COMBINED SEISMIC-FIRE RISK: THE ROLE OF NON STRUCTURAL ELEMENTS

Daniele Perrone
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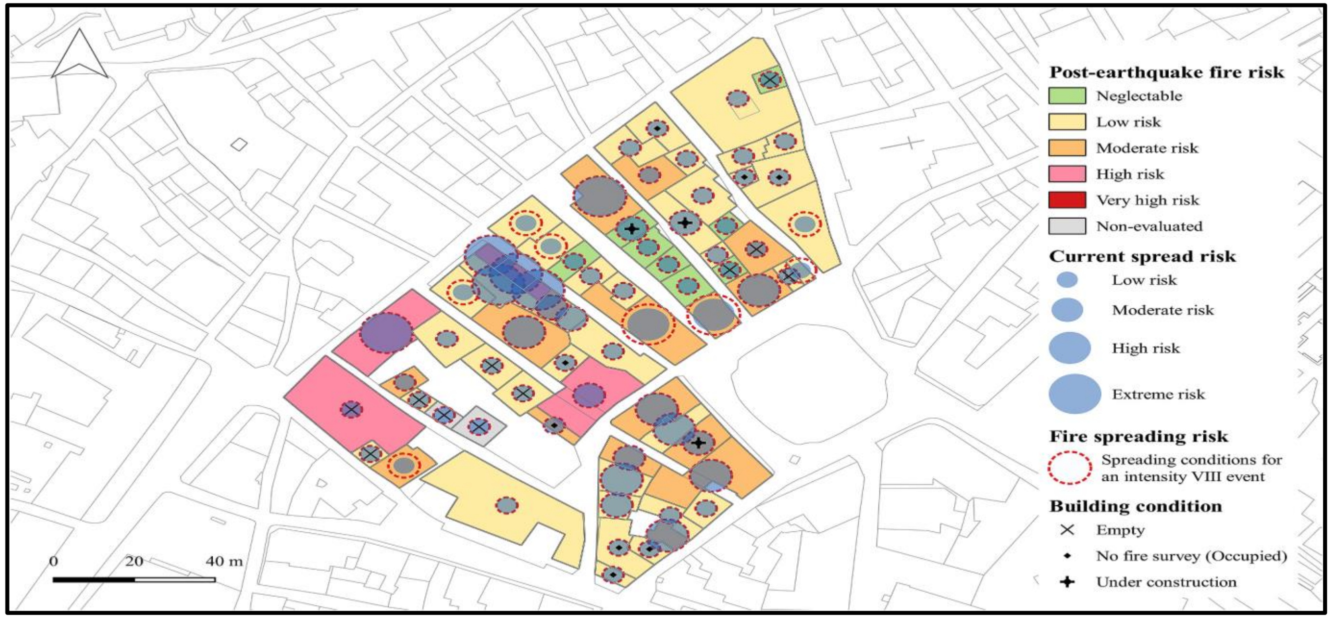
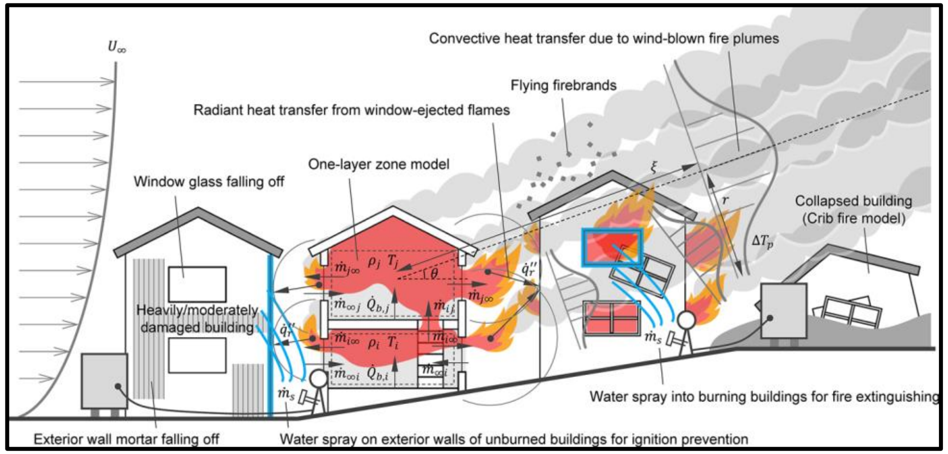
POST-EARTHQUAKE FIRE RISK:
A POTENTIALLY HIGHLY IMPACTING PHENOMENON

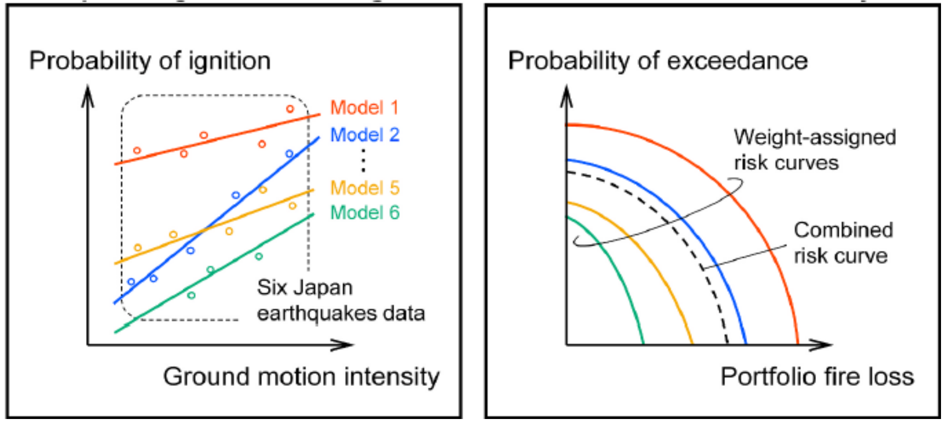


Discrete seismic damage grade (D_k)	Risk associated with fire ignition (SF_I) Low	Moderate	High	Extreme
No or slight damage	Neglectable	Low risk	Low risk	Moderate risk
Moderate damage	Low risk	Low risk	Moderate risk	High risk
Severe damage	Low risk	Moderate risk	High risk	Very high risk
Very severe damage	Moderate risk	High risk	Very high risk	Very high risk
Destruction	High risk	Very high risk	Very high risk	Very high risk

P.B. Julià et al. “Post-earthquake fire risk assessment of historical urban areas: A scenario-based analysis applied to the Historical Cicy Centre of Leiria, Portugal» (2021)



T. Nishino “Probabilistic urban cascading multi-hazard risk assessment methodology for ground shaking and post-earhquake fires“ (2023)



T. Nishino “Post-earthquake fire ignition model uncertainty in regional probabilistic shaking–fire cascading multi-hazard risk assessment: A study of earthquakes in Japan” (2023)

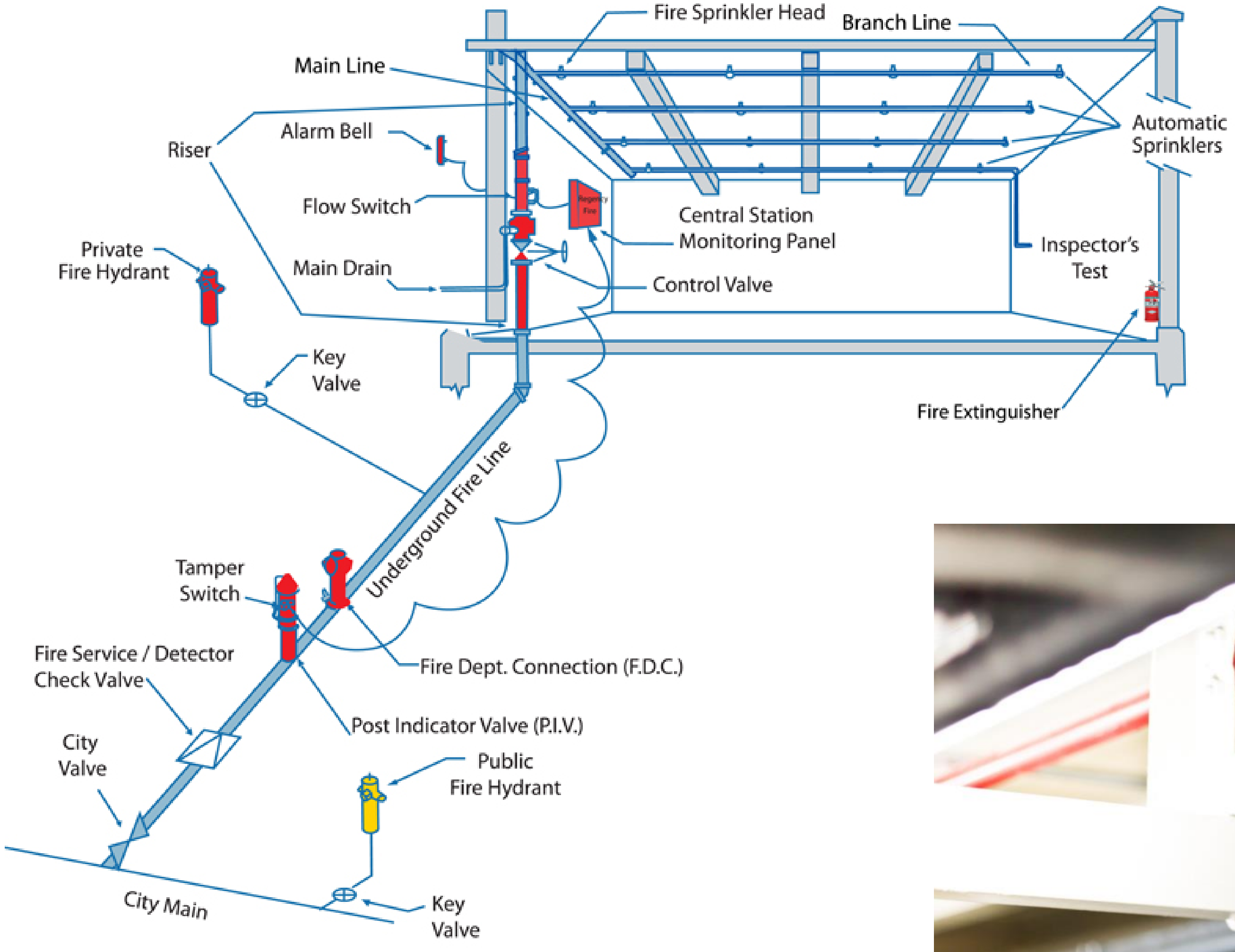
THE ROLE OF NON-STRUCTURAL COMPONENTS IN FIRE IGNITION

A building exposed to strong ground motions, depending on its structural and occupancy type, could generate various sources of potential ignitions due to non-structural elements:

1. Damages to building utility networks such as gas and electricity due to structural damage or excessive structural deformation.
2. Disruptions and damages to ignitable nonstructural component and braced contents and equipment due to structural damages.
3. Overturning of flammable and ignitable unbraced hazardous contents and equipment due to floor accelerations

THE ROLE OF NON-STRUCTURAL COMPONENTS IN FIRE IGNITION

WHAT ABOUT SPRINKLER PIPING SYSTEMS?



