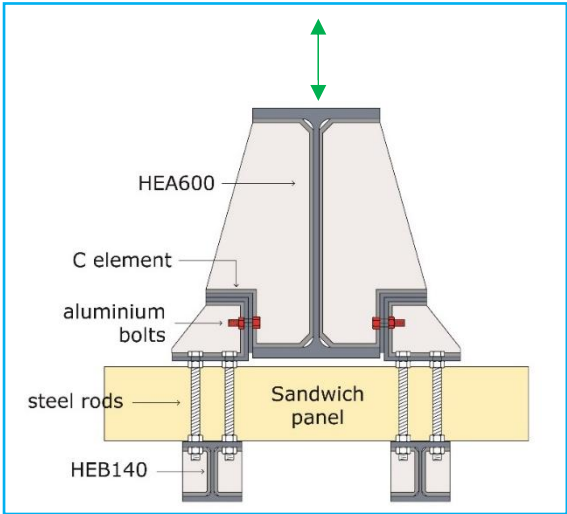
Combined configuration of Detail 3.1 or Detail 3.2 with Detail 4+5



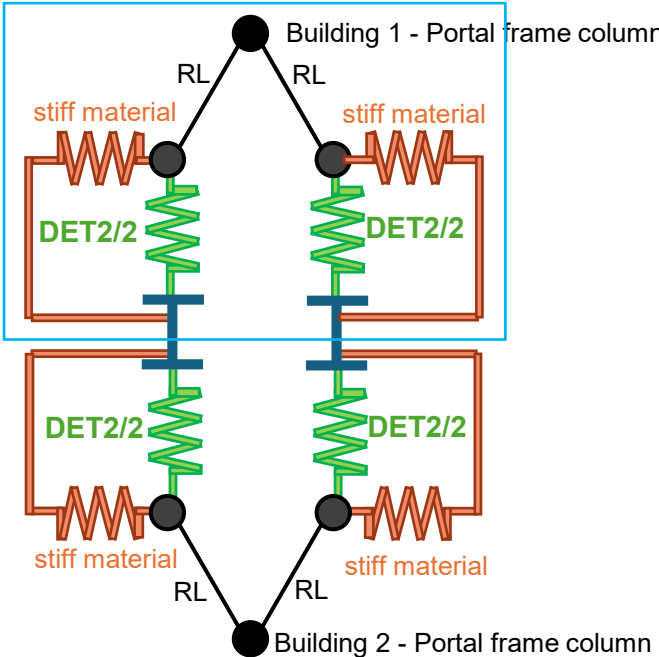
Numerical model configuration



Detail configuration of Detail 1 or Detail 2



Numerical model configuration





# Time-history analyses

European database for accelerograms selections



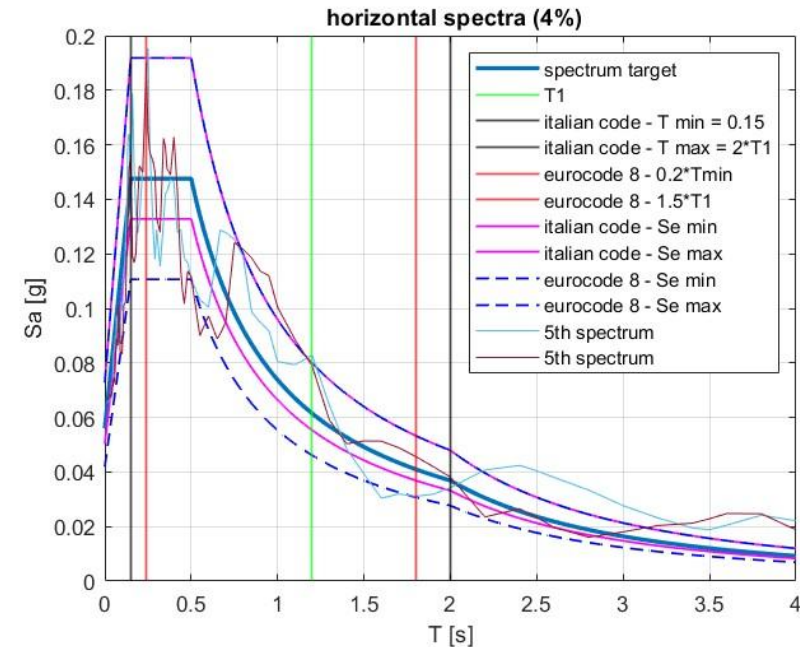
Italian database for accelerograms selections



National Institute of Geophysics and Volcanology

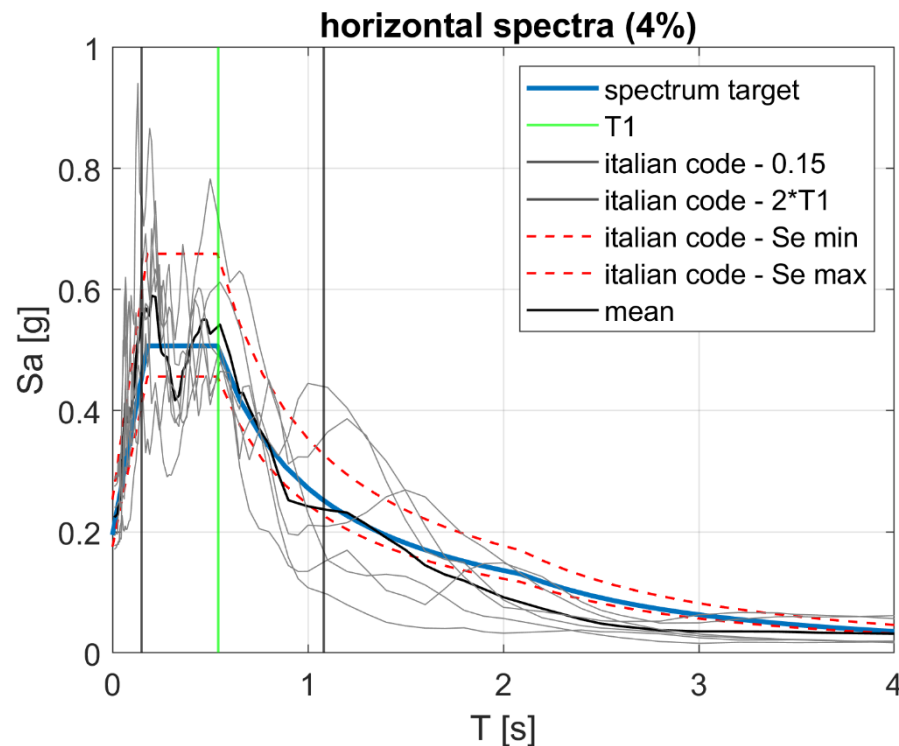
## Selection criteria of the accelerograms:

- Elastic target spectrum (horizontal and vertical);
- Period range that comprises the first period of the structure (in accordance with either the EC8 and the Italian Code);
- Range of magnitude (3.5 - 7) and distance (1-100 km) of the events;
- Compatible directions for the event were horizontals;
- Events characterized by different soil classification were selected to investigate the effect.

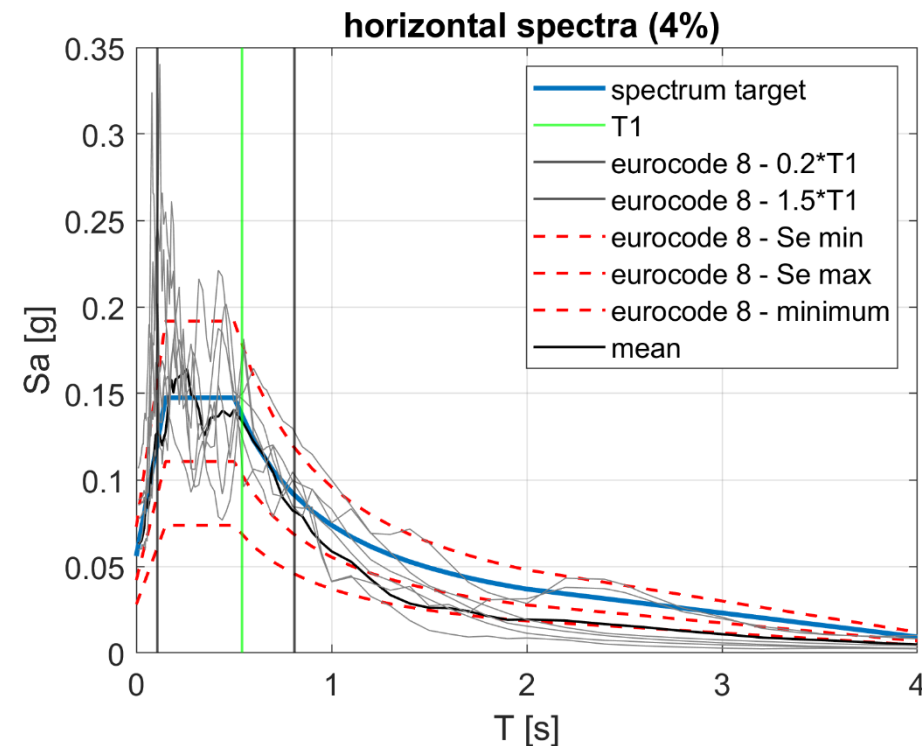


# Spectrum-compatible accelerograms

Moderate seismicity accelerograms

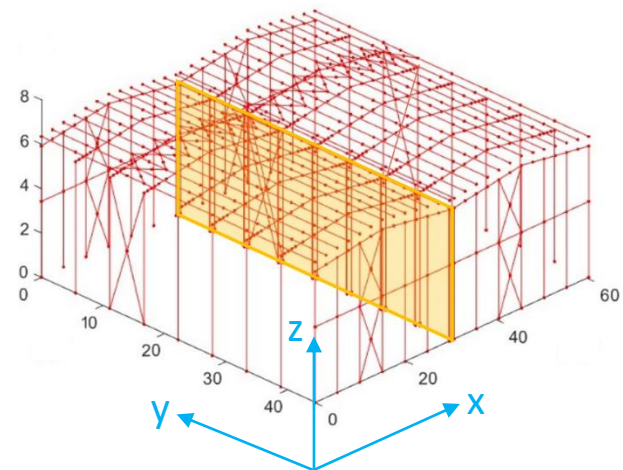


Low seismicity accelerograms

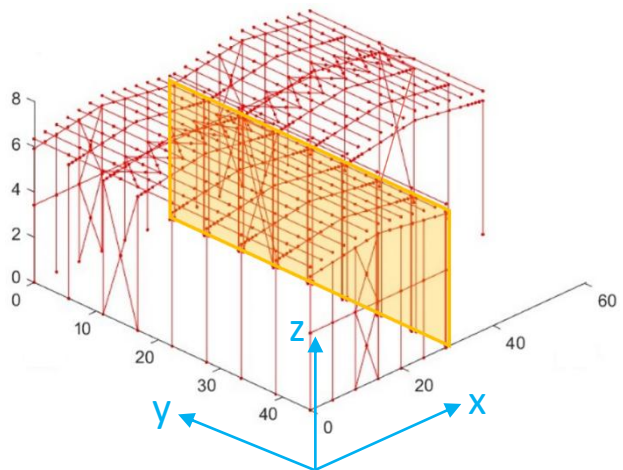


After performing a modal analysis of each model, the periods of the structure were identified and a series of three accelerograms for the moderate seismicity and three accelerograms for the low seismicity were obtained from the Italian and European database, taking into account only the horizontal directions. Considering EC8 provisions, the maximum value obtained from the three analyses were taken into account.

