Fragility Function Uncertainty Quantification in Infilled RC Frame Buildings

Speaker: **Al Mouayed Bellah Nafeh** – IUSS Pavia

When: **12th June 2023**

Where: **Athens, Greece**

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Outline

- Motivation
- Simplified Assessment
- Uncertainty Quantification
- Case Study Example
- Conclusion

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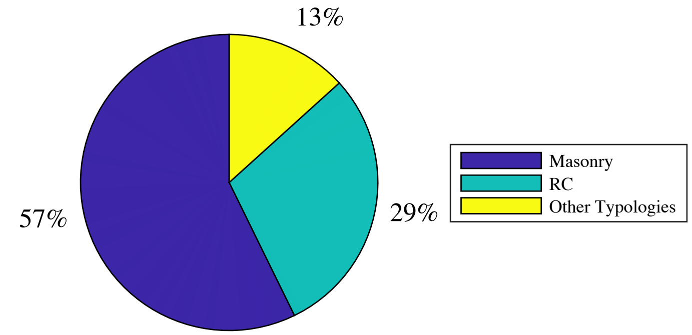
Motivation

- **Statistical Significance in Regional Building Stocks**
- **High Vulnerability to Ground-Shaking Events**
- **Accurate Response Characterisation**
- **Reduction of Uncertainty in Risk- and Loss-Based Applications**
- **Improved Decision-Making and Overall Community Resilience**



Residential buildings by construction material

Motivation

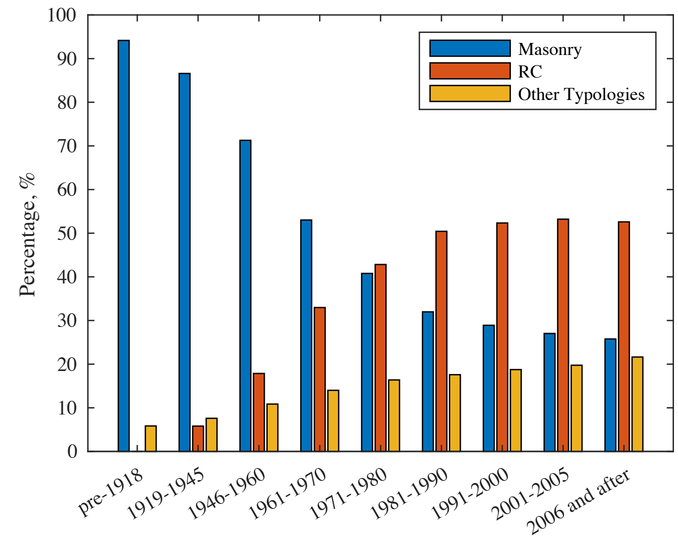
Statistical Significance in Regional Building Stocks

High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation

Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience



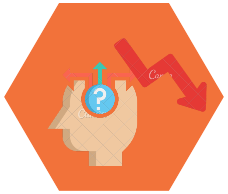
Residential buildings by period of construction and construction material

Motivation

Statistical Significance in Regional Building Stocks

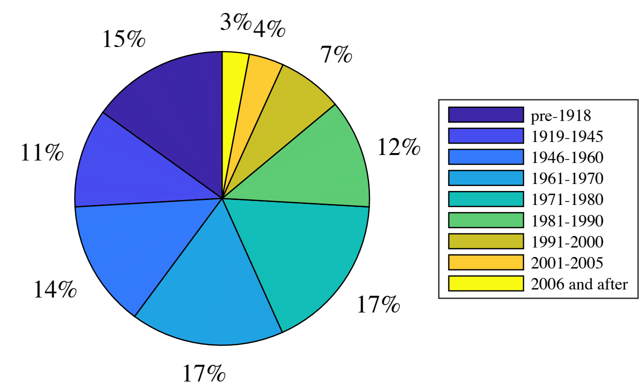
High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation



Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience



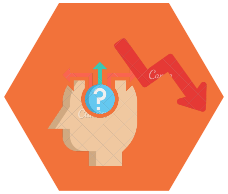
Residential buildings by period of construction

Motivation

Statistical Significance in Regional Building Stocks

High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation



Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience

Damage observations following earthquake events

Motivation

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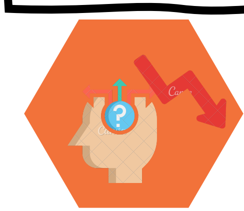
High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation



Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience

Predicted ≈ Observed

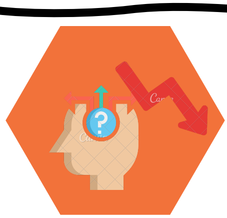
Analytical >> Empirical

Motivation

Statistical Significance in Regional Building Stocks

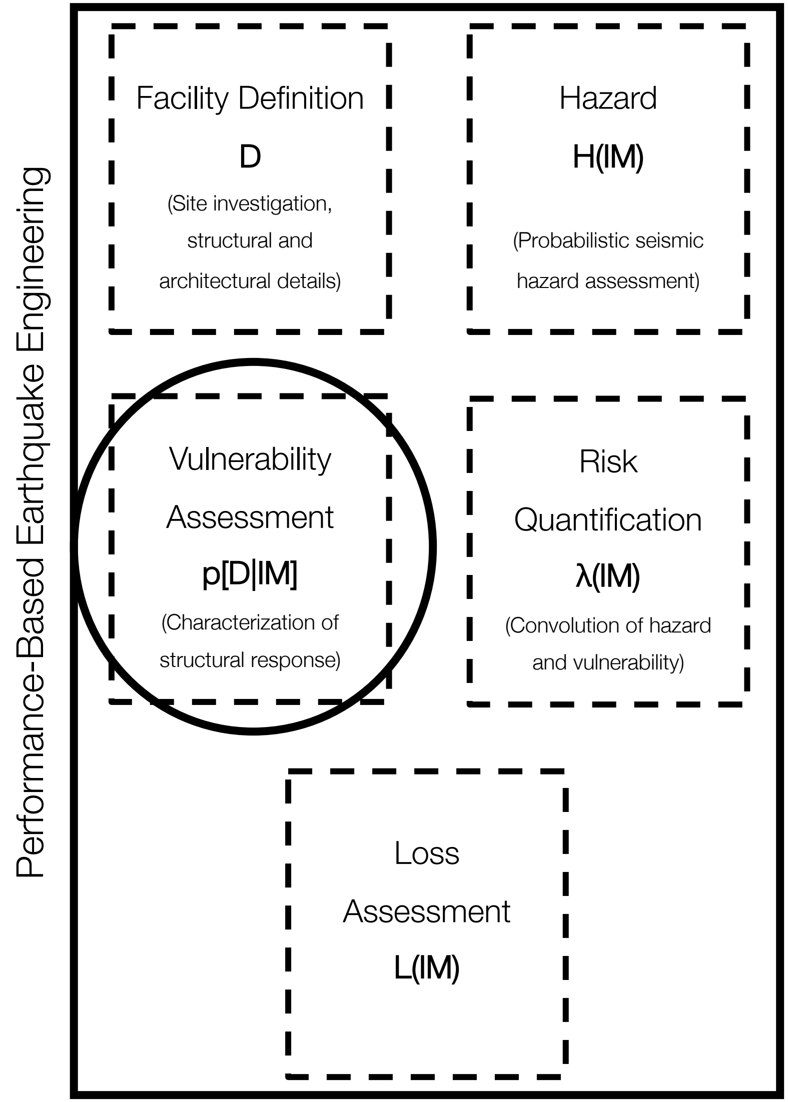
High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation



Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience



Motivation

Statistical Significance in Regional Building Stocks

High Vulnerability to Ground-Shaking Events

Accurate Response Characterisation

Reduction of Uncertainty in Risk- and Loss-Based Applications

Improved Decision-Making and Overall Community Resilience

- *Adequate characterization of structural response*
- *Reduction and mitigation of seismic risk*
- *Drafting prioritization schemes and policies*
- *Retrofitting and structural rehabilitation*
- *Adequate allocation of resources*
- *Minimization of direct and indirect seismic losses*

