VIII SEISMIC ACADEMY

Evento Digitale
1 Luglio 2021

DEVELOPMENT OF A FRAMEWORK FOR THE EVALUATION OF SEISMIC PERFORMANCE FACTORS FOR NON-STRUCTURAL ELEMENTS

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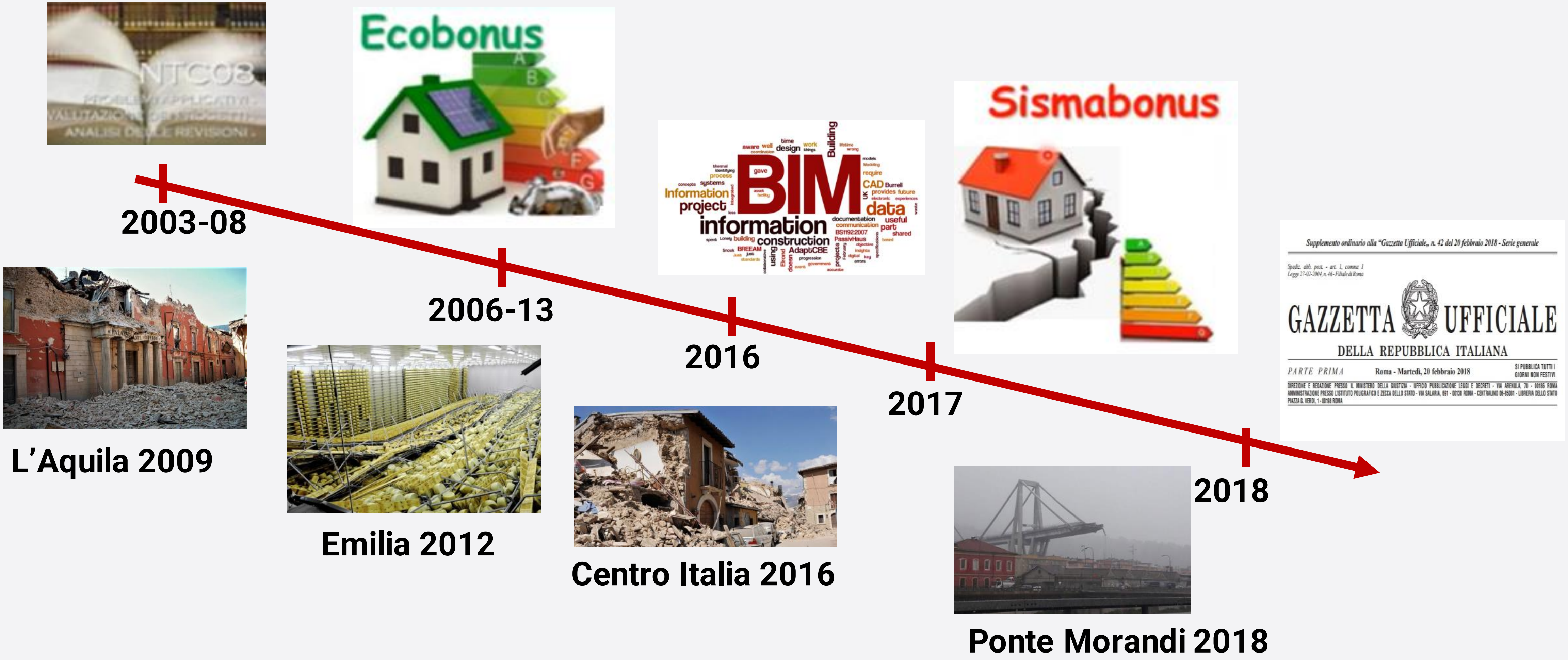
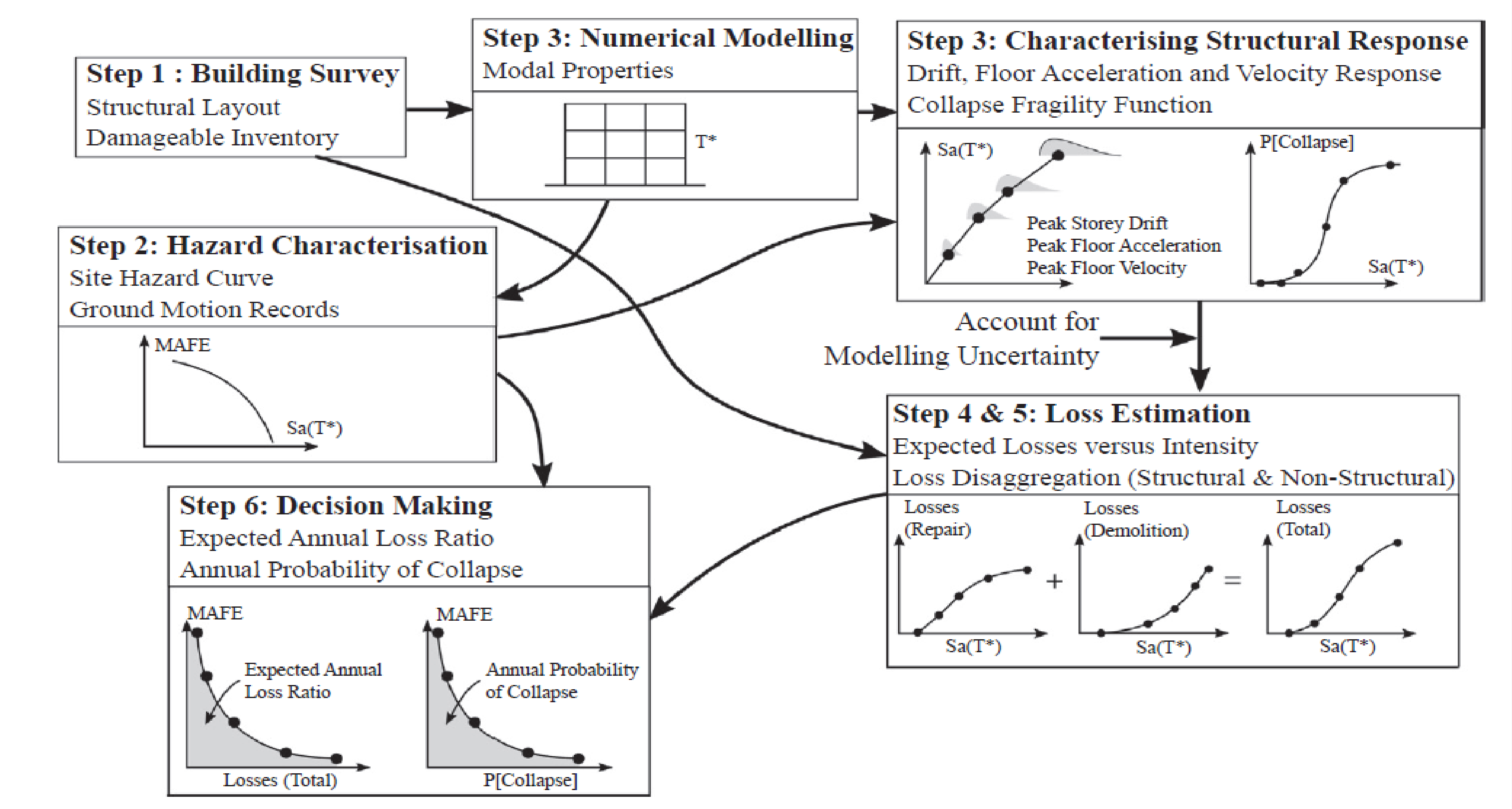
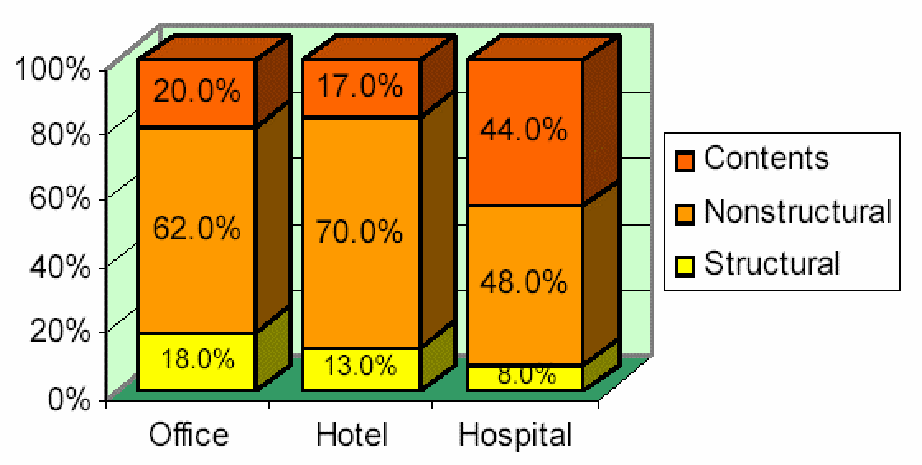
THE EVOLUTION OF THE SEISMIC DESIGN METHODOLOGIES AND BUILDING CODES

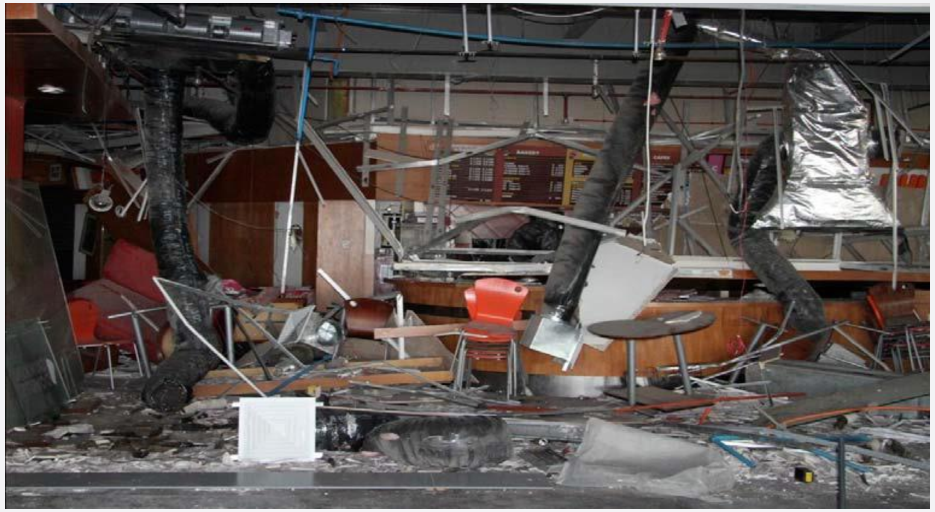


THE PERFORMANCE-BASED EARTHQUAKE ENGINEERING

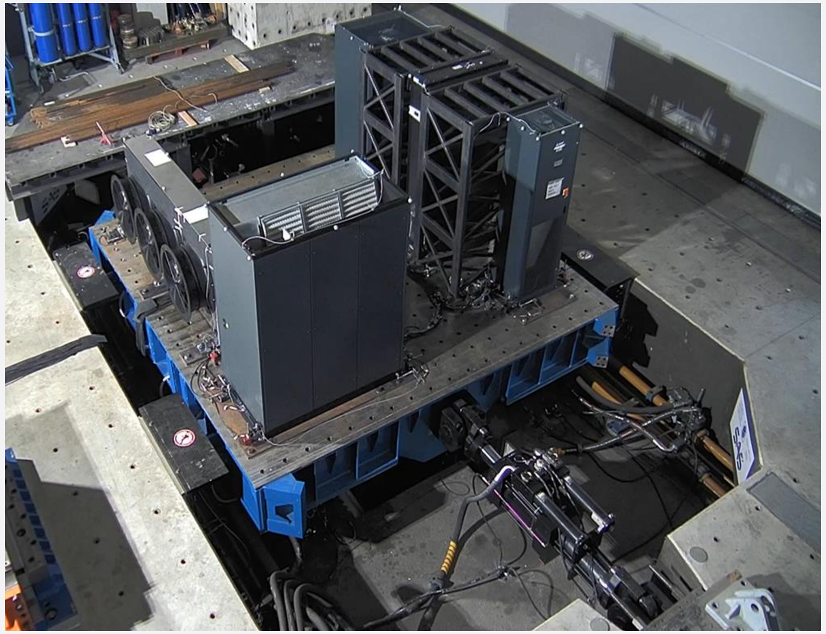


THE IMPORTANCE OF NON-STRUCTURAL ELEMENTS





ARE THE SEISMIC DESIGN AND QUALIFICATION METHODOLOGIES FOR NON-STRUCTURAL ELEMENTS WELL ESTABLISHED?