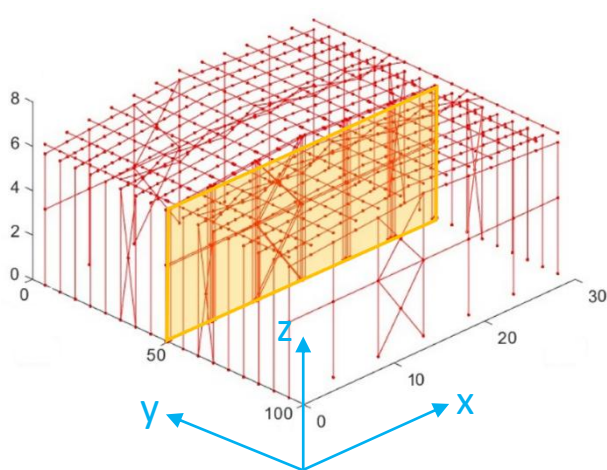
# Case study 1 dynamic properties



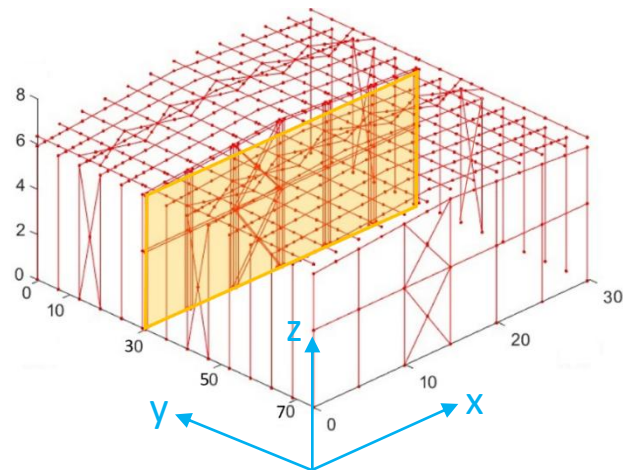
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric

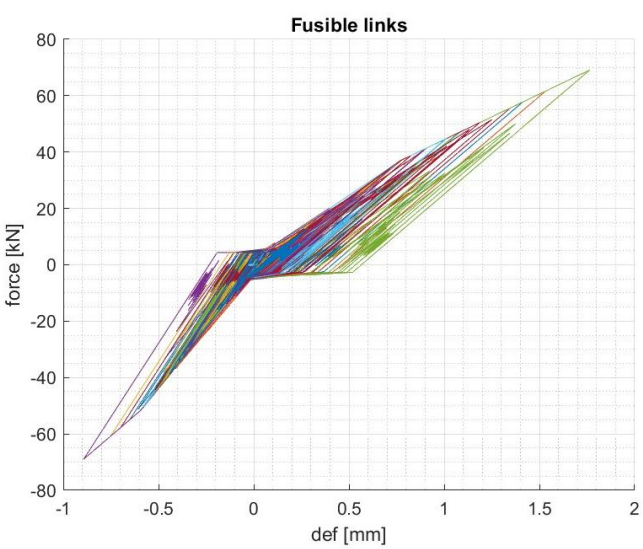
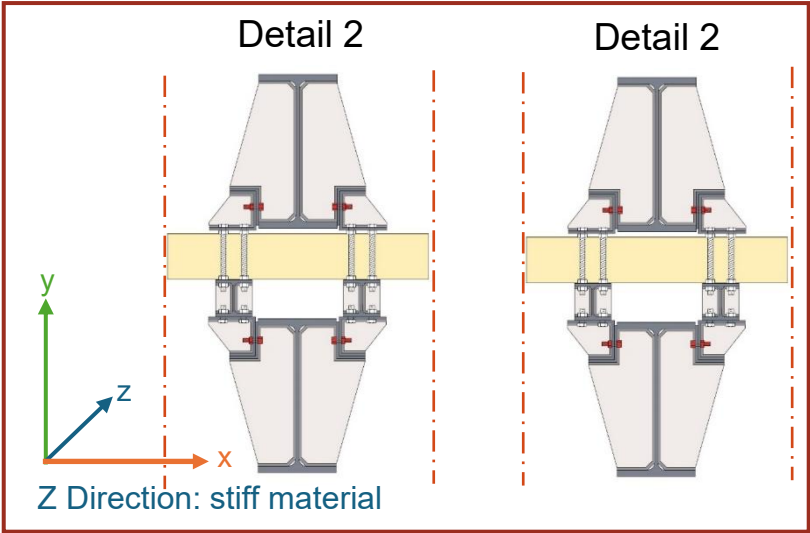
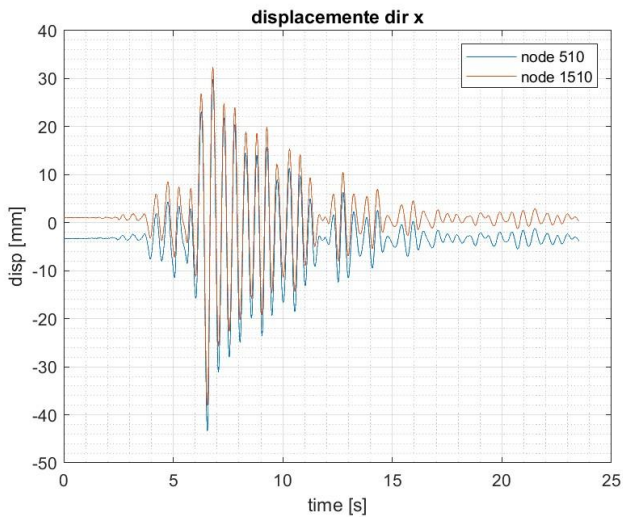
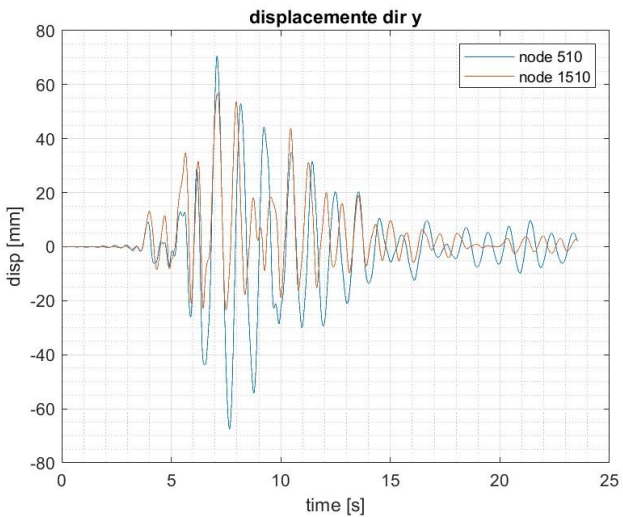
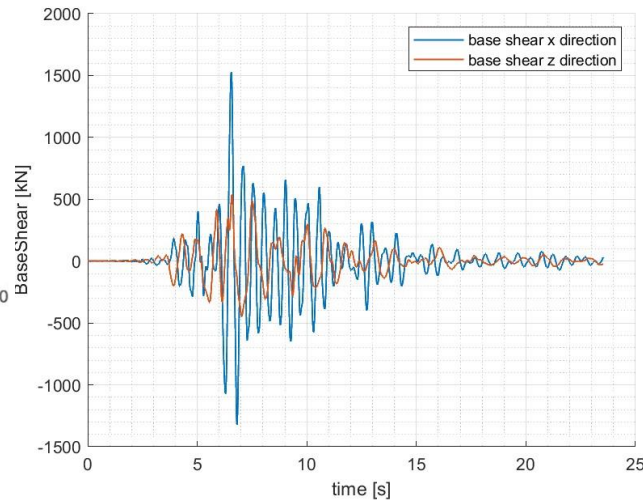
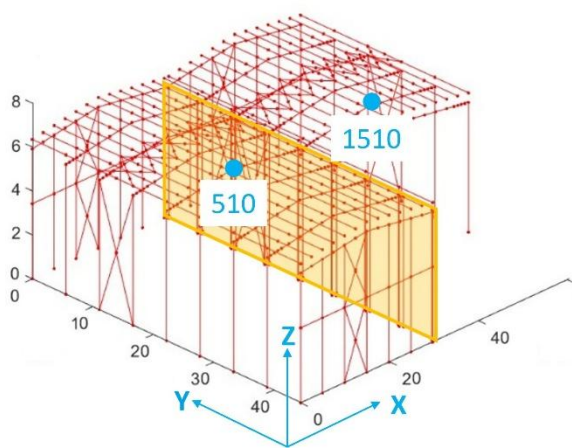


Model parallel asymmetric

Symmetric configuration					Asymmetric configuration				
Mode	T [s]	Ux [%]	Uy [%]	Rz [%]	Mode	T [s]	Ux [%]	Uy [%]	Rz [%]
1°	0.63	50.6	0.0	4.1	1°	0.56	13.8	0.00	8.39
7°	0.58	0.0	77.0	10.8	3°	0.54	0.04	71.1	10.8
8°	0.55	0.0	16.5	38.6	10°	0.42	0.00	19.7	41.7

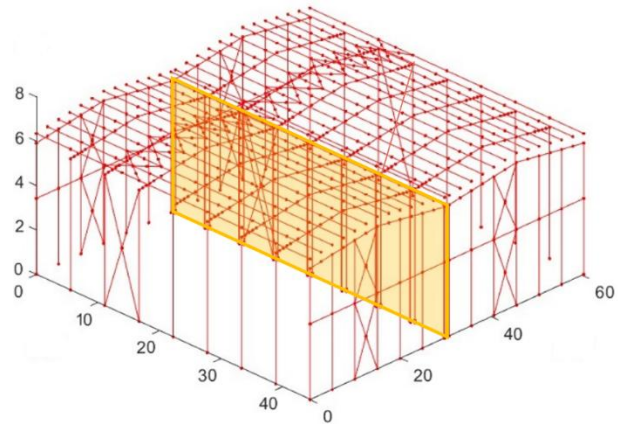
Symmetric configuration					Asymmetric configuration				
Mode	T [s]	Ux [%]	Uy [%]	Rz [%]	Mode	T [s]	Ux [%]	Uy [%]	Rz [%]
1°	0.63	27.8	0.0	29.5	1°	0.63	23.6	0.0	27.2
4°	0.62	24.2	0.0	27.8	4°	0.61	25.2	0.0	35.2
13°	0.58	0.0	92.3	0.2	11°	0.53	0.0	90.3	0.2

