IMPACT OF SPATIAL VARIABILITY OF STRENGTH AND STIFFNESS PROPERTIES ON THE SEISMIC BEHAVIOUR OF TIMBER-FRAME STRUCTURES

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Topics

Introduction

- How seismic design provisions influence the robustness of multi-storey timber buildings?

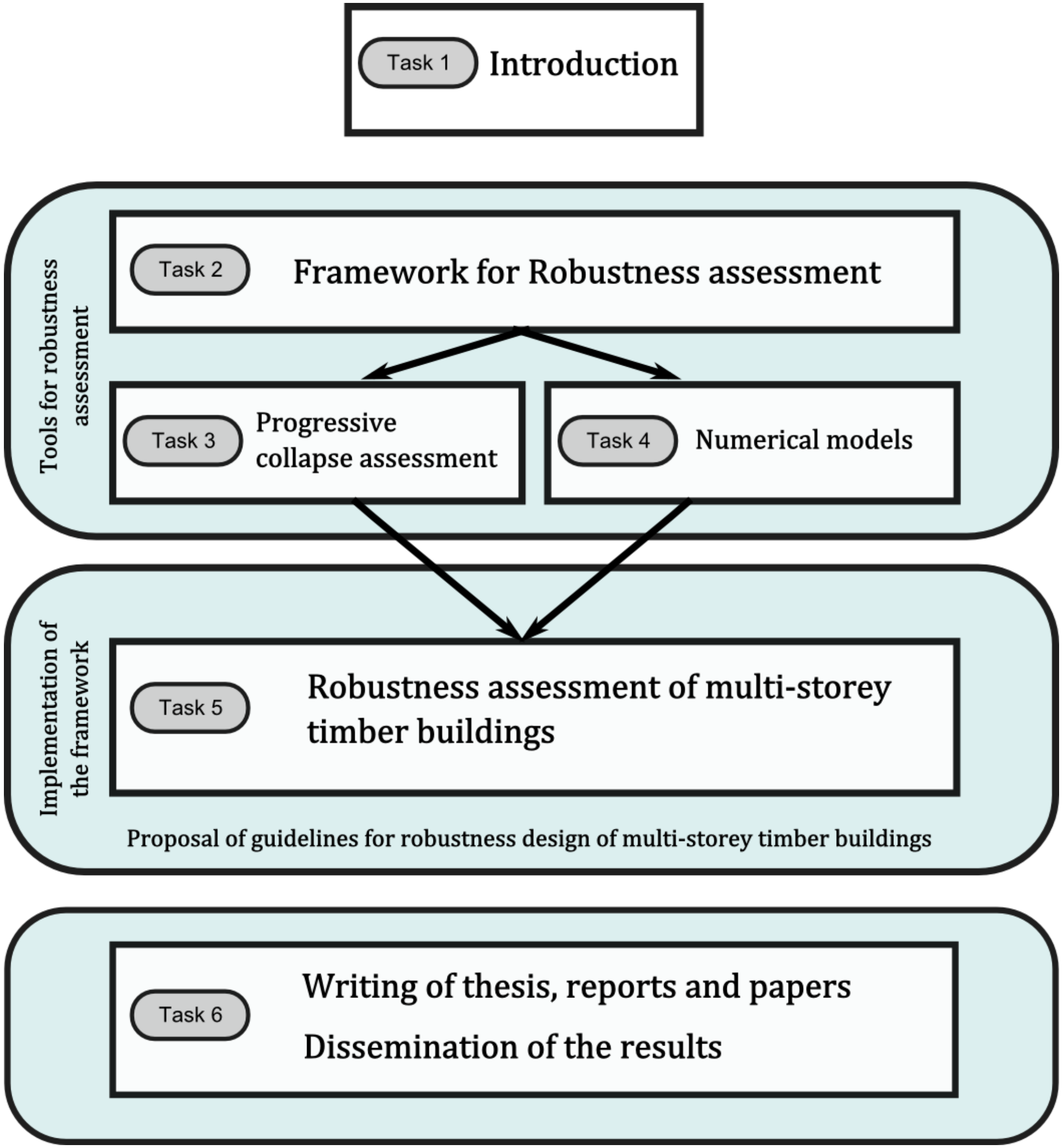
Seismic design provisions

- Simplicity;
- Uniformity;
- Symmetry;
- Redundancy;
- Bi-directional strength and stiffness;
- Torsional resistance and stiffness;
- Diaphragmatic behavior at the storey level;
- Adequate foundations;

Robustness design recommendations

- Alternate load paths;
- Effective horizontal ties;
- Vertical ties to ensure stability;
- Effective anchorage of suspended floors to walls;
- Ductility;
- Redundancy;
- Compartmentalization;

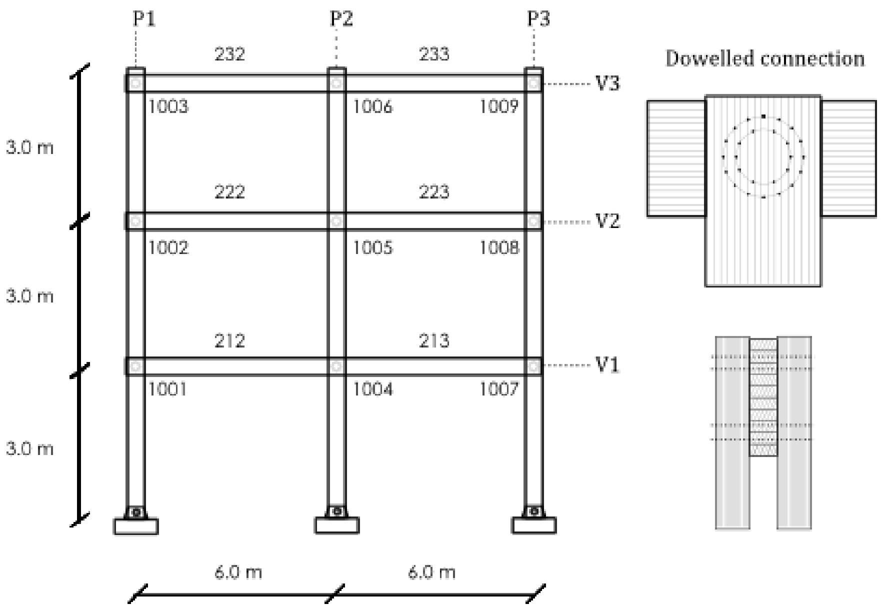
Introduction



Objectives

- Evaluate the impact of epistemic and aleatory uncertainties on the seismic behavior
- Evaluate the fragility of timber structures, explicitly considering uncertainty in both demand and capacity (critical in timber)
- Assess the seismic response of structures through Multi-Record Incremental Dynamic Analysis
- Evaluate probabilities of damage through fragility functions

Numerical model



Timber elements - Linear elastic

- Continuous beams and columns

Material nonlinearities (connections)

- Zero-length elements
- Pinching4 model (hysteretic with pinching)

Geometric nonlinearities

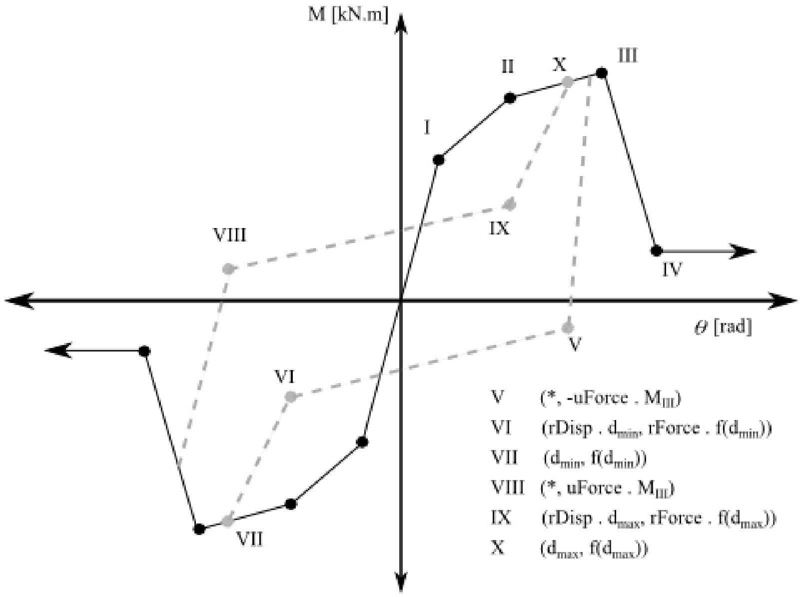
- P-Delta effects
- Corotational transformation