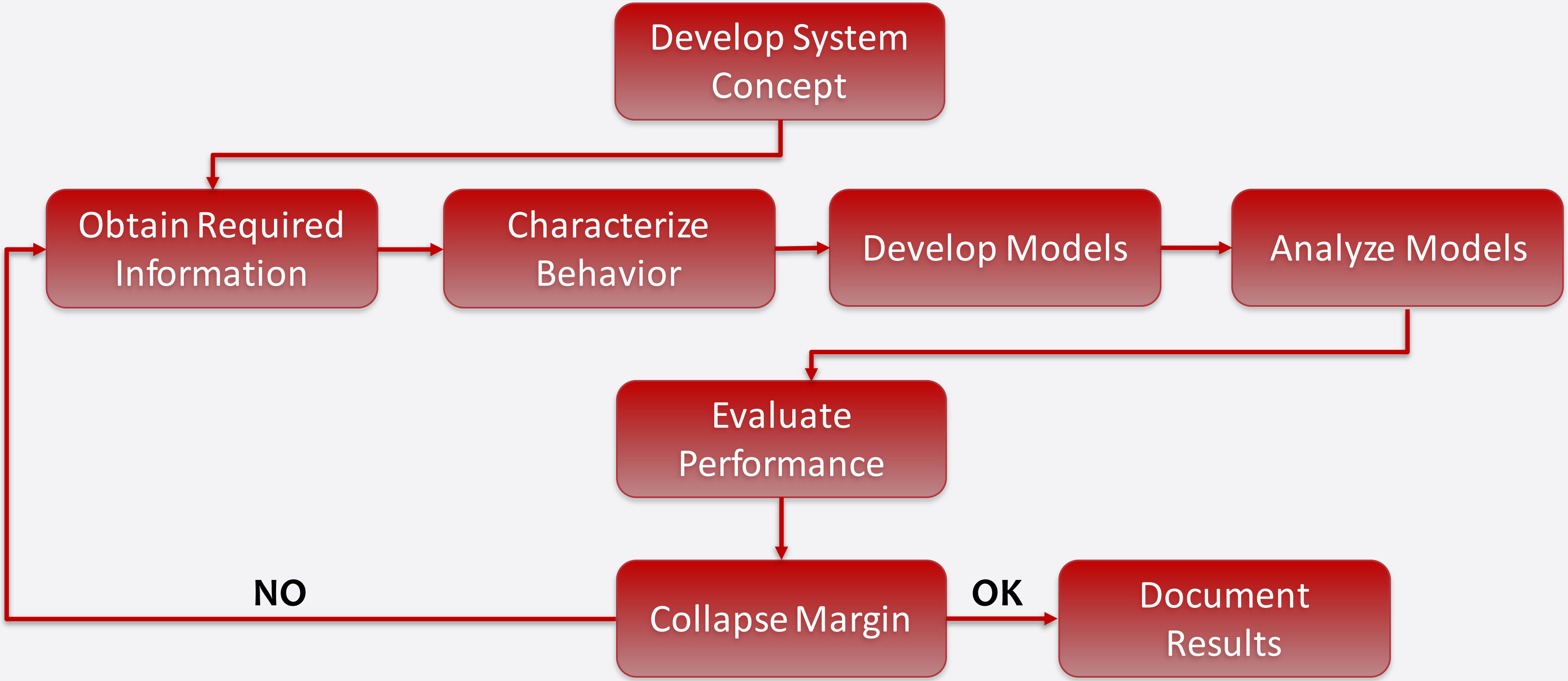
Courtesy Eucentre Foundation

SOME SHORTCOMINGS

1. A methodology for quantifying the seismic performance of non-structural elements is missing;
2. All the design procedures available in the international building codes account for force-based approaches, which are characterized by many shortcomings;
3. The seismic qualification procedures still require some improvements and are not well established around the world.

FEMA P695

QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS



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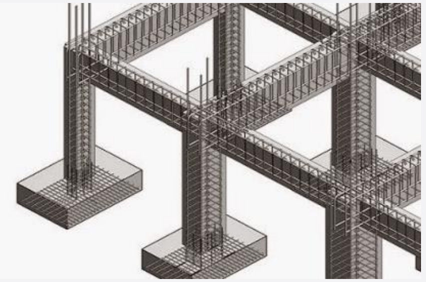
QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS

Obtain Required Information

Identify Intended Application

Establish Design Requirements

Acquire Test Data



Assess Quality of Design Requirements and Test Data

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QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS

Characterize Behavior

- Consider Configuration Issues
- Consider Behavioral Effects
- Develop Index Archetype Configurations
- Define Archetype Design Space
- Identify Performance Groups

Identify Design Variables

Table 4-1 Configuration Design Variables and Related Physical Properties

Design Variable	Related Physical Properties
Occupancy and Use	• Typical framing layout • Distribution of seismic-force-resisting system components • Gravity load intensity • Component overstrength
Elevation and Plan Configuration	• Distribution of seismic-force-resisting components • Typical framing layout • Permitted vertical (strength and stiffness) irregularities • Beam spans, number of framing bays, system regularity • Wall length, aspect ratio, plan geometry, wall coupling • Braced bay size, number of braced bays, bracing configuration • Diaphragm proportions, strength, and stiffness (or flexibility) • Ratio of seismic mass to seismic-force-resisting components • Ratio of tributary gravity load to seismic load
Building Height	• Story heights • Number of stories
Structural Component Type	• Moment frame connection types • Bracing component types • Shear wall sheathing and fastener types • Isolator properties and types
Seismic Design Category	• Design ground motion intensity • Special design/detailing requirements • Application limits
Gravity Load	• Gravity load intensity • Typical framing layout • Ratio of tributary gravity load to seismic load • Component overstrength

Identify Performance Group

Table 4-3 Generic Performance Group Matrix

Performance Group Summary					
Group No.	Grouping Criteria: Basic Configuration	Design Load Level: Gravity	Design Load Level: Seismic	Period Domain	Number of Archetypes
PG-1	Type 1	High	Max SDC	Short	≥ 3
PG-2				Long	≥ 3
PG-3			Min SDC	Short	≥ 3
PG-4				Long	≥ 3
PG-5		Low	Max SDC	Short	≥ 3
PG-6				Long	≥ 3
PG-7			Min SDC	Short	≥ 3
PG-8				Long	≥ 3
PG-9	Type 2	High	Max SDC	Short	≥ 3
PG-10				Long	≥ 3
PG-11			Min SDC	Short	≥ 3
PG-12				Long	≥ 3
PG-13		Low	Max SDC	Short	≥ 3
PG-14				Long	≥ 3
PG-15			Min SDC	Short	≥ 3
PG-16				Long	≥ 3
PG-17	Type N	High	Max SDC	Short	≥ 3
PG-18				Long	≥ 3
PG-19			Min SDC	Short	≥ 3
PG-20				Long	≥ 3
PG-21		Low	Max SDC	Short	≥ 3
PG-22				Long	≥ 3
PG-23			Min SDC	Short	≥ 3
PG-24				Long	≥ 3

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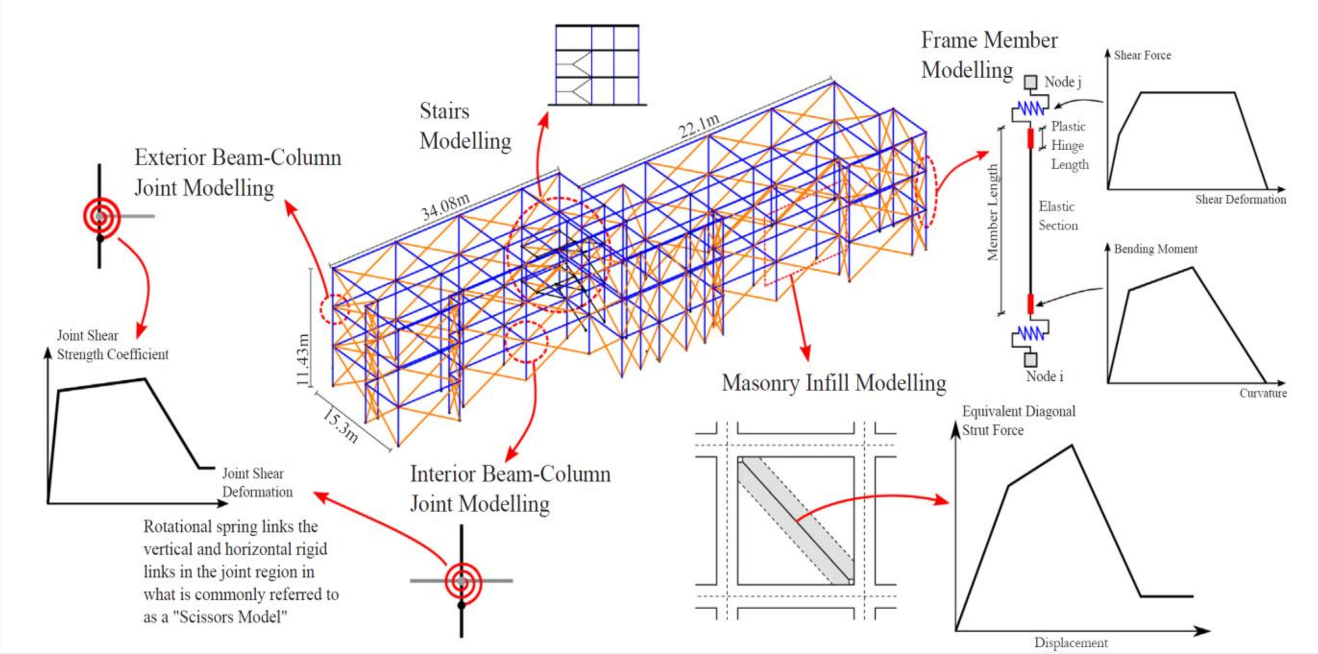
QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS

Develop Models



- Apply Design Requirements
- Utilize Test Data
- Prepare Index Archetype Designs
- Prepare Index Archetype Models
- Calibrate Models
- Establish Criteria for Non-Simulated Collapse Modes
- Assess Quality of Index Archetype Models

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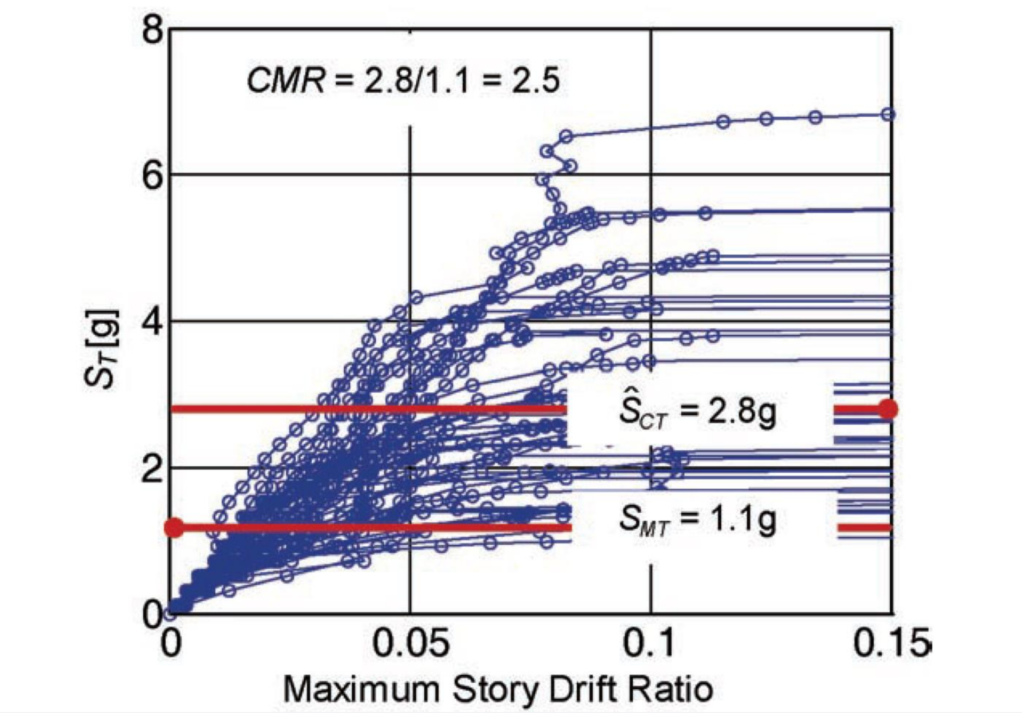
QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS

Analyze Models

Perform Nonlinear Static Analysis

Perform Nonlinear Dynamic Analyses

Calculate:
- Period-based ductility
- Median Collapse Intensity
- Collapse Margin Ratio



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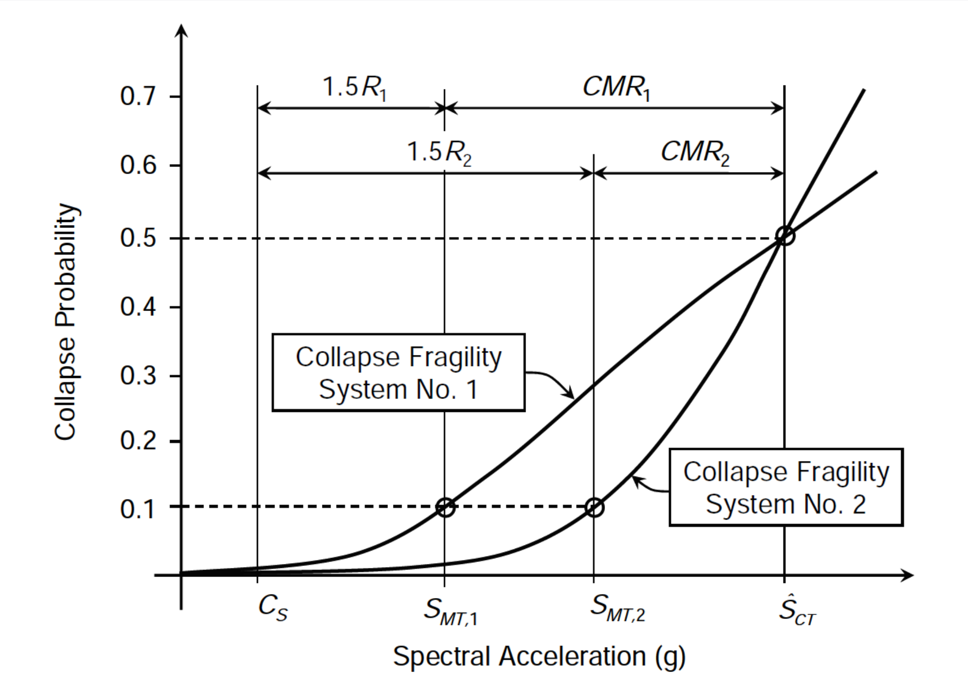
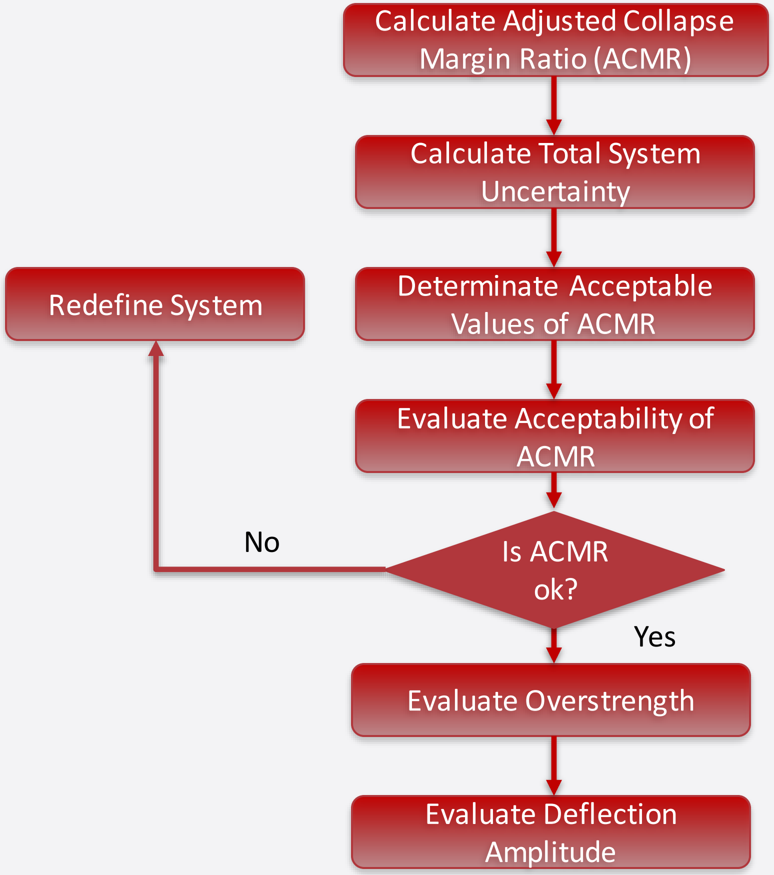
QUANTIFICATION OF BUILDING SEISMIC PERFORMANCE FACTORS

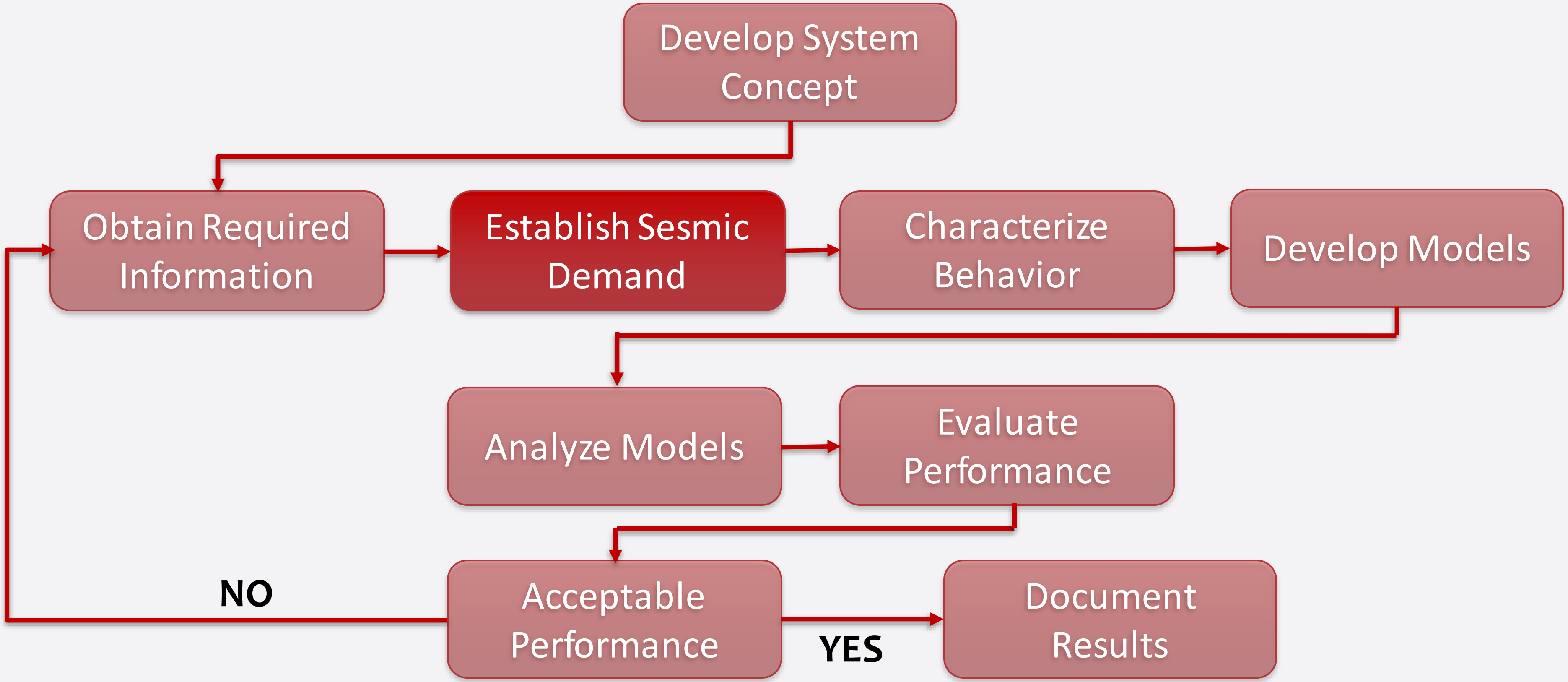
Evaluate Performance





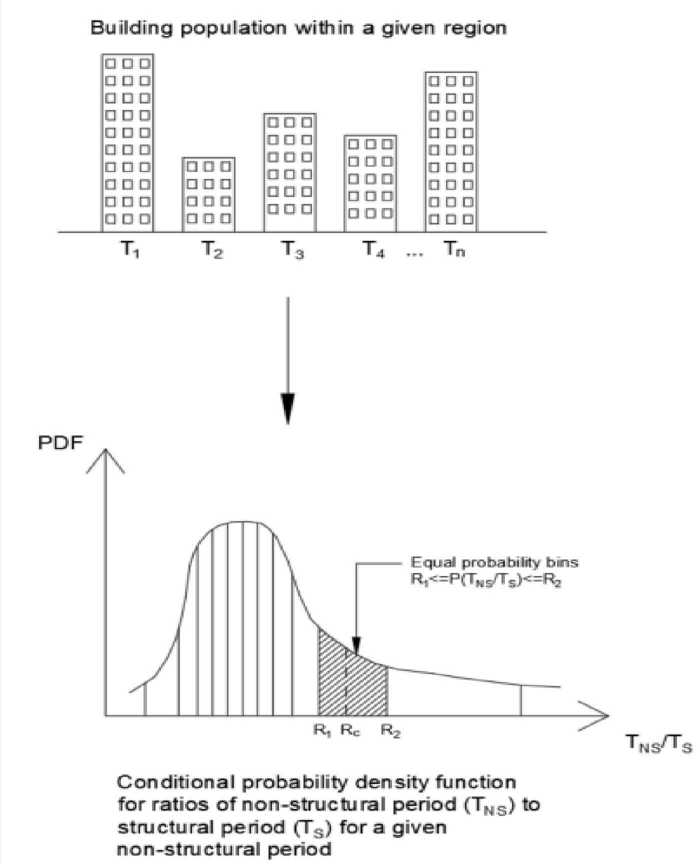
IS THE FEMA P695 APPLICABLE FOR QUANTIFYING PERFORMANCE PARAMETERS FOR NON-STRUCTURAL ELEMENTS?