# Case study 1 – Detail 2 example

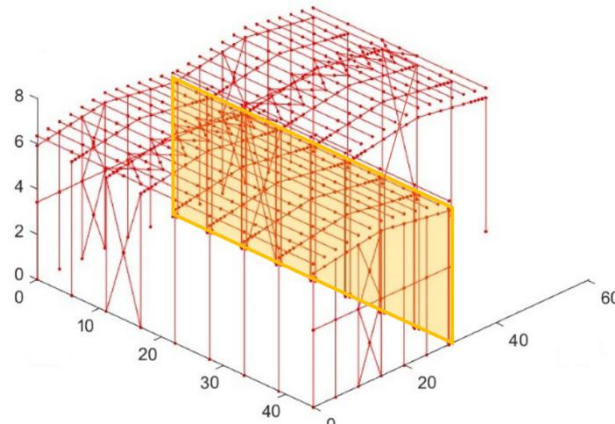




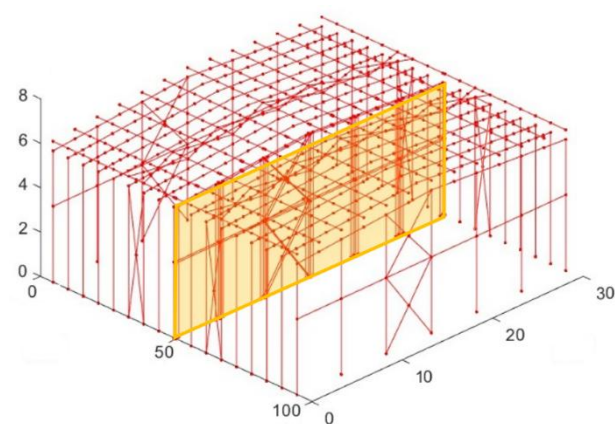
# Case study 1 outputs



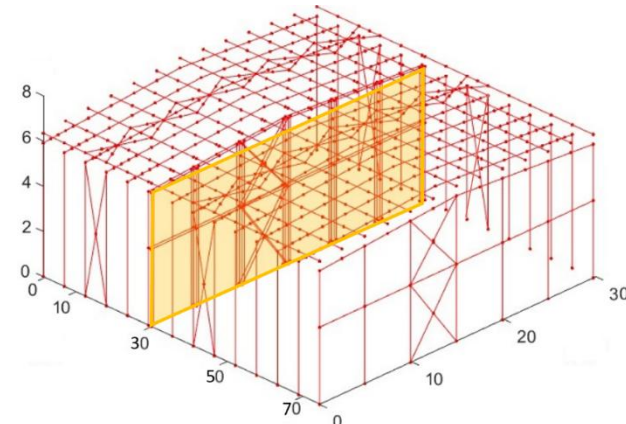
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric



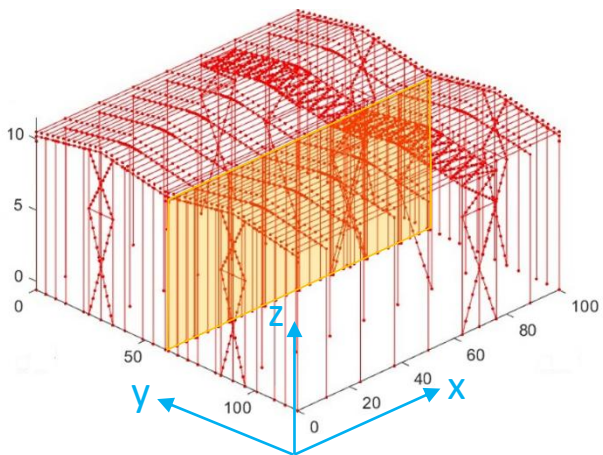
Model parallel asymmetric

	ORTH SYMM	ORTH ASYM	PAR SYMM	PAR ASYM	FUSIBLE LINK CAPACITY
DETAIL 1	12 kN	13 kN	-	-	22 kN
DETAIL 2	95 kN	70 kN	-	-	110 kN
DETAIL 3.1	42 kN	11 kN	58 kN	13 kN	115 kN
DETAIL 3.2	65 kN	19 kN	14 kN	13 kN	115 kN

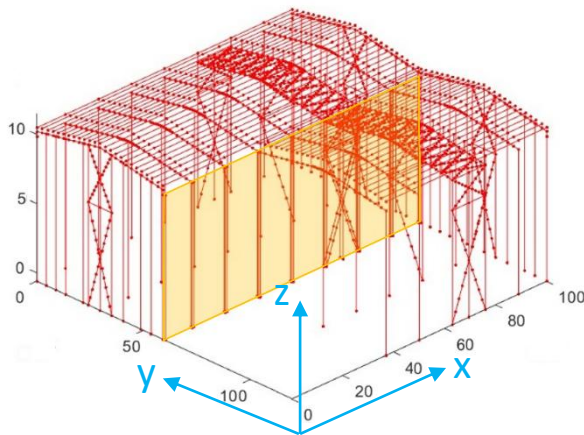
- None of the details overcame its capacity
- Different first periods ( $T_1$ ) of the symmetric and asymmetric structures led to the selection of different set of accelerograms.



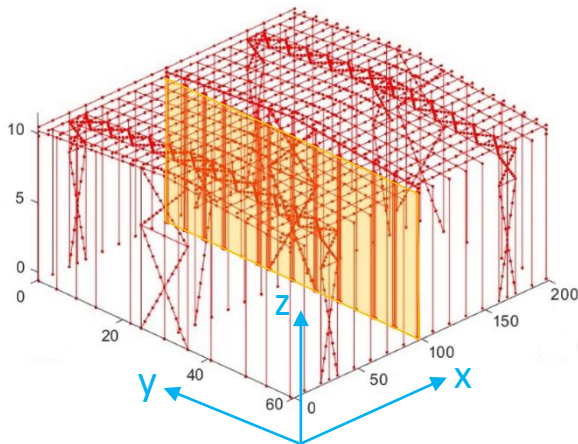
# Case study 3 dynamic properties



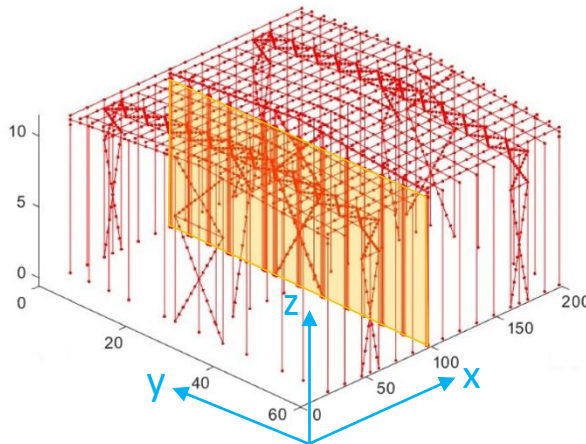
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric

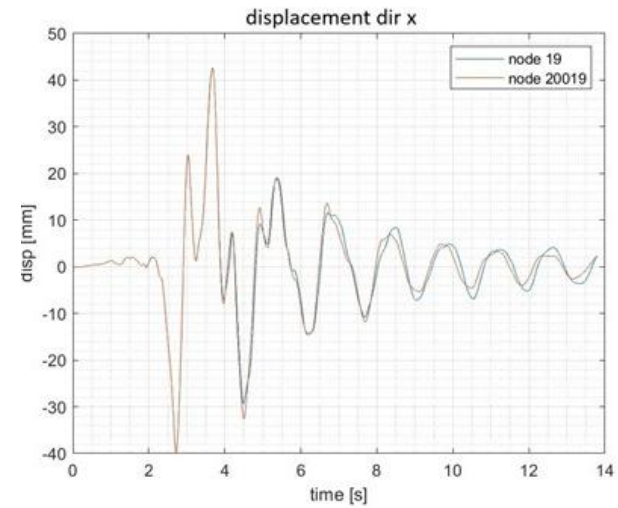
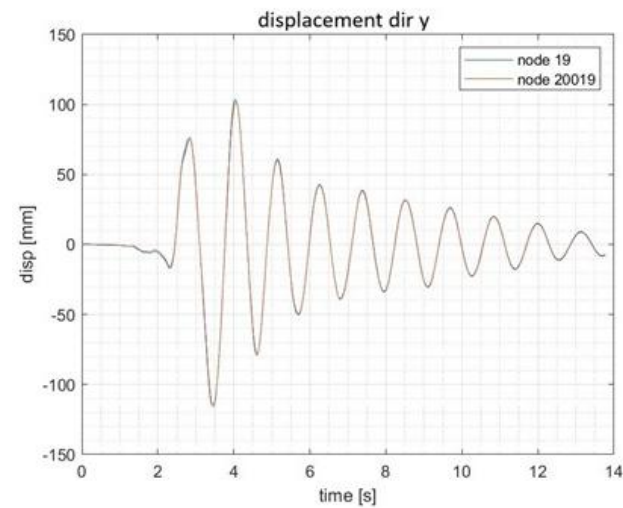
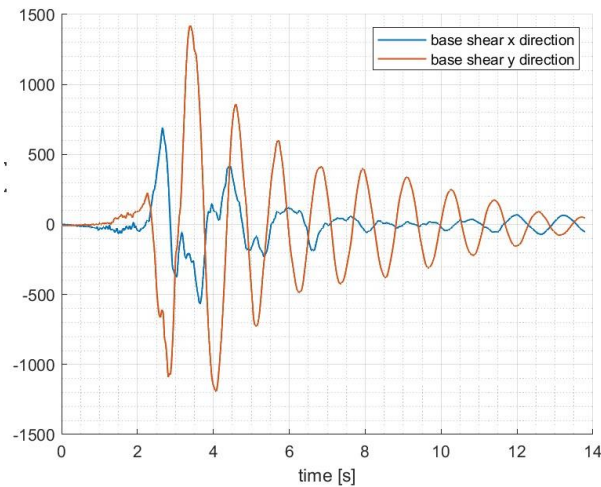
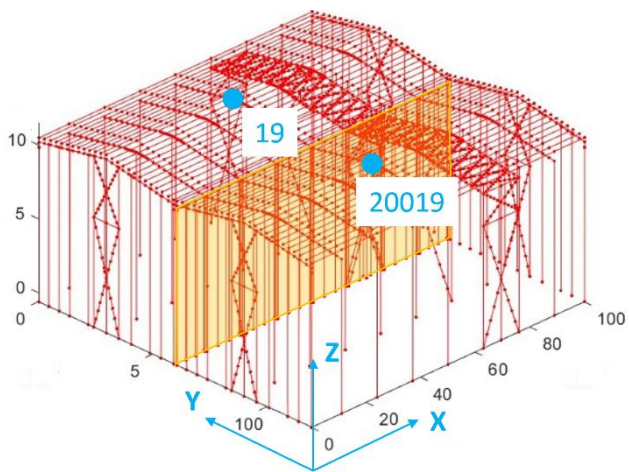


Model parallel asymmetric

Symmetric configuration					Asymmetric configuration				
Mode	T [s]	Ux [%]	Uy [%]	Rz [%]	Mode	T [s]	Ux [%]	Uy [%]	Rz [%]
1°	1.14	0.04	39.4	5.78	1°	1.14	0.02	45.5	3.18
2°	1.11	0.04	32.8	7.98	2°	1.11	0.06	29.5	13.2
3°	1.09	61.4	0.02	9.21	3°	1.09	21.9	0.44	4.35