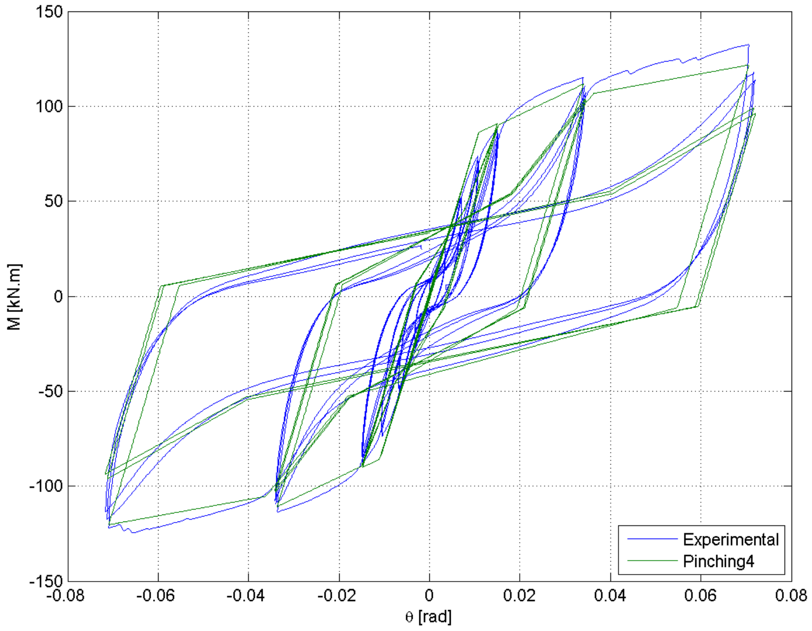
Design:

The structure under study was designed through a spectral analysis to fulfil the requirements of Eurocode 8 (EC8).

Numerical model

Moment – resisting joints (cyclic behavior)



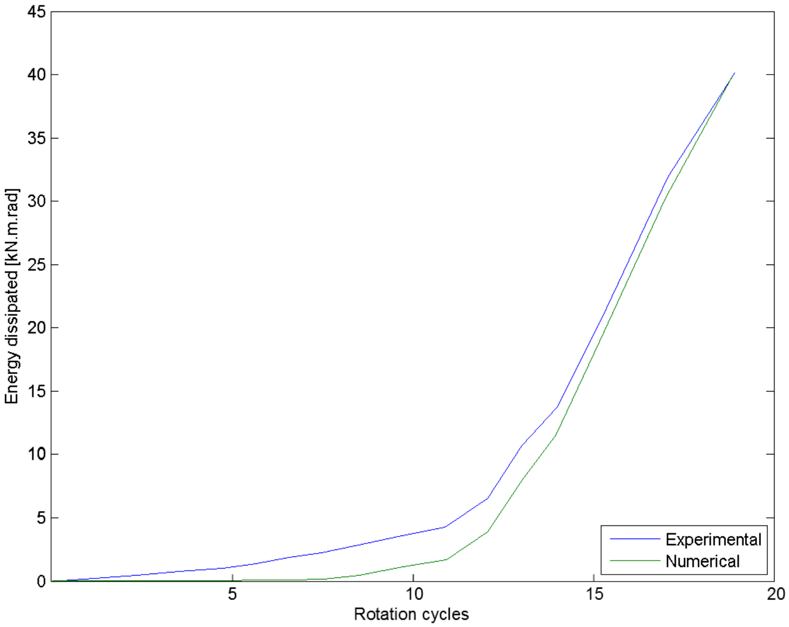


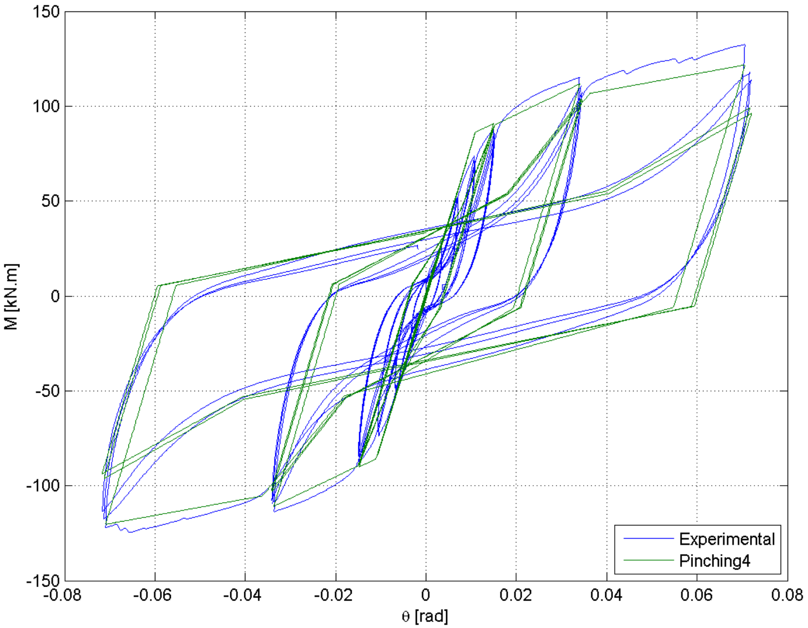
Calibration:

Approximate the computational model to the experimental results in terms of maximum strength and dissipated energy per cycle.

Numerical model

Moment – resisting joints (cyclic behavior)





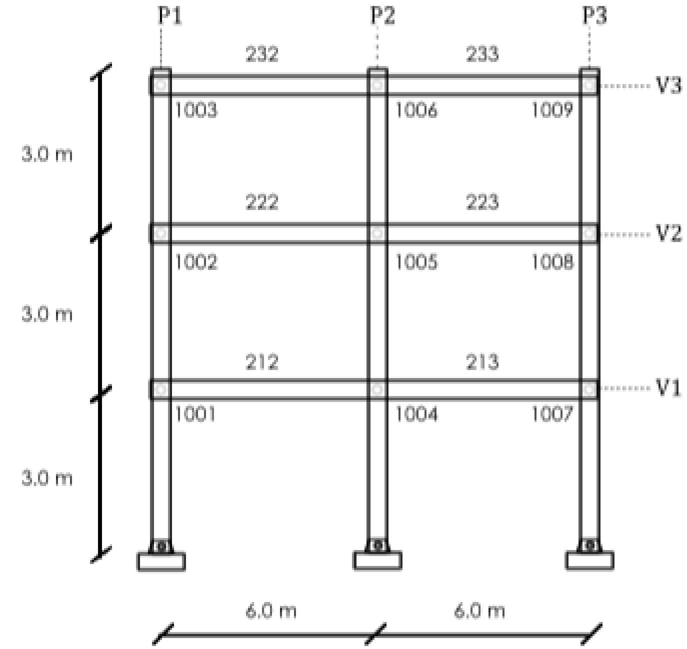
Cycling degradation of strength and stiffness:

i) unloading stiffness degradation

ii) reloading stiffness degradation

iii) strength degradation.

Probabilistic framework



Timber elements

Reference material properties (PMC)

Properties	Dist.	X_k	$COV[X]$	$E[X]$
R_m	LN	*24*	*0.15*	*31*
E_m	LN	*9600*	*0.13*	*11.5*
ρ_{den}	N	*385*	*0.1*	*420*

Other material properties (PMC)

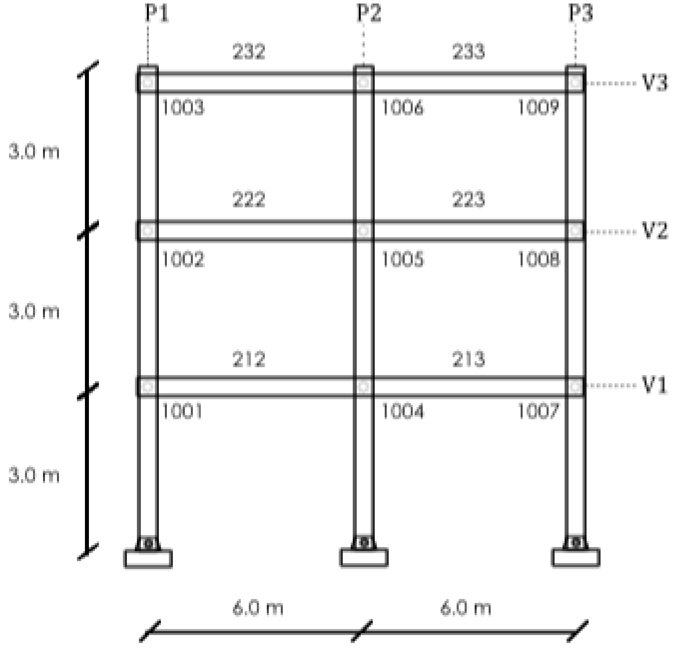
Properties	Dist.	$COV[X]$	$E[X]$
$R_{t,0}$	LN	$1.2\ COV[R_m]$	$0.6E[R_m]$
$R_{c,0}$	LN	$0.8\ COV[R_m]$	$5E[R_m]^{0.45}$
G_v	LN	$COV[E_m]$	$E[E_m]/16$
R_v	LN	$COV[R_m]$	$0.2E[R_m]^{0.8}$