Motivation

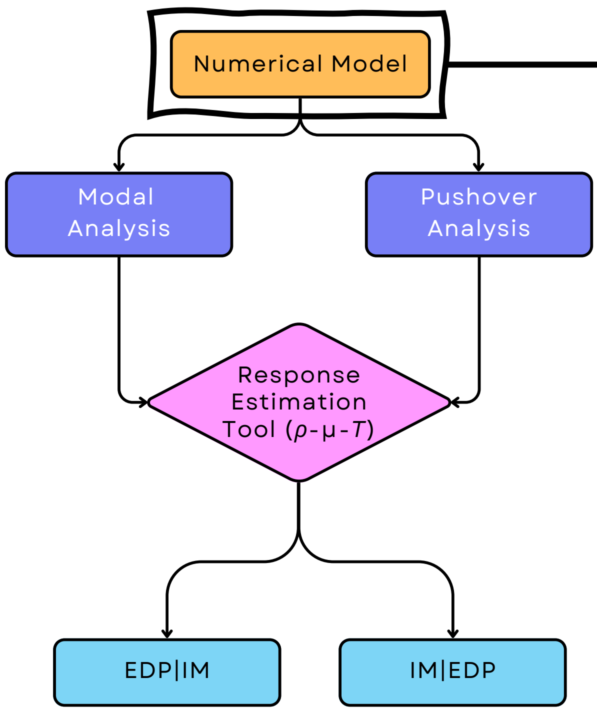
Simplified Assessment

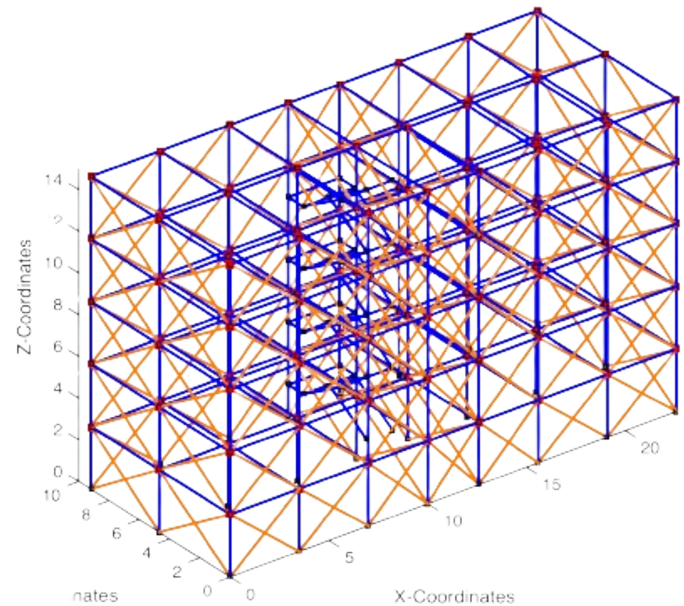
Uncertainty Quantification

Case Study Example

Conclusion

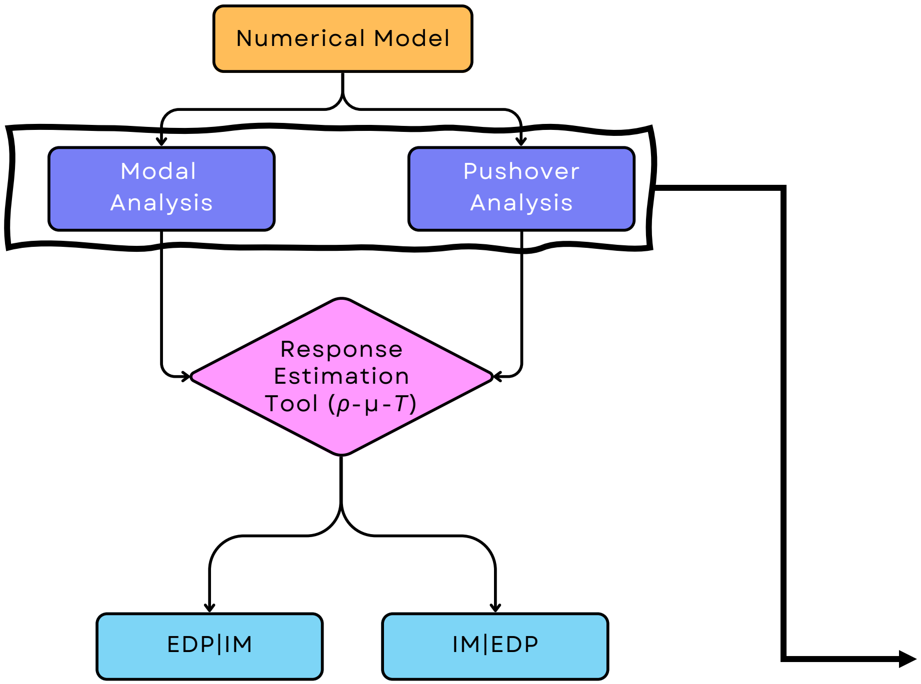
Simplified Assessment

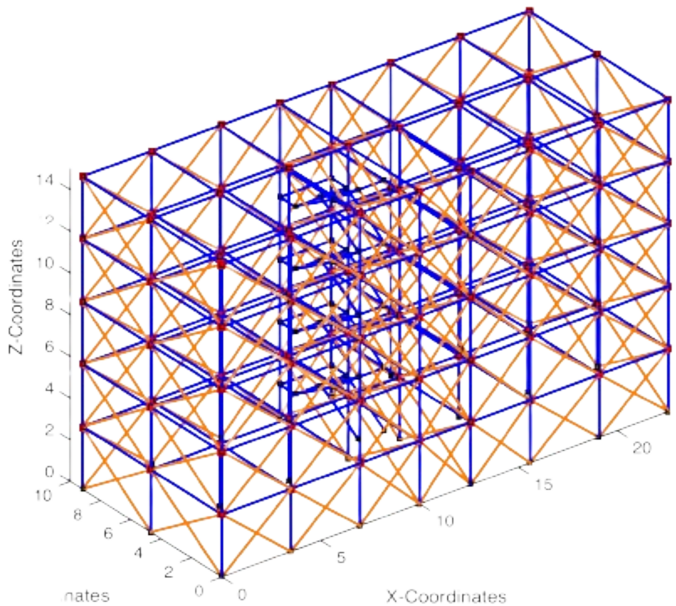




- Detailed numerical model;
- Must account for all possible inelastic mechanisms and failure modes;