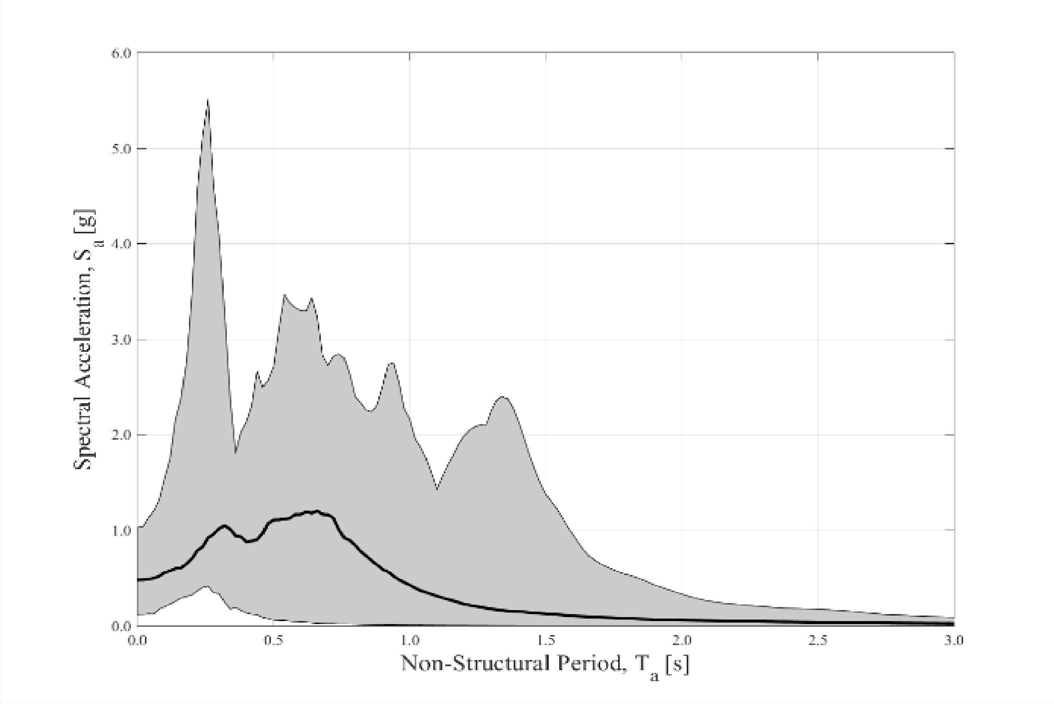
PROPOSED FRAMEWORK FOR THE QUANTIFICATION OF SEISMIC PERFORMANCE FACTOR FOR NON-STRUCTURAL BUILDING ELEMENTS



PROPOSED FRAMEWORK FOR THE QUANTIFICATION OF SEISMIC PERFORMANCE FACTOR FOR NON-STRUCTURAL BUILDING ELEMENTS

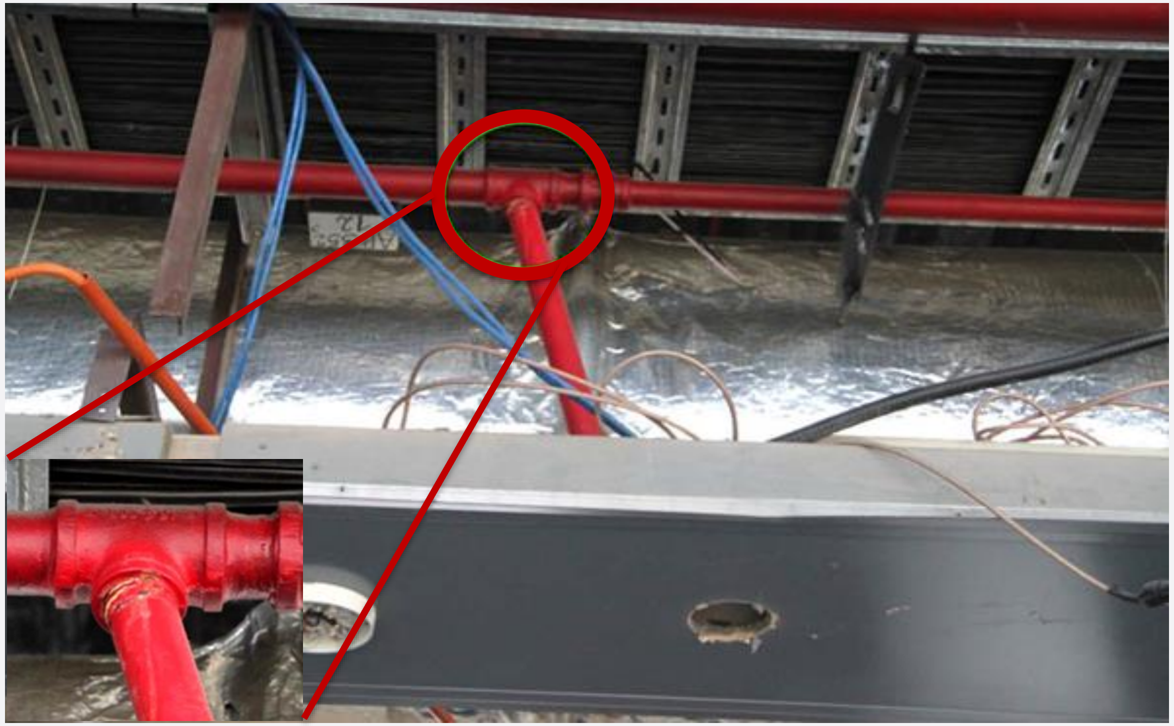
Establish Seismic Demand



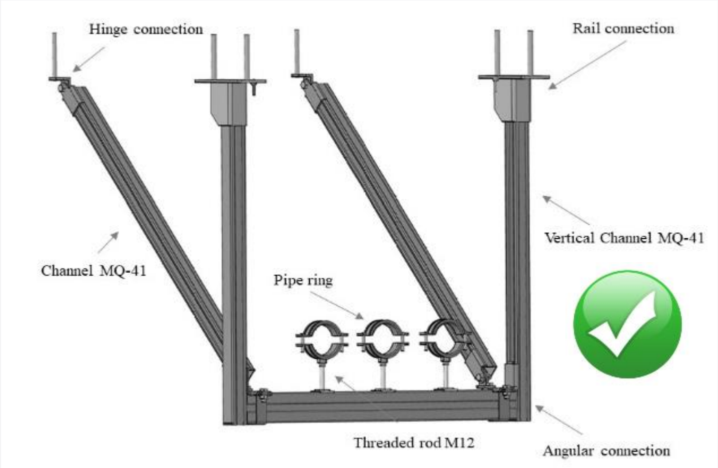


ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

TYPICAL DAMAGE



HOW TO AVOID



THE QUESTION

$$F_a = \frac{S_a \gamma_a}{q_a} W_a \; ?$$

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Obtain Required Information

↓

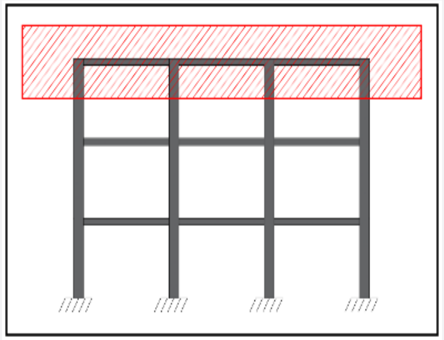
Establish Design Requirements

THE EUROCODE 8 DESIGN APPROACH HAS BEEN CONSIDERED FOR THE DESIGN OF THE ARCHETYPES

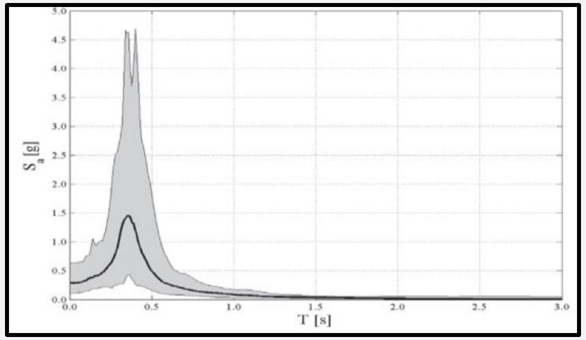
$$F_a = \frac{S_a \gamma_a}{q_a} W_a$$

$$S_a = a_g S \left(\frac{3(1 + z/H)}{1 + (1 - T_a/T_n)^2} - 0.5 \right)$$

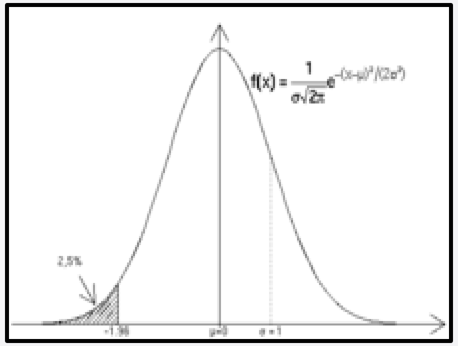
z/H



T_a/T_n



$$F_a \leq \frac{F_{Rk}}{\gamma_m}$$



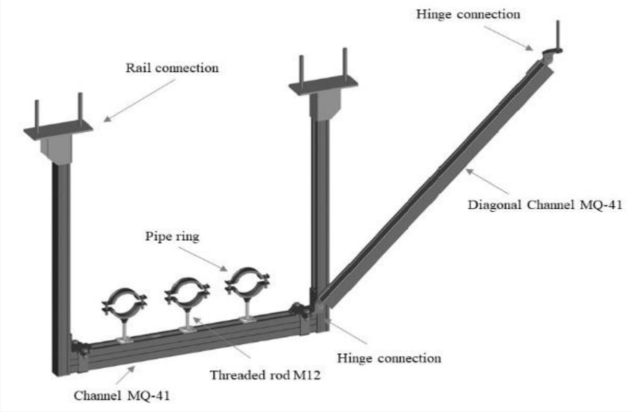
ADDITIONAL PRESCRIPTIVE RULES FOR SPACING

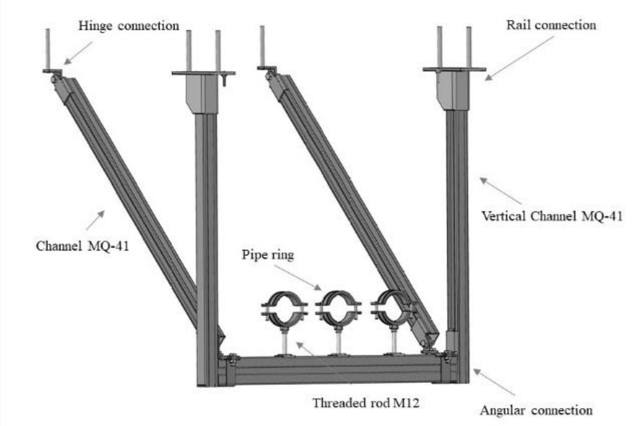
ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Obtain Required Information

↓

Test data





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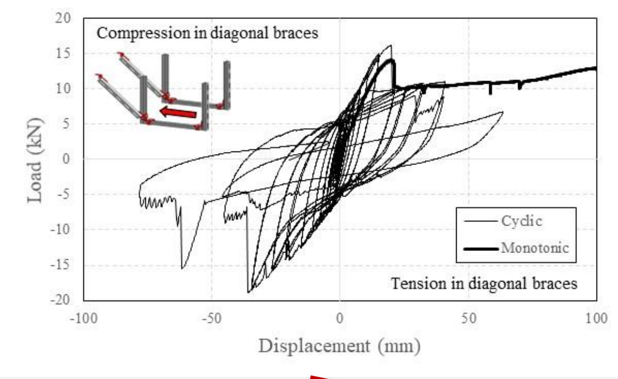
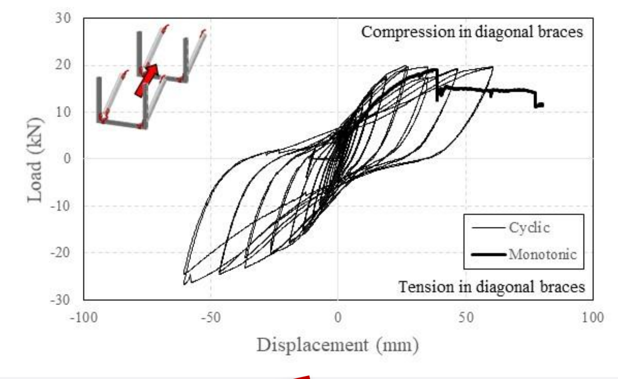
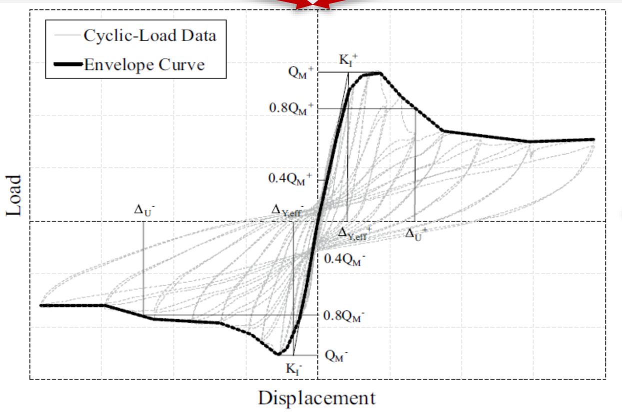
Obtain Required Information