Intra-element correlation coefficient matrix

	E_m	ρ_{den}	$R_{t,0}$	$R_{c,0}$	G_v	R_v
R_m	*0.8*	*0.6*	*0.8*	*0.8*	*0.4*	*0.4*
E_m	*1*	*0.6*	*0.6*	*0.6*	*0.6*	*0.4*
ρ_{den}		*1*	*0.4*	*0.8*	*0.6*	*0.6*
$R_{t,0}$			*1*	*0.5*	*0.4*	*0.6*
$R_{c,0}$				*1*	*0.4*	*0.4*
G_v					*1*	*0.6*

Probabilistic framework

Timber elements



Inter-element correlation coefficient matrix

	V1	*V2*	*V3*	*P1*	*P2*	*P3*
V1	*1.0*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
V2		*1*	*0.8*	*0.8*	*0.8*	*0.8*
V3			*1*	*0.8*	*0.8*	*0.8*
P1				*1*	*0.8*	*0.8*
P2					*1*	*0.8*
P3						*1*

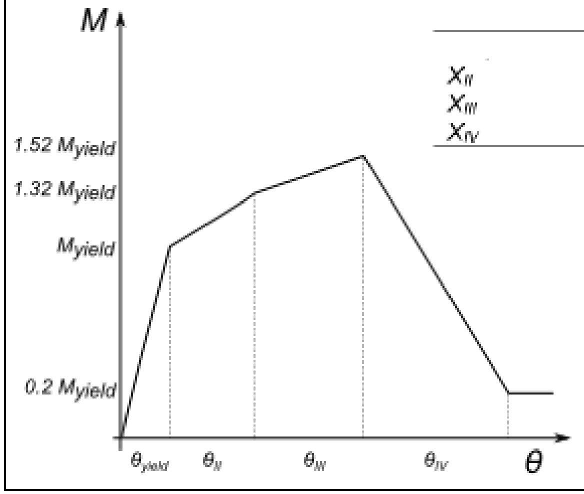
High correlation coefficients

- manufacturing process of wood engineering products
- elements with similar lengths

Probabilistic framework

Moment – resisting joints (backbone)

Each connection has its own properties resulting on a spatial variability

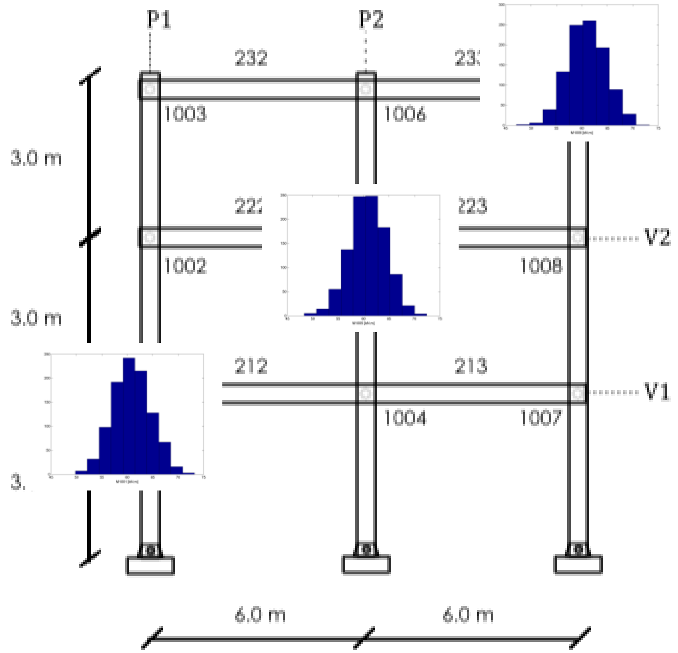


	Dist.	COV[X]	E[X]
X_{II}	LN	0.4	2
X_{III}	LN	0.4	3
X_{IV}	LN	0.4	5

$$\theta_{II} = \theta_{yield} + X_{II}\theta_{yield}$$

$$\theta_{III} = \theta_{II} + X_{III}\theta_{yield}$$

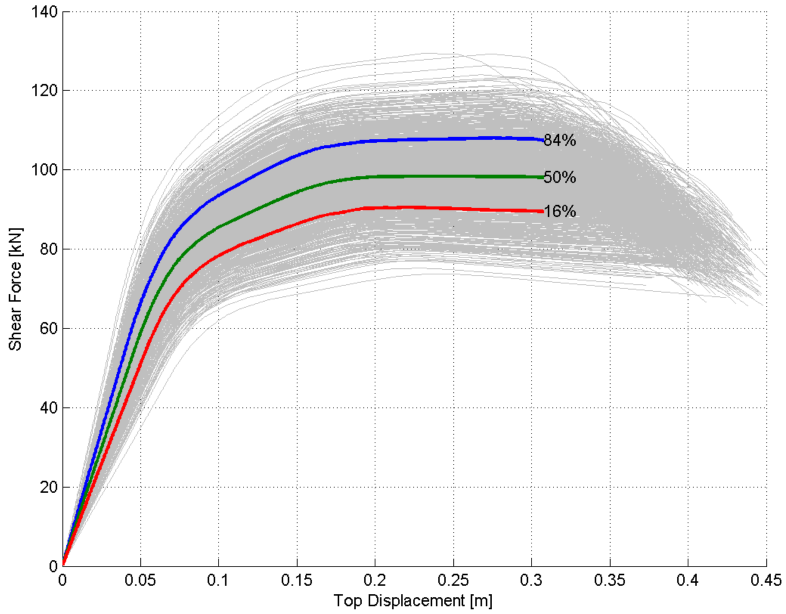
$$\theta_{IV} = \theta_{III} + X_{IV}\theta_{yield}$$



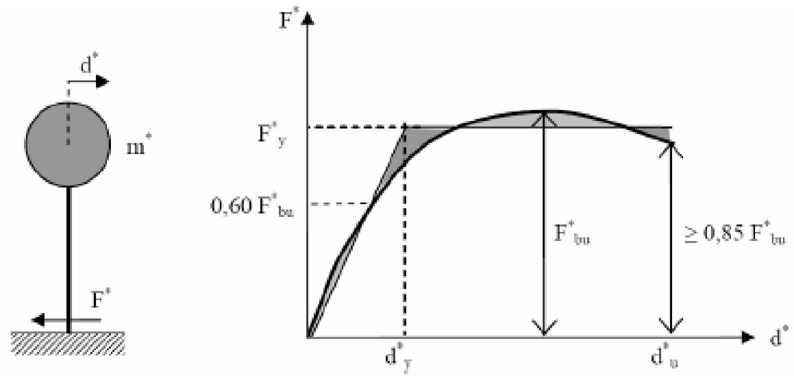
Pushover analysis

Lateral load distribution is in agreement with the configuration of the first vibration mode.

$$\{p_i\} = \{M\}\{\phi_i\}$$



Equivalent SDOF with bilinear inelastic behaviour



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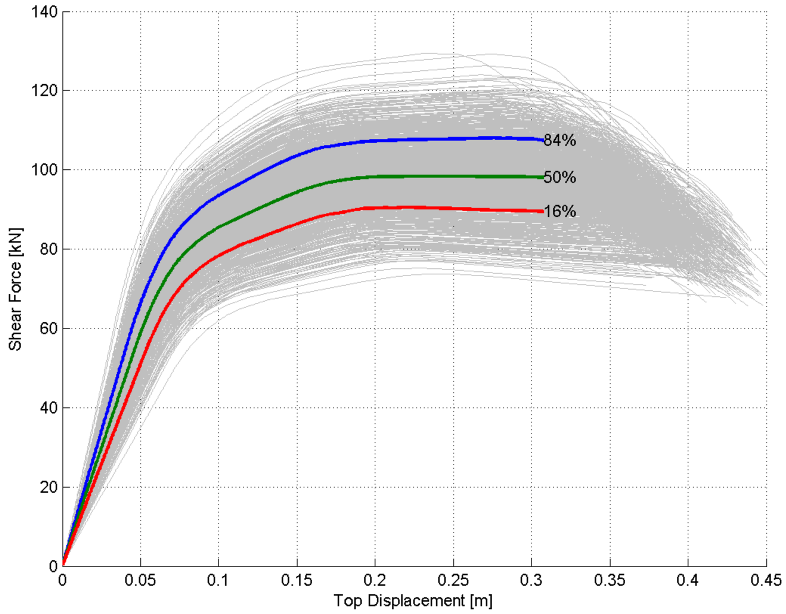
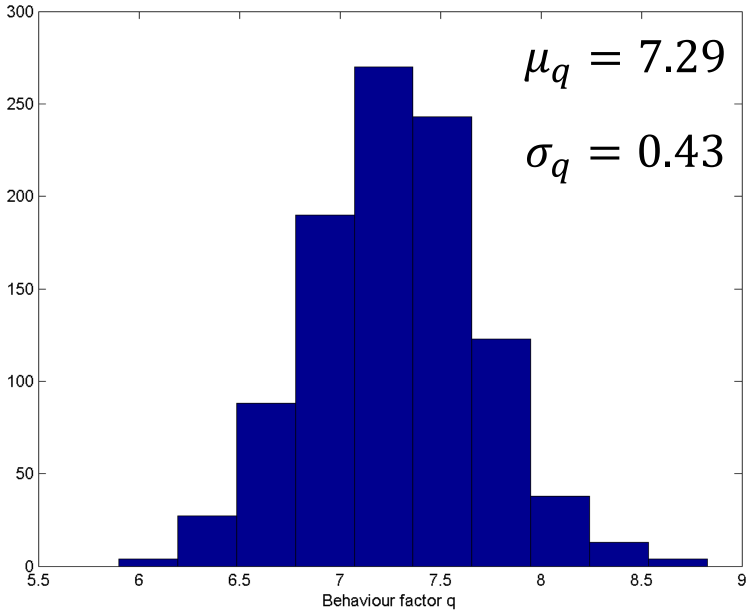