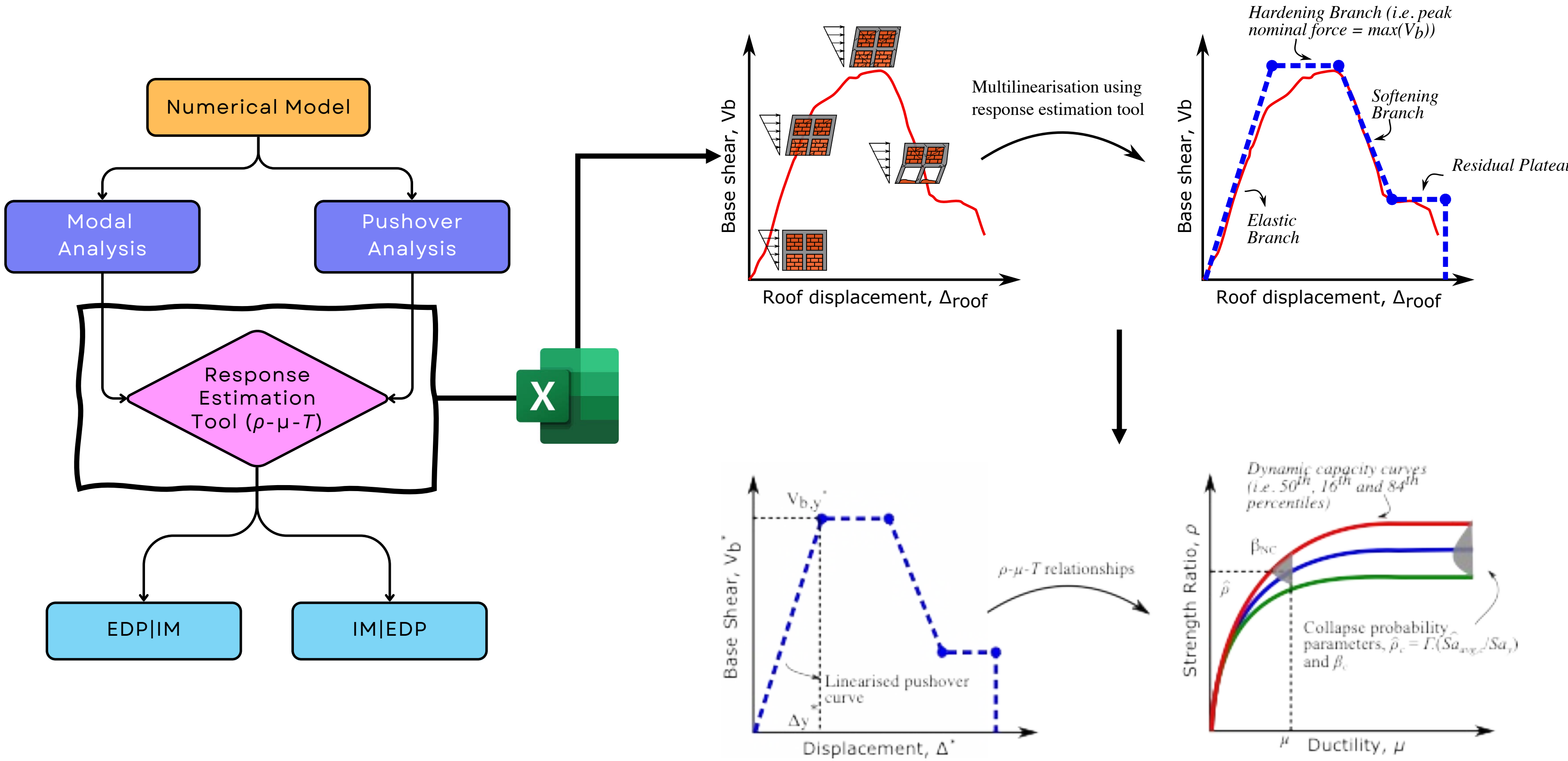
Response Evaluation Tool



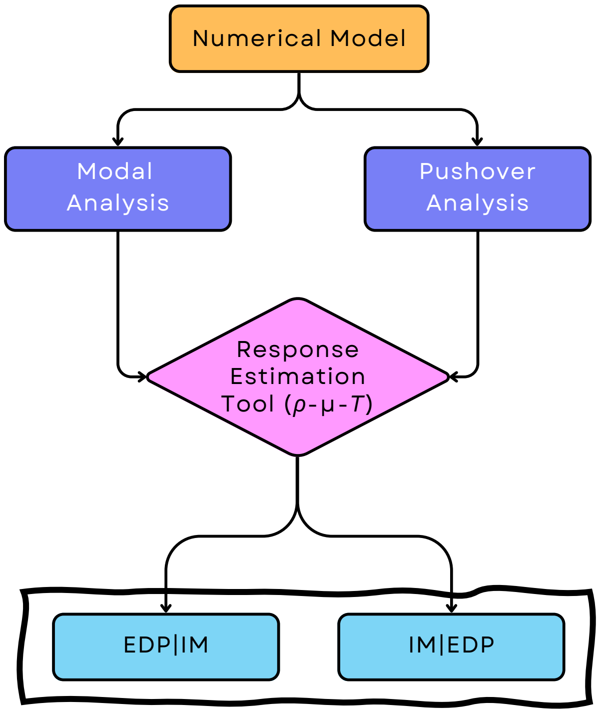


- Perform eigenvalue analysis to extract first-mode shape ordinates;
- Perform nonlinear static pushover to characterize the lateral response of the MDOF system (i.e., base-shear vs roof displacement);