↓

Test data



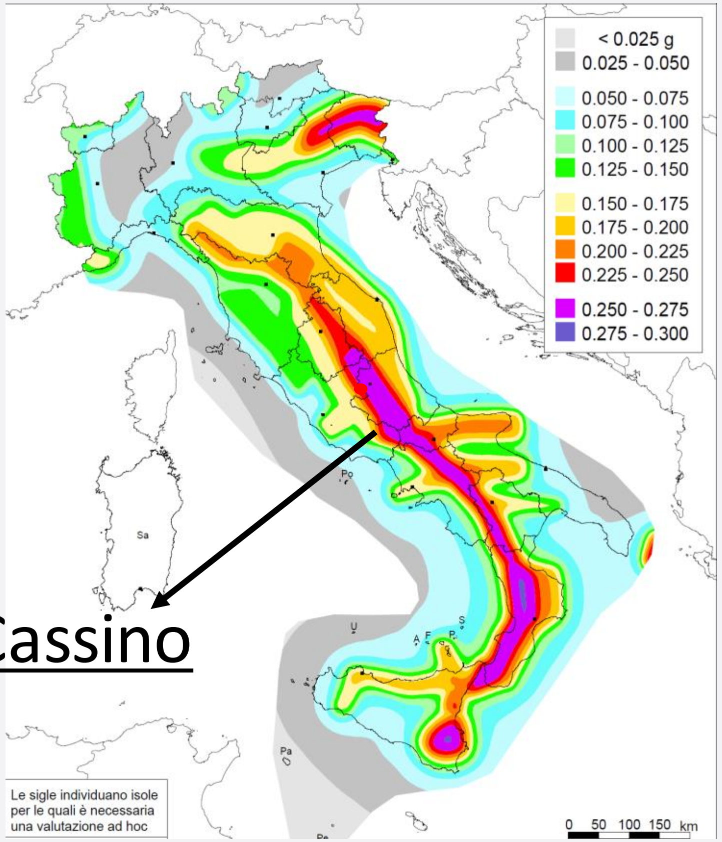


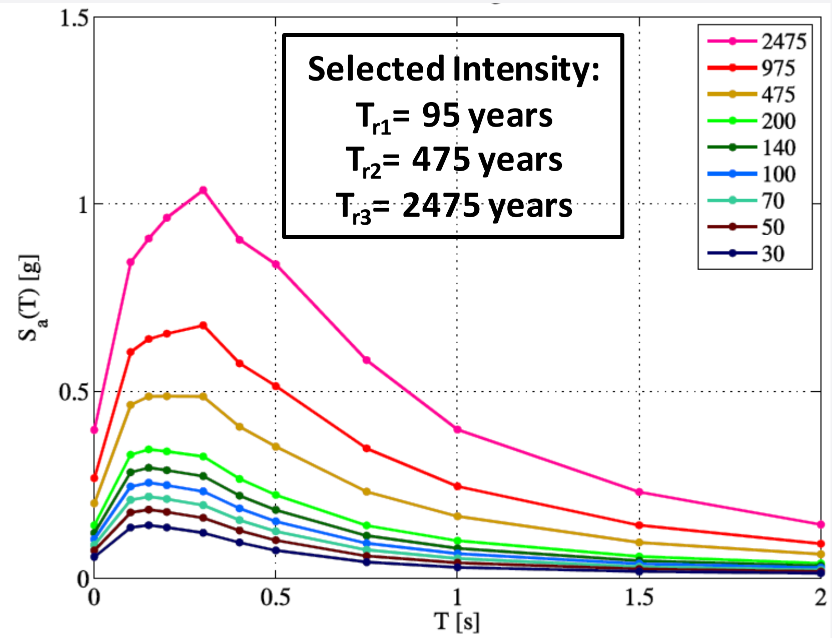


Suspended piping restraint installation	Q_M (kN)	$\Delta_{Y,eff}$ (mm)	Δ_U (mm)	μ_{eff}
Transverse	15.79	13.12	24.87	1.9
Longitudinal	22.08	17.32	53.46	3.1

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Establish Seismic Demand





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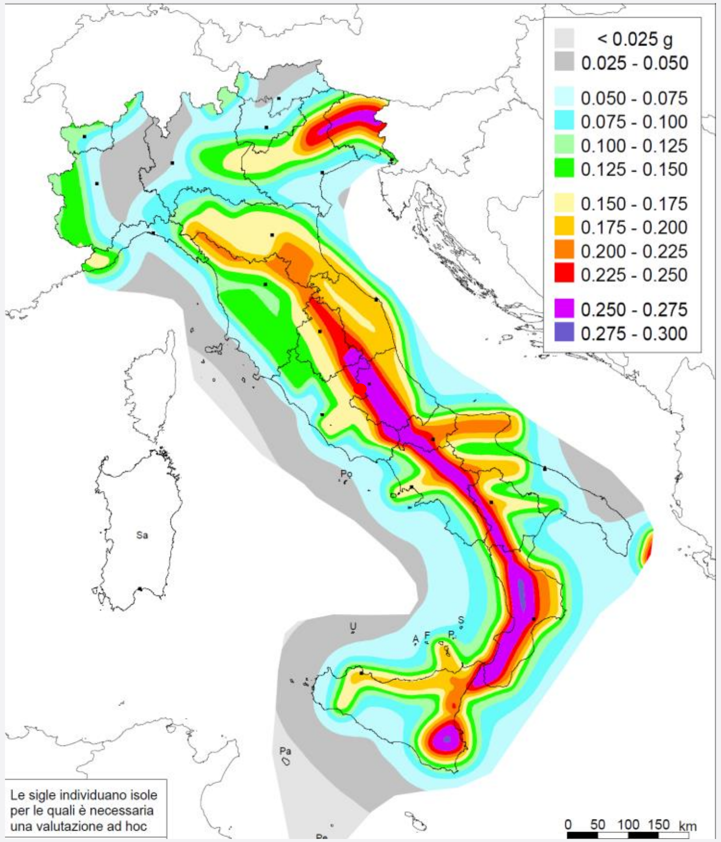
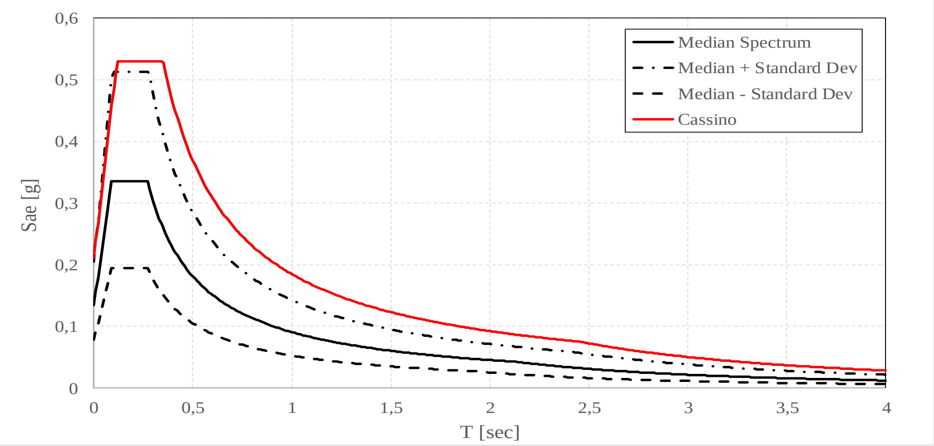
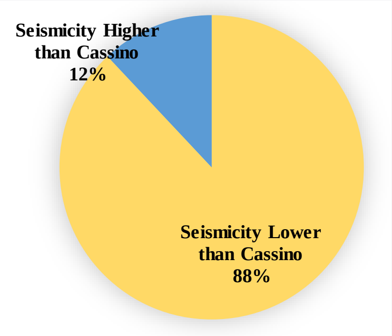
Establish Seismic Demand

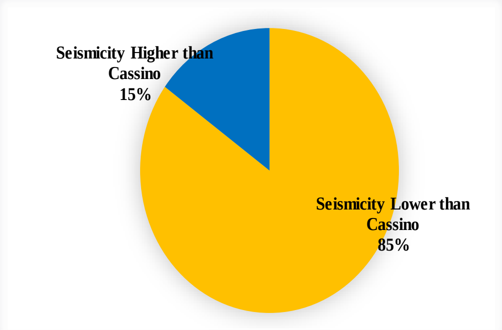




Italy



Europe



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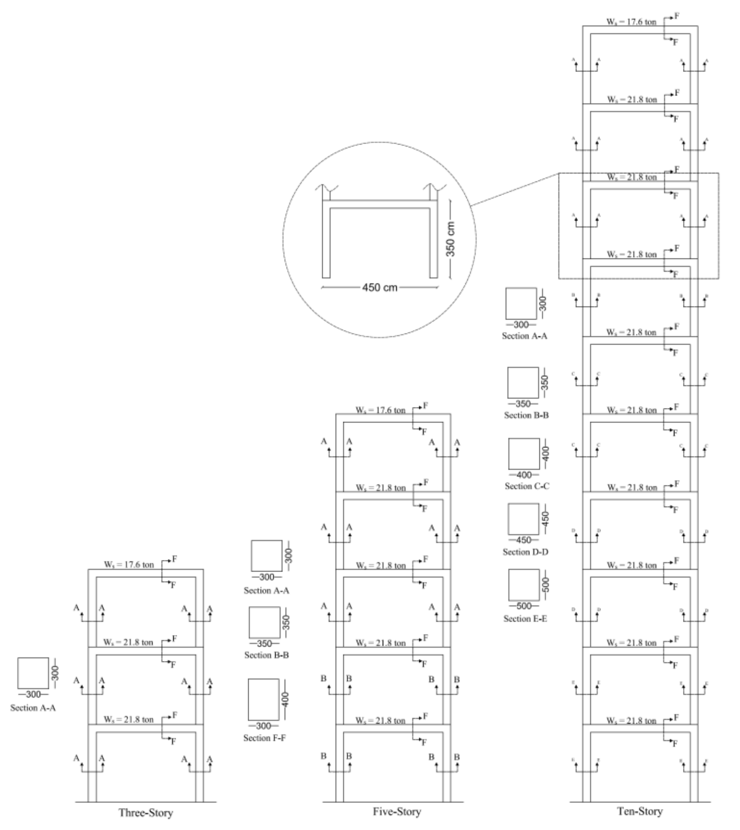
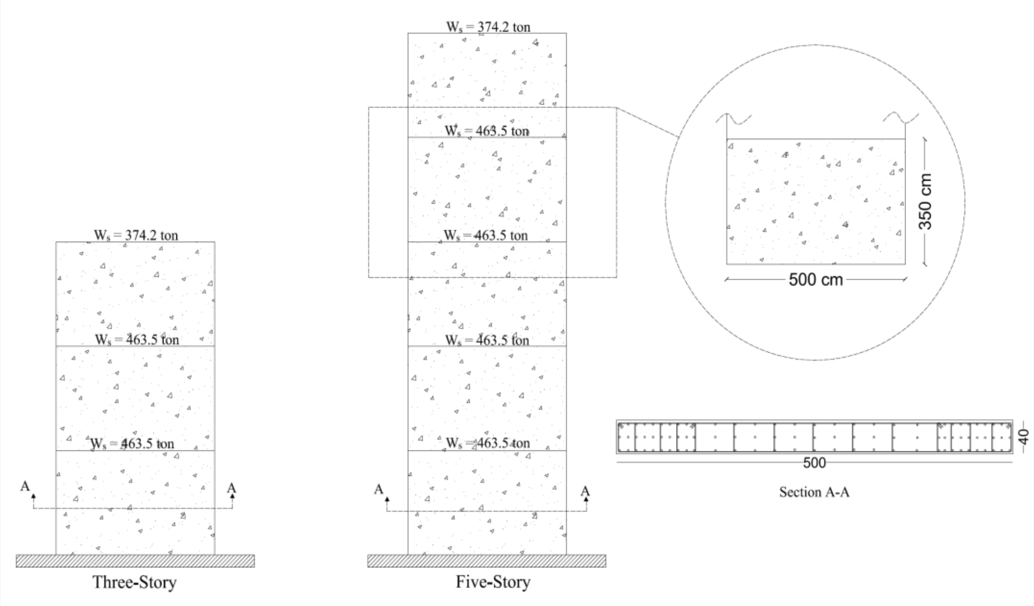
Establish Seismic Demand