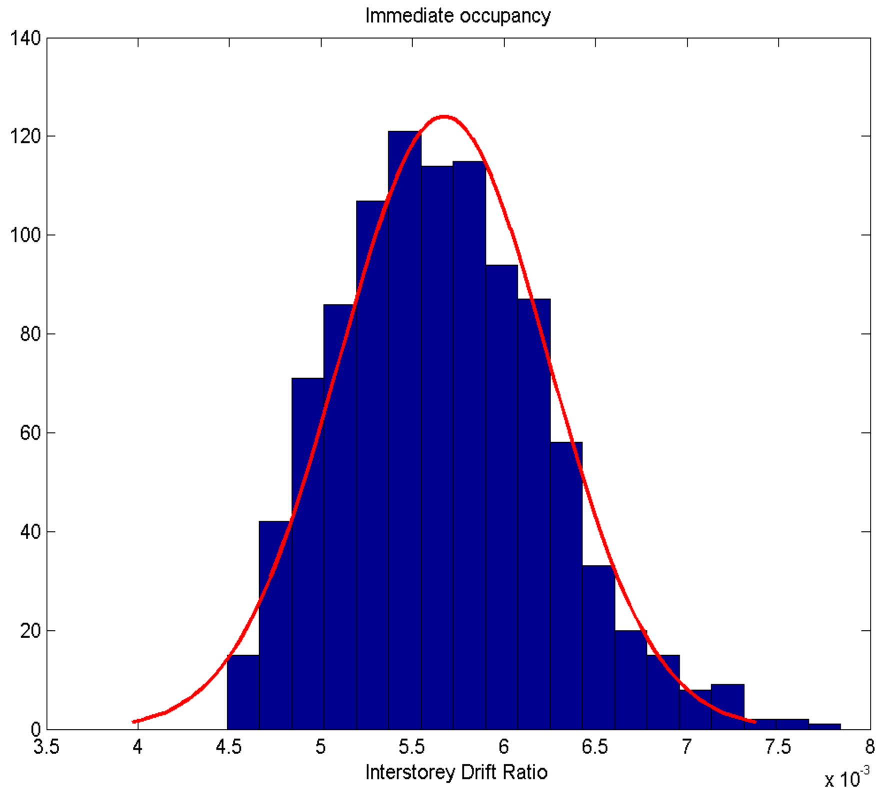
EC8 : *q = 4.0*

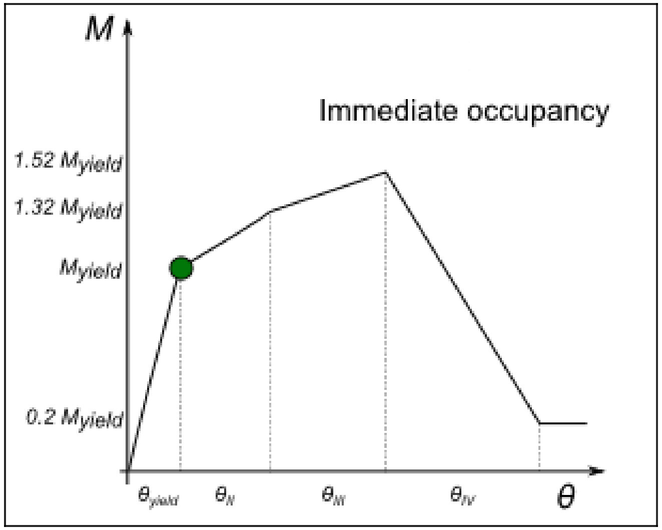
Characteristic value : *q = 6.6*

Pushover analysis

Useful information for Incremental Dynamic Analysis:

- Inter-storey drift ratios for the limit states considered





Immediate occupancy (LN)

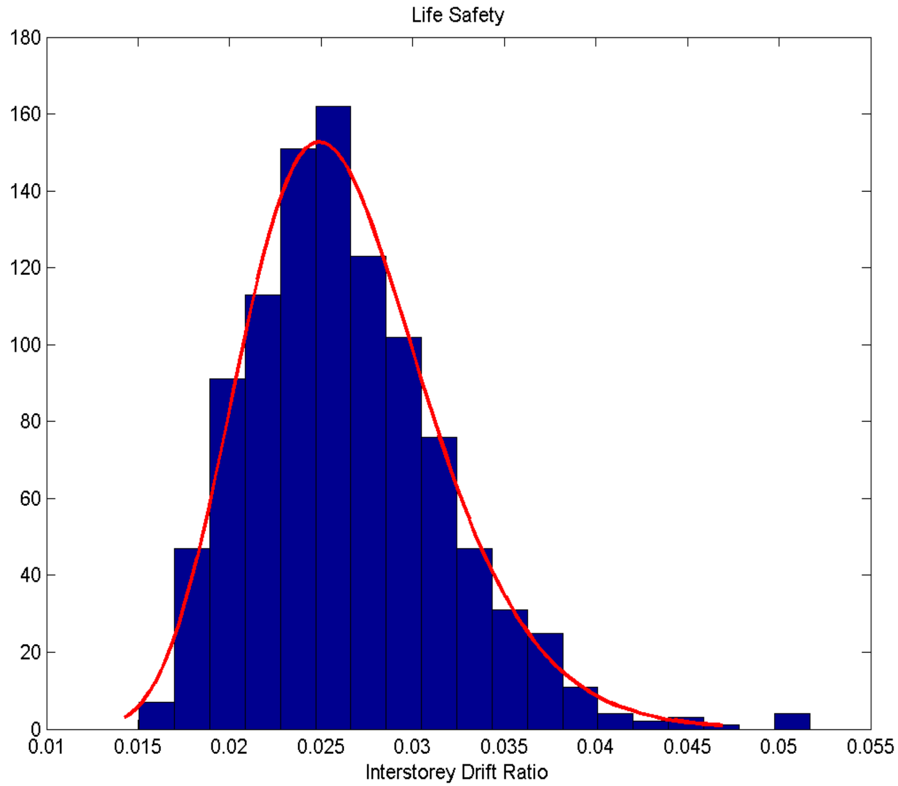
Median	Cov
0.0057	10%

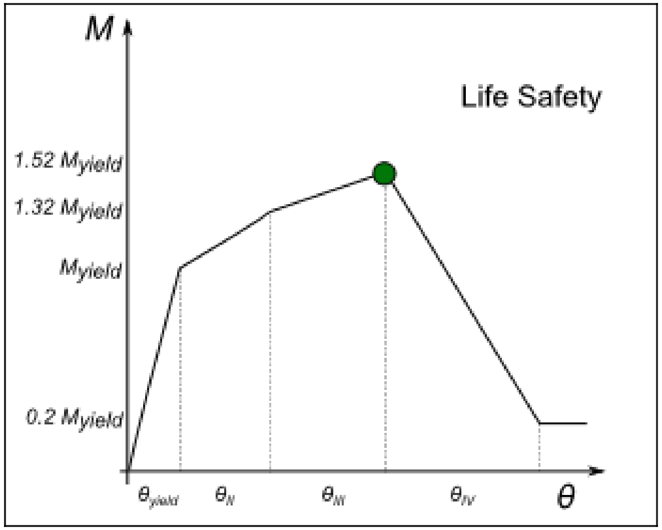
16%	84%
0.0051	0.0062

Pushover analysis

Useful information for Incremental Dynamic Analysis:

- Inter-storey drift ratios for limit states considered





Life Safety (LN)

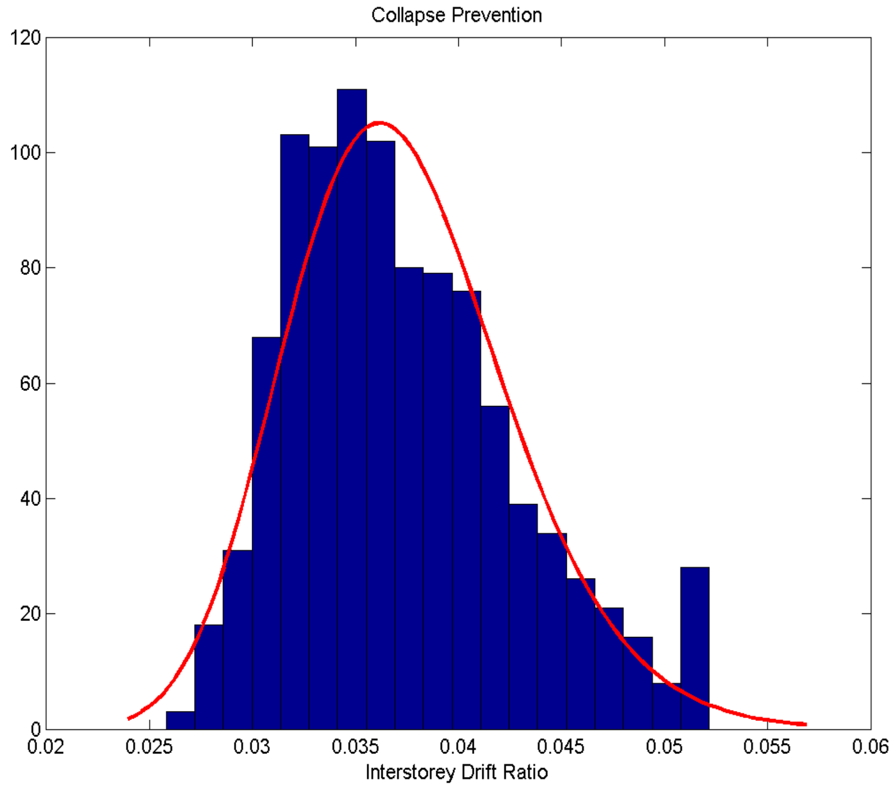
Median	Cov
0.0257	20%

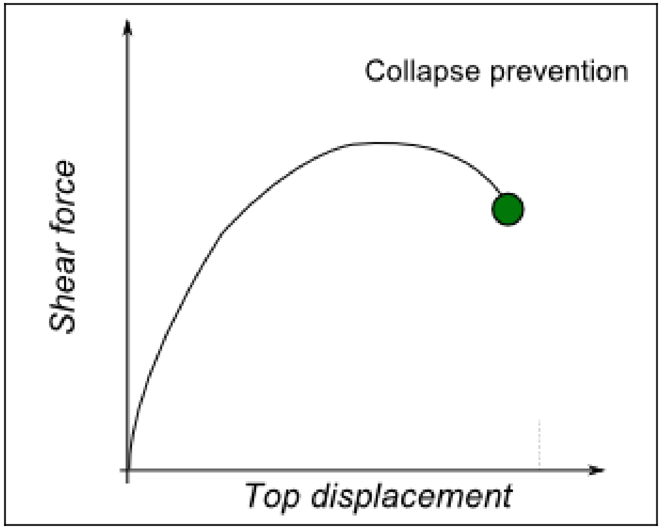
16%	84%
0.0212	0.0315

Pushover analysis

Useful information for Incremental Dynamic Analysis:

- Inter-storey drift ratios for limit states considered





Collapse prevention (LN)

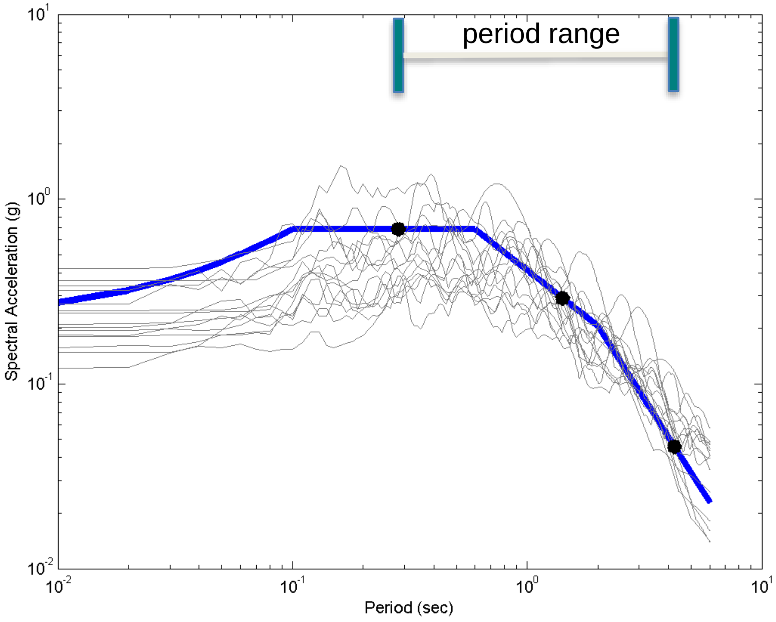
Median	Cov
0.0365	15%

16%	84%
0.0320	0.0428

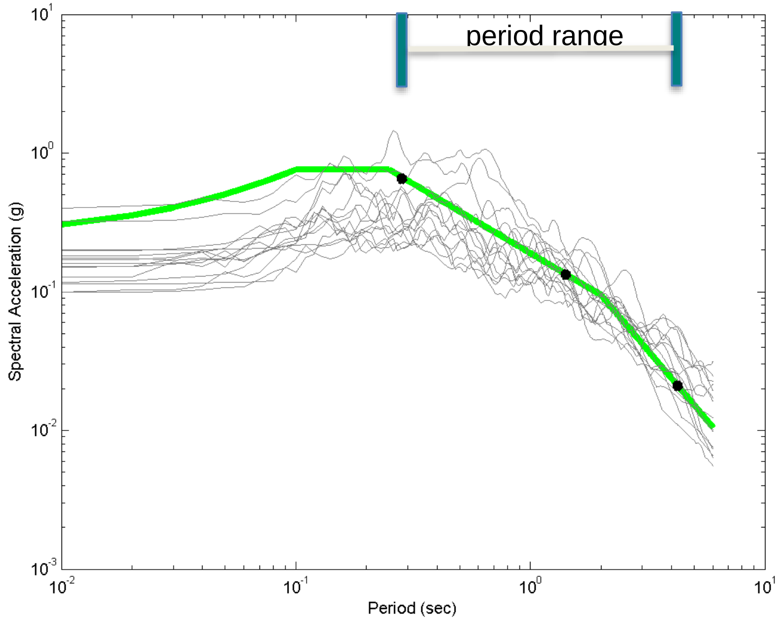
Multi-Record Incremental Dynamic Analysis

- Plot recorded damage measurements (inter-storey drift) versus an intensity measure ("first-mode" spectral acceleration)
- Includes record-to-record variability (aleatory uncertainties)
- 30 records resulting in 15 scaled accelerograms used for each design spectrum of Lisbon
- A period range from $0.2T_{1,median}$ to $3T_{1,median}$ was chosen to scale

$$T_{median} = 1.42s$$



Design response spectrum (Type1)