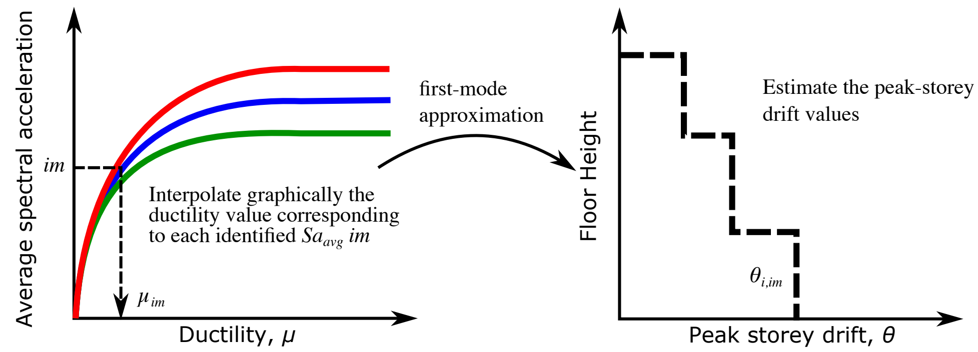
Response Evaluation Tool



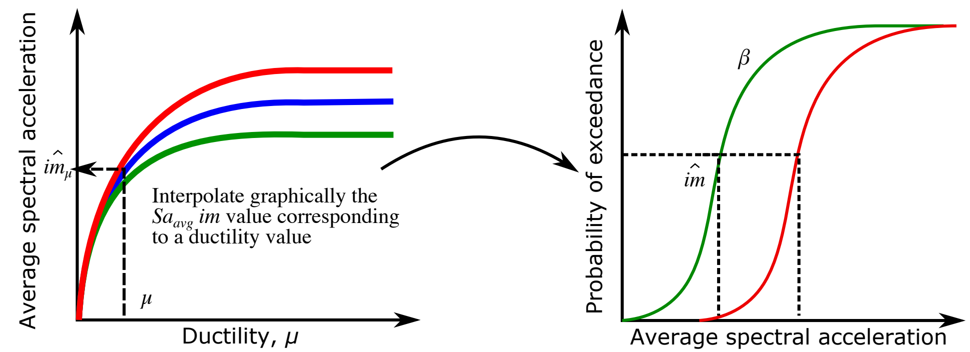
Response Evaluation Tool



EDP|IM or $\mu|Sa_{avg}$



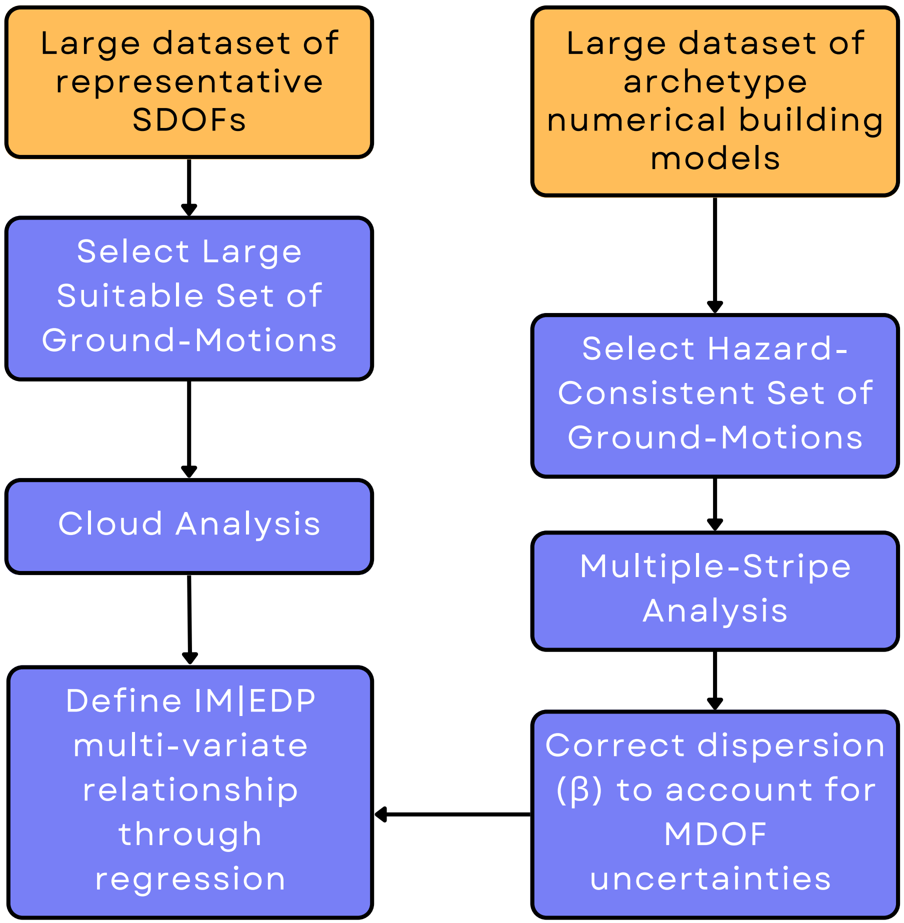
IM|EDP or $Sa_{avg}|\mu$

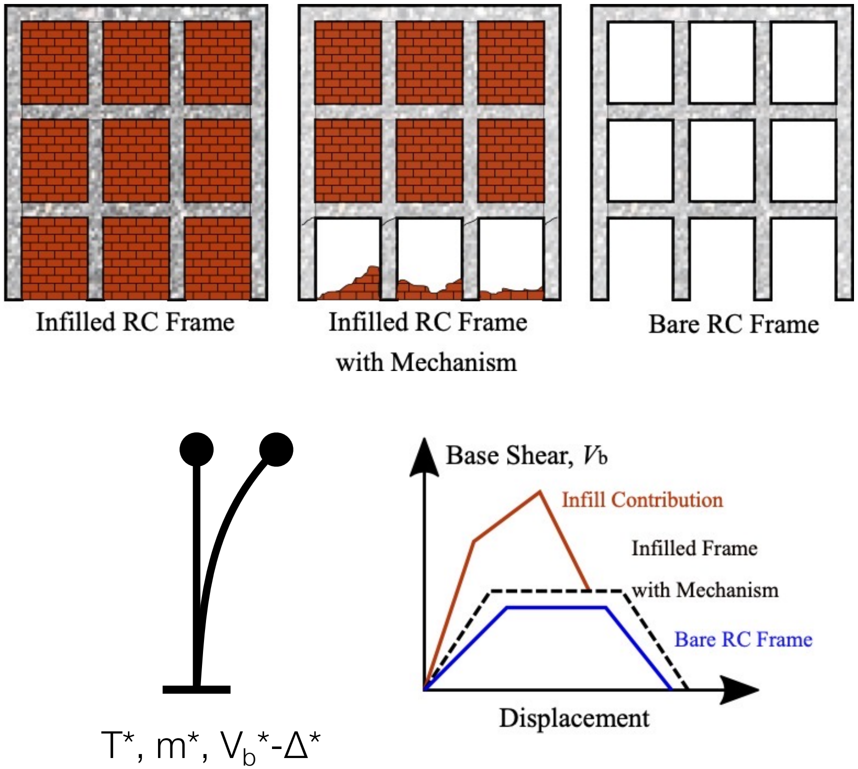


Uncertainty Quantification

Uncertainty Quantification

Initial Approach

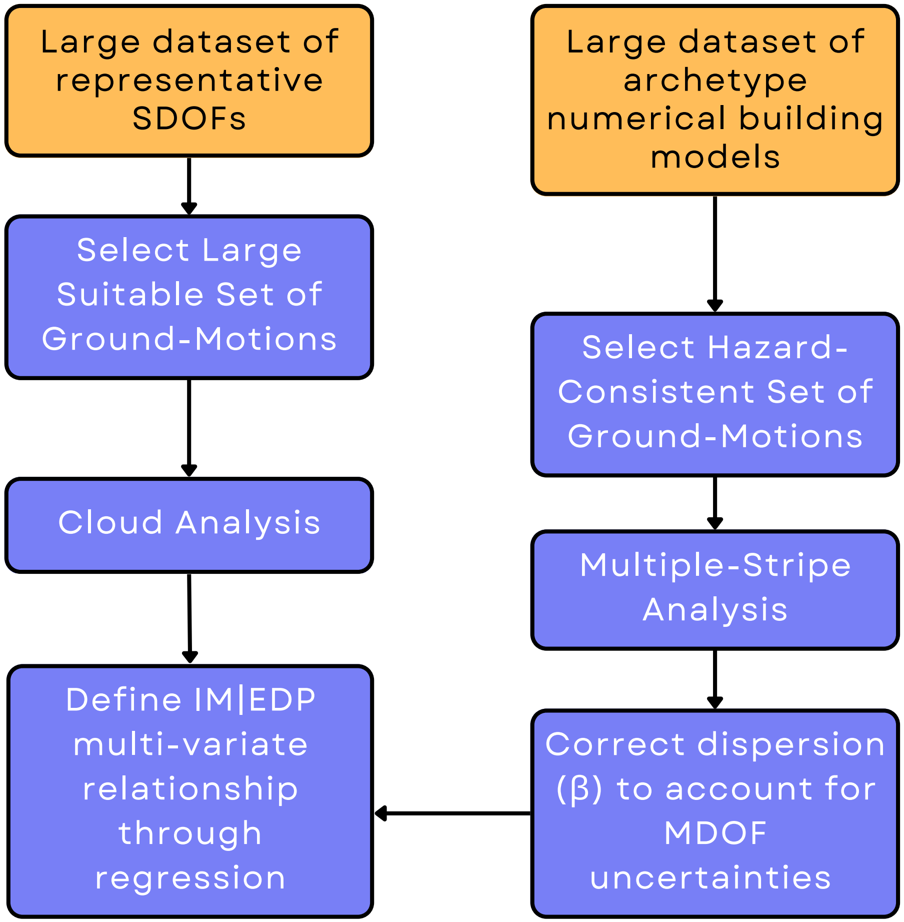


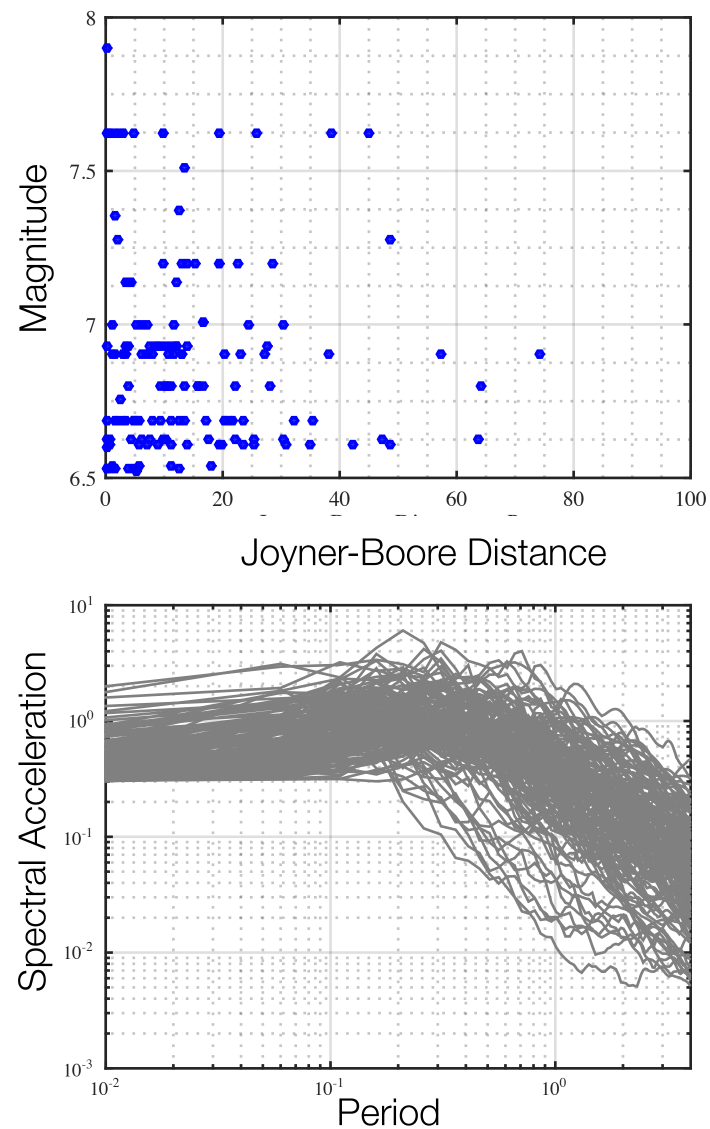


Equivalent SDOF Definition

Uncertainty Quantification

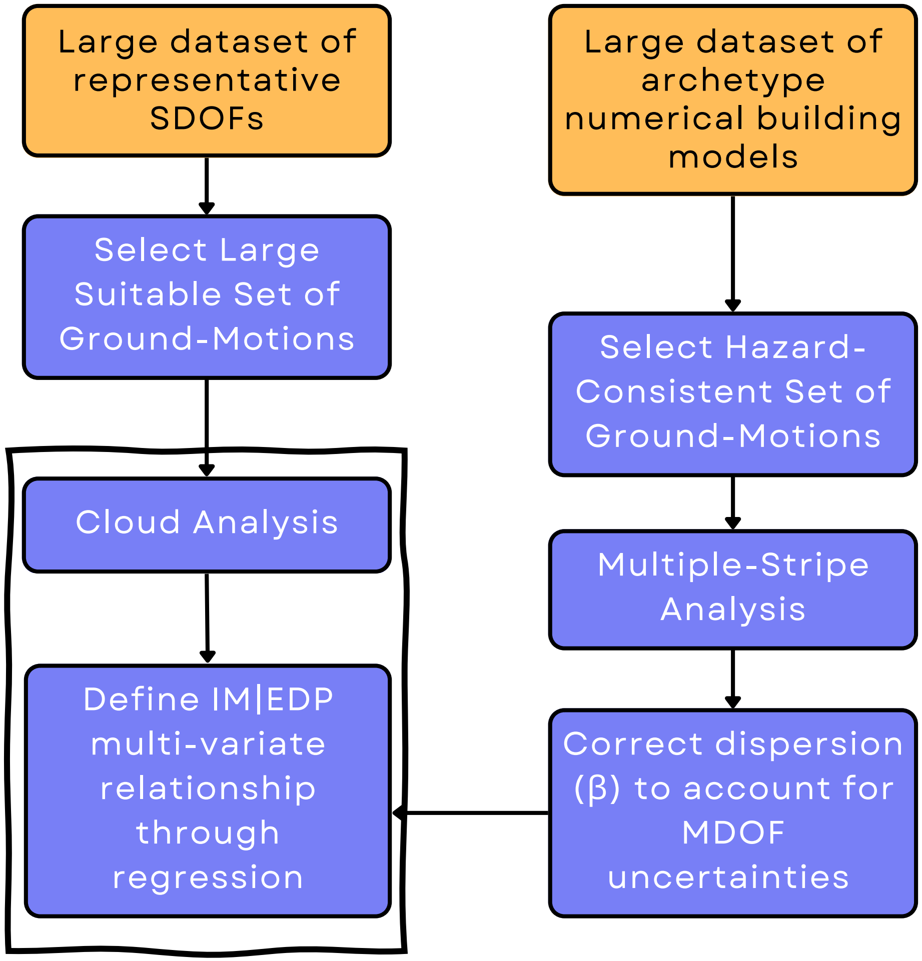
Initial Approach

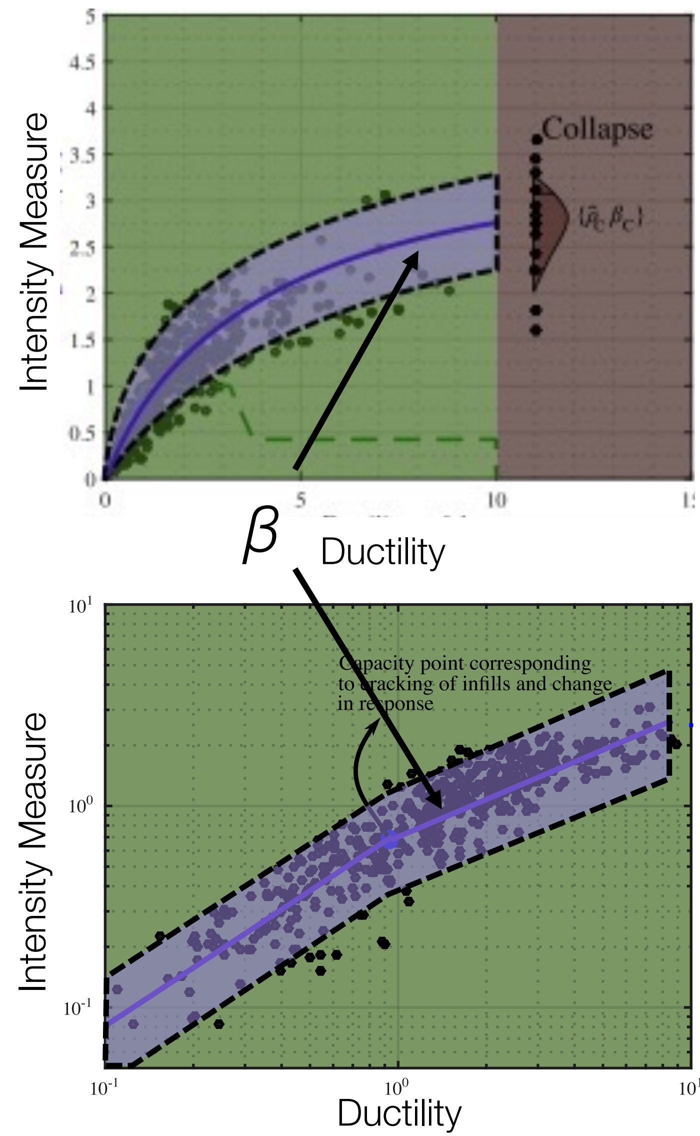




Uncertainty Quantification