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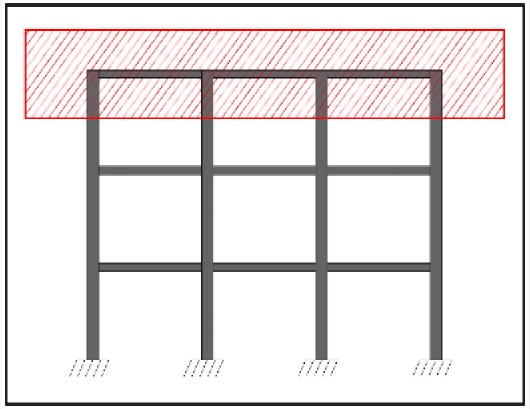
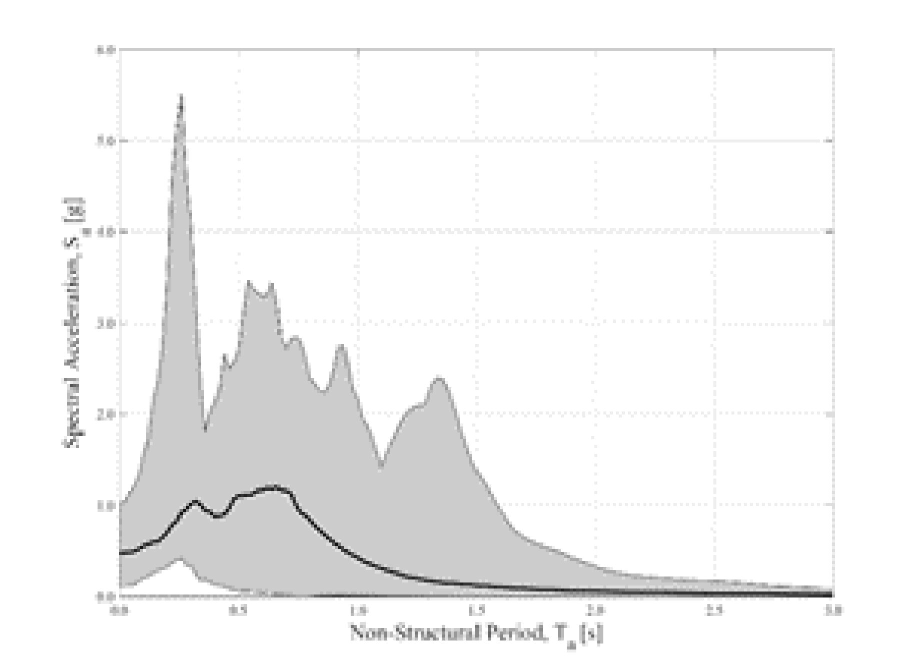
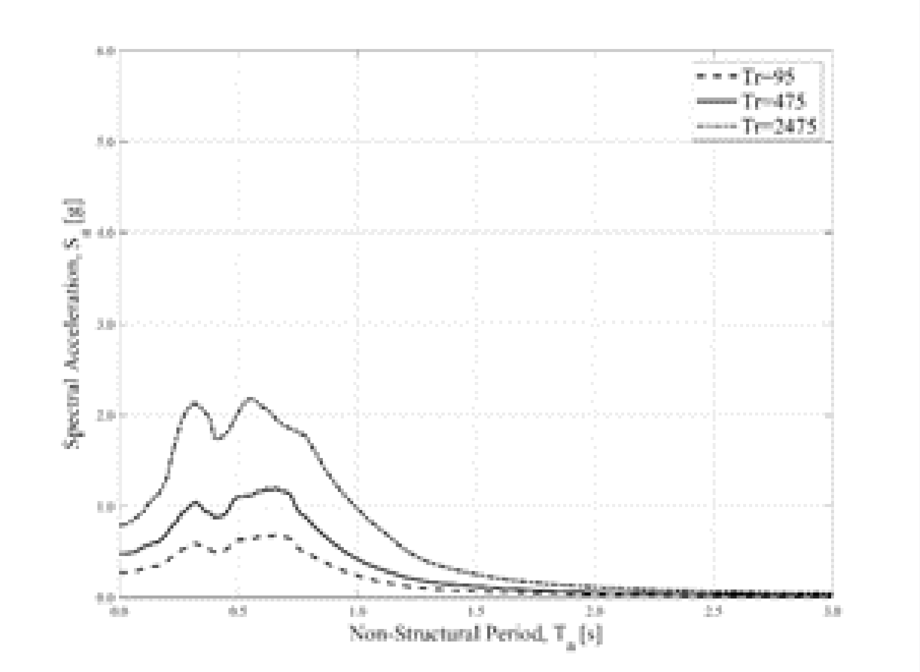
Establish Seismic Demand







ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

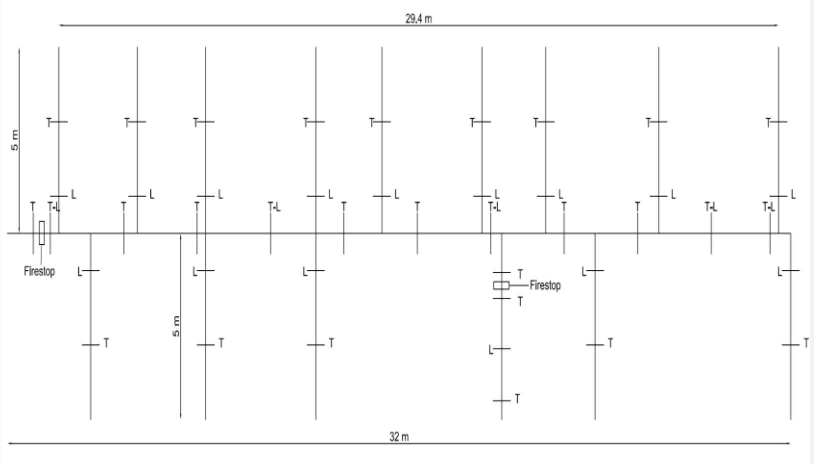
Characterize Behavior

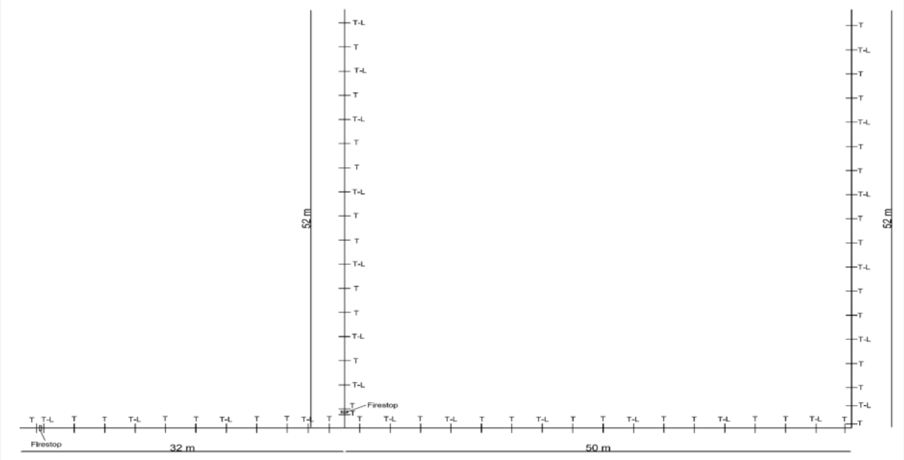
↓

Define Archetype representative of the design space

↓

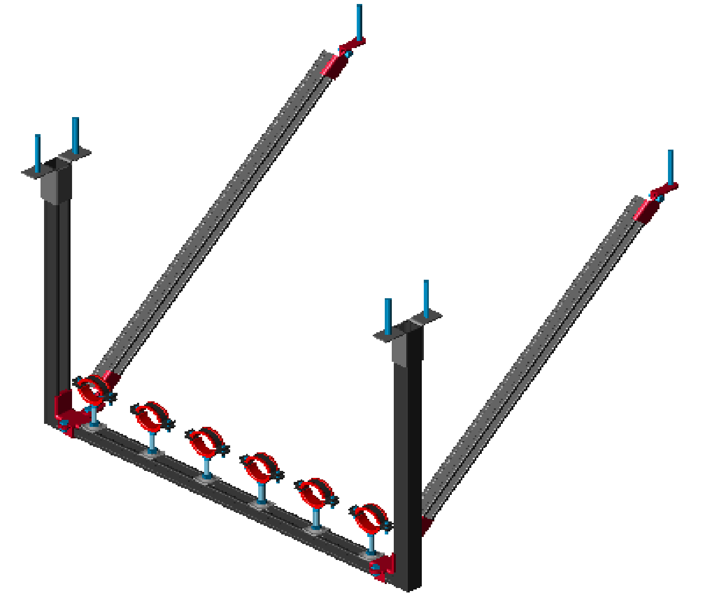
1. Geometrical configuration



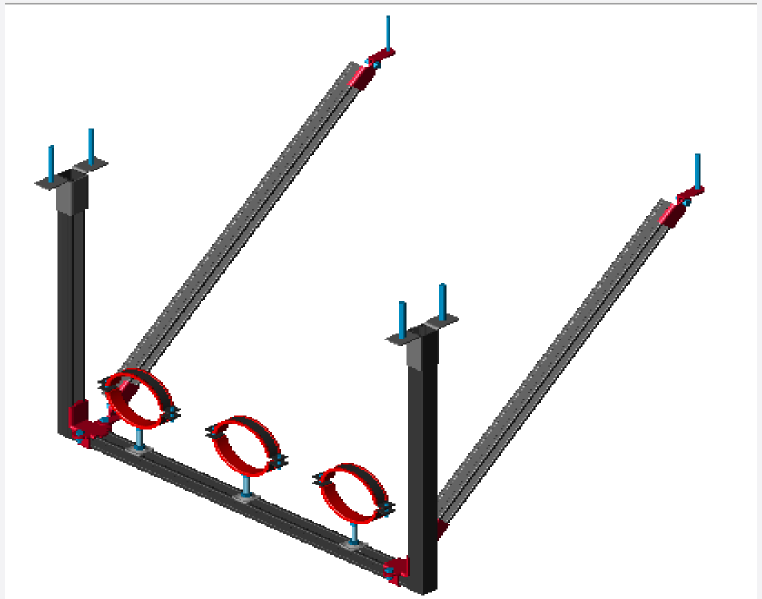


ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

- Characterize Behavior
- ↓
- Define Archetype representative of the design space
- ↓
- 2. Number of pipes and material