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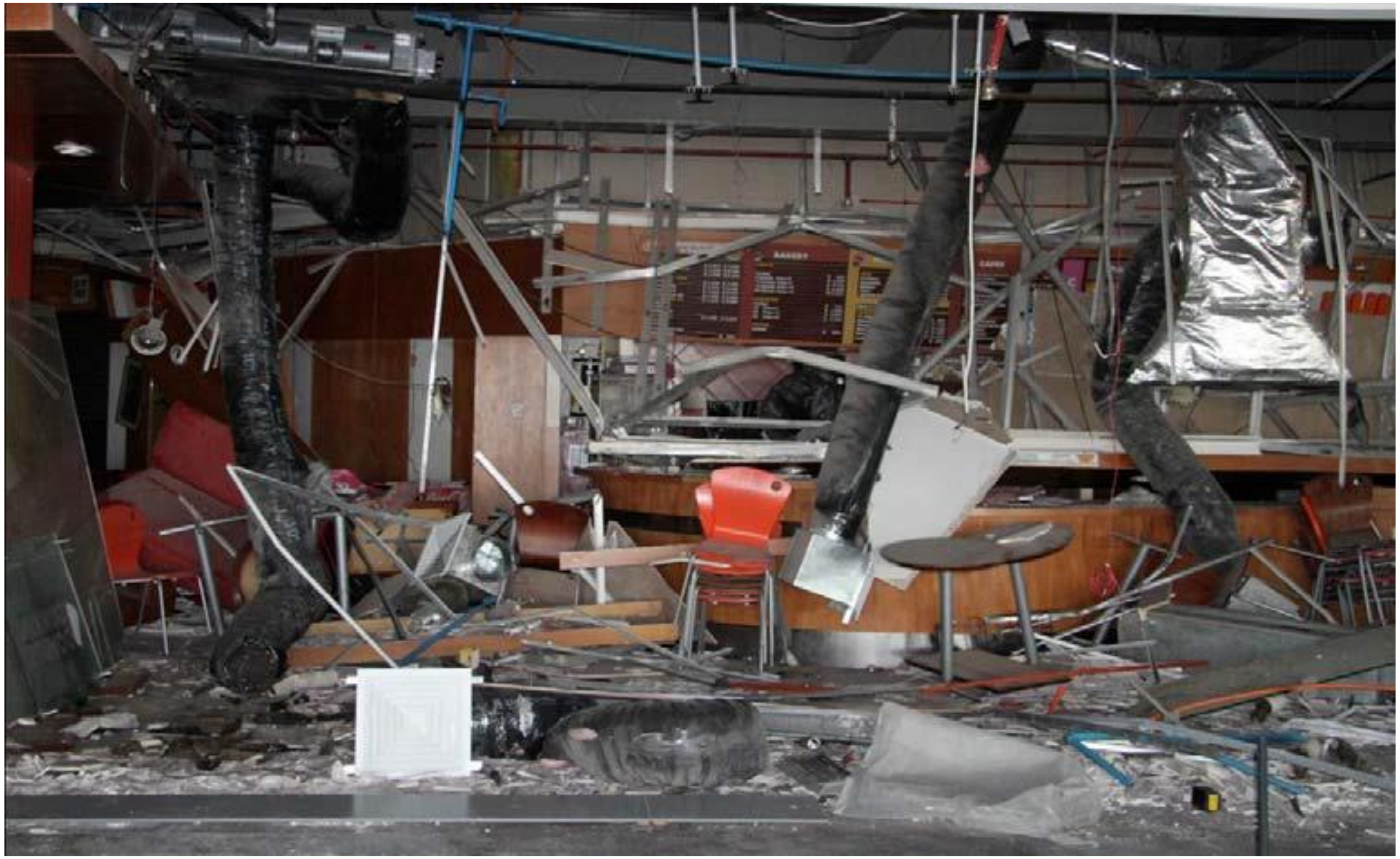
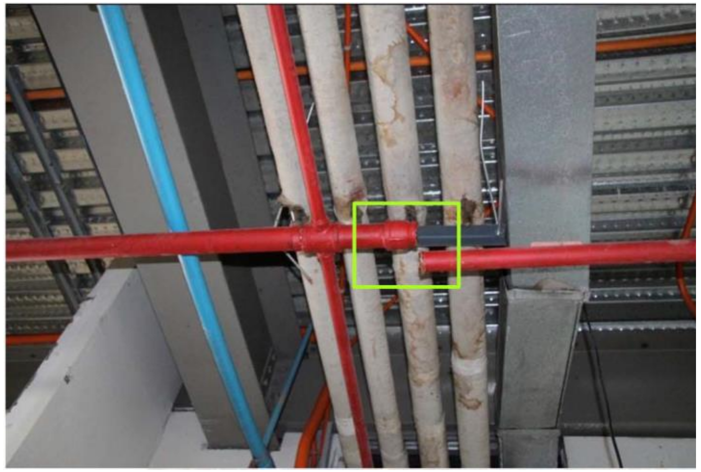


Miranda E, Mosqueda G, Retamales R, Pekcan G (2012) Performance of nonstructural components during the February 27, 2010 Chile Earthquake. Earthq Spectra 28(S1):S453–S471

WHAT ABOUT SPRINKLER PIPING SYSTEMS?



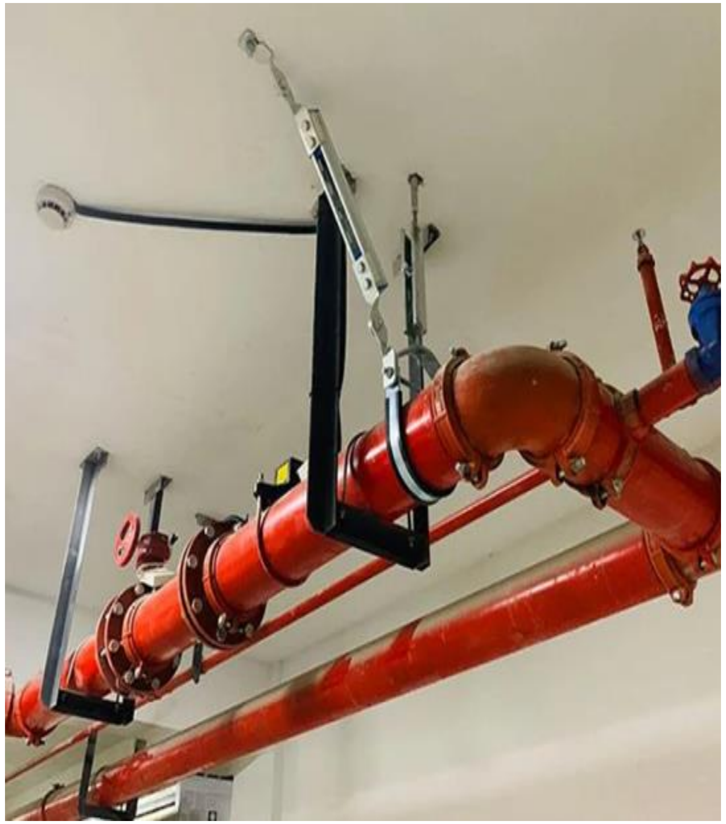
Miranda E, Mosqueda G, Retamales R, Pekcan G (2012) Performance of nonstructural components during the February 27, 2010 Chile Earthquake. Earthq Spectra 28(S1):S453–S471

WHAT ABOUT SPRINKLER PIPING SYSTEMS?

Main sources of seismic vulnerability in fire sprinkler piping systems:

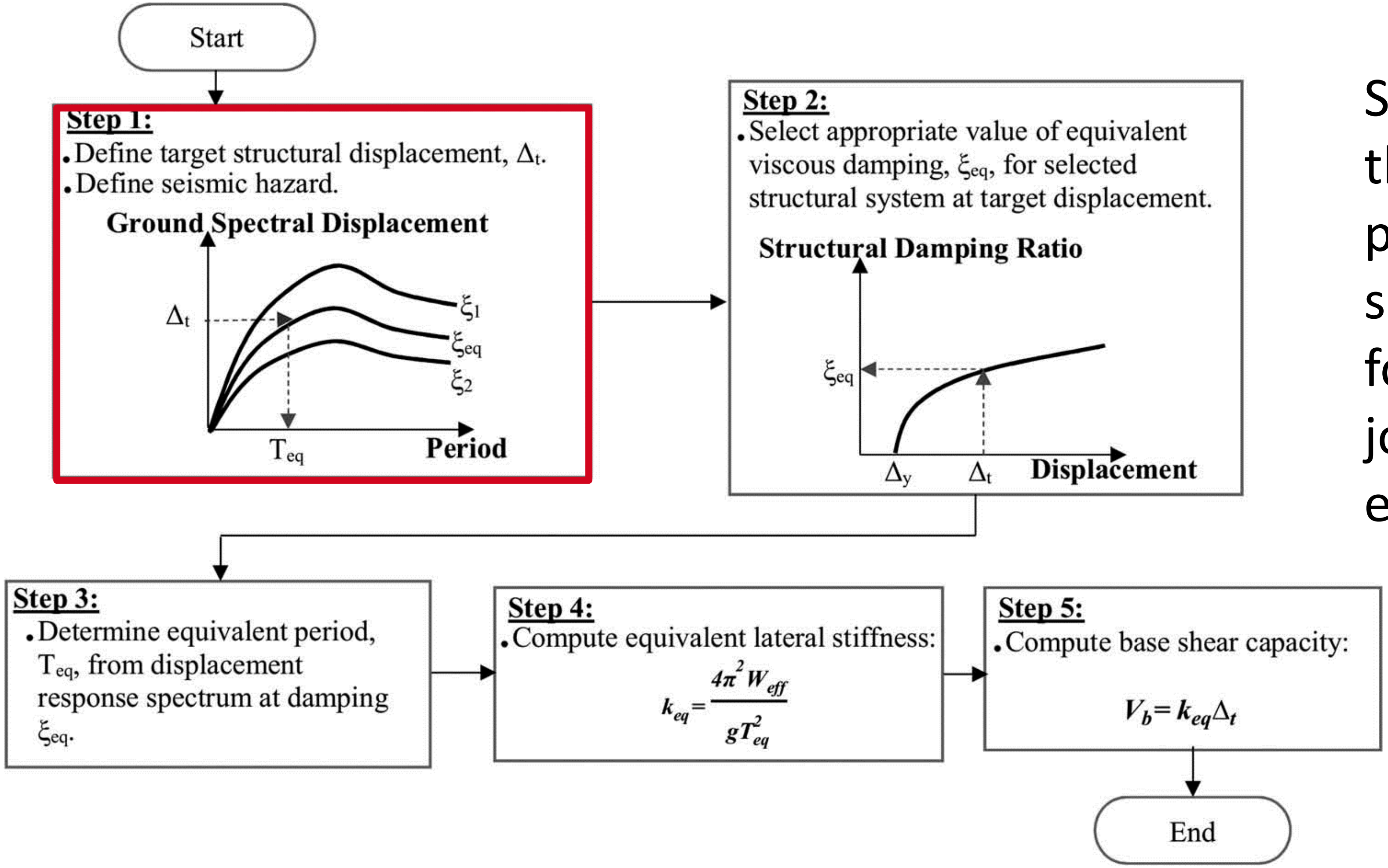
Piping joints

Sway bracing systems



Firestopping

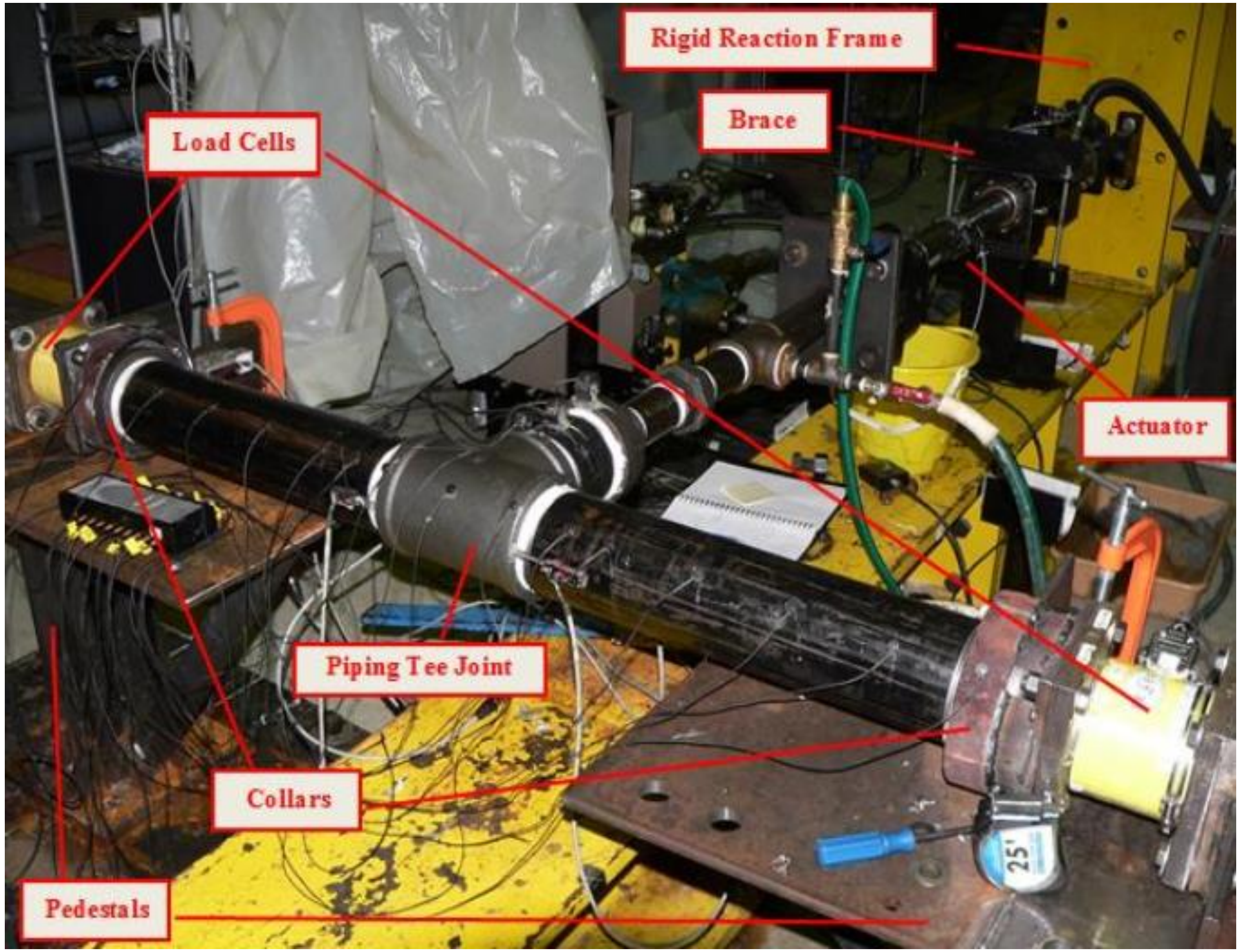
PERFORMANCE BASED SEISMIC DESIGN NON-STRUCTURAL ELEMENTS: FOCUS ON SPRINKLER PIPING SYSTEMS

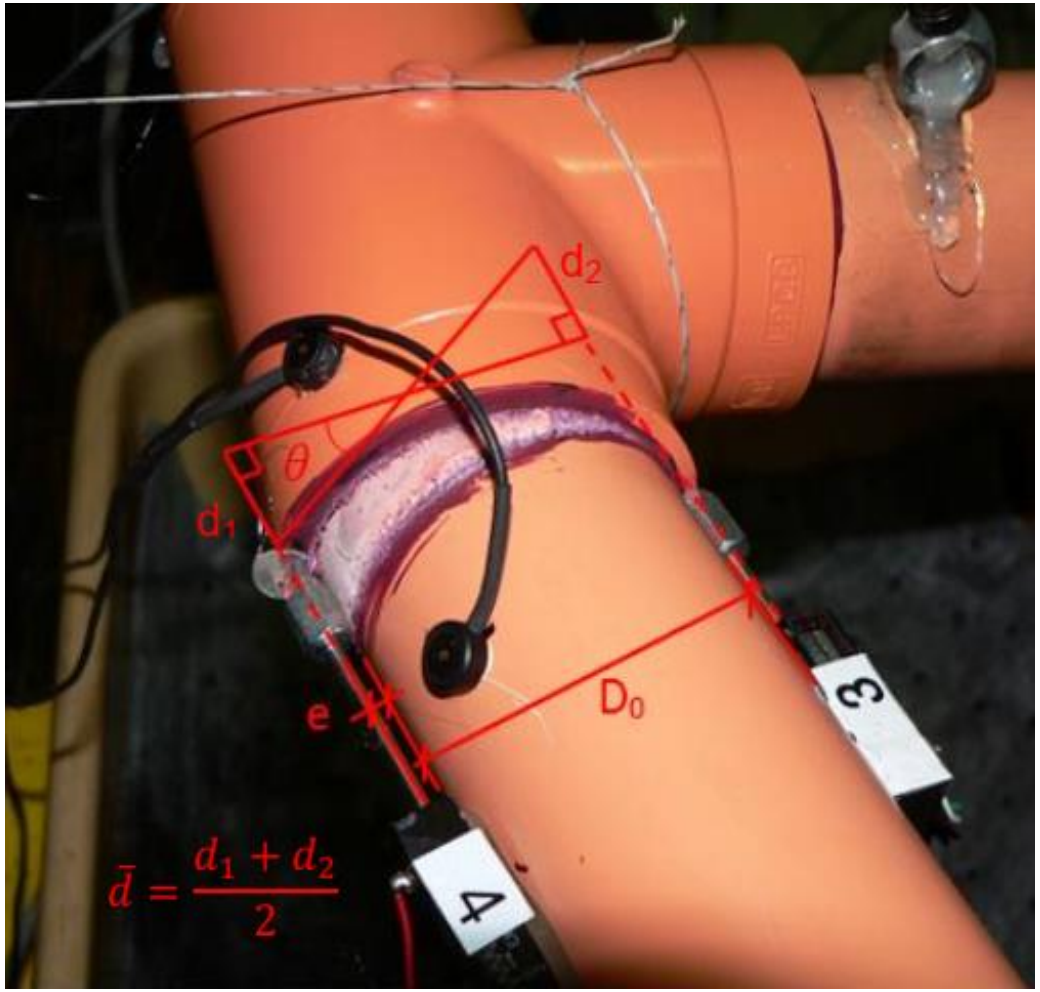


Sway bracing systems govern the performance of sprinkler piping systems, and they should be designed accounting for the performance of piping joints and firestopping elements.

Experimental data are required

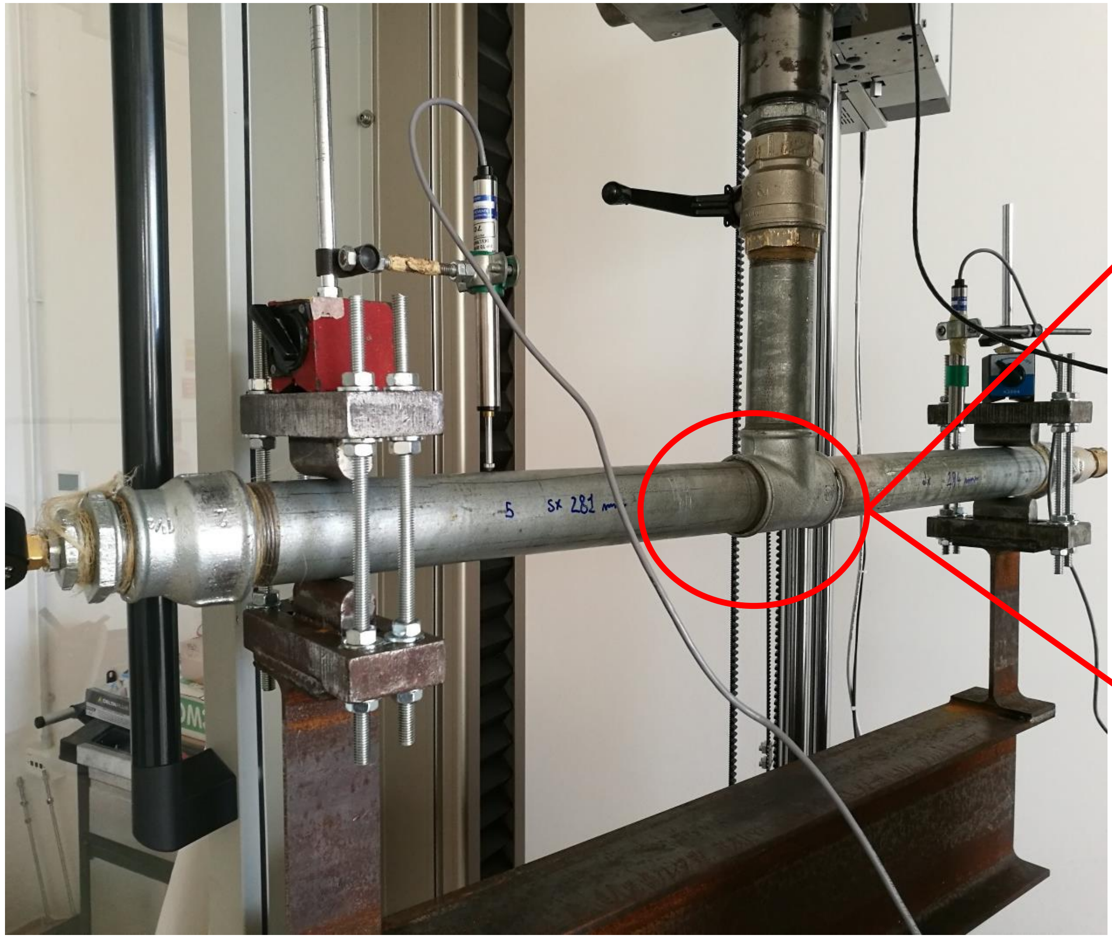
SEISMIC RESPONSE OF PIPING JOINTS

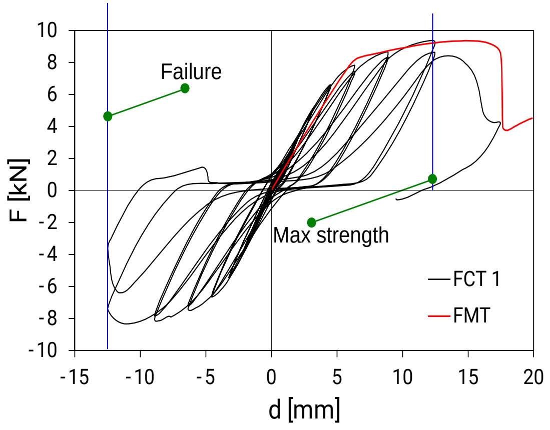


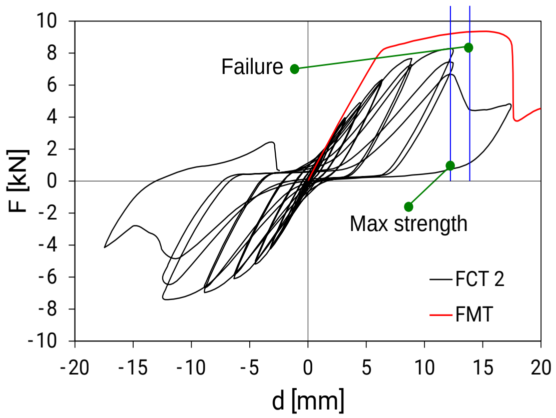


Tian Y, Filiatrault A, Mosqueda G. (2014) Experimental Seismic Fragility of pressurized fire suppression sprinkler piping joints. Earthquake Spectra 30(4).