Initial Approach



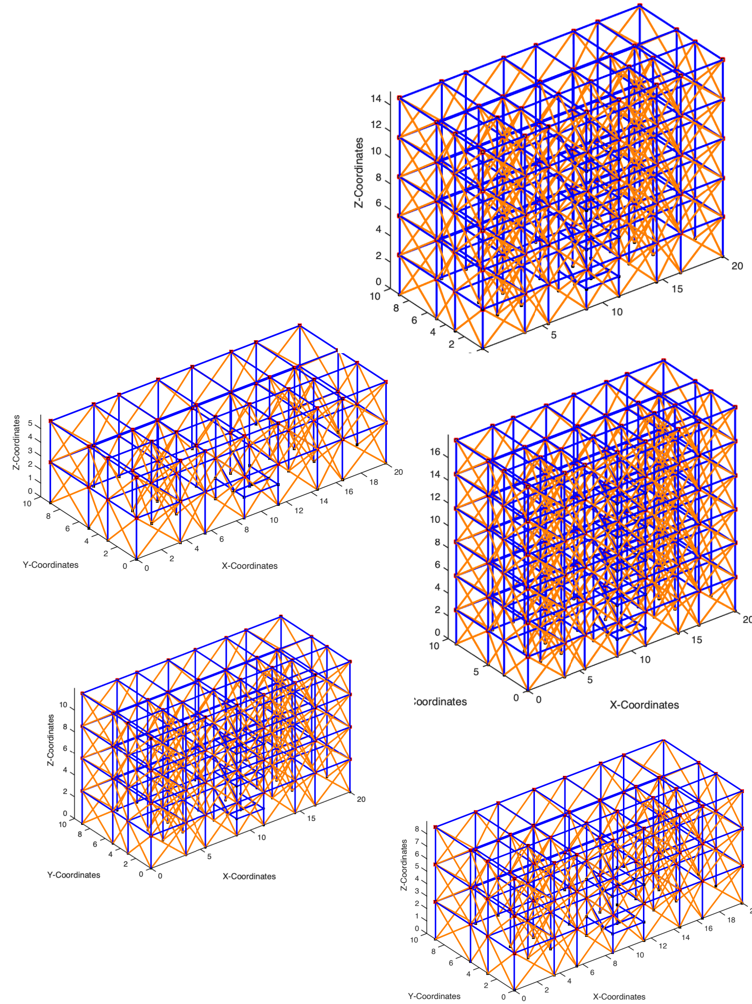


Uncertainty Quantification

Correction

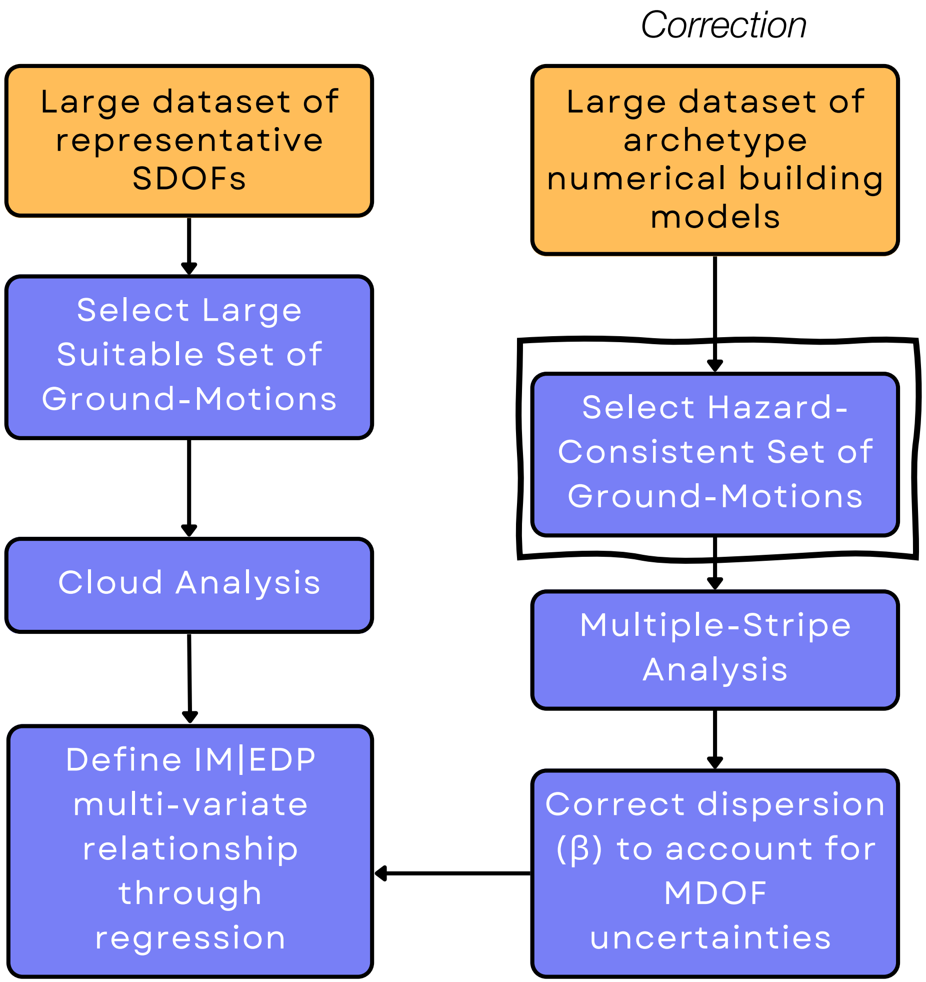
Large dataset of representative SDOFs → Select Large Suitable Set of Ground-Motions → Cloud Analysis → Define IM|EDP multi-variate relationship through regression

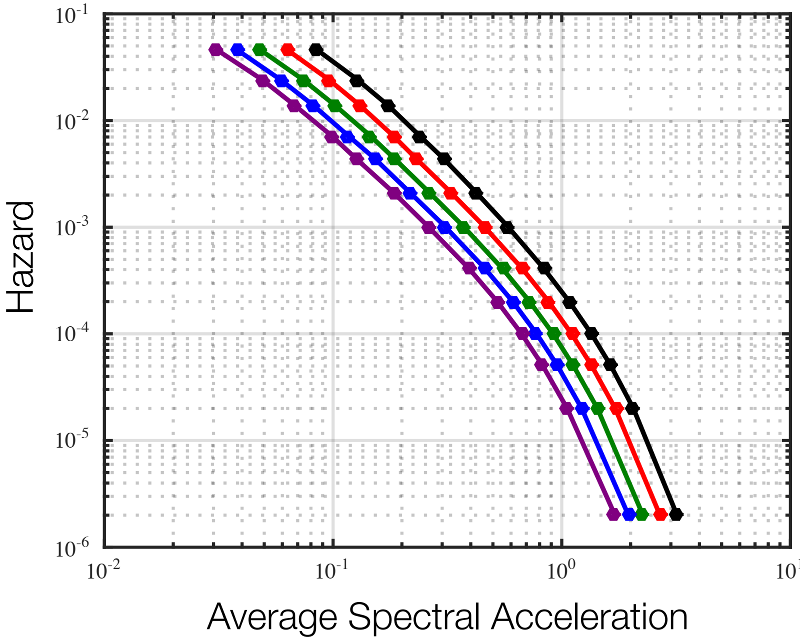
Large dataset of archetype numerical building models → Select Hazard-Consistent Set of Ground-Motions → Multiple-Stripe Analysis → Correct dispersion (β) to account for MDOF uncertainties → Define IM|EDP multi-variate relationship through regression