Symmetric configuration					Asymmetric configuration				
Mode	T [s]	Ux [%]	Uy [%]	Rz [%]	Mode	T [s]	Ux [%]	Uy [%]	Rz [%]
1°	1.13	0.05	19.1	24.1	1°	1.13	0.02	21.7	23.4
2°	1.11	0.25	19.3	23.7	2°	1.11	0.01	21.4	33.4
4°	1.09	81.3	0.08	0.41	6°	1.05	75.4	0.04	0.15

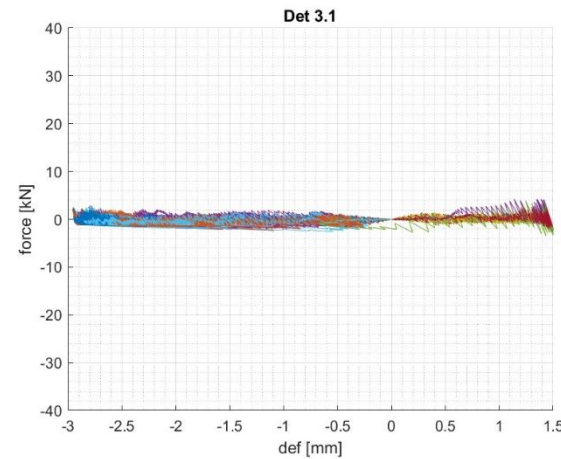
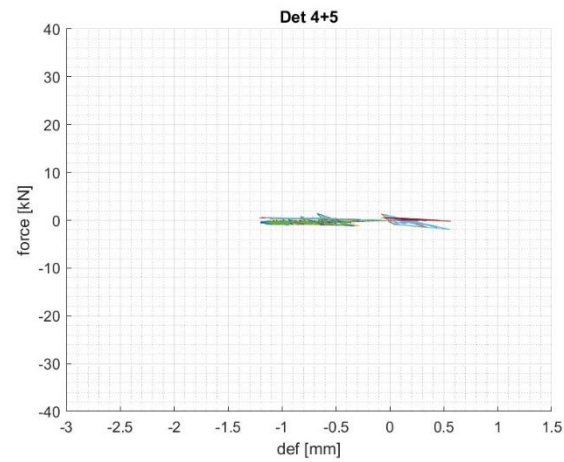
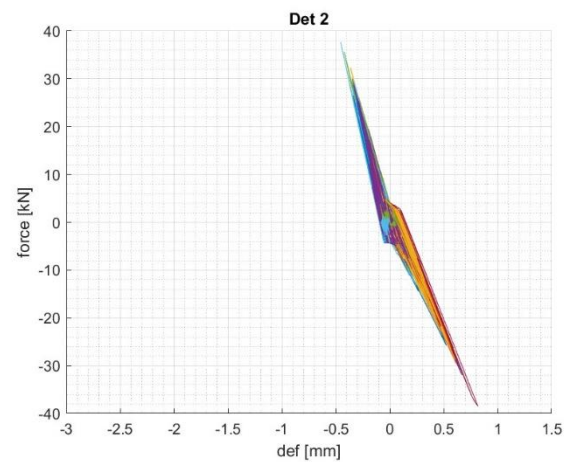
# Case study 3 – Detail 2 example



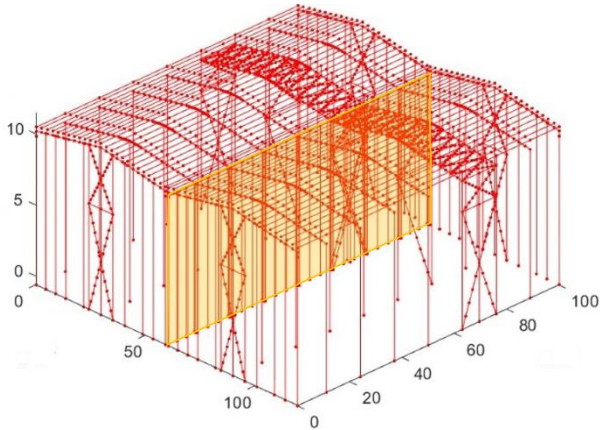
Detail 3145

Detail 2

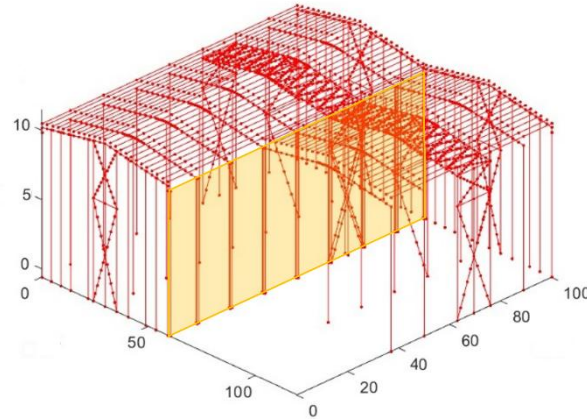
Z Direction: stiff material



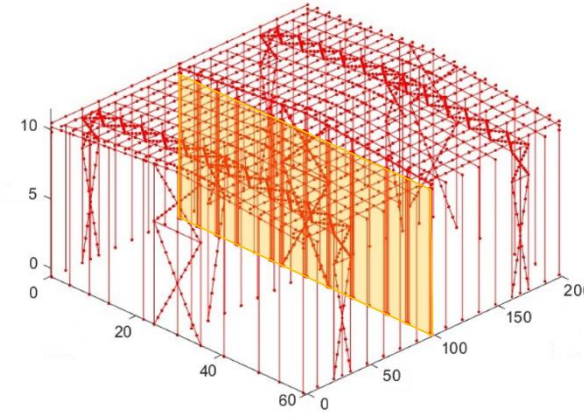
# Case study 3 outputs



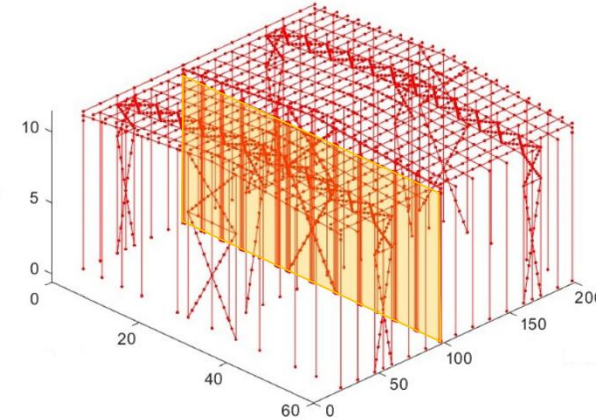
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric



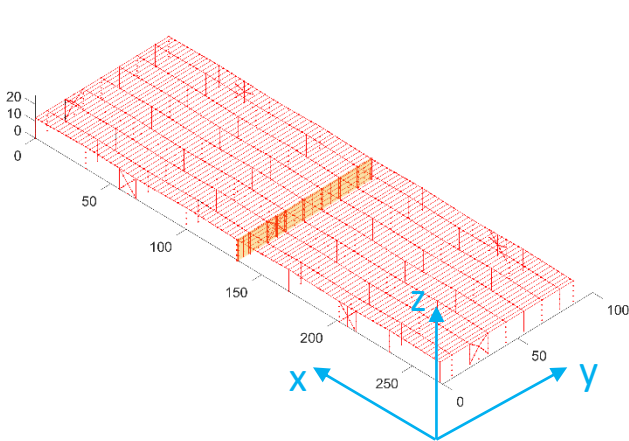
Model parallel asymmetric

	ORTH SYMM	ORTH ASYM	PAR SYM	PAR ASYM	FUSIBLE LINK CAPACITY
DETAIL 1	5 kN	7 kN	-	-	22 kN
DETAIL 2	49 kN	52 kN	-	-	110 kN
DETAIL 3.1	36 kN	37 kN	11 kN	16 kN	115 kN
DETAIL 3.2	36 kN	39 kN	11 kN	16 kN	115 kN

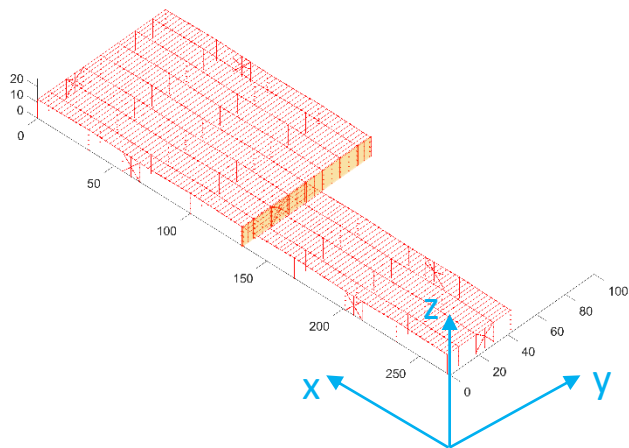
- None of the details overcame its capacity.
- Equal first periods ( $T_1$ ) of the symmetric and asymmetric structures led to the use of the same set of accelerograms.
- Lower values on the parallel configurations due to the presence of more columns equipped with fusible links.



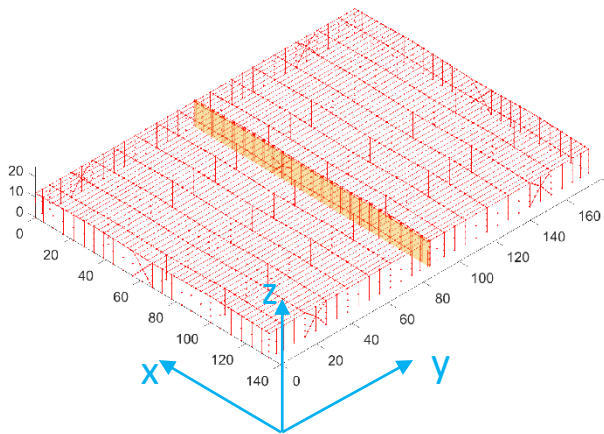
# Case study 4 dynamic properties



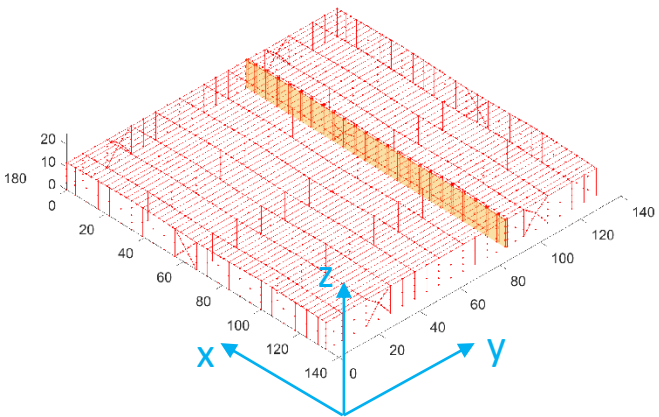
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric

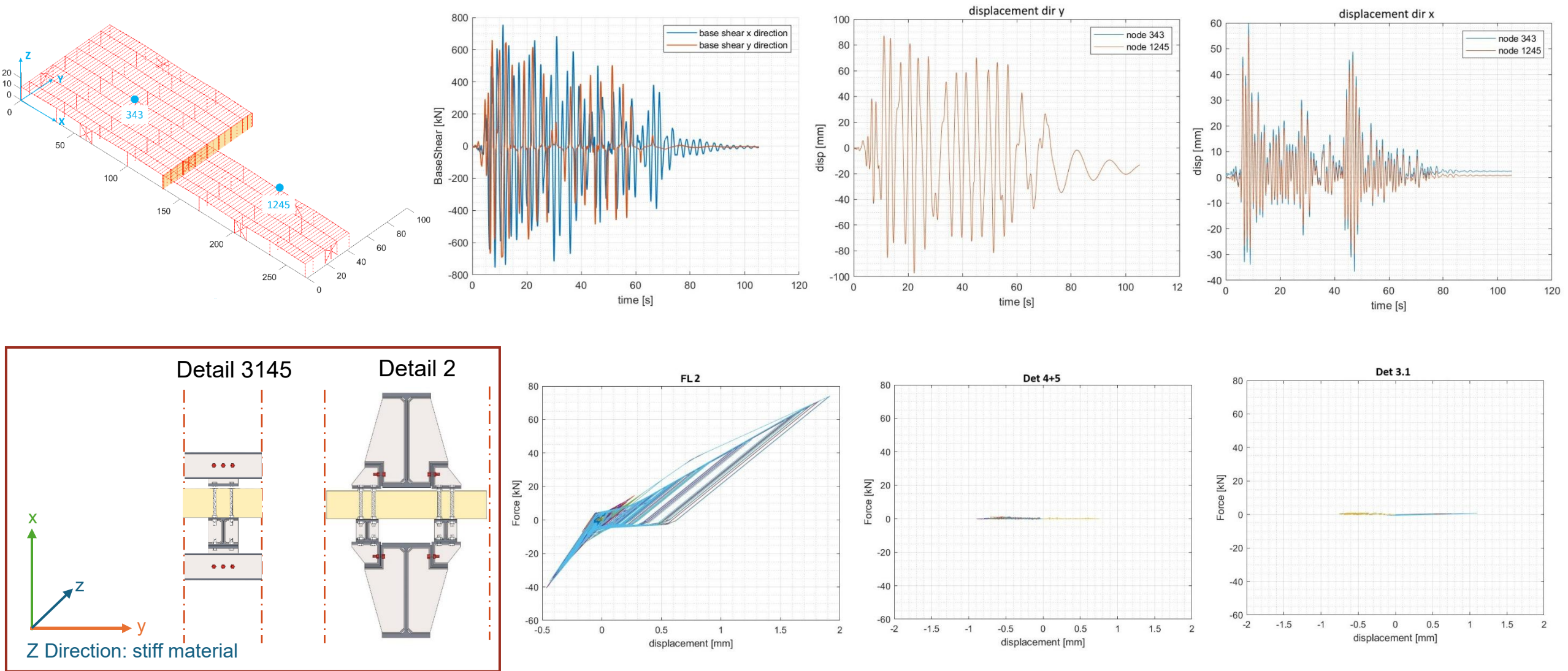


Model parallel asymmetric

Symmetric configuration					Asymmetric configuration				
Mode	T[s]	Ux [%]	Uy [%]	Rz [%]	Mode	T[s]	Ux [%]	Uy [%]	Rz [%]
1°	2.38	67.1	0.00	0.11	1°	2.48	25.5	0.00	3.66
3°	2.27	0.00	98.5	0.00	2°	2.16	39.8	0.00	2.18
52°	0.66	0.00	0.00	61.5	4°	1.98	0.64	82.9	0.13

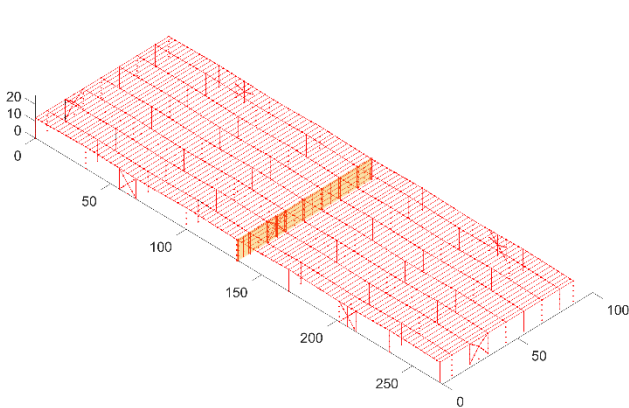
Symmetric configuration					Asymmetric configuration				
Mode	T [s]	Ux [%]	Uy [%]	Rz [%]	Mode	T[s]	Ux [%]	Uy [%]	Rz [%]
1°	2.59	24.1	0.00	4.29	1°	2.59	29.8	0.00	0.47
2°	2.59	20.2	0.00	4.78	2°	2.39	18.7	0.00	2.14
5°	2.24	0.00	98.5	0.00	8°	1.88	0.00	98.2	0.15

# Case study 4 – Detail 2 example

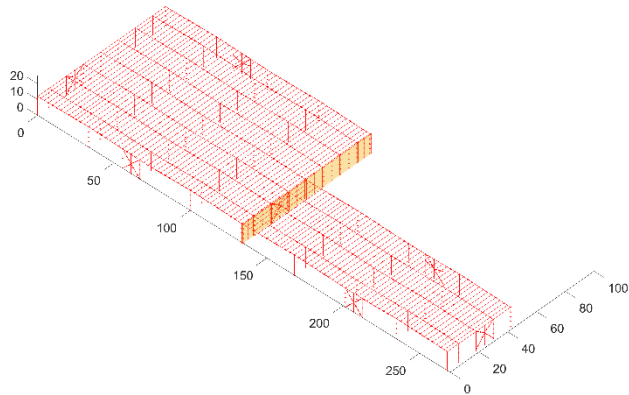




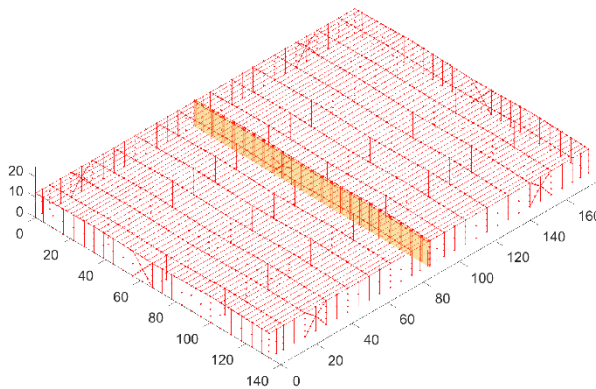
# Case study 4 outputs



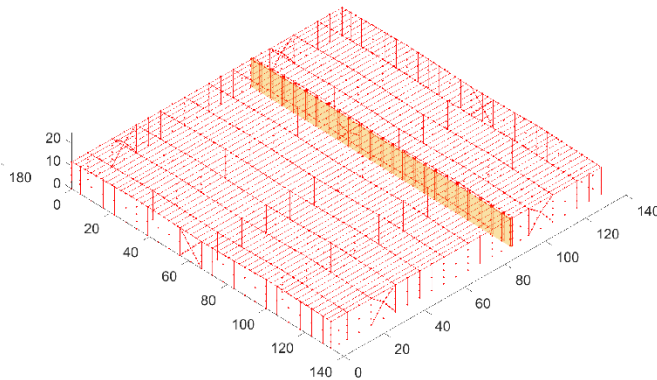
Model orthogonal symmetric



Model orthogonal asymmetric



Model parallel symmetric

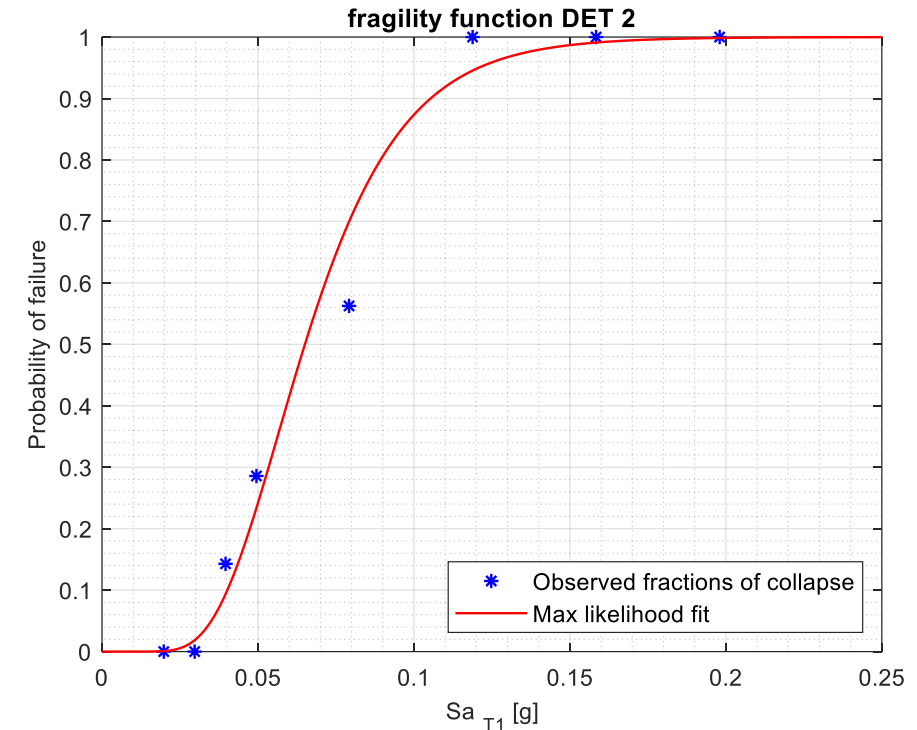
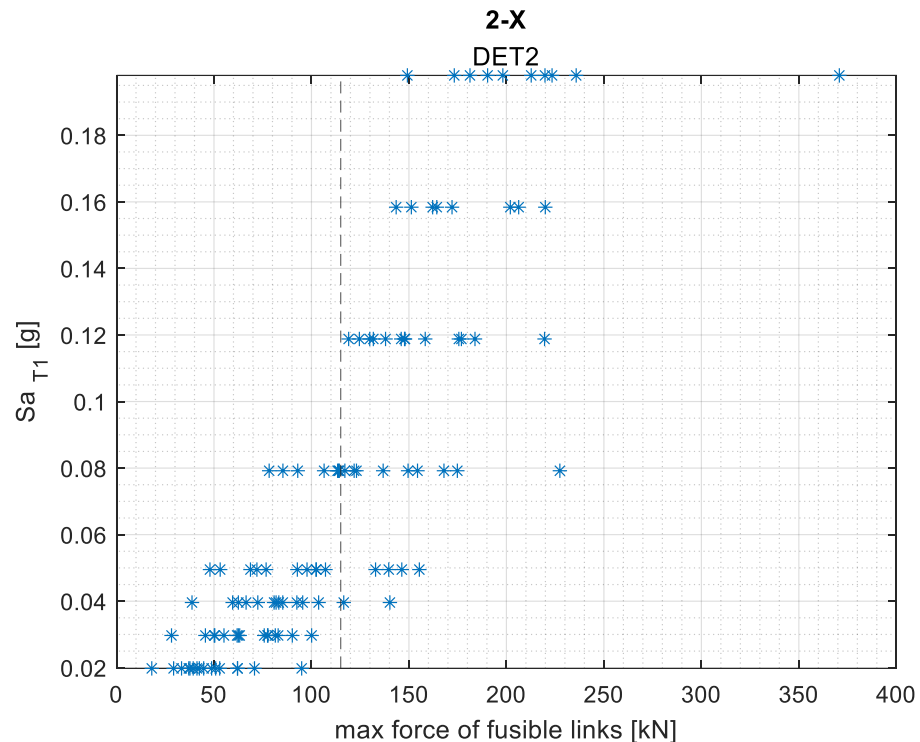


Model parallel asymmetric

	ORTH SYM	ORTH ASYM	PAR SYM	PAR ASYM	FUSIBLE LINK CAPACITY
DETAIL 1	3.15	16.8	-	-	22 kN
DETAIL 2	68.5 kN	82.1 kN	-	-	110 kN
DETAIL 3.1	84.1 kN	102.8 kN	3.0 kN	5.1 kN	115 kN
DETAIL 3.2	68.8 kN	98.1 kN	12.6 kN	12.6 kN	115 kN

- None of the details overcame its capacity.
- Different first periods ( $T_1$ ) of the symmetric and asymmetric structures led to the selection of different set of accelerograms.
- Lower values on the parallel configurations due to the presence of more columns equipped with fusible links.