Six composite Mepla pipes with a diameter equal to 50 mm



Three steel pipes with a diameter equal to 127 mm

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Characterize Behavior

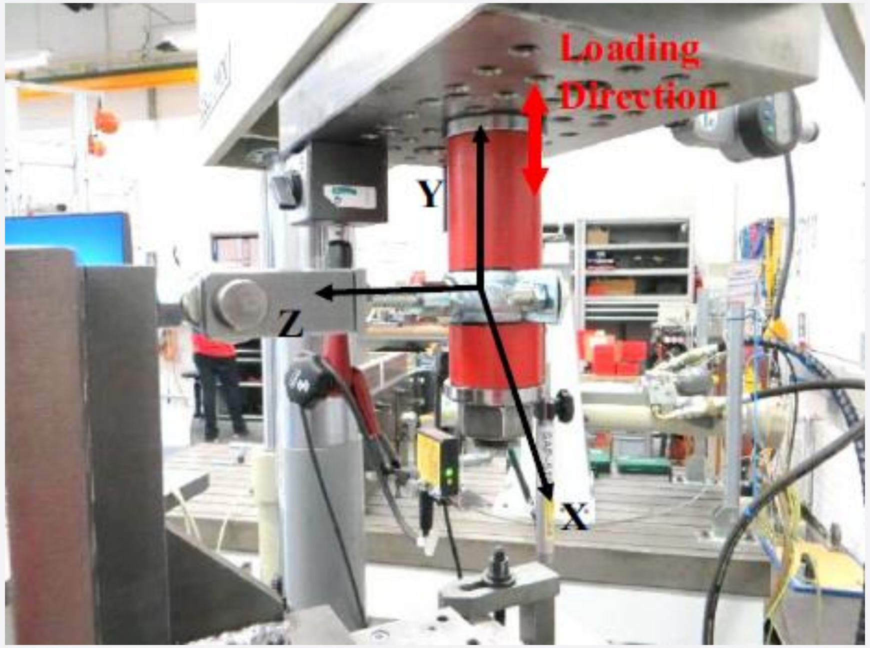
↓

Define Archetype representative of the design space

↓

3. Pipe ring typology

Stiff pipe ring



Soft pipe ring

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Characterize Behavior

↓

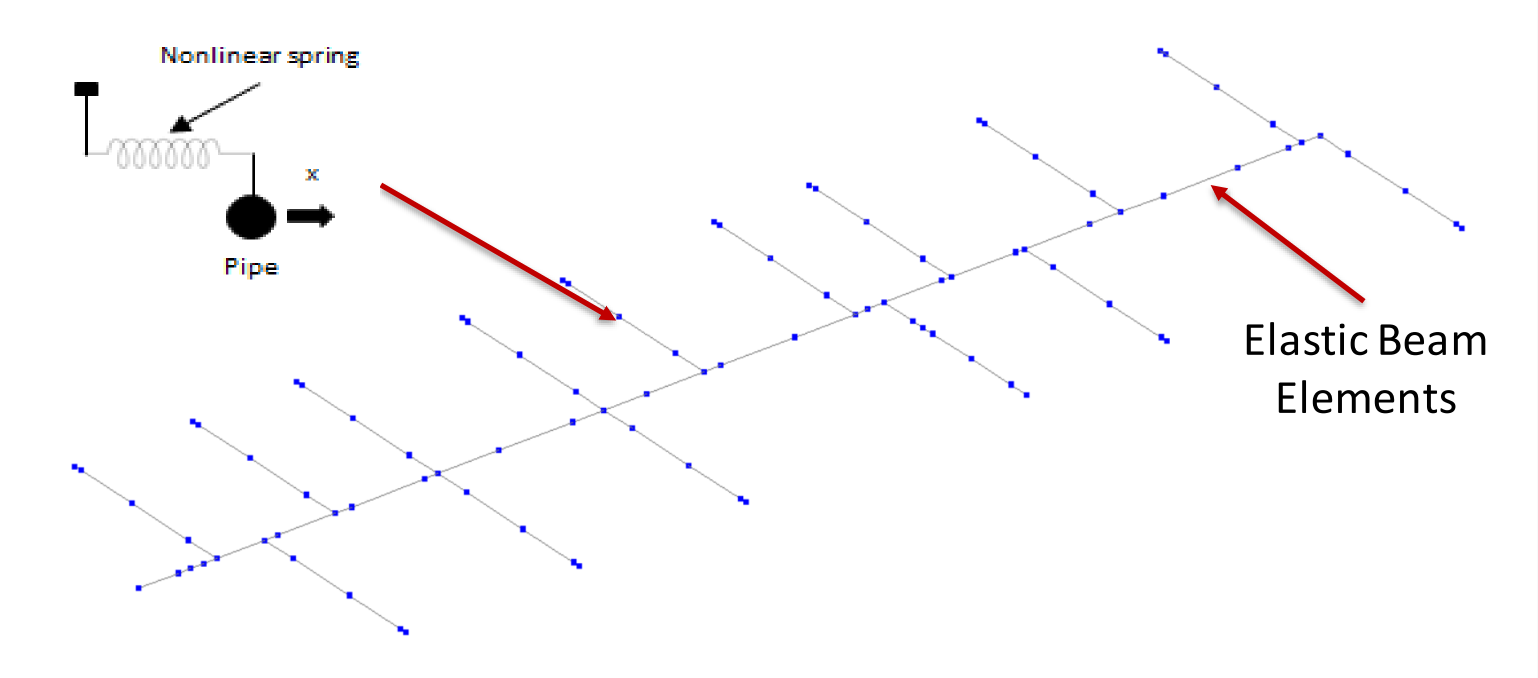
Define Archetype representative of the design space

Archetype ID	Geometry	Pipe material	Pipe diameter (mm)	Pipe ring typology	q_a
		Performance group PG-1			
1	W-B	Composite Mepla	50	Soft pipe ring	1
2	W-B	Composite Mepla	50	Soft pipe ring	2
3	W-B	Composite Mepla	50	Soft pipe ring	4
		Performance group PG-2			
4	W-B	Composite Mepla	50	Stiff pipe ring	1
5	W-B	Composite Mepla	50	Stiff pipe ring	2
6	W-B	Composite Mepla	50	Stiff pipe ring	4
		Performance group PG-3			
7	W-B	Steel pipe	127	Soft pipe ring	1
8	W-B	Steel pipe	127	Soft pipe ring	2
9	W-B	Steel pipe	127	Soft pipe ring	4
		Performance group PG-4			
10	W-B	Steel pipe	127	Stiff pipe ring	1
11	W-B	Steel pipe	127	Stiff pipe ring	2
12	W-B	Steel pipe	127	Stiff pipe ring	4
		Performance group PG-5			
13	WO-B	Composite Mepla	50	Soft pipe ring	1
14	WO-B	Composite Mepla	50	Soft pipe ring	2
15	WO-B	Composite Mepla	50	Soft pipe ring	4
		Performance group PG-6			
16	WO-B	Composite Mepla	50	Stiff pipe ring	1
17	WO-B	Composite Mepla	50	Stiff pipe ring	2
18	WO-B	Composite Mepla	50	Stiff pipe ring	4
		Performance group PG-7			
19	WO-B	Steel pipe	127	Soft pipe ring	1
20	WO-B	Steel pipe	127	Soft pipe ring	2
21	WO-B	Steel pipe	127	Soft pipe ring	4
		Performance group PG-8			
22	WO-B	Steel pipe	127	Stiff pipe ring	1
23	WO-B	Steel pipe	127	Stiff pipe ring	2
24	WO-B	Steel pipe	127	Stiff pipe ring	4

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Develop Models

OpenSees



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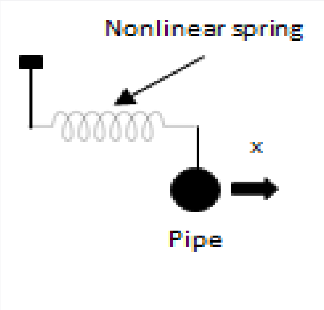
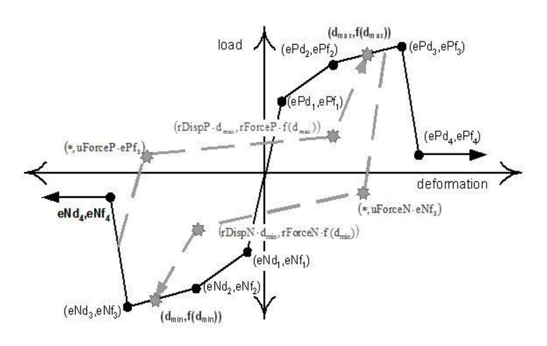
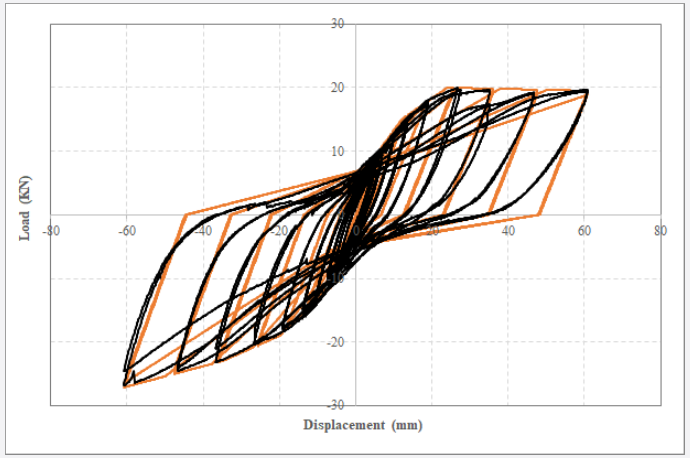
Develop Models