SEISMIC RESPONSE OF PIPING JOINTS



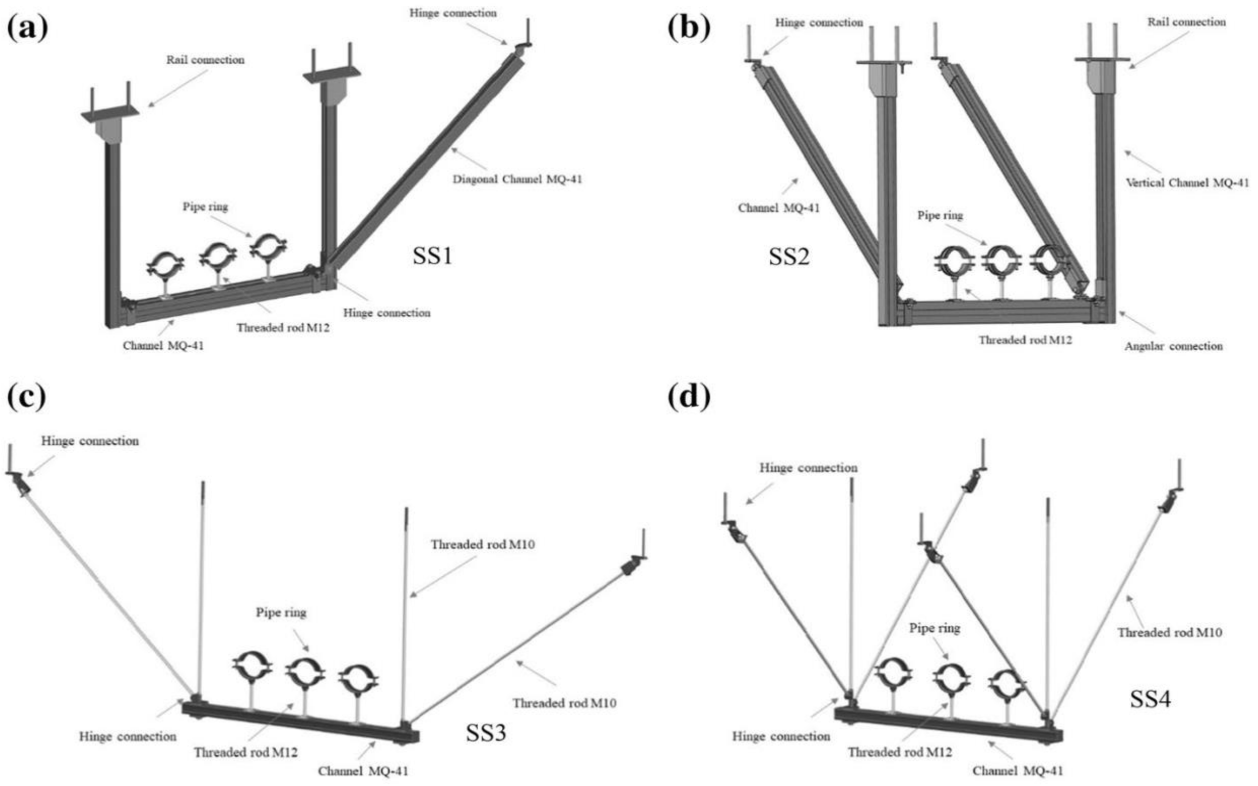




Blasi G, Aiello M.A., Maddaloni G, Pecce M.R. (2018) Seismic response evaluation of medical gas and fire-protection pipelines. Engineering Structures 173:1039-1053.

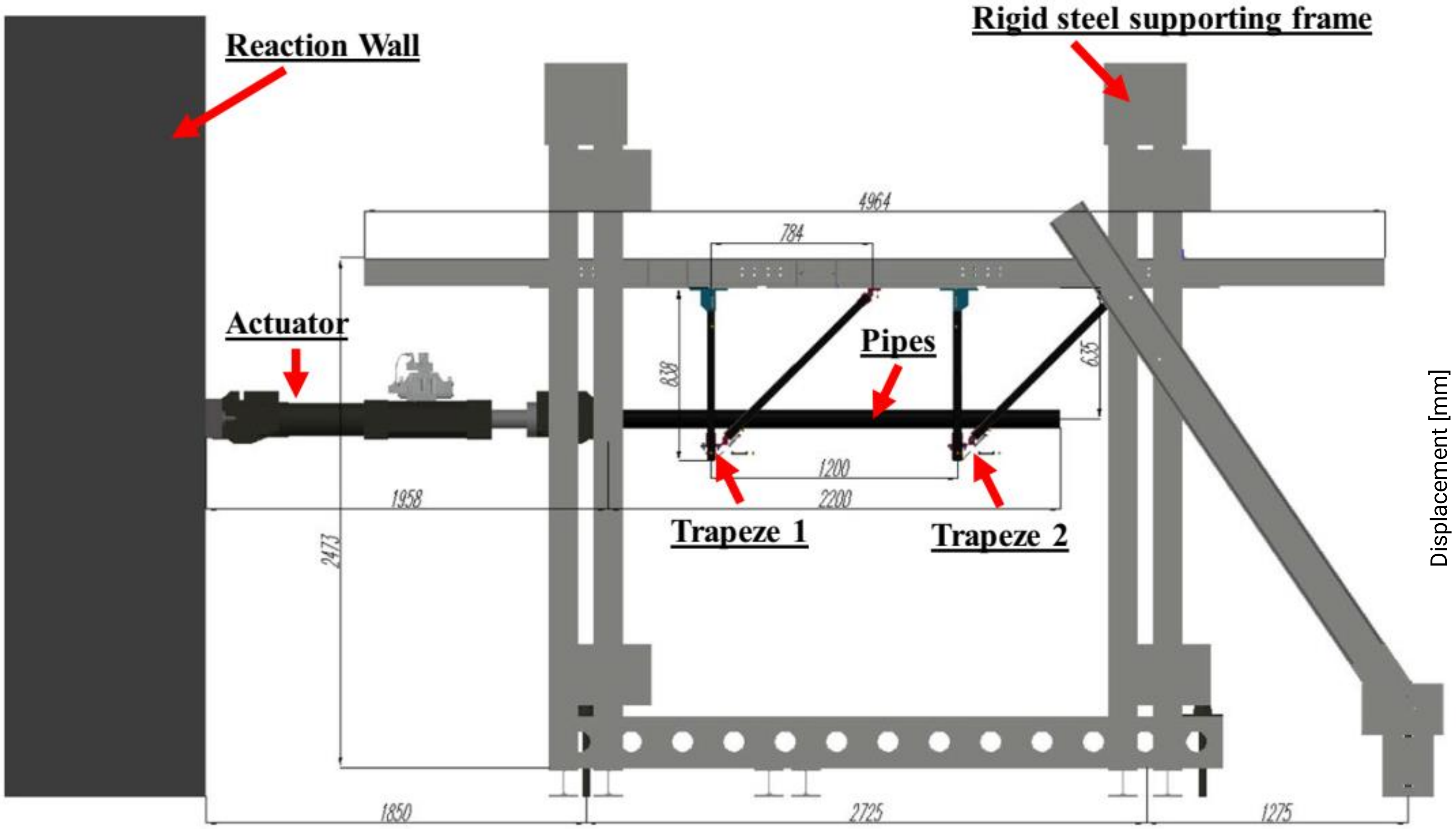
SEISMIC RESPONSE OF SUSPENDED PIPING RESTRAINT INSTALLATIONS

EUCENTRE-HILTI Collaborative research project

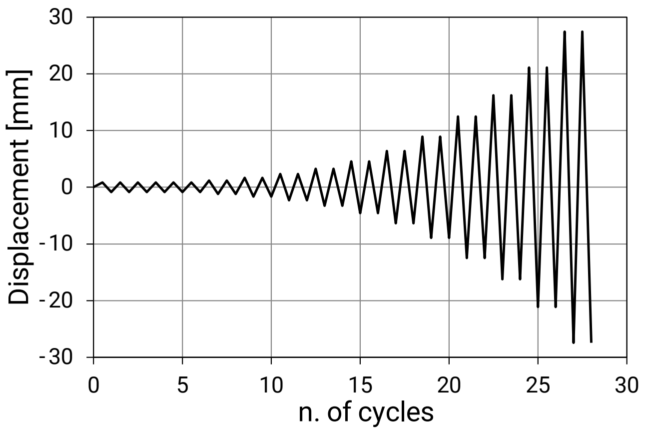


Perrone D, Filiatrault A, Peloso S, Brunesi E, Beiter C, Piccinin R (2020) Experimental seismic response evaluation of suspended piping restraint installations. Bulletin of Earthquake Engineering, https://doi.org/10.1007/s10518-019-00755-5

SEISMIC RESPONSE OF SUSPENDED PIPING RESTRAINT INSTALLATIONS



FEMA 461
Quasi static protocol



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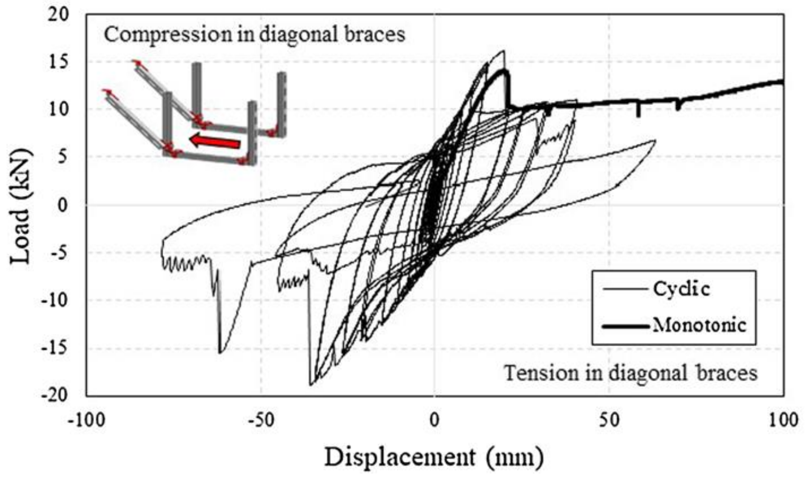