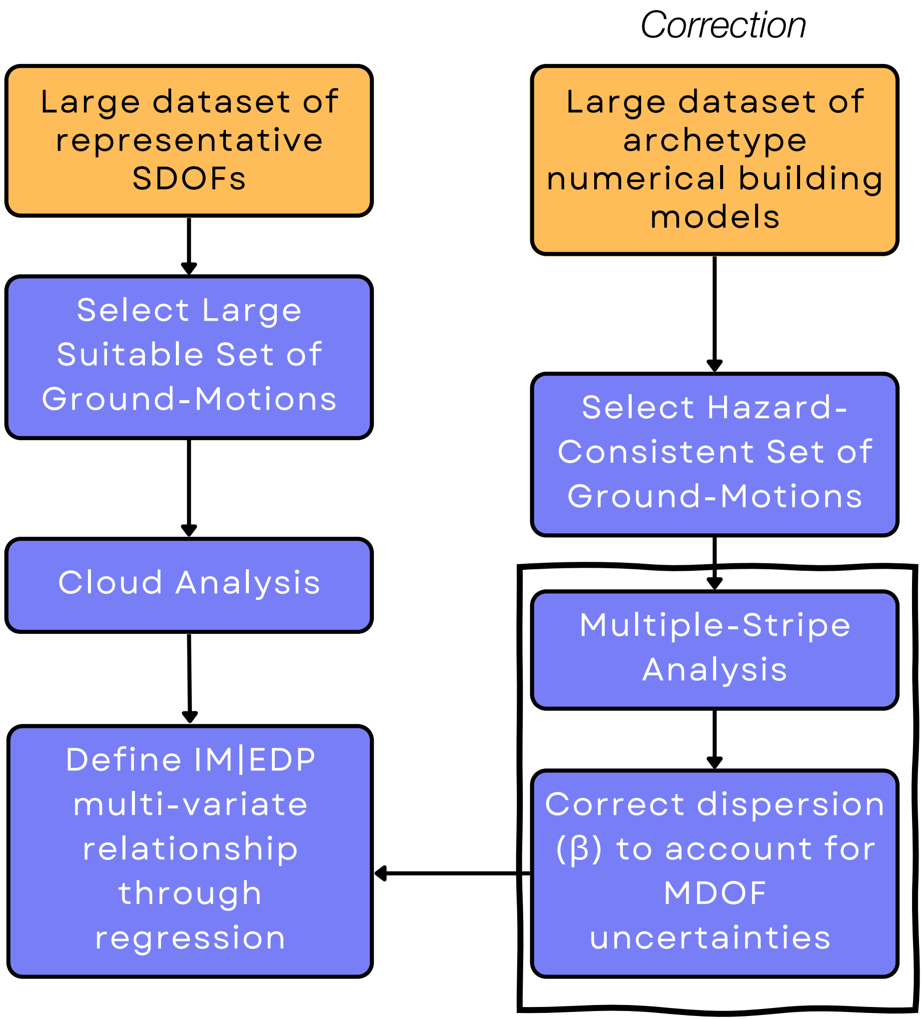
Total 105 low-rise and mid-rise infilled RC building archetypes

Uncertainty Quantification





Probabilistic seismic hazard assessment expressing the hazard in L'Aquila, Italy in terms of the average spectral acceleration corresponding to conditioning periods of T=0.2-0.6s*



Correction
Large dataset of representative SDOFs
Select Large Suitable Set of Ground-Motions
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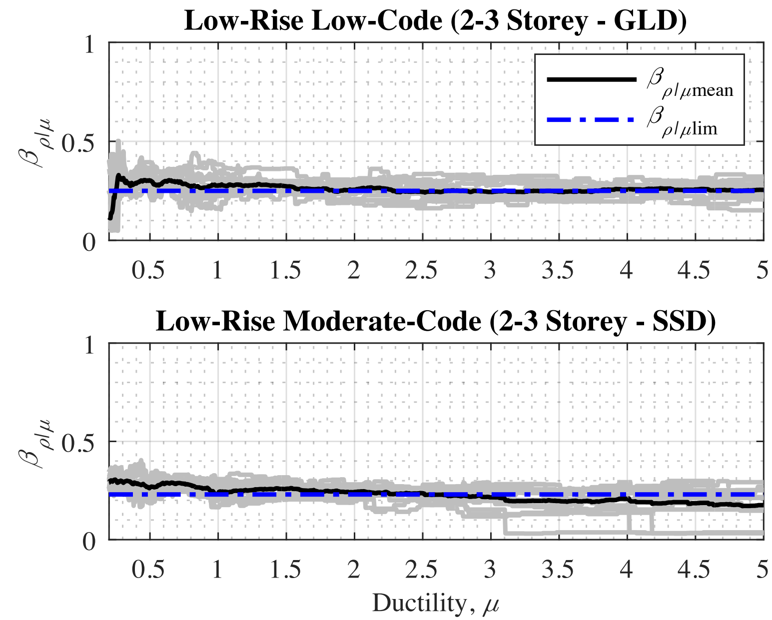
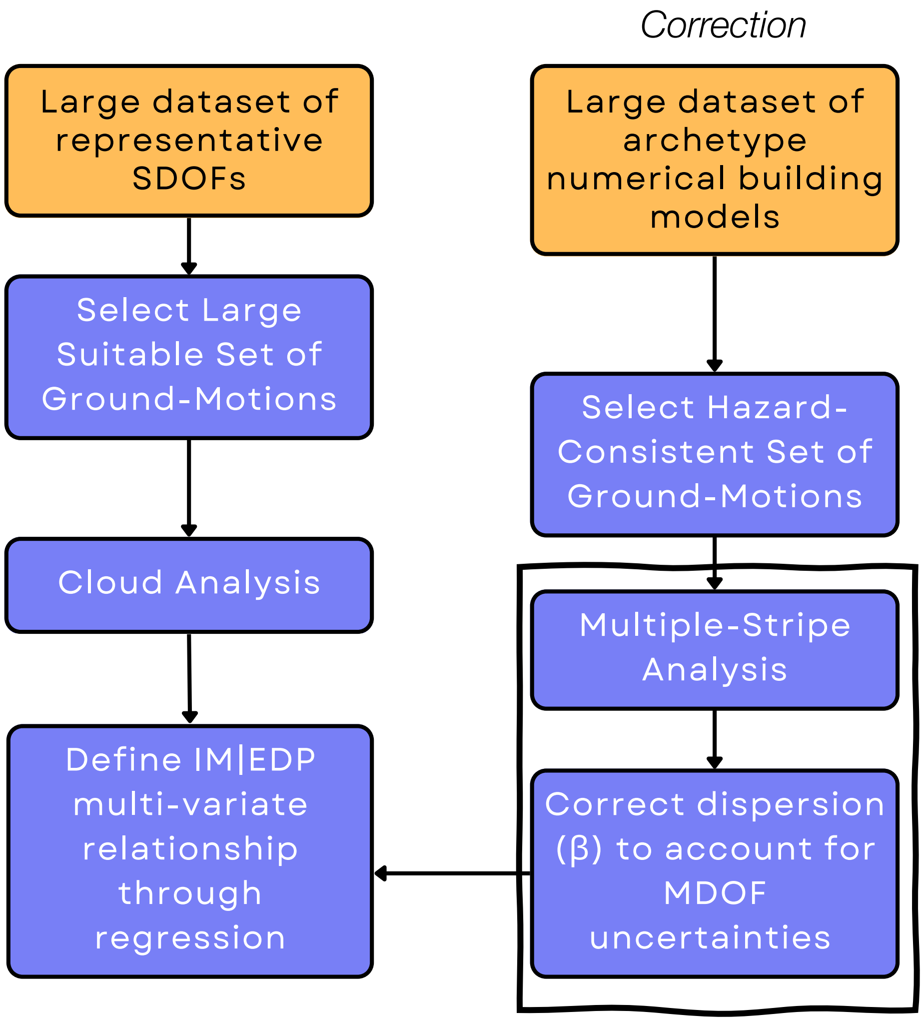