# Fragility functions



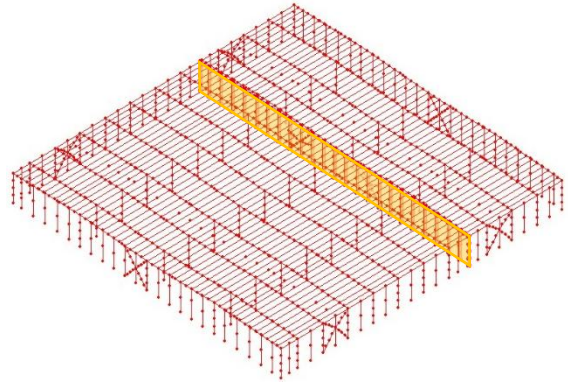
A fragility curve expresses the probability of exceedance of an engineering demand parameter (EDP) given an intensity measure (IM).

Analysis method: *Multiple Stripe Analysis*

- Selection of 20 ground motions
- *Intensity measure* (IM):  
Spectral acceleration at first period
- *Engineering demand parameter* (EDP):
  - Fusible links resistance (local EDP);
  - Peak interstorey drift (global EDP)

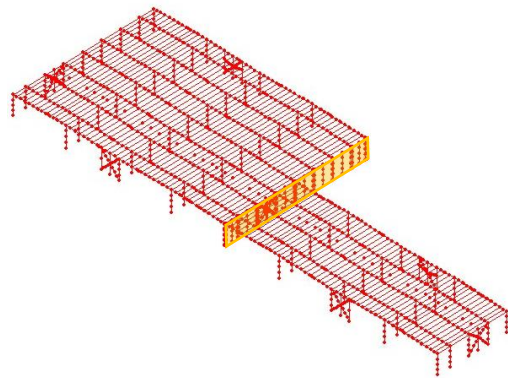
# Fragility functions

## 1 BUILDING: case study 4



WALL  
PARALLEL

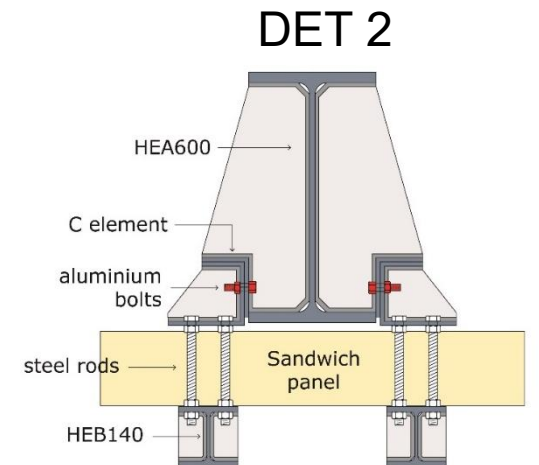
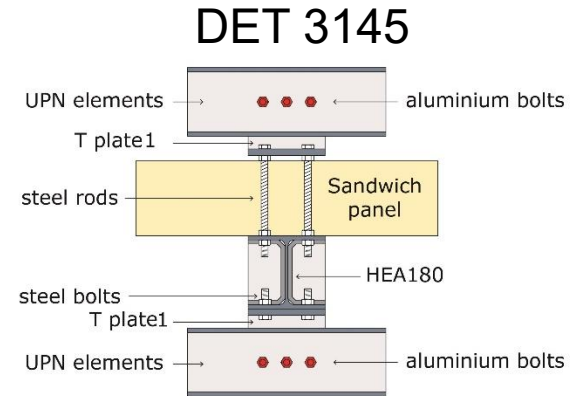
DET 3145



WALL  
ORTHOGONAL

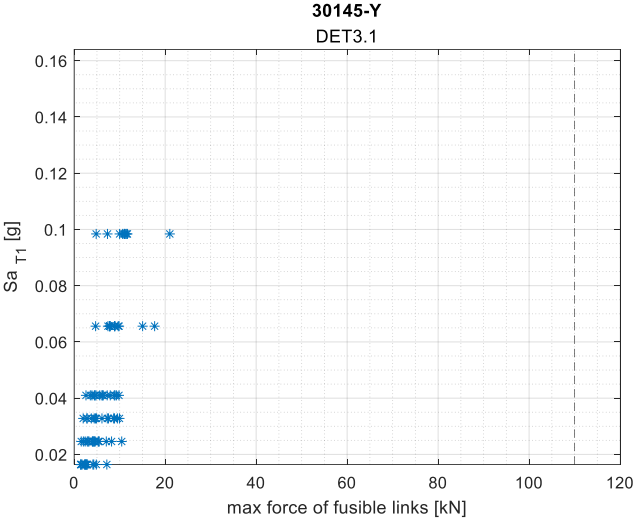
DET 3145

DET 2

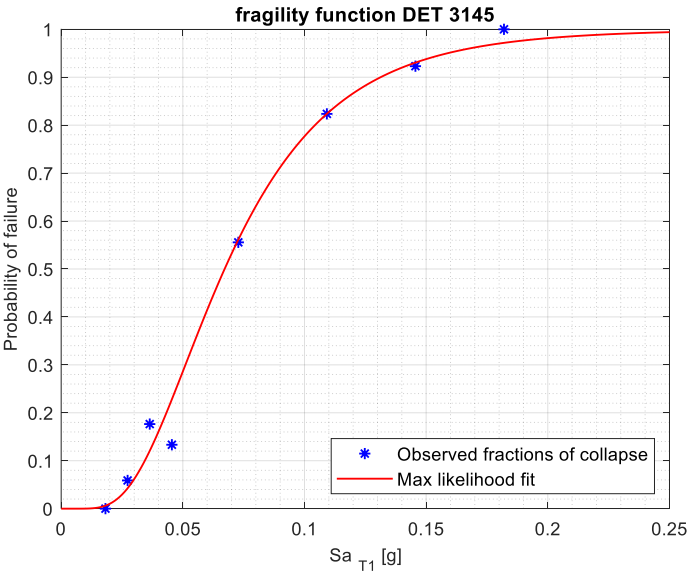
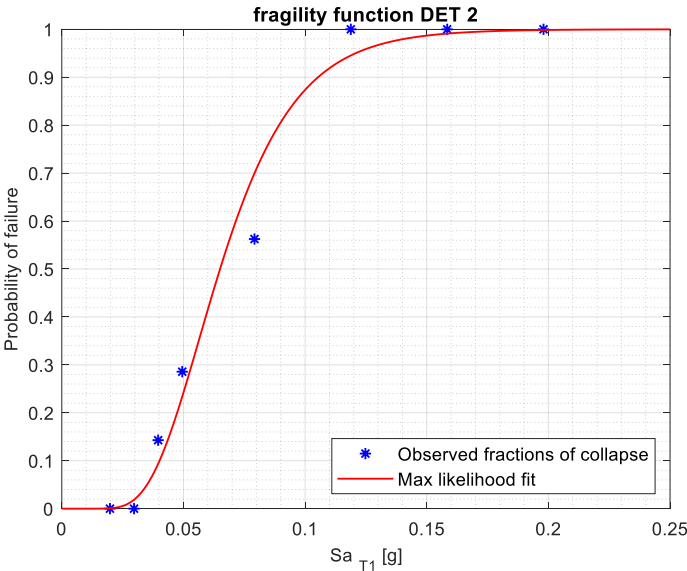
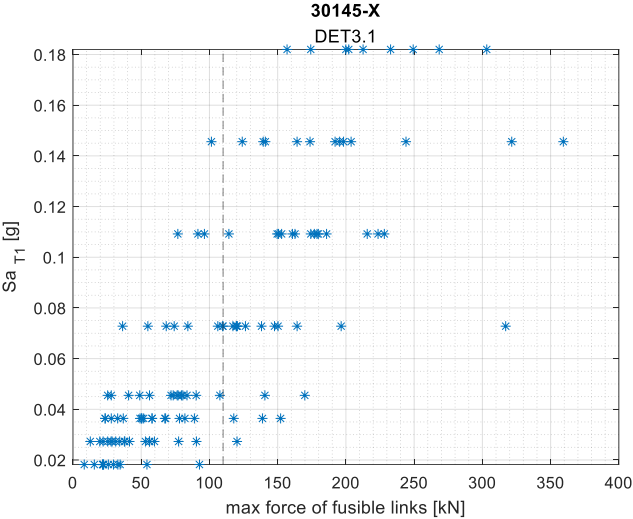
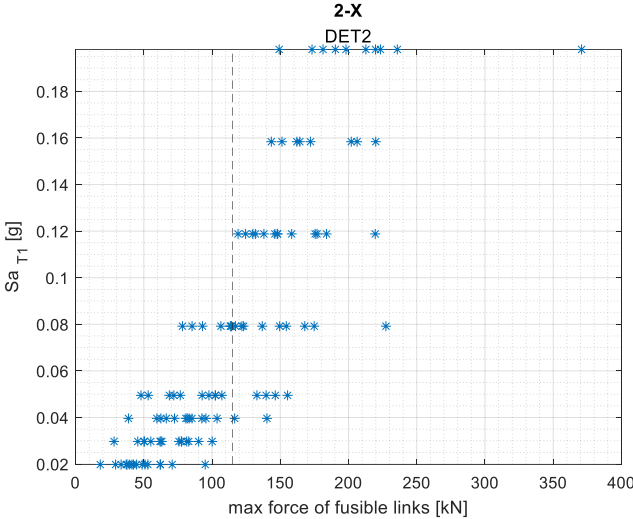


# Fragility functions

Wall parallel to the portal frames



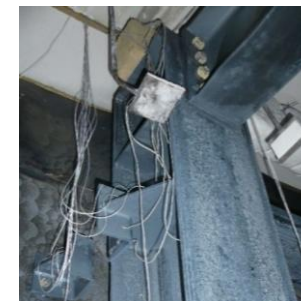
Wall orthogonal to the portal frames



# Conclusions

- The nonlinear dynamic parametric analyses performed highlighted a good behaviour of the fusible links with no failures.
- Higher forces were observed on the orthogonal configurations due to the presence of less fusible links connections with respect to the parallel ones.
- Despite involving different set of accelerograms, the asymmetric configurations highlighted slightly higher values with respect to the symmetric ones.
- Despite accelerograms characterized by different parameters, the fusible links response was mainly influenced by the structure configuration and wall position.
- The fragility functions highlighted consistent results with respect to the parametric numerical analyses in terms of higher forces in the fusible links in accordance with the structure configuration.
- The probability of failure of 50% for the two details considered occurs at the same level of IM.
- In accordance with the experimental and numerical results, Detail 2 probability of failure occurs at lower level of IM with respect to Detail 3145.