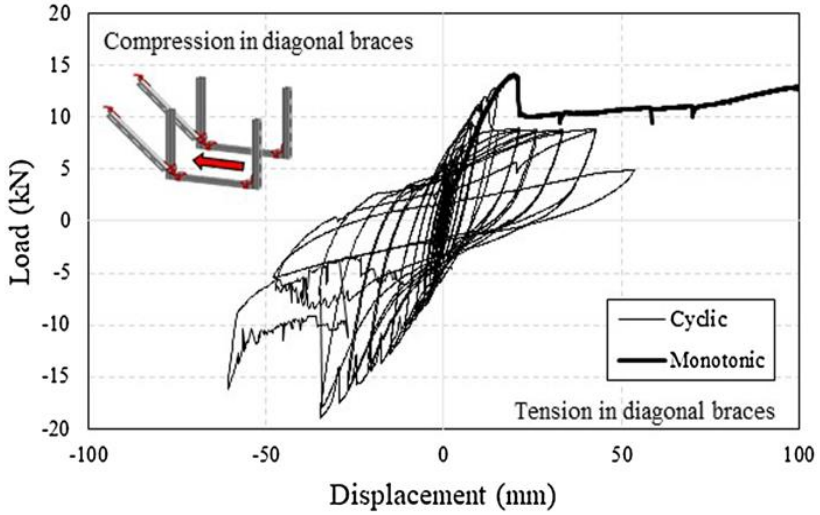

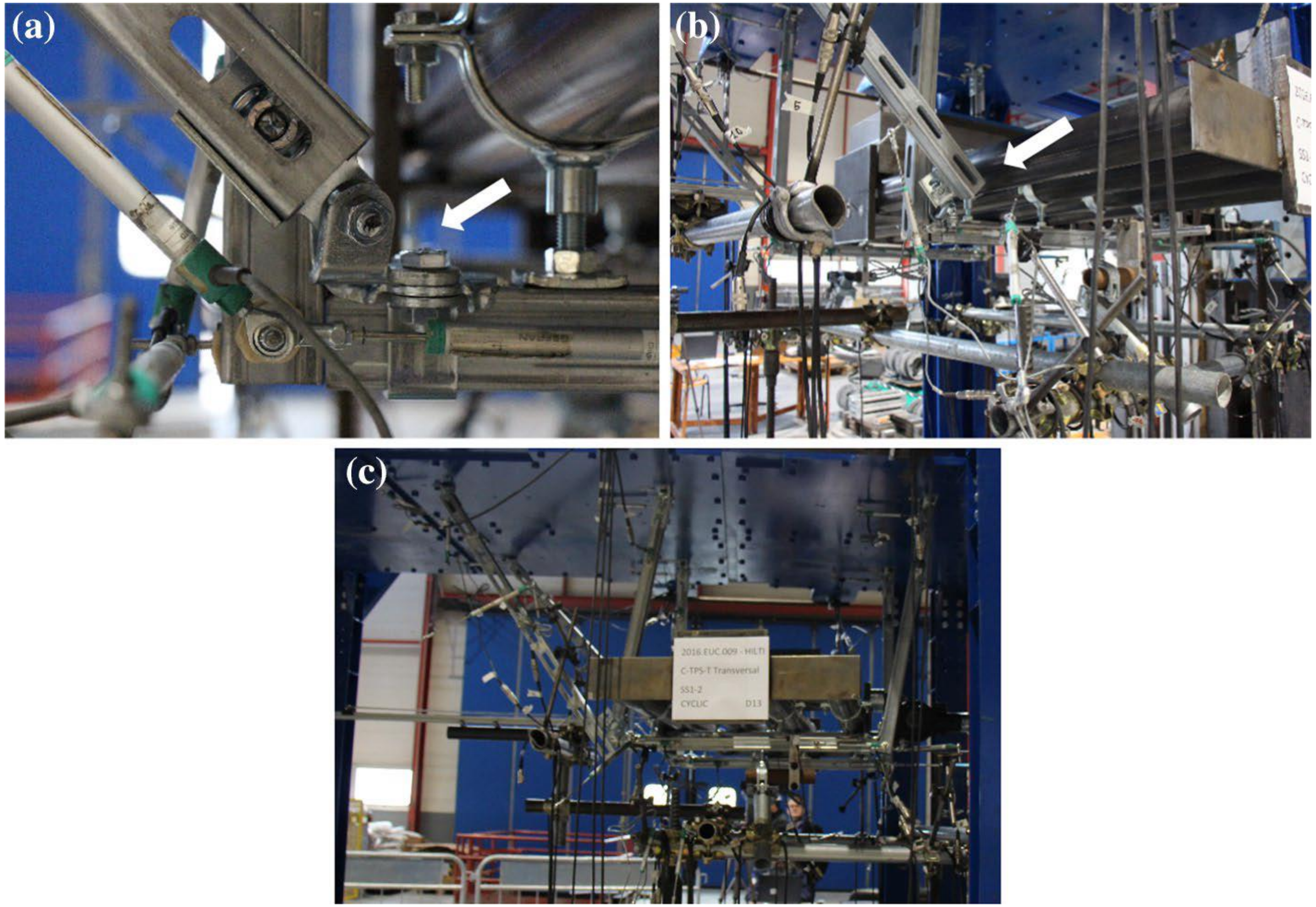

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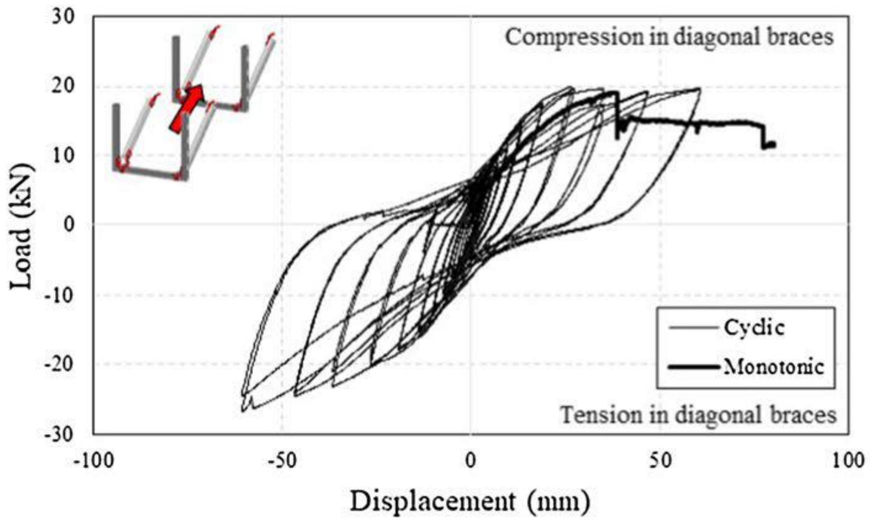

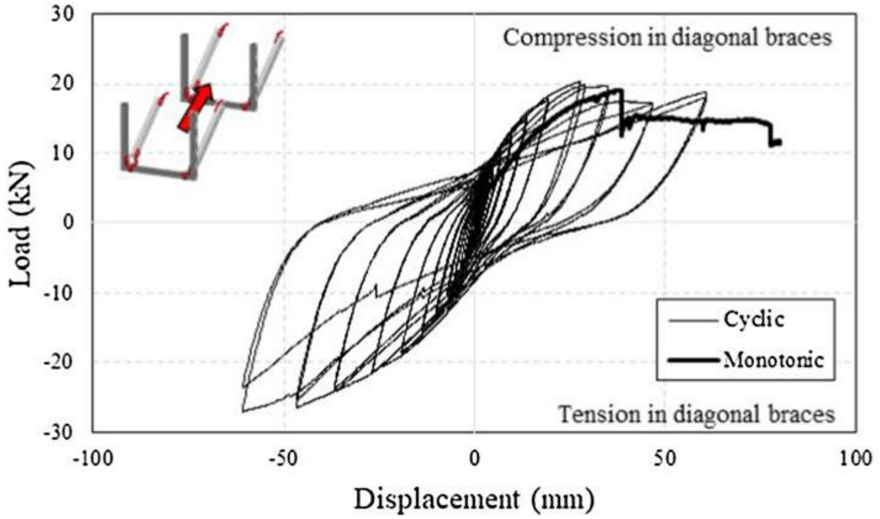

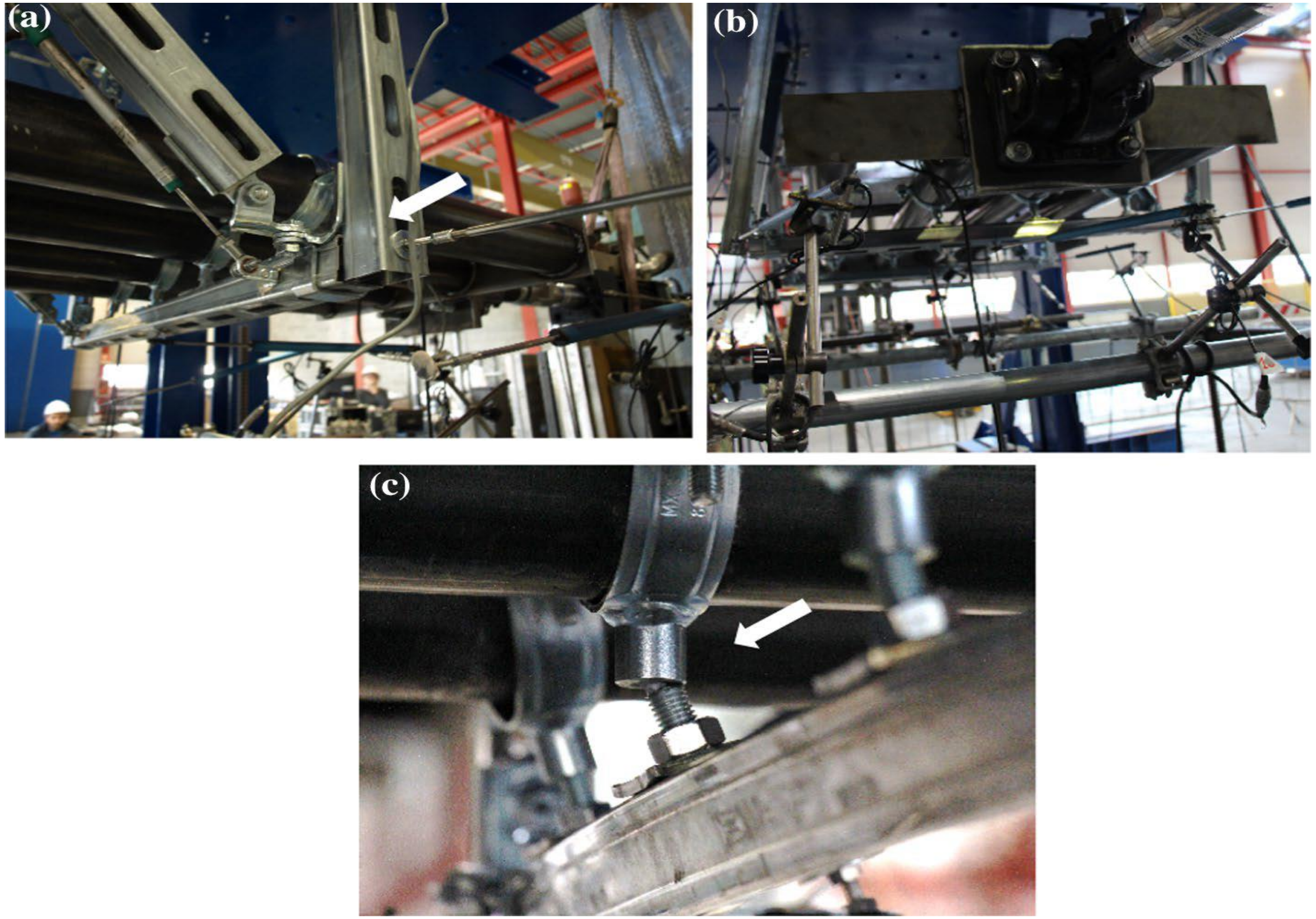

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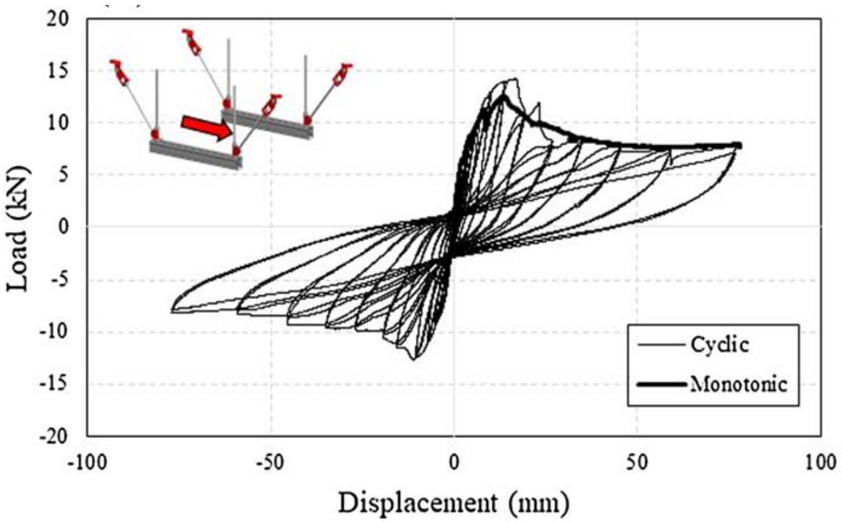