Low-Rise Low-Code (2-3 Storey - GLD)
Low-Rise Moderate-Code (2-3 Storey - SSD)
$\beta_{\rho|\mu}$
$\beta_{\rho|\mu\mathrm{mean}}$
$\beta_{\rho|\mu\mathrm{lim}}$
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Ductility, μ



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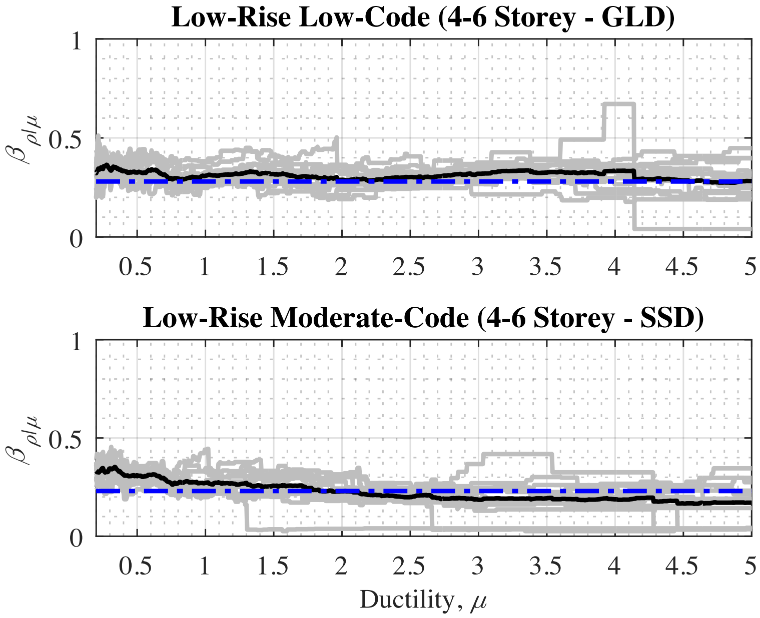

Low-Rise Low-Code (4-6 Storey - GLD)
Low-Rise Moderate-Code (4-6 Storey - SSD)
$\beta_{\rho|\mu}$
Ductility, μ
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Uncertainty Quantification

Suggested value of IM|EDP uncertainty for low and mid-rise infilled RC buildings

Seismic Code Level	Number of Stories	Taxonomy Code	Suggested Dispersion, β
Low (GLD)	Low-rise (2-3)	LC-LR	0.25
	Mid-rise (4-6)	LC-MR	0.23
Moderate (SSD)	Low-rise (2-3)	MC-LR	0.28
	Mid-rise (4-6)	MC-MR	0.23

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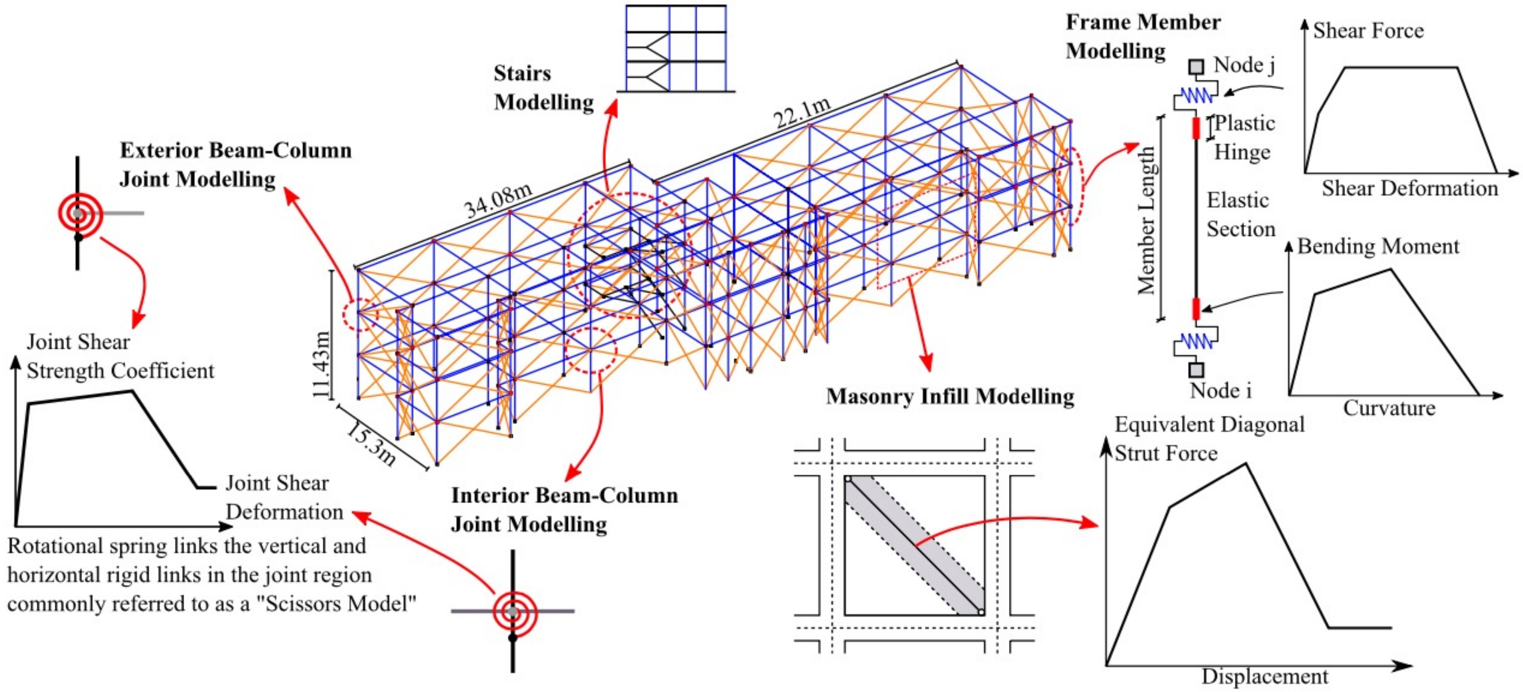
Case Study Example

- Three-storey RC school building with masonry infills;
- Located in Napoli, Italy;
- Constructed in the 1960s, before the introduction of modern seismic design guidelines;



General layout and numerical modelling techniques of the case study school building.

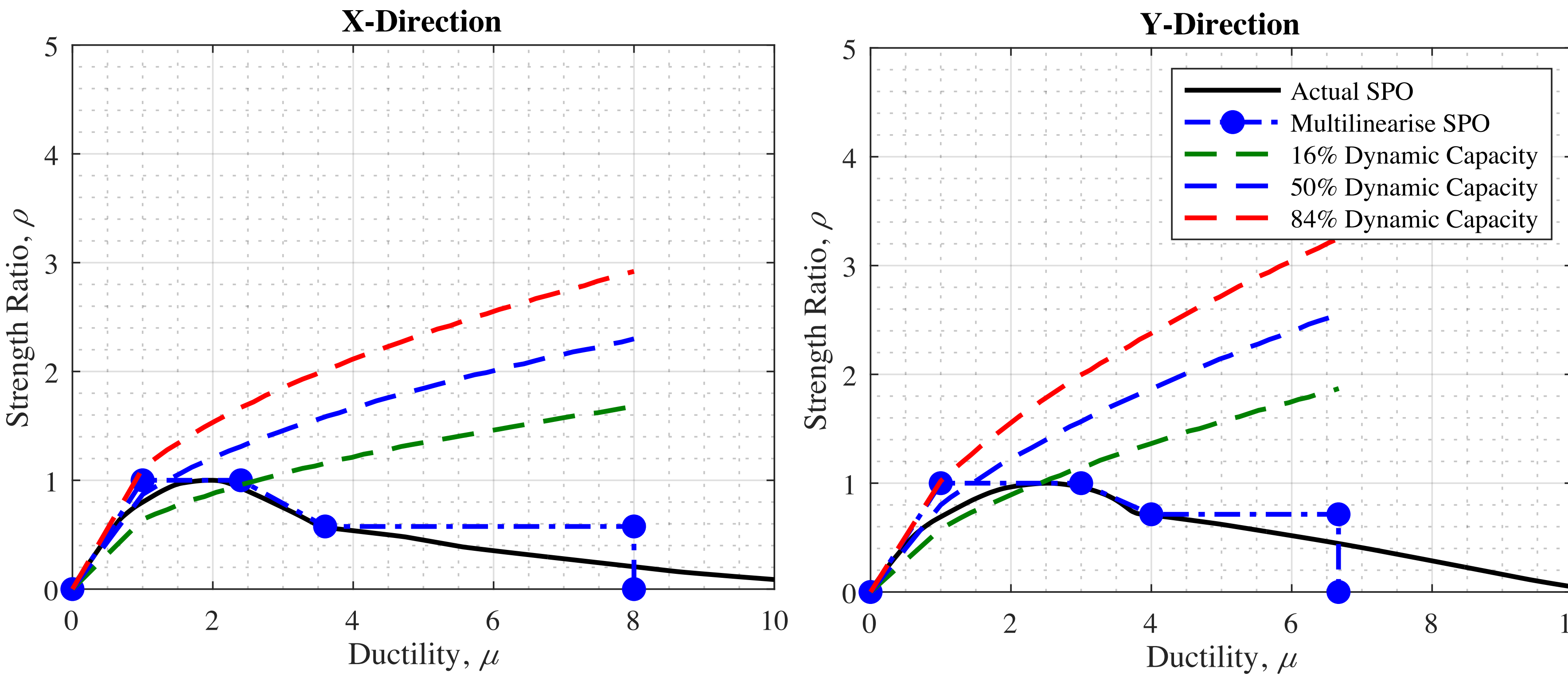
Case Study Example

Summary of the modal properties of the case study building in both principal directions