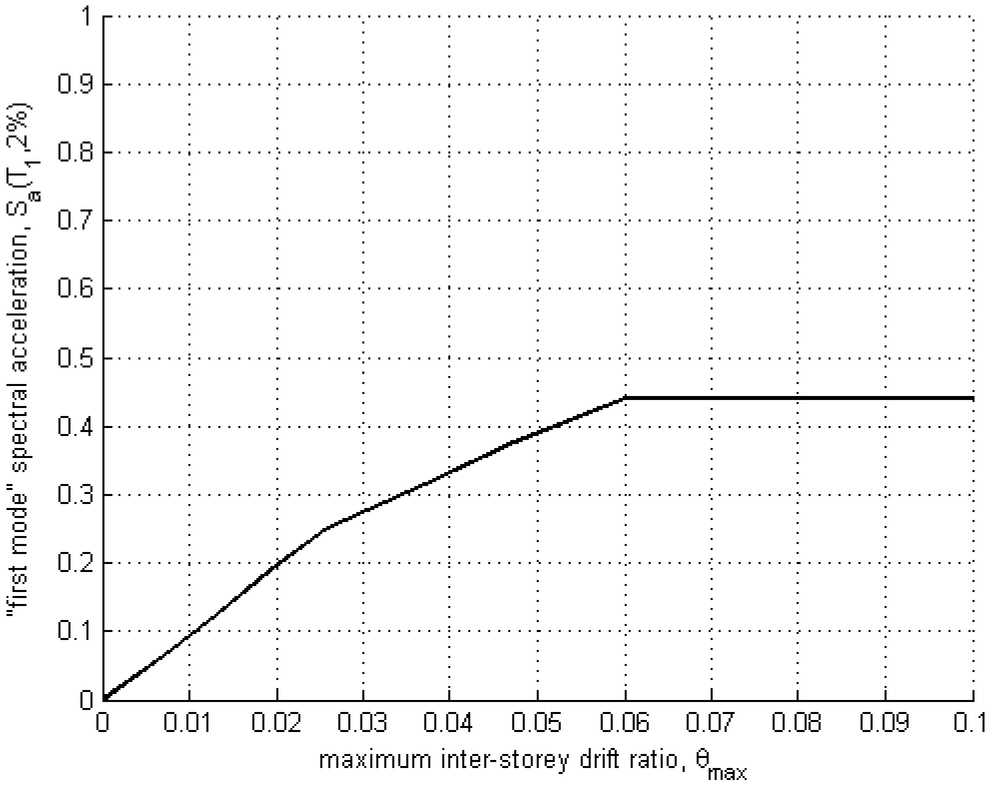


Design response spectrum (Type2)

Multi-Record Incremental Dynamic Analysis

3-storey timber frame subjected to four different records

- **A softening case**
- Local hardening
- Severe hardening
- Weaving behavior



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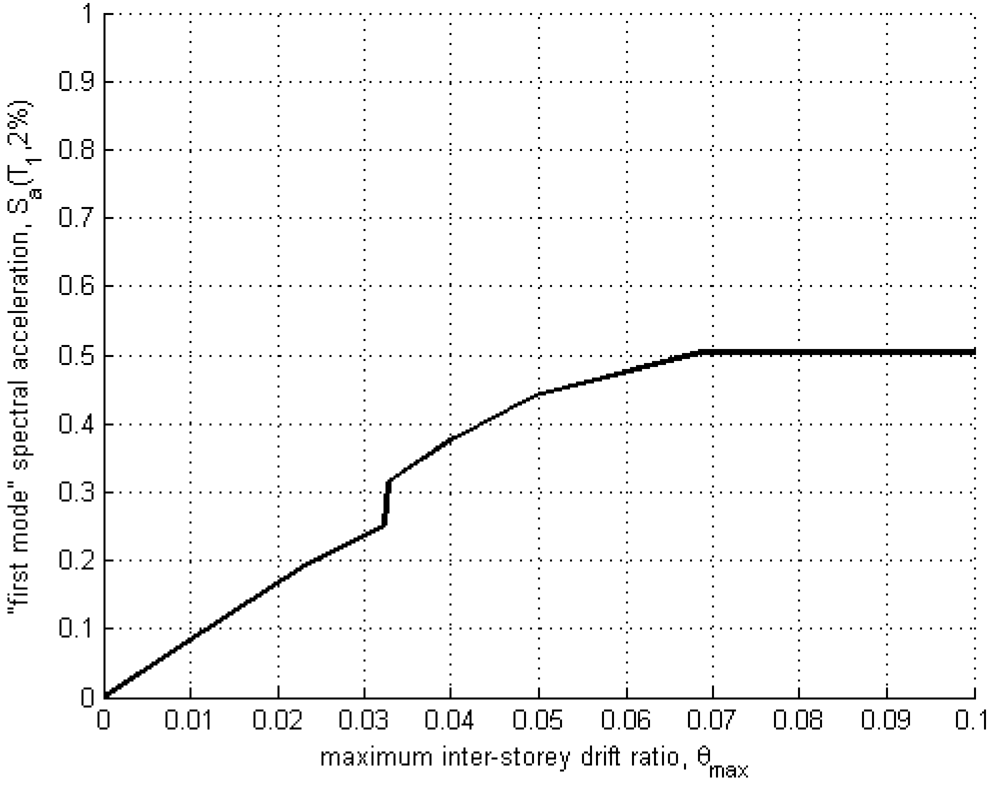

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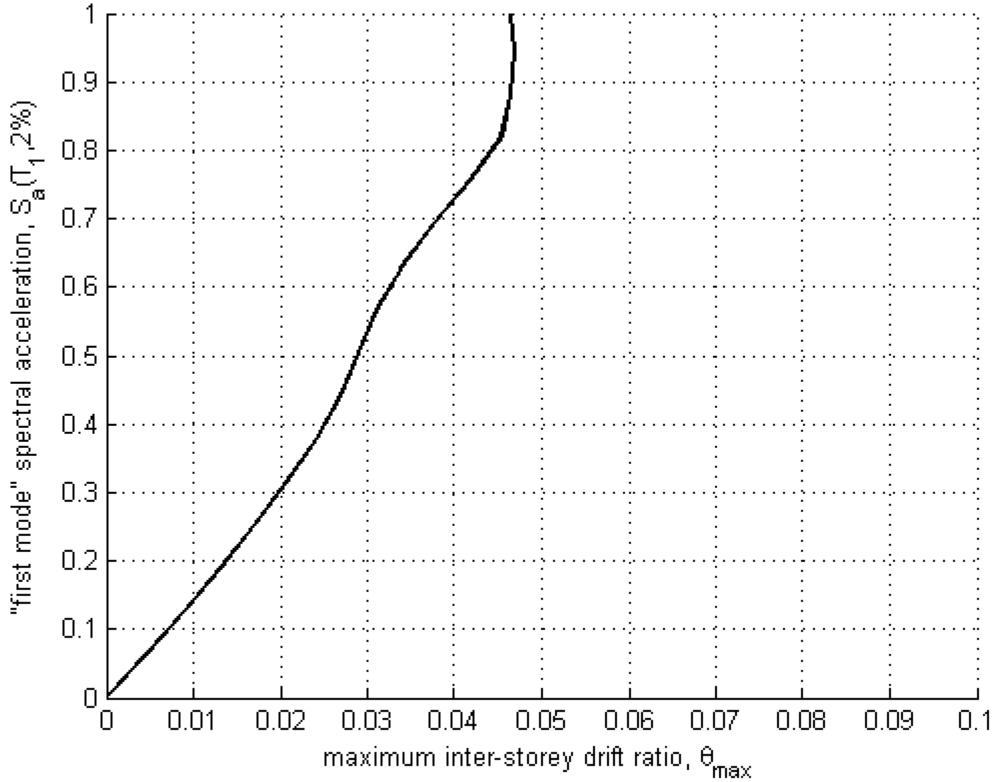
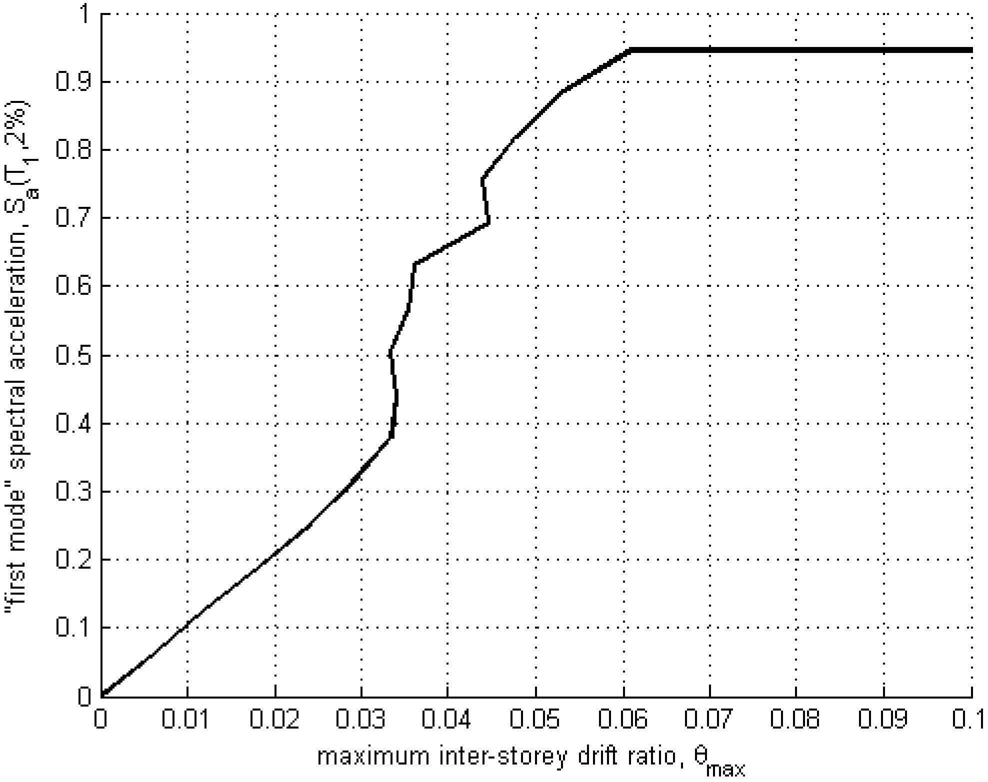