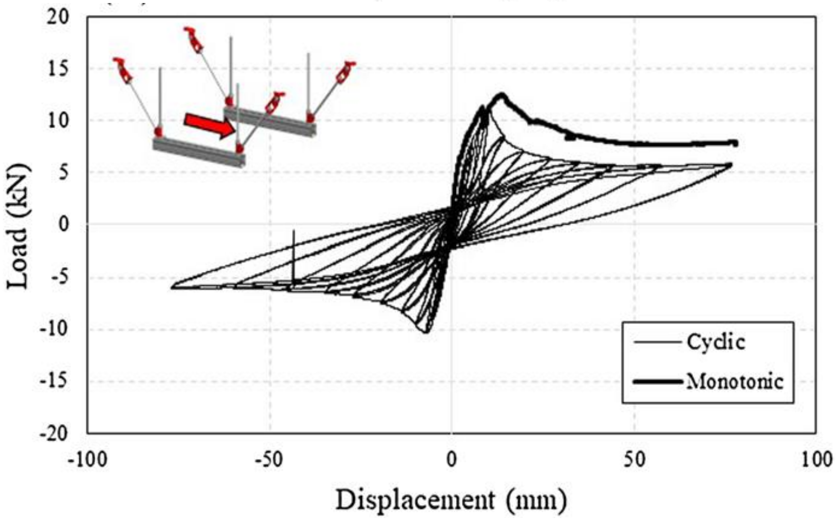

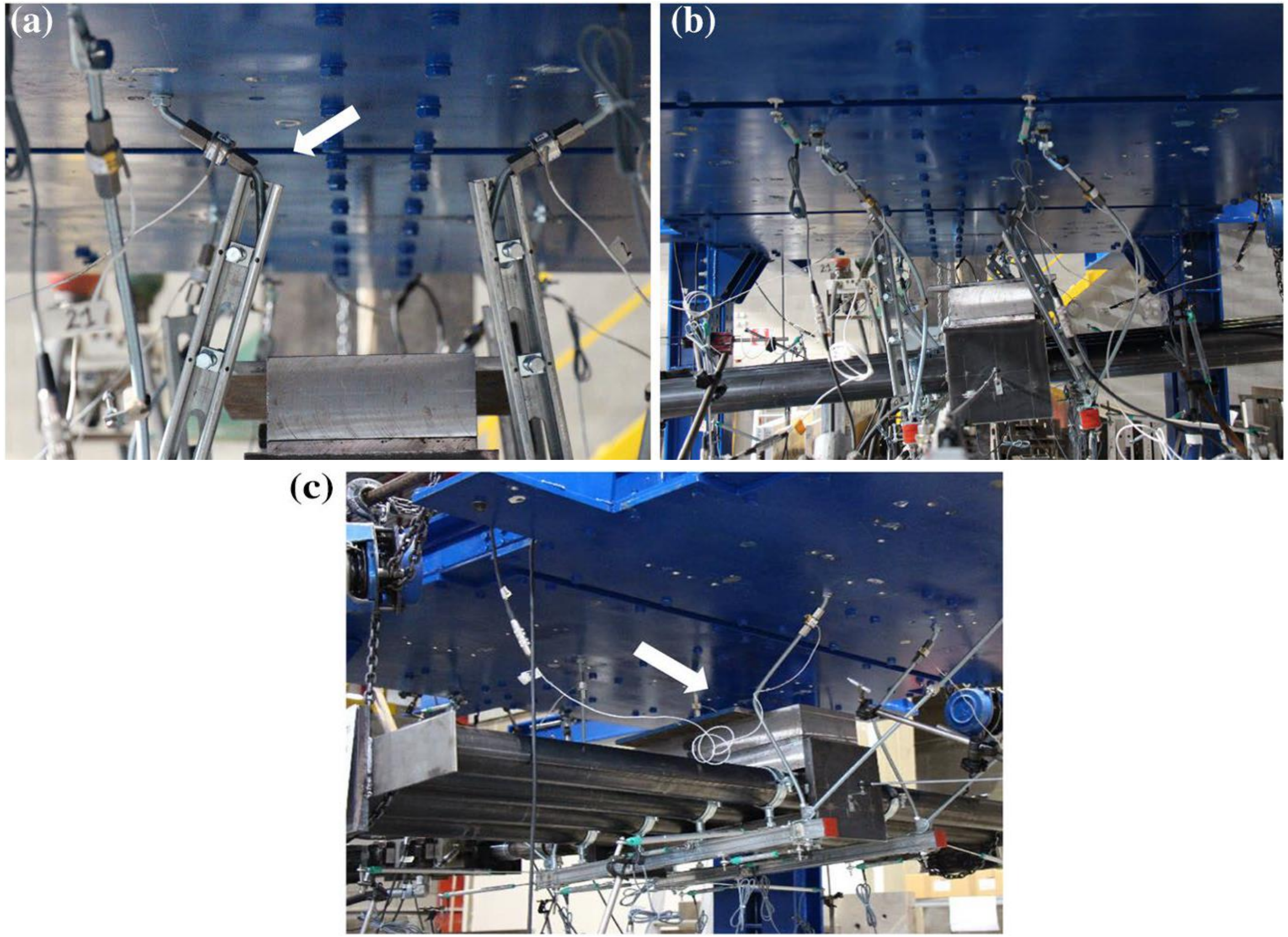

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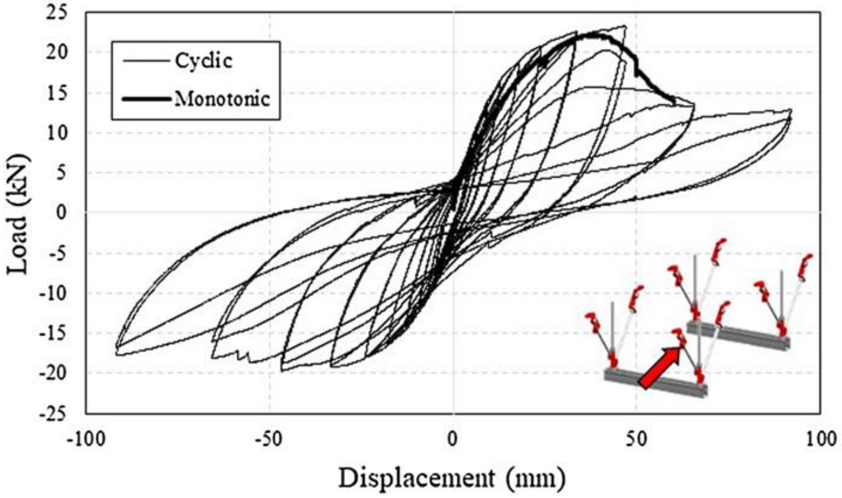
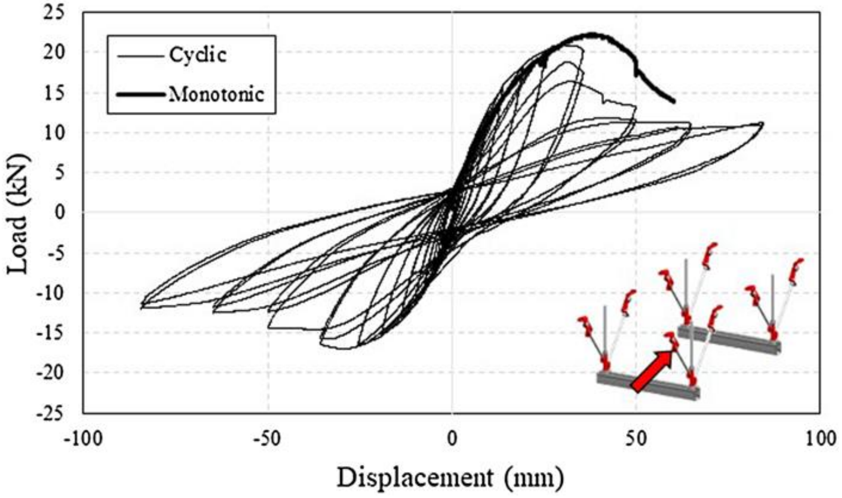
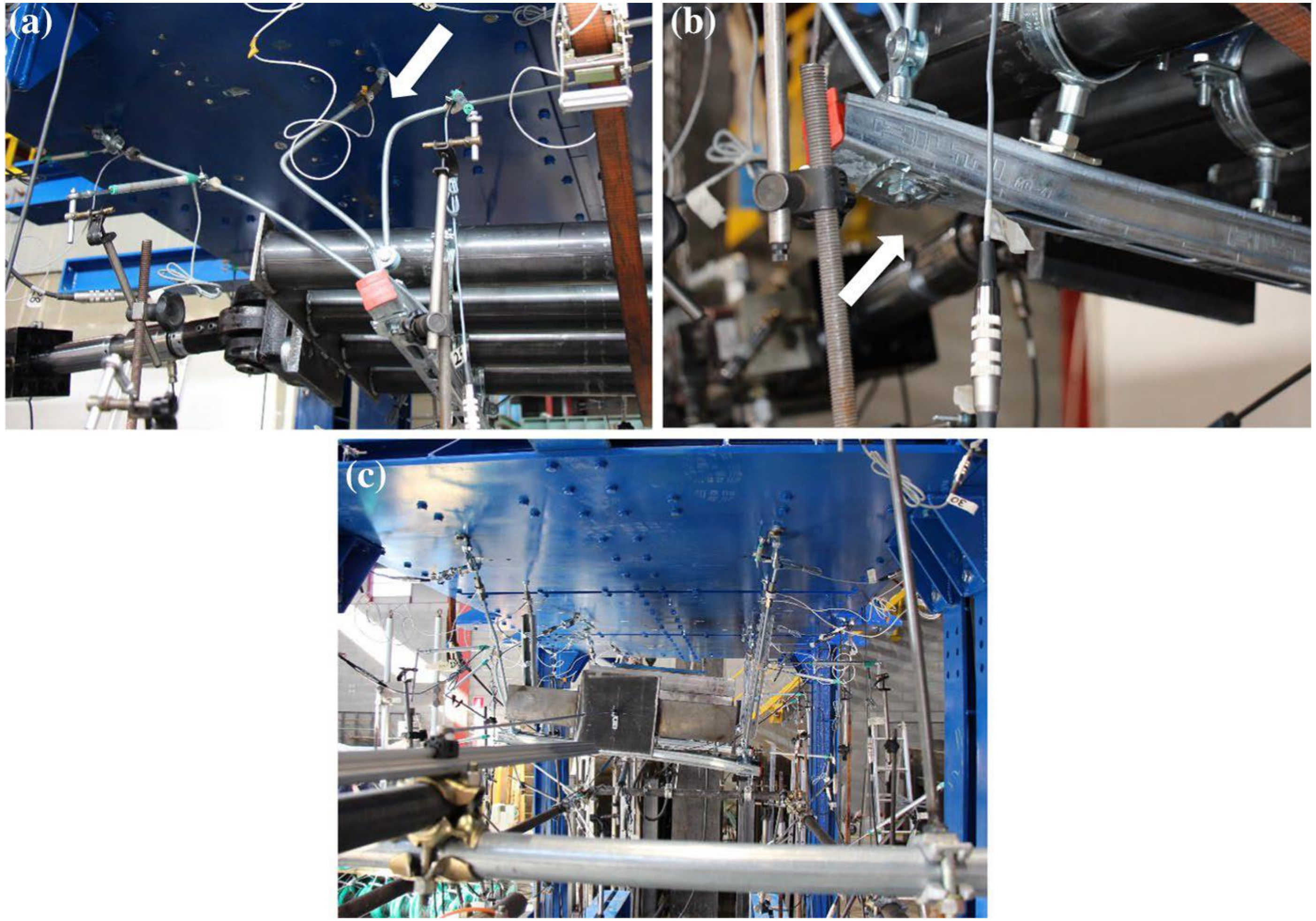
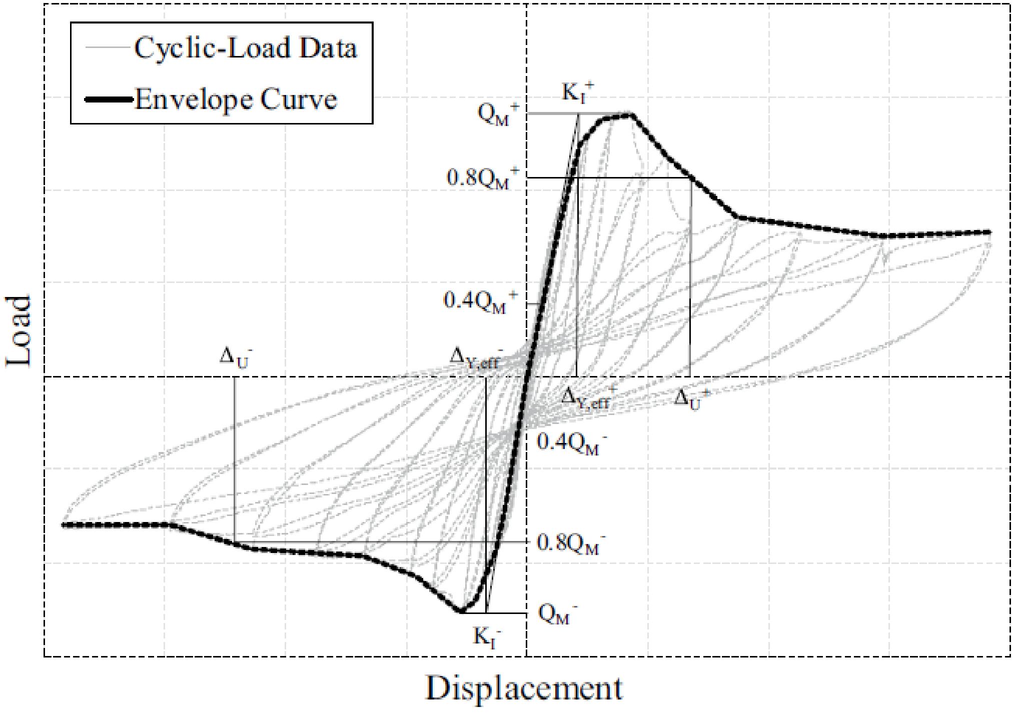