Floor No.	Mass, m_i [tonnes]	X-Direction			Y-Direction (Weaker Direction)		
		First-mode shape, Φ	Period, T_1 [s]	Yield spectral acceleration, Sa_y [g]	First-mode shape, Φ	Period, T_1 [s]	Yield spectral acceleration, Sa_y [g]
Base	0	0.00	0.62	0.42	0.00	0.36	0.40
First	985	0.22			0.22		
Second	960	0.56			0.57		
Third	806	1.00			1.00		

Case Study Example

Summary of the static pushover analyses of the case study building in both principal directions



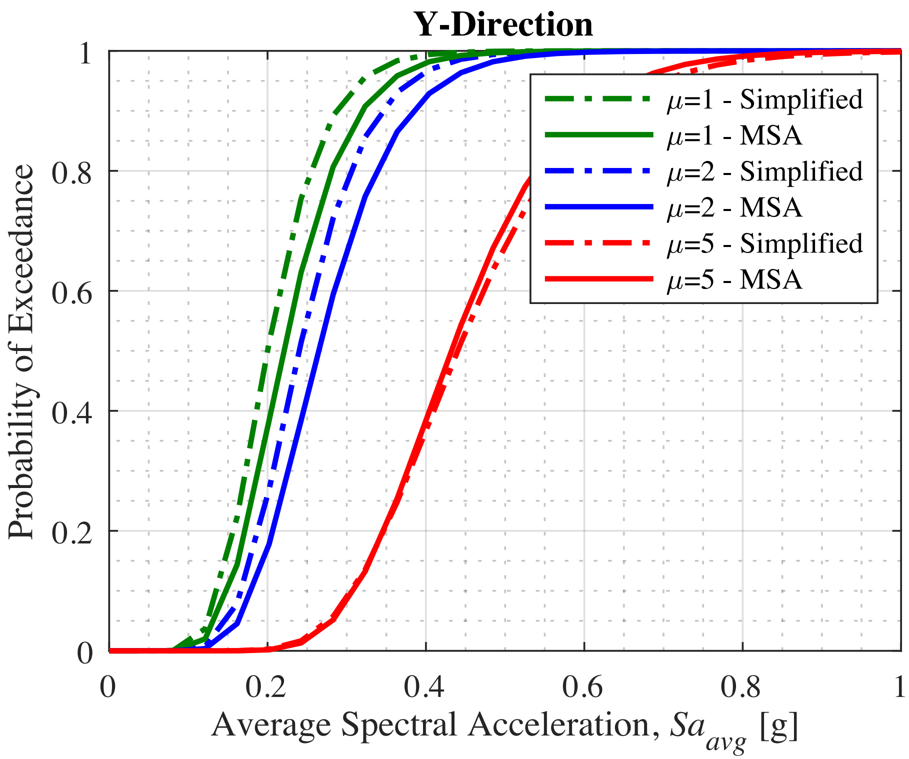
Case Study Example

Summary of the fragility function comparisons

Ductility Thresholds	Simplified Assessment		Extensive Assessment (MSA)	
	Median intensity, Sa_{avg} [g]	Dispersion, β	Median intensity, Sa_{avg} [g]	Dispersion, β
μ=1	0.20	0.25	0.22	0.28
μ=2	0.24		0.27	0.26
μ=5	0.44		0.43	0.26

Case Study Example

Summary of the fragility function comparisons



Case Study Example

Seismic Risk Calculation:

- Classical Approach:

$$\lambda = \int_0^{+\infty} P[\mu \geq \mu | IM = s] |dH(s)|$$

- Pushover-Based Risk Estimation (PB-Risk):

1. Second-order approximation of the hazard function:

$$H(s) = k_0 \exp\left[-k_2 ln^2(s) - k_1 \ln(s)\right]$$

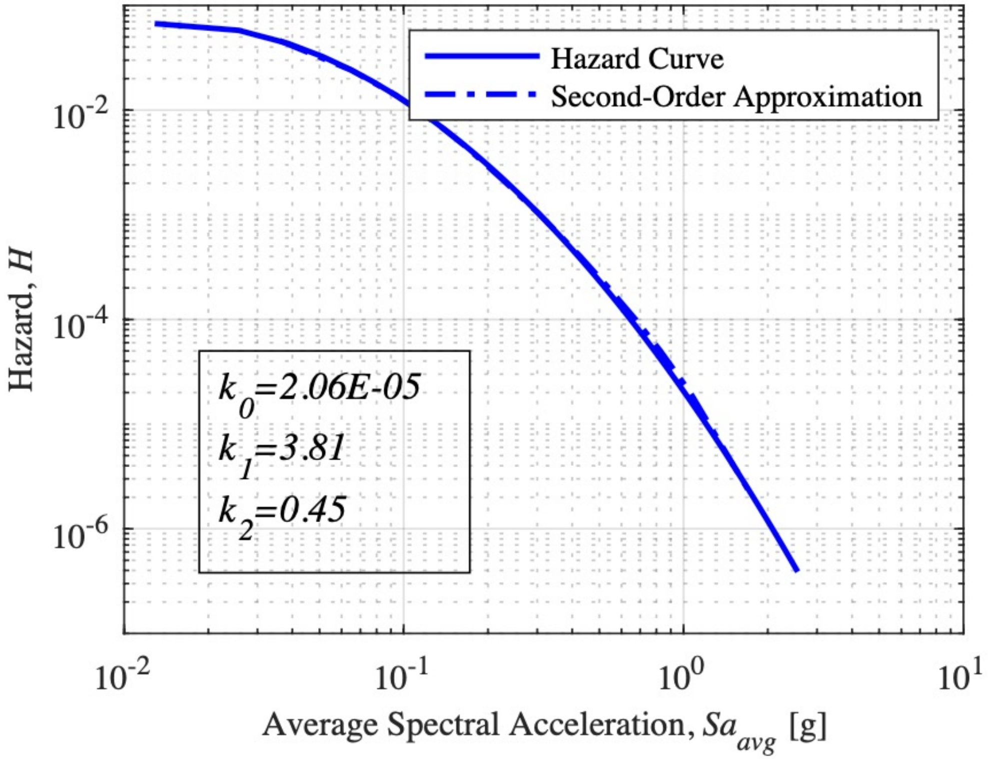
2. Application of IM-based closed form expressions:

$$\lambda = \sqrt{p} k_0^{1-p} [H(s)]^p \exp\left[\frac{k_1^2}{4k_2}(1-p)\right]$$

$$p = \frac{1}{1 + 2k_2\beta^2}$$

Case Study Example

Seismic hazard characterization and second-order approximation



Case Study Example

Summary of the risk assessment comparisons

Ductility Thresholds	PB-Risk	Classical	Error in MAFE estimation
	Mean annual frequency of exceedance (MAFE), λ		
μ=1	0.0031	0.0029	6.89%
μ=2	0.0021	0.0019	10.52%
μ=5	4.92E-04	5.02E-04	1.6%

Motivation

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Conclusion

- A simplified tool for the seismic performance assessment of infilled RC frames was presented;
- The epistemic uncertainty associated with structural response (IM|EDP) was quantified for the infilled RC typology and different sub-taxonomies;
- The suggested values of the record-to-record variability could be incorporated with other simplified methodologies for the derivation of fragility functions or risk metrics (e.g. *PB-Risk*);
- The suggested values were validated on a case-study school buildings where an adequate match in terms of vulnerability and risk parameters was observed;
- Good agreement between the results of classical and simplified methodologies;

Useful Links and References*

Links:

- Database of Archetype Building Models:

https://github.com/gerardjoreilly/Infilled-RC-Building-Database

- Response Estimation Tool for Infilled RC Frame Structures:

https://github.com/gerardjoreilly/Infilled-RC-Building-Response-Estimation

Publications:

- Nafeh A.M.B., O'Reilly G.J. (2022) Unbiased simplified seismic fragility estimation of non-ductile infilled RC structures. Soil Dynamics and Earthquake Engineering 157:107253. https://doi.org/10.1016/j.soildyn.2022.107253
- *PB-Risk:* Nafeh, A.M.B., O'Reilly, G.J. (2023) Simplified pushover-based seismic risk assessment methodology for existing infilled frame structures. Bulletin of Earthquake Engineering 21, 2337–2368 https://doi.org/10.1007/s10518-022-01600-y

Thank you for your attendance

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