# Thank you for your attention!

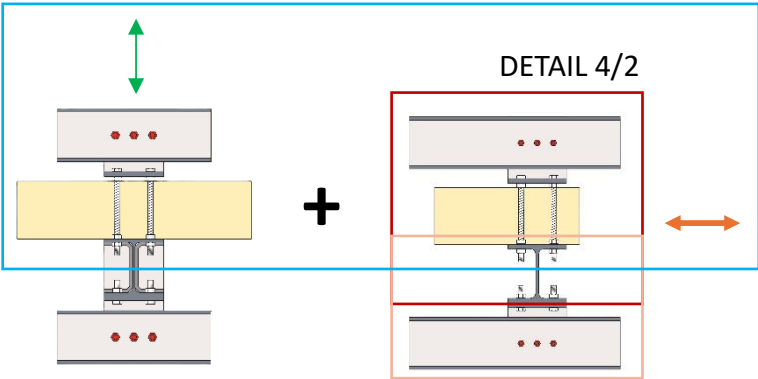
Sara Pasquali  
Nicola Tondini  
Gabriele Zanon



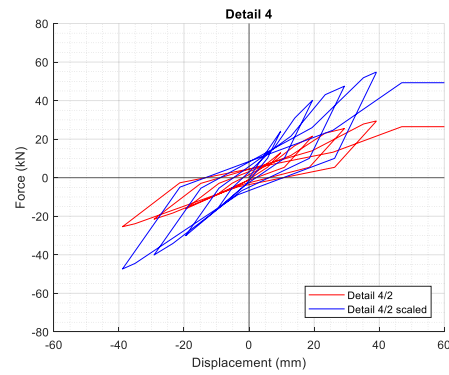
UNIVERSITÀ  
DI TRENTO

# Building configuration: Detail 3145

## Combined configuration

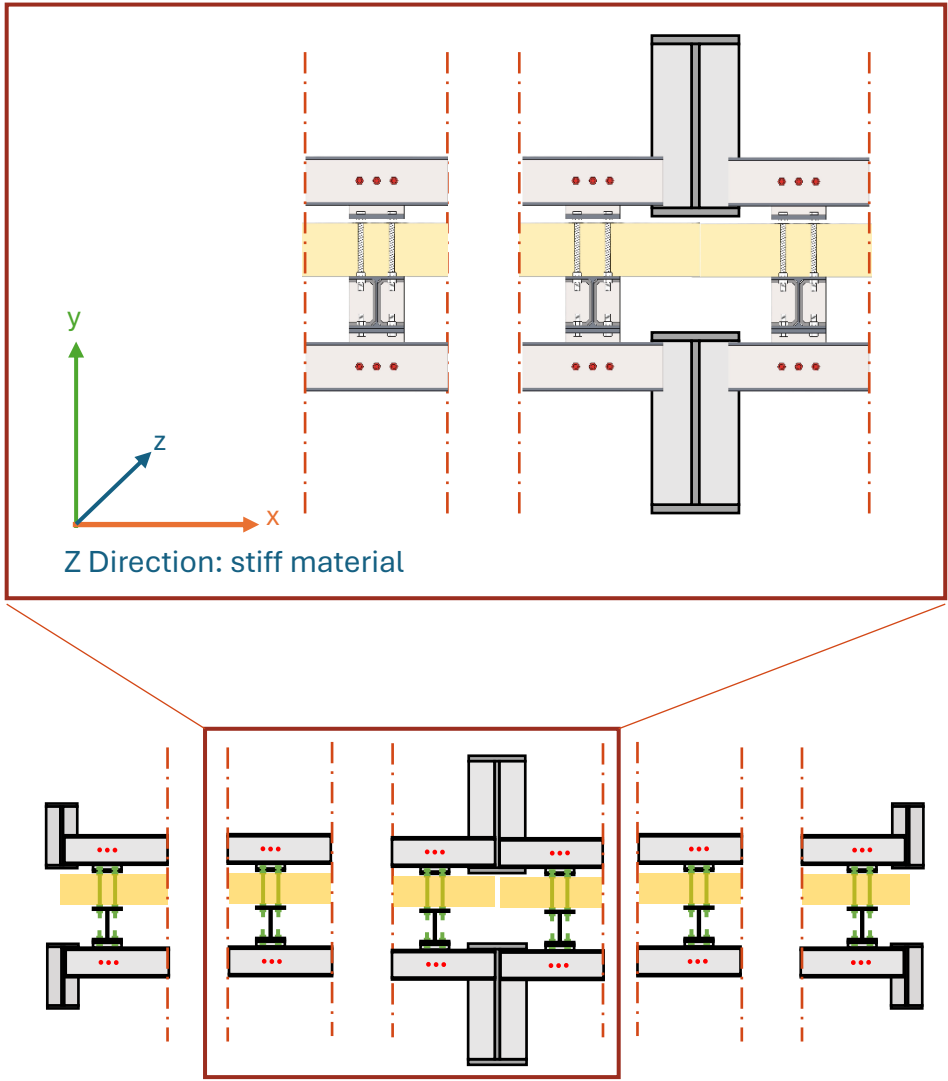
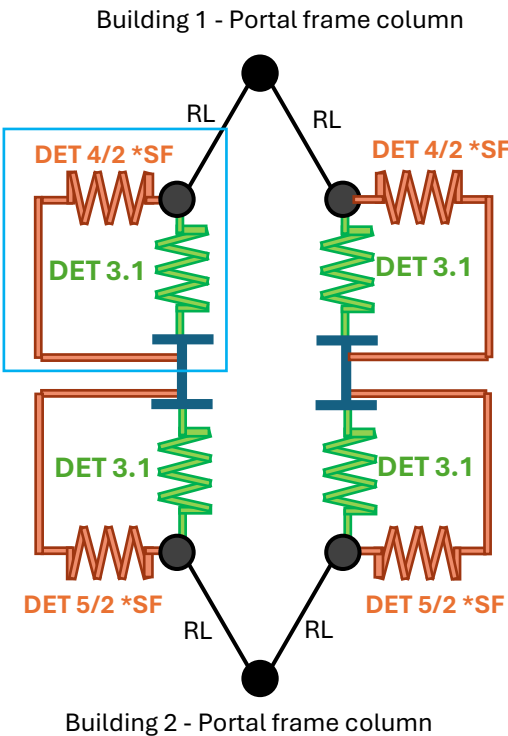


Each group of fusible links is represented by two springs, one for each direction:  
In y direction Detail 3.1 material is applied,  
In x direction, Detail 4+5 material is applied, obtained for M12 aluminium bolts, scaled to be compared with M16 aluminium bolts.



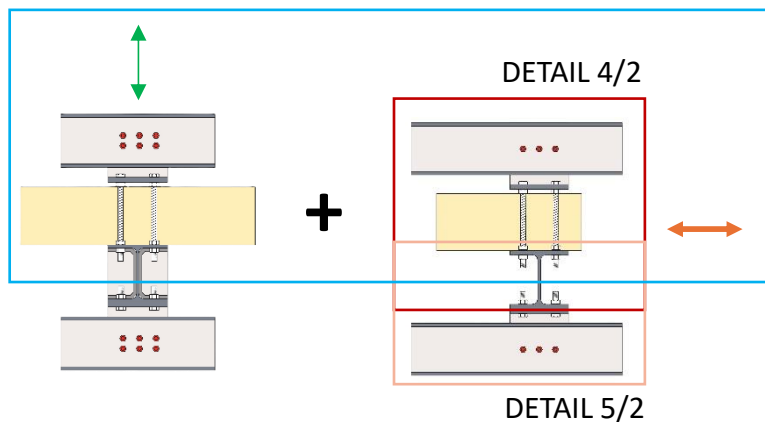
$$SF = \frac{A_{res\ M16}}{A_{res\ M12}}$$