Multi-Record Incremental Dynamic Analysis

3-storey timber frame subjected to four different records

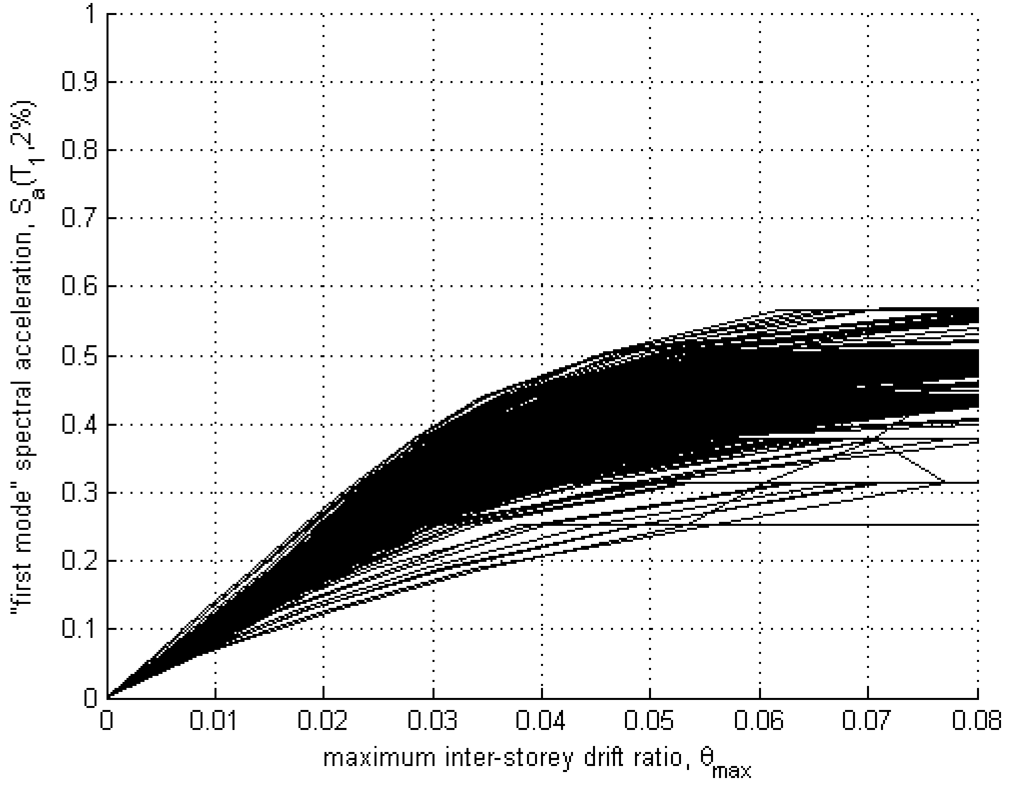
- A softening case
- Local hardening
- Severe hardening
- **Weaving behavior**



Multi-Record Incremental Dynamic Analysis

Fixed earthquake record (Type 1)

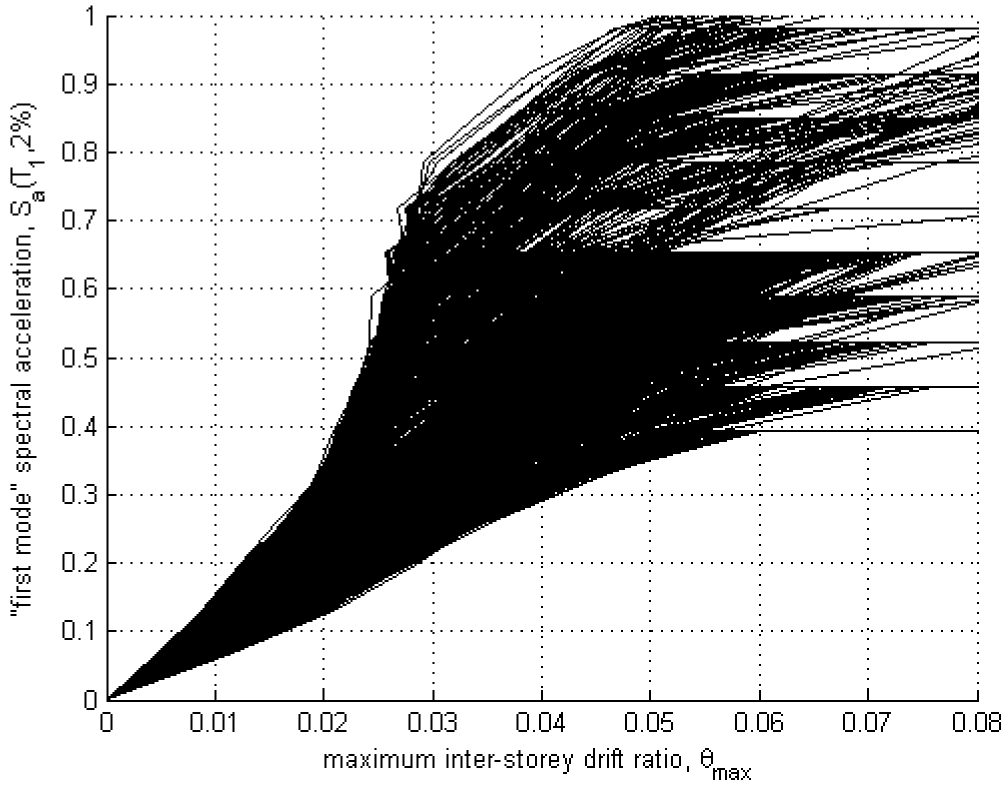
- A softening case
- Local hardening
- Severe hardening
- Weaving behavior



Multi-Record Incremental Dynamic Analysis

Fixed earthquake record (Type 2)

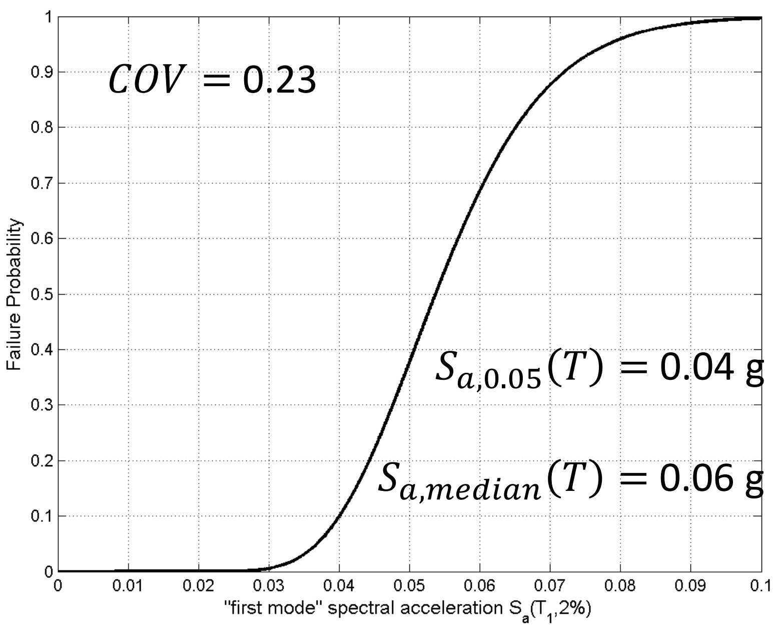
- A softening case
- Local hardening
- Severe hardening
- Weaving behavior