SEISMIC RESPONSE OF SUSPENDED PIPING RESTRAINT INSTALLATIONS

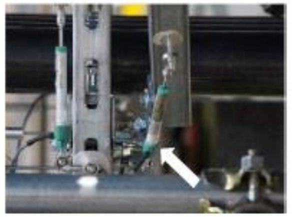
Definition of performance design parameters

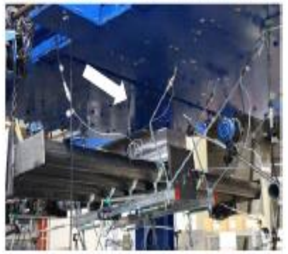


Test ID	Configura-tion	Test pro-tocol	Qm (kN)	K_I (kN/mm)	$\Delta_{Y,eff}$ (mm)	Δ_U (mm)	μ_{eff}	E_{af} (kNmm)	ξ_{eq} (%)
1	SS1	Monotonic	14.1	1.0	14.3	21.1	1.5	–	–
2	SS1	Cyclic	17.4	1.4	13.1	28.4	2.2	939.8	18
3	SS1	Cyclic	15.8	1.4	12.0	25.1	2.1	622.4	18
4	SS2	Monotonic	19.1	1.0	19.1	38.9	2.0	–	–
5	SS2	Cyclic	23.4	1.6	17.0	60.7	3.6	1581.2	15
6	SS2	Cyclic	23.7	1.5	15.8	60.8	3.8	1703.0	16
7	SS3	Monotonic	12.5	2.7	4.6	21.2	4.6	–	–
8	SS3	Cyclic	13.4	2.5	5.6	24.1	4.3	670.6	12
9	SS3	Cyclic	10.9	1.8	6.2	13.4	2.2	511.0	11
10	SS4	Monotonic	22.2	1.3	17.2	50.0	2.9	–	–
11	SS4	Cyclic	21.4	1.6	13.5	69.6	5.1	1320.3	14
12	SS4	Cyclic	18.9	1.7	11.4	46.4	4.1	865.6	13

SEISMIC RESPONSE OF SUSPENDED PIPING RESTRAINT INSTALLATIONS

Definition of performance design parameters

Configuration	Performance objective	EDP $\mu_{eff,exp}$	Damage description	Photographs
SS1	DL	Monotonic Test = 1.5 Cyclic Test 1 = 1.5 Cyclic Test 2 = 1.3 **Mean = 1.4**	Yielding of the channel hinge connecting the brace channel and the vertical channel in one of the two trapezes	
	LS	Monotonic Test = 7.0 Cyclic Test 1 = 6.0 Cyclic Test 2 = 5.1 **Mean = 6.0**	Significant rotation of the specimen around the vertical axis Disconnection of the diagonal braces from the horizontal channels Sliding between one diagonal brace and the hinge connection with the rigid floor (only in Test 2) The gravity load carrying capacity of the specimen was not compromised by the induced damage	 

Configuration	Performance objective	EDP $\mu_{eff,exp}$	Damage description	Photographs
SS3	DL	Monotonic Test = 1.7 Cyclic Test 1 = 1.3 Cyclic Test 2 = 1.1 **Mean = 1.4**	Buckling of the diagonal braces in the out of plane direction Global rotation of the specimen due to different deformation of the braces	
	LS	Monotonic Test = 17.0 Cyclic Test 1 = 13.6 Cyclic Test 2 = 12.3 **Mean = 14.3**	Significant deformation of the vertical and diagonal rods Rotation around the horizontal and perpendicular axis of the pipes The gravity load carrying capacity of the specimen was not compromised by the induced damage	 

SEISMIC RESPONSE OF FIRESTOPPING SYSTEMS

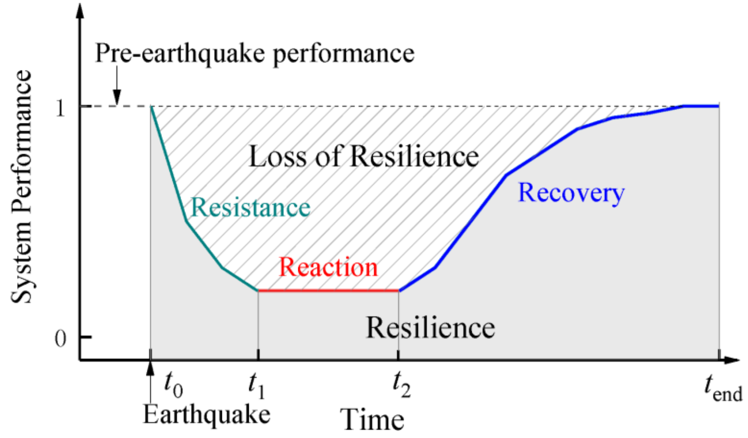
Ye Z, Abu A, Fleischmann C, Dhakal R.P. (2023) Performance of firestopping systems: State-of-the-art and research needs in earthquake-prone regions, Development in the Built Environment

ENRICH

ENHANCING THE RESILIENCE OF ITALIAN HEALTHCARE AND HOSPITAL FACILITIES

AIM OF THE PROJECT

The project aims at enhancing the resilience of Italian Healthcare and Hospital Facilities by improving functional adaptivity and seismic performance of non-structural elements



PARTNERS

Università degli Studi di Napoli Federico II

Università del Salento

National Research Council of Italy

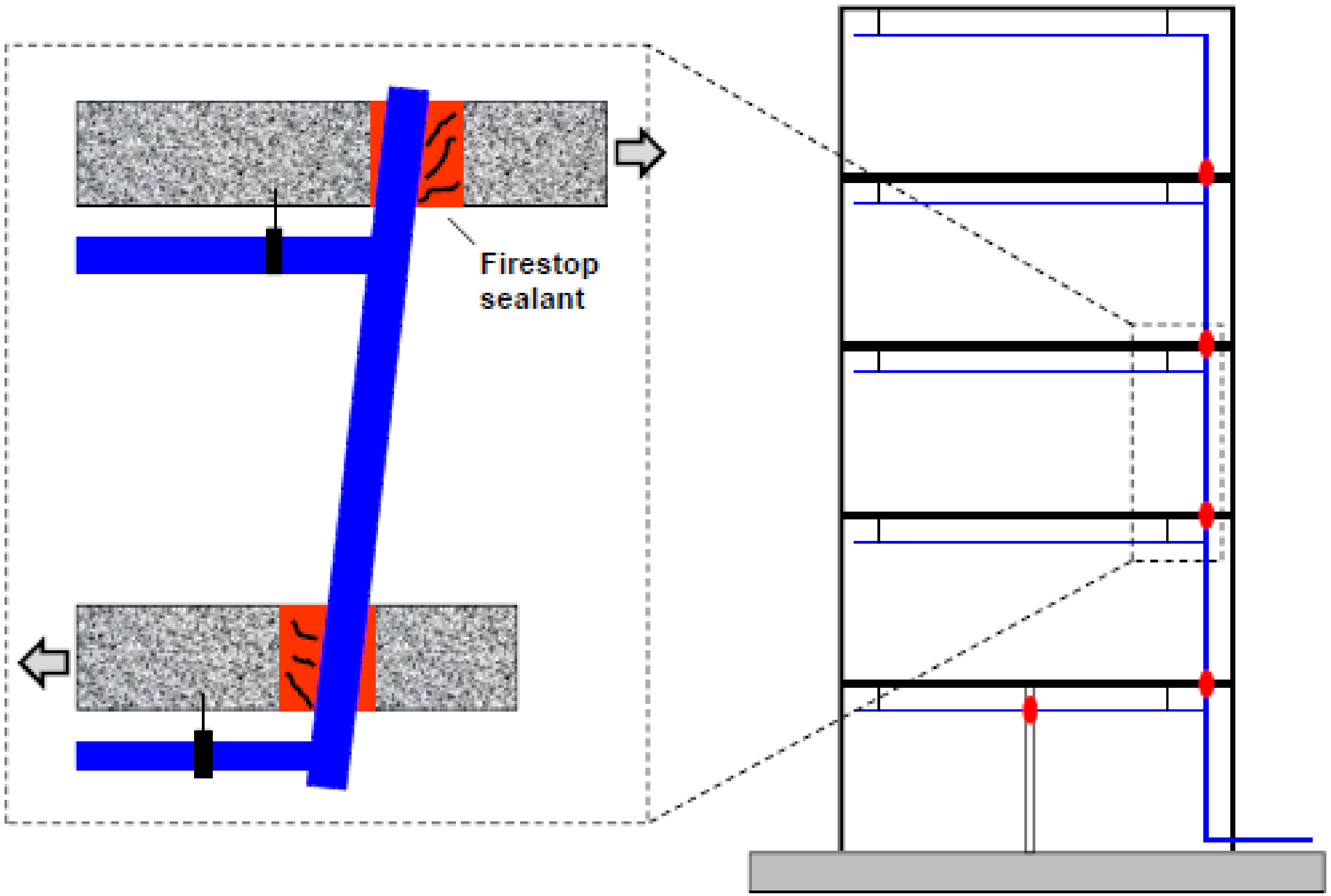
Università degli Studi del Sannio Benevento