OpenSees







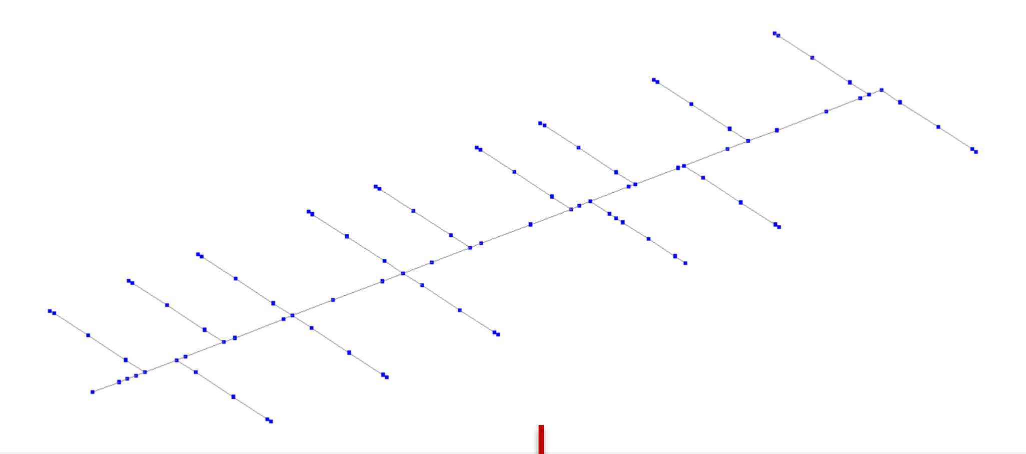
Numerical Approach

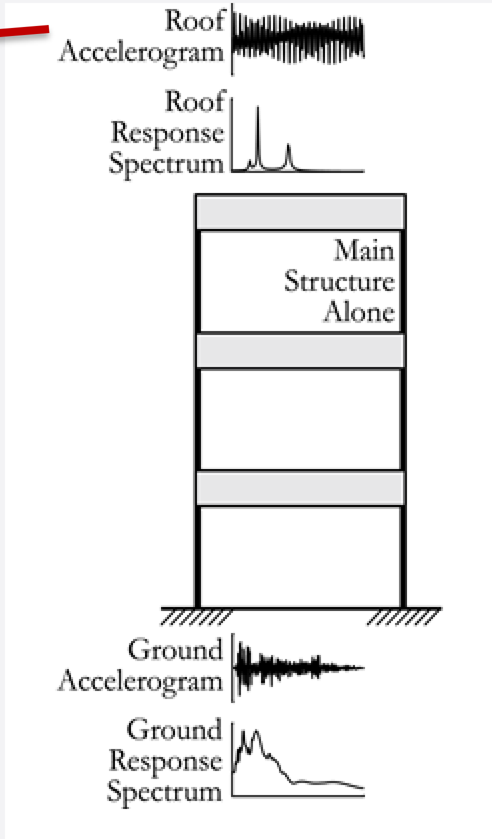
Tool:
Pinching4Material
OpenSees

Numerical VS Experimental

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Analyze Models





ENGINEERING DEMAND PARAMETERS: DUCTILITY DEMAND

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Analyze Models

ENGINEERING DEMAND PARAMETERS:
DUCTILITY DEMAND

Archetype ID	q_a	Ductility demand											
		T_r = 95 years				T_r = 475 years				T_r = 2475 years			
		Transverse		Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal	
		m	m+ s	m	m+ s	m	m+ s	m	m+ s	m	m+ s	m	m+ s
Performance group PG-1													
1	1	0.49	0.55	0.21	0.29	0.63	0.85	0.30	0.47	0.80	1.27	0.39	0.61
2	2	0.49	0.55	0.21	0.29	0.63	0.85	0.30	0.47	0.80	1.27	0.39	0.61
3	4	0.49	0.55	0.21	0.29	0.63	0.85	0.30	0.47	0.80	1.27	0.39	0.61
Performance group PG-2													
4	1	0.48	0.55	0.22	0.30	0.64	0.84	0.32	0.51	0.79	1.26	0.43	0.74
5	2	0.48	0.55	0.22	0.30	0.64	0.84	0.32	0.51	0.79	1.26	0.43	0.74
6	4	0.48	0.55	0.22	0.30	0.64	0.84	0.32	0.51	0.79	1.26	0.43	0.74
Performance group PG-3													
7	1	0.33	0.42	0.17	0.25	0.40	0.70	0.24	0.40	0.76	1.15	0.44	0.64
8	2	0.34	0.49	0.18	0.30	0.51	0.86	0.26	0.53	0.84	1.10	0.50	0.64
9	4	0.40	0.54	0.24	0.33	0.51	0.86	0.32	0.58	0.91	1.00	0.54	0.79
Performance group PG-4													
10	1	0.34	0.45	0.18	0.26	0.51	0.81	0.30	0.48	0.76	1.10	0.45	0.67
11	2	0.37	0.49	0.20	0.26	0.55	0.86	0.30	0.52	0.84	1.24	0.53	0.72
12	4	0.41	0.57	0.24	0.34	0.52	0.92	0.33	0.59	0.90	1.33	0.54	0.77
Performance group PG-5													
13	1	0.47	0.71	0.15	0.25	0.62	0.90	0.28	0.44	0.84	1.26	0.45	0.67
14	2	0.47	0.71	0.15	0.25	0.62	0.90	0.28	0.44	0.84	1.26	0.45	0.67
15	4	0.47	0.71	0.15	0.25	0.62	0.90	0.28	0.44	0.84	1.26	0.45	0.67
Performance group PG-6													
16	1	0.47	0.61	0.17	0.27	0.64	0.96	0.30	0.50	0.77	1.24	0.49	0.71
17	2	0.47	0.61	0.17	0.27	0.64	0.96	0.30	0.50	0.77	1.24	0.49	0.71
18	4	0.47	0.61	0.17	0.27	0.64	0.96	0.30	0.50	0.77	1.24	0.49	0.71
Performance group PG-7													
19	1	0.40	0.53	0.16	0.26	0.56	1.05	0.27	0.52	1.02	1.30	0.46	0.71
20	2	0.35	0.75	0.14	0.42	0.56	1.45	0.36	0.73	1.16	1.51	0.68	0.90
21	4	0.48	0.87	0.22	0.57	0.79	2.24	0.40	1.11	1.59	2.68	1.02	1.26
Performance group PG-8													
22	1	0.42	0.59	0.17	0.30	0.60	1.12	0.30	0.55	0.91	1.45	0.52	0.77
23	2	0.44	0.63	0.22	0.36	0.58	1.53	0.28	0.97	1.12	1.57	0.70	0.92
24	4	0.48	0.87	0.24	0.60	0.84	1.75	0.42	1.11	1.76	2.20	1.16	1.39

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Evaluate Performance

↓

Define Performance Objectives

Performance groups	Sway braced trapeze performance parameters				
	Bracing direction	Q_M (kN)	$\Delta_{Y,eff}$ (mm)	Δ_U (mm)	μ_{eff}
PG1 and PG5	Longitudinal	14.81	34.78	176.33	5.1
	Transverse	6.96	19.97	25.95	1.3
PG2 and PG6	Longitudinal	14.81	31.28	80.28	2.6
	Transverse	6.96	20.21	26.70	1.3
PG3 and PG7	Longitudinal	15.56	36.60	170.30	4.7
	Transverse	6.96	21.79	67.60	3.1
PG4 and PG8	Longitudinal	15.56	34.00	80.00	2.4
	Transverse	6.96	20.11	47.91	2.4

ACHIEVEMENT OF PERFORMANCE OBJECTIVES

DAMAGE LIMITATION PERFORMANCE OBJECTIVE: EFFECTIVE DUCTILITY CAPACITY (μ_{eff})=1.0

LIFE SAFETY PERFORMANCE OBJECTIVE: EFFECTIVE DUCTILITY CAPACITY (μ_{eff})=$\Delta_U/\Delta_{Y,eff}$

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Evaluate Performance

ALL ARCHETYPES PASS THE PERFORMANCE EVALUATION

For this case study, q_a = 4 is adequate for the forced-based seismic design of sway braced trapezes

Archetype ID	q_a	Pass/Fail criterion											
		T_r = 95 years				T_r = 475 years				T_r = 2475 years			
		Transverse		Longitudinal		Transverse		Longitudinal		Transverse		Longitudinal	
		$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion	$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion	$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion	$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion	$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion	$\frac{\mu+\sigma}{\mu_{eff}}$	Pass/Fail Criterion
Performance group PG-1													
1	1	0.55	Pass	0.29	Pass	0.66	Pass	0.09	Pass	0.98	Pass	0.12	Pass
2	2	0.55	Pass	0.29	Pass	0.66	Pass	0.09	Pass	0.98	Pass	0.12	Pass
3	4	0.55	Pass	0.29	Pass	0.66	Pass	0.09	Pass	0.98	Pass	0.12	Pass
Performance group PG-2													
4	1	0.55	Pass	0.30	Pass	0.65	Pass	0.20	Pass	0.97	Pass	0.29	Pass
5	2	0.55	Pass	0.30	Pass	0.65	Pass	0.20	Pass	0.97	Pass	0.29	Pass
6	4	0.55	Pass	0.30	Pass	0.65	Pass	0.20	Pass	0.97	Pass	0.29	Pass
Performance group PG-3													
7	1	0.42	Pass	0.25	Pass	0.22	Pass	0.08	Pass	0.37	Pass	0.14	Pass
8	2	0.49	Pass	0.30	Pass	0.28	Pass	0.11	Pass	0.35	Pass	0.14	Pass
9	4	0.54	Pass	0.33	Pass	0.28	Pass	0.12	Pass	0.32	Pass	0.14	Pass
Performance group PG-4													
10	1	0.45	Pass	0.26	Pass	0.34	Pass	0.20	Pass	0.46	Pass	0.28	Pass
11	2	0.49	Pass	0.26	Pass	0.36	Pass	0.22	Pass	0.52	Pass	0.30	Pass
12	4	0.57	Pass	0.34	Pass	0.38	Pass	0.25	Pass	0.55	Pass	0.32	Pass
Performance group PG-5													
13	1	0.71	Pass	0.25	Pass	0.69	Pass	0.09	Pass	0.97	Pass	0.13	Pass
14	2	0.71	Pass	0.25	Pass	0.69	Pass	0.09	Pass	0.97	Pass	0.13	Pass
15	4	0.71	Pass	0.25	Pass	0.69	Pass	0.09	Pass	0.97	Pass	0.13	Pass
Performance group PG-6													
16	1	0.61	Pass	0.27	Pass	0.74	Pass	0.19	Pass	0.95	Pass	0.27	Pass
17	2	0.61	Pass	0.27	Pass	0.74	Pass	0.19	Pass	0.95	Pass	0.27	Pass
18	4	0.61	Pass	0.27	Pass	0.74	Pass	0.19	Pass	0.95	Pass	0.27	Pass
Performance group PG-7													
19	1	0.53	Pass	0.26	Pass	0.34	Pass	0.11	Pass	0.42	Pass	0.15	Pass
20	2	0.75	Pass	0.42	Pass	0.47	Pass	0.15	Pass	0.49	Pass	0.19	Pass
21	4	0.87	Pass	0.57	Pass	0.72	Pass	0.24	Pass	0.87	Pass	0.27	Pass
Performance group PG-8													
22	1	0.59	Pass	0.30	Pass	0.47	Pass	0.23	Pass	0.60	Pass	0.32	Pass
23	2	0.63	Pass	0.36	Pass	0.64	Pass	0.40	Pass	0.65	Pass	0.38	Pass
24	4	0.87	Pass	0.60	Pass	0.73	Pass	0.46	Pass	0.92	Pass	0.58	Pass

ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Evaluate Performance

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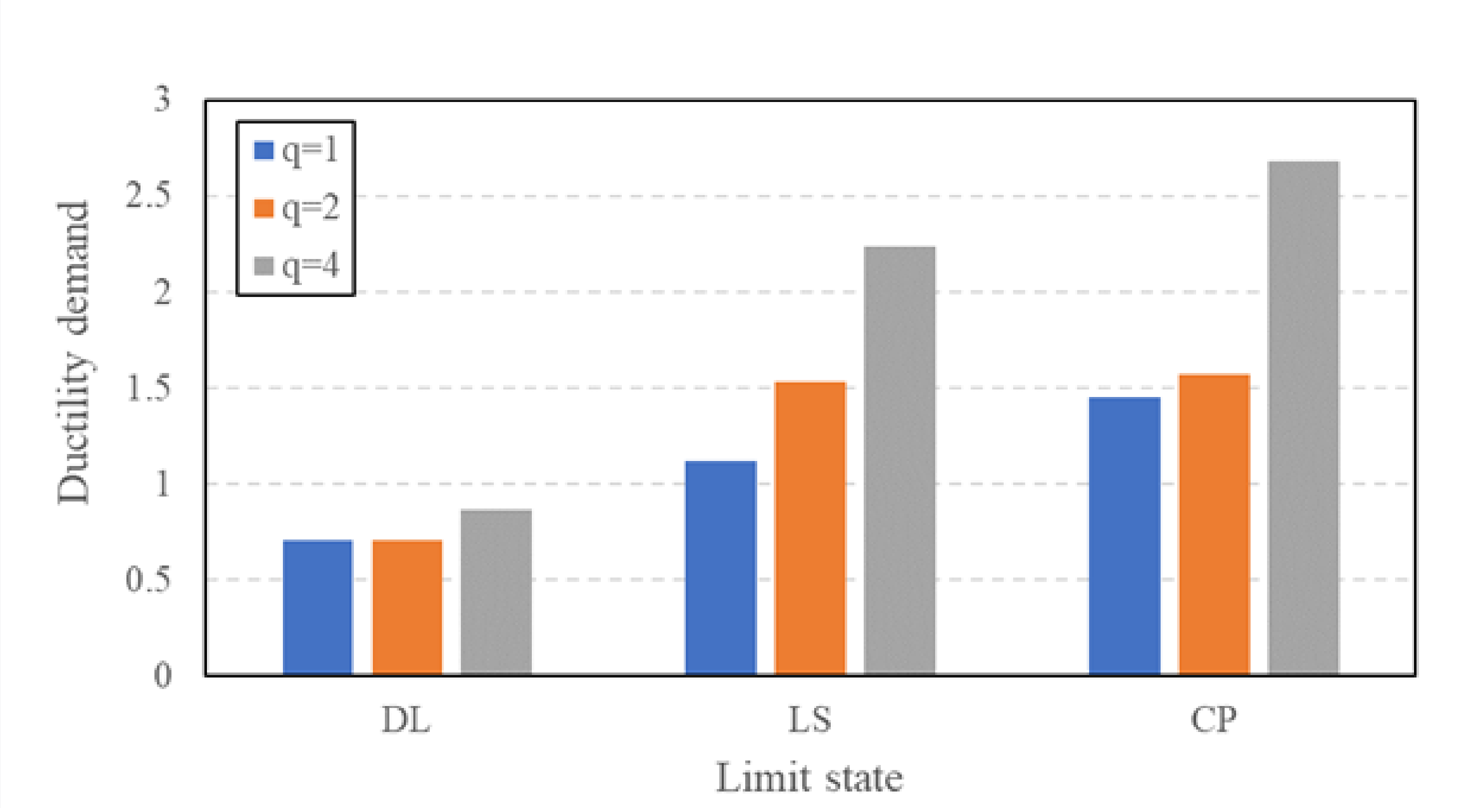
Calibration of q_a factor



ILLUSTRATIVE CASE STUDY EXAMPLE: QUANTIFICATION OF BEHAVIOR FACTOR FOR SUSPENDED PIPING SEISMIC RESTRAINT INSTALLATIONS

Document Results

In this last phase of the framework, the information on the behaviour of the analysed sway braced trapezes, the definition of the archetypes and their design, the development of the numerical models, the NLTHAs results, the performance objectives and the proposed design procedure should be summarized in a document to be submitted to a review panel.

CONCLUSIONS

1. Although significant efforts have been done in the last years to improve seismic performance of non-structural elements many efforts are still required to achieve the same level of knowledge available for structural systems.
2. A methodology for quantifying the seismic performance of non-structural elements has been proposed;
3. The methodology can be applied to many typologies of non-structural elements;
4. Few experimental/numerical data are available in the literature in order to apply the methodology, define performance objectives and improve design provisions.

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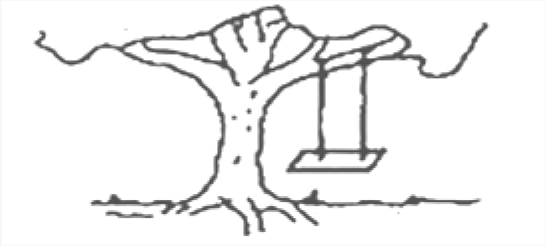

What the client wanted.

The architect's solution.

The structural engineer's solution.

The non-structural engineer's Solution.

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