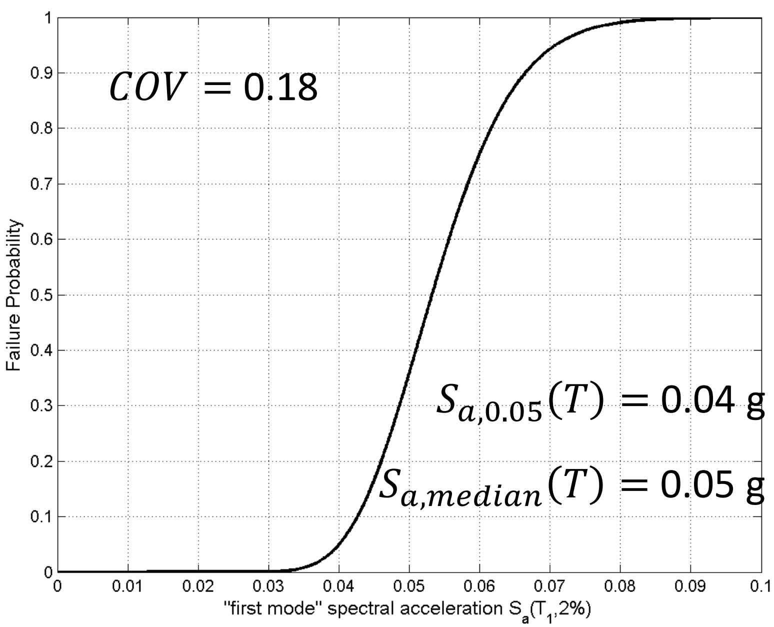
Fragility curves

- Probability of occurrence of a given damage state for a given seismic intensity

- Damage state : Immediate occupancy



Fragility curve (Type1)

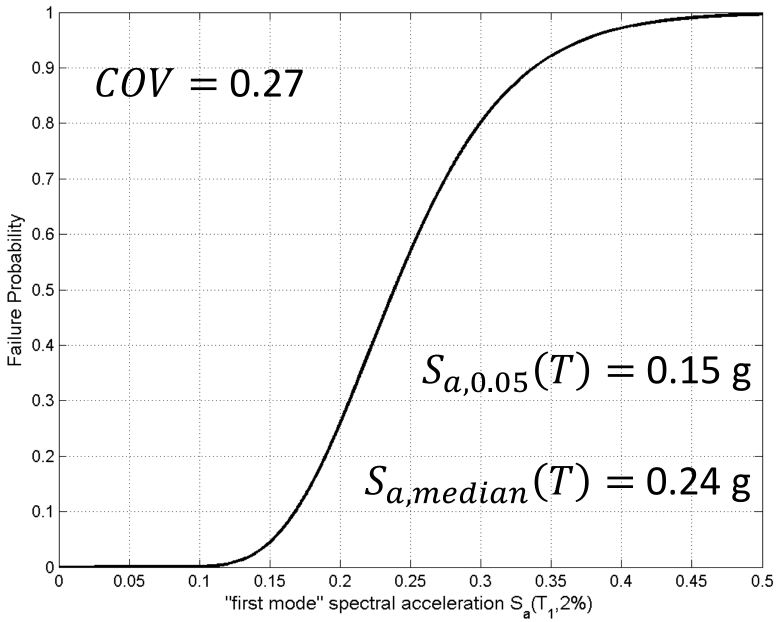


Fragility curve (Type2)

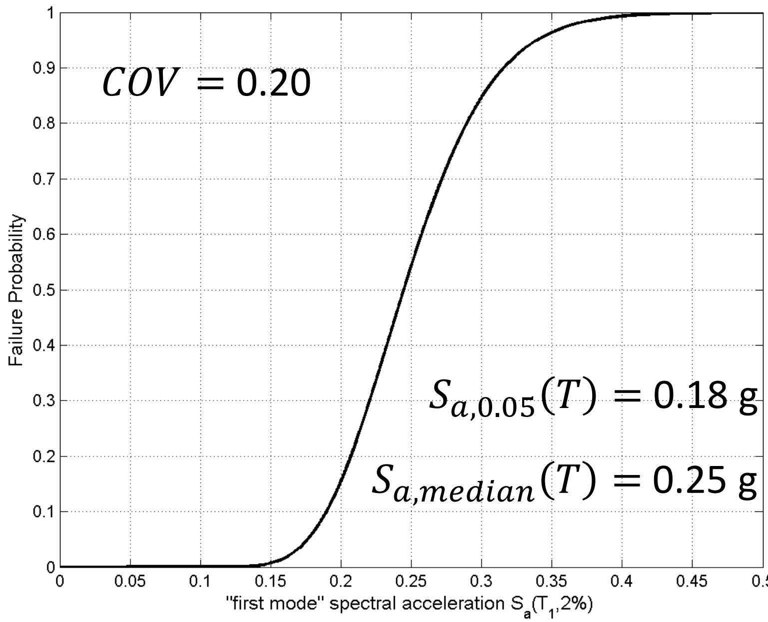
Fragility curves

- Probability of occurrence of a given damage state for a given seismic intensity

	Type 1	Type 2
- Damage state : Life safety	$S_d(T)$ =0.05 g	$S_d(T)$ =0.054 g



Fragility curve (Type1)

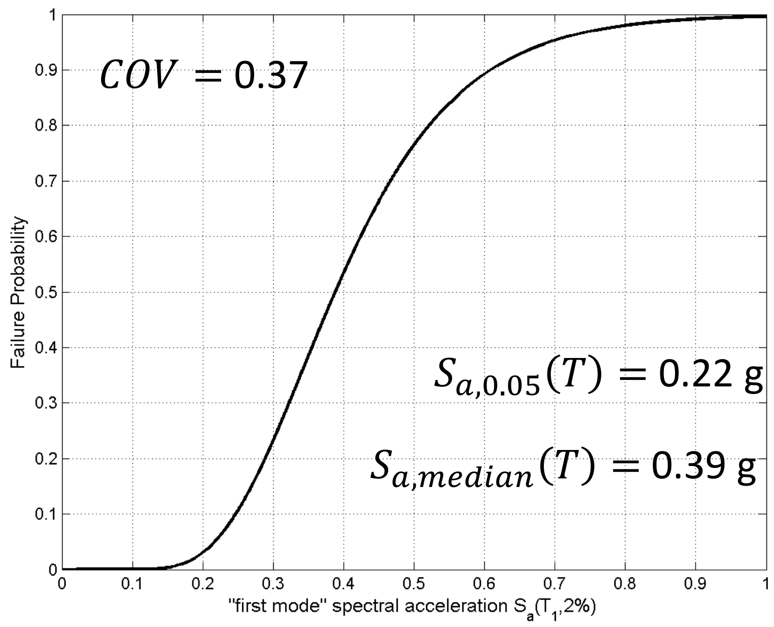


Fragility curve (Type2)

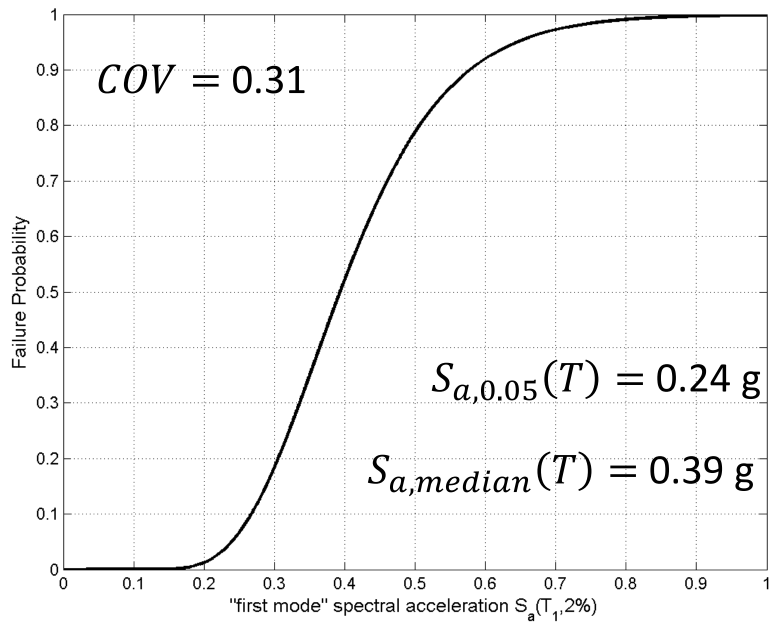
Fragility curves

- Probability of occurrence of a given damage state for a given seismic intensity

	Type 1	Type 2
- Damage state : Collapse prevention	$S_d(T)$ =0.05 g	$S_d(T)$ =0.054 g



Fragility curve (Type1)



Fragility curve (Type2)

Conclusions

- Pushover analysis showed the seismic response variability due to model uncertainties
- Behavior factor reached was higher than the admitted in the Eurocode 8 for Hyperstatic portal frame with doweled and bolted joints (*q = 4.0*)
- Multi-Record Incremental Dynamic Analysis showed how the structural response can differ for different acceleration records (aleatory uncertainties) and mechanical properties (epistemic uncertainties)
- From fragility functions it was possible to conclude that the structure is safe for the damage scenarios considered

Future developments

- Evaluate correlations between seismic responses and ductility properties
- Compare results with other structures in order to study different levels of ductility properties (global and local)
- Study the ground motion duration effects
- Evaluate the propensity to collapse of these structures through robustness assessment framework performing progressive collapse analysis of damaged structures
- Assess relationships between seismic capacity and robustness measurements

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