## Numerical model configuration

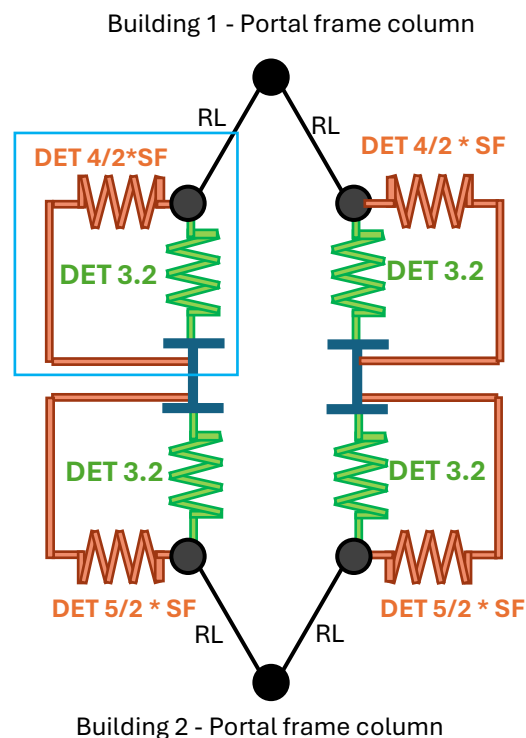


# Building configuration: Detail 3245

Combined configuration



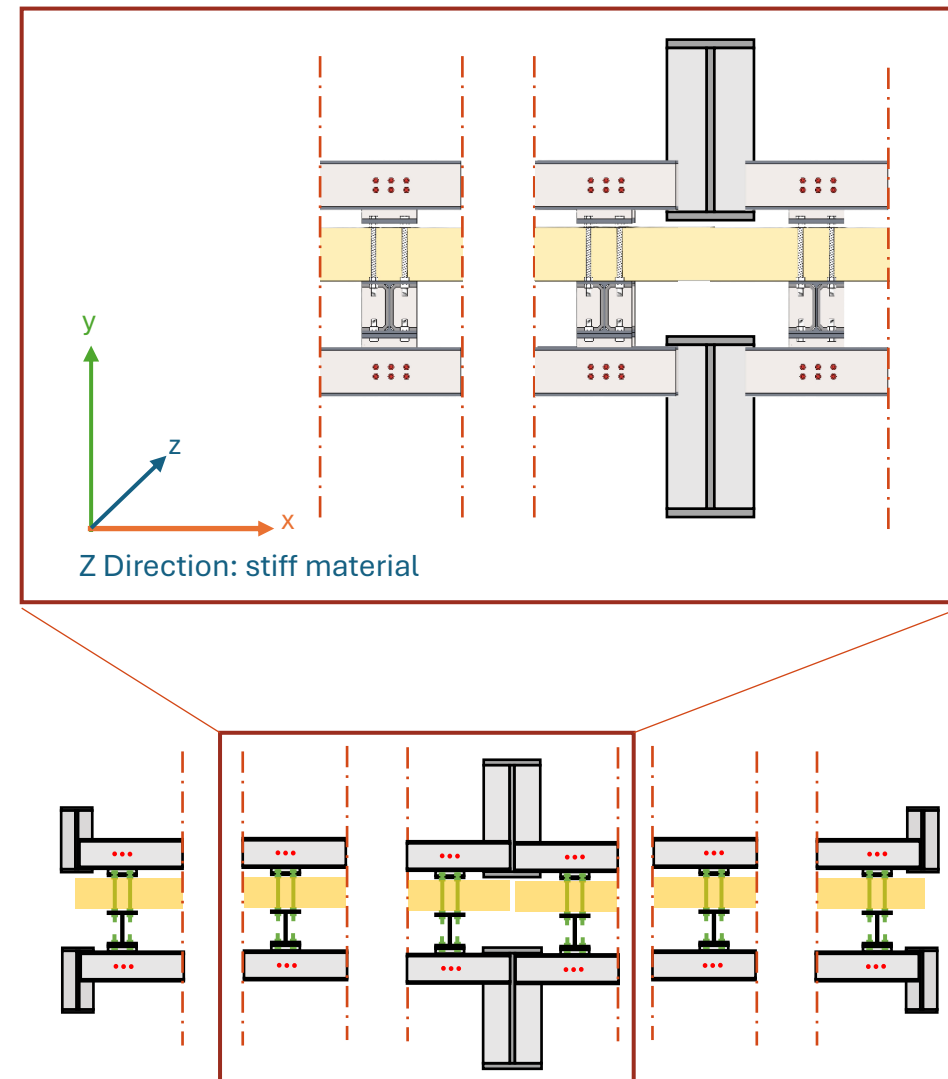
Numerical model configuration



Each group of fusible links is represented by two springs, one for each direction:

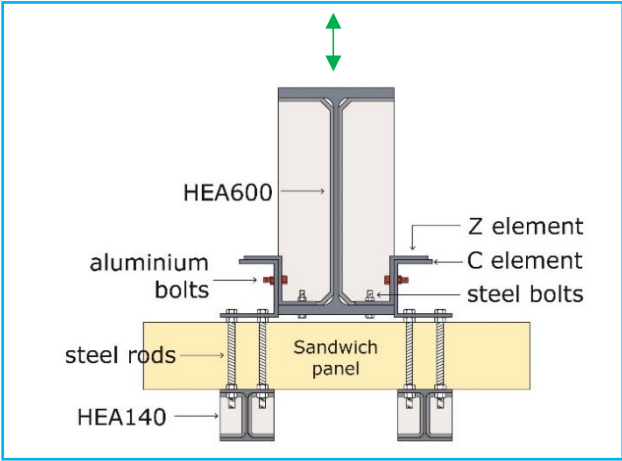
- In y direction, Detail 3.2 material is applied
- In x direction, Detail 4+5 material is applied, obtained for M12 aluminium bolts, scaled to be compared with the same amount of M12 aluminium bolts tested in Detail 3.2.

$$SF = \frac{A_{res6M12}}{A_{res3M12}}$$

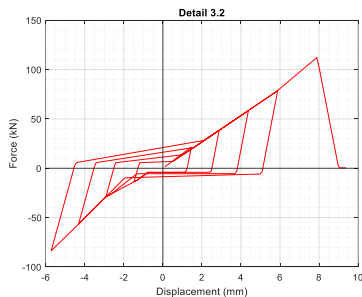
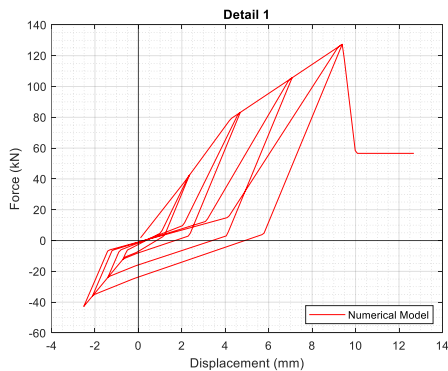


# Building configuration: Detail 1

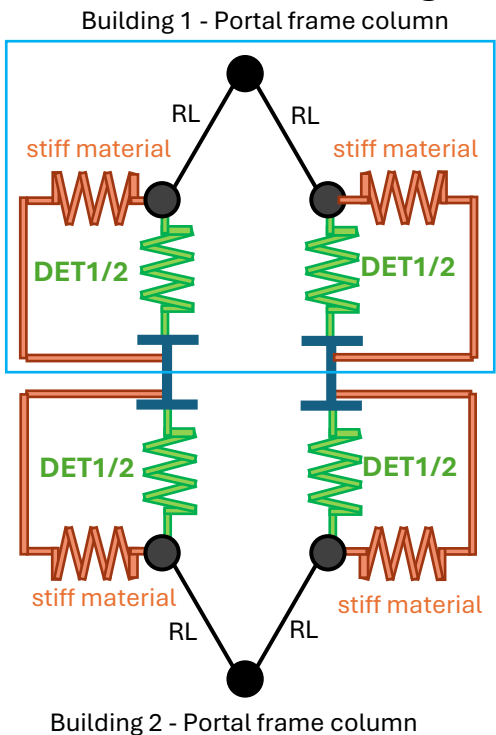
Test configuration



Test calibration



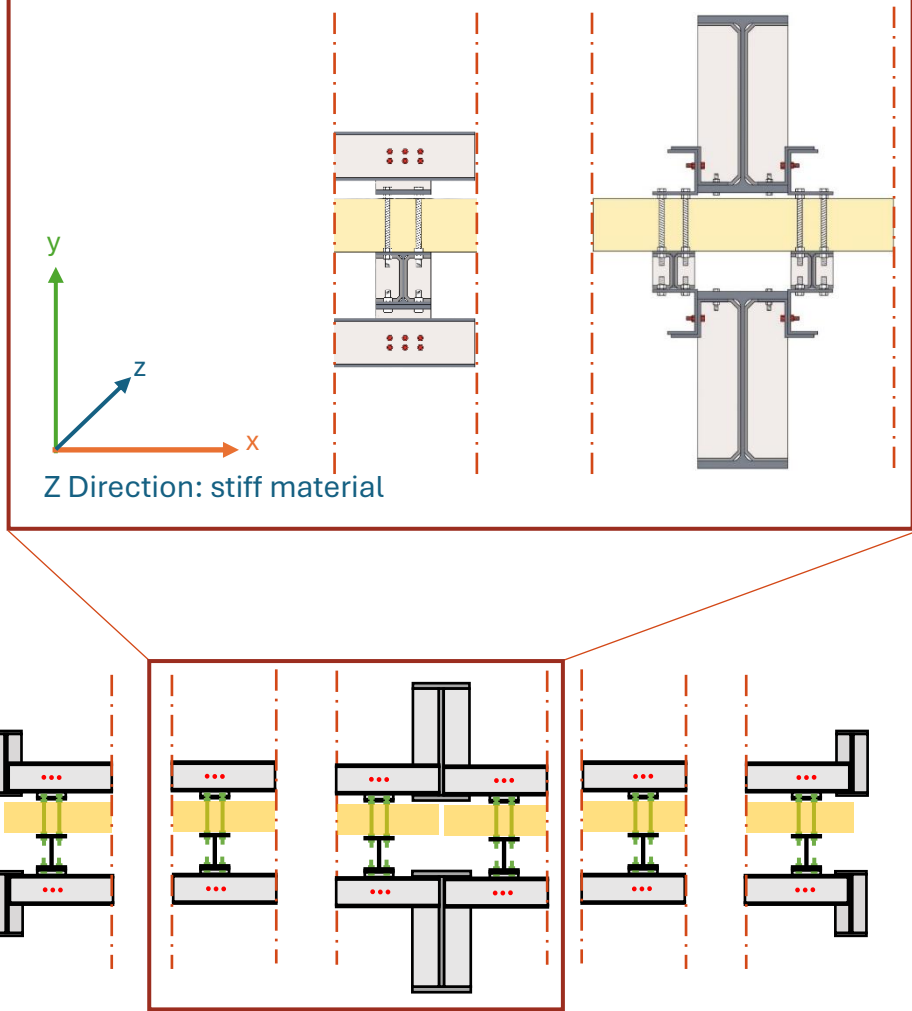
Numerical model configuration



\*Detail 3.2, combined with Detail 4+5, originally tested for moderate seismicity, scaled to be comparable with low seismicity level considering 1 shear plane instead of 2, and the resistance of the detail was halved.

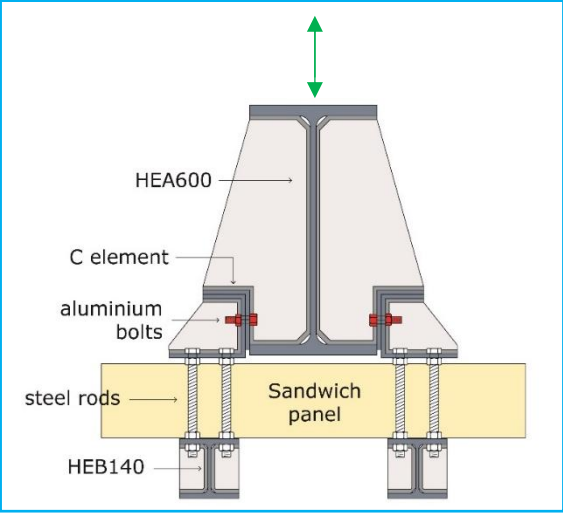
Detail 3245 – low version\*

Detail 1

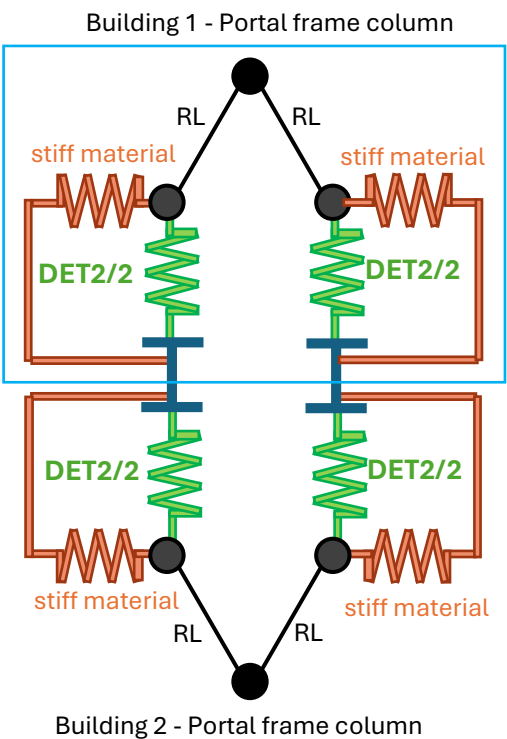


# Building configuration: Detail 2

Test configuration



Numerical model configuration



Test calibration