Istituto Nazionale di Geofisica e Vulcanologia

SEISMIC RESPONSE OF FIRESTOPPING SYSTEMS

During visual inspections in Italian strategic facilities the absence of adequate firestopping systems has been observed.

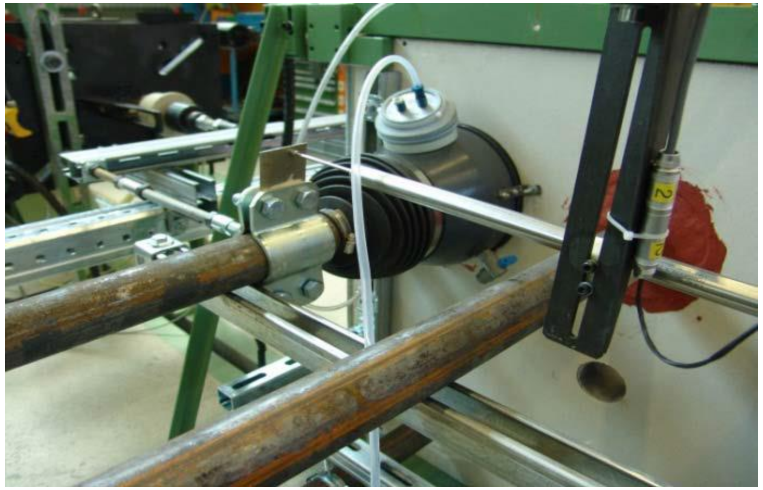
SEISMIC RESPONSE OF FIRESTOPPING SYSTEMS

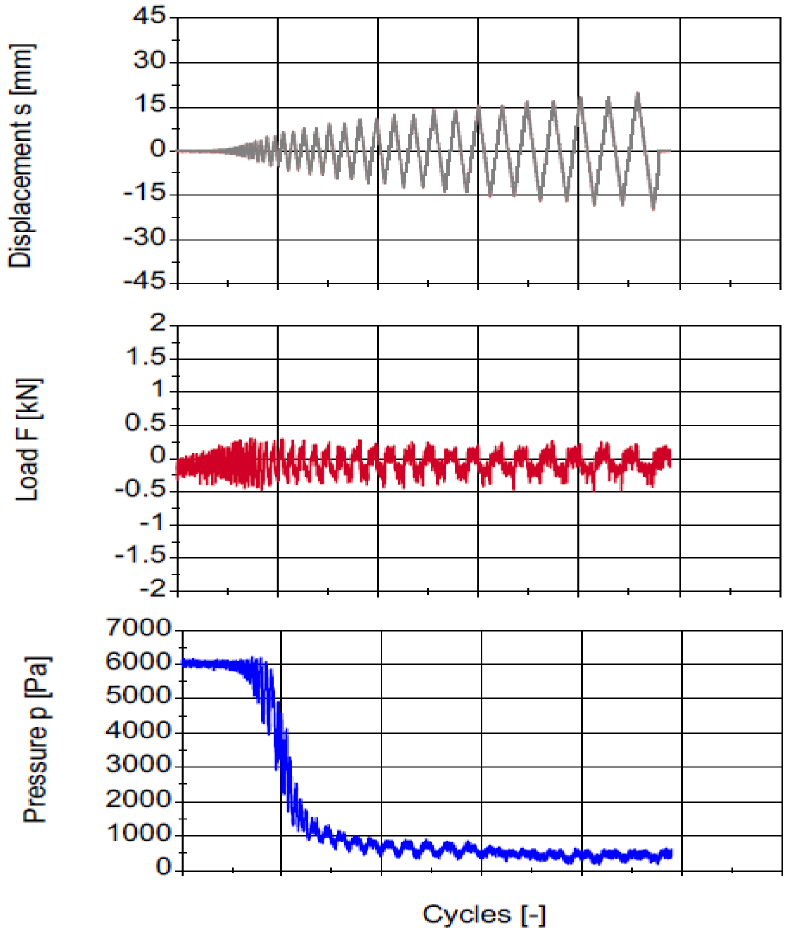


Firestopping systems are subjected to relative displacements of the structural and non-structural elements.

It is required to design the sway bracing systems also looking at the target displacements of firestopping systems.

SEISMIC RESPONSE OF FIRESTOPPING SYSTEMS





Hoehler M.S., Lutz C., Schulze P (2012) Testing passive fire-resistance systems for fire following earthquakes. Structural Congress 2012 ASCE.

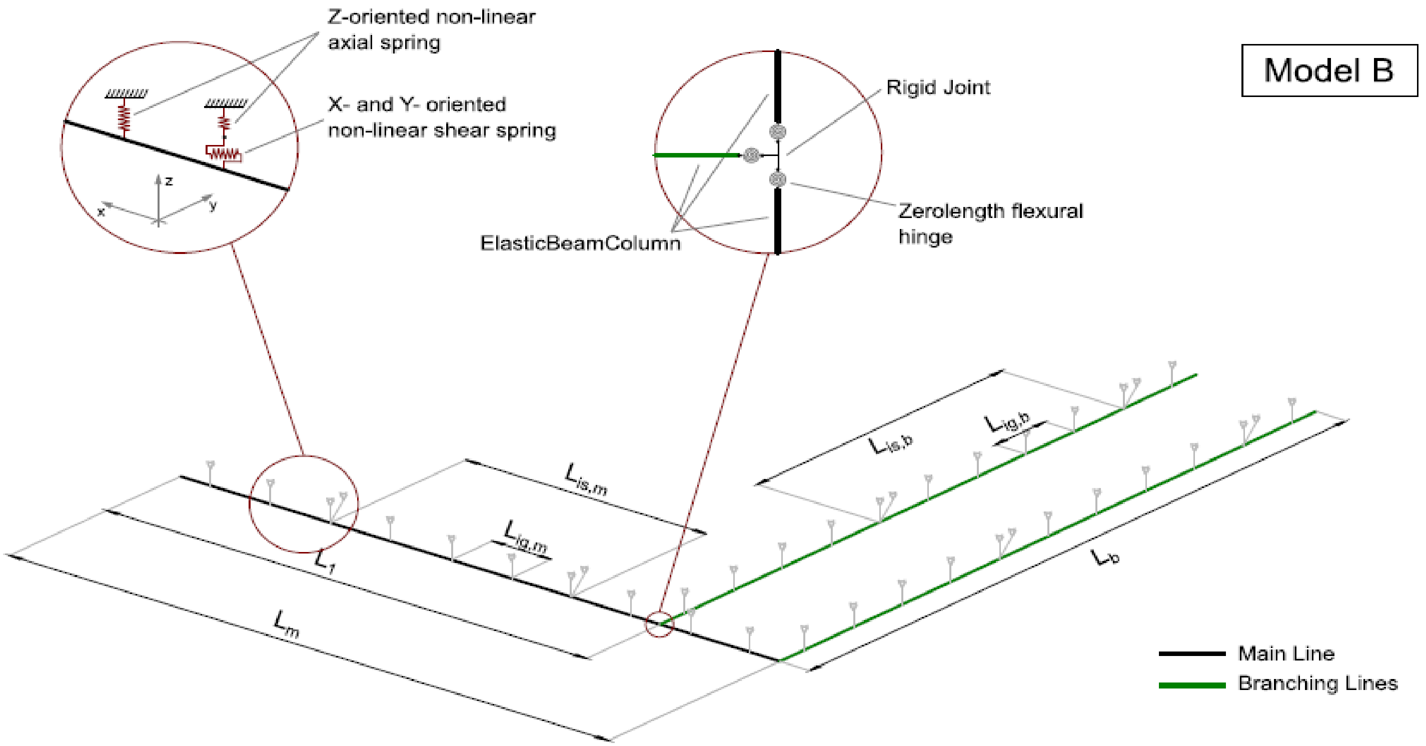
EXPERIMENTAL PROGRAM IN COLLABORATION WITH HILTI

Two typologies of firestop systems will be tested in both longitudinal and transverse direction using a universal testing machine. The loading protocol will be defined according to ASTM E3037 and FEMA 461

Archetype	ID Test	Wall	Pipe	Firestop	Loading Direction	N. Test
1	1_1	Concrete	Steel pipe	Type 1	Longitudinal	3
	1_2	Concrete	Steel pipe	Type 1	Transverse	3
2	2_1	Concrete	Steel pipe	Type 2	Longitudinal	3
	2_2	Concrete	Steel pipe	Type 2	Transverse	3
3	3_1	Gypsum	Steel pipe	Type 1	Longitudinal	3
	3_2	Gypsum	Steel pipe	Type 1	Transverse	3
4	4_1	Gypsum	Steel pipe	Type 2	Longitudinal	3
	4_2	Gypsum	Steel pipe	Type 2	Transverse	3

NUMERICAL SIMULATIONS

Following the experimental tests, specific numerical parametric analyses will be performed to define design provisions regarding the spacing between seismic trapeze installations close to the passive fire-resistance systems.



CONCLUSIONS

- The seismic performance of non-structural elements is of paramount importance in the assessment of combined seismic-fire risk, both in terms of fire ignition probability and risk reduction.
- Sprinkler piping systems represent a key aspect in the risk evaluation, and they should be designed according to performance-based seismic design procedures
- Experimental studies are still required to characterize the behaviour of the critical elements in sprinkler piping systems (i.e. firestopping systems)
- Once the seismic performance of sprinkler piping systems will be completely characterized, this data could be used to better investigate the post-earthquake fire risk in critical facilities.

THANKS

HILTI

Seismic Design of non-structural Elements: a journey from fixation, across the support system and ventilated façade, to the fire protection

Paolo Baccarini
Eng. Director

Thanks for your attention!

Paolo Baccarini
Eng. Director