# Towards the assessment and risk classification of existing building typologies using storey-loss functions

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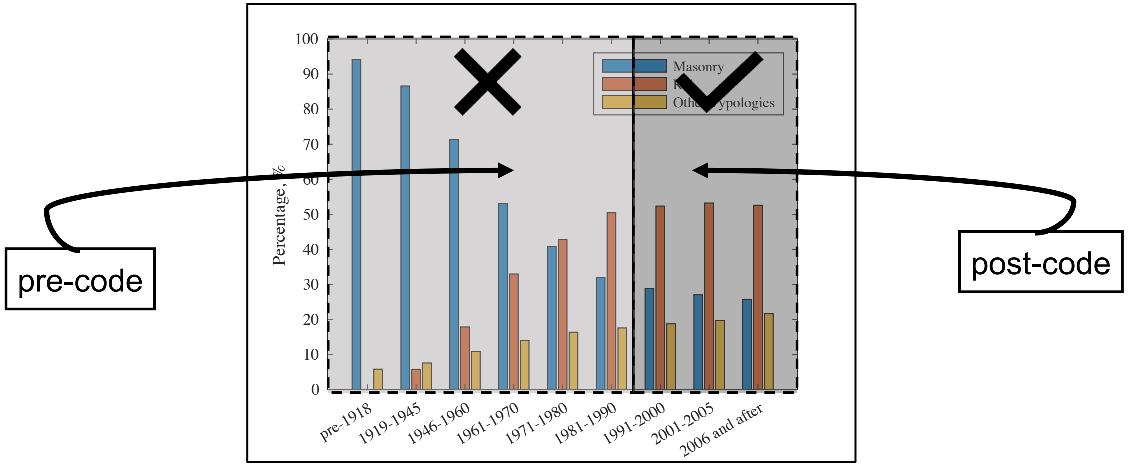
# Introduction

- National housing census infer that the majority of the existing built-environment was constructed prior to the introduction of modern seismic design provisions (e.g., NTC2018, EC8)
- Past earthquake reconnaissance observations highlighted the vulnerability of the existing pre-code regional building stock to ground-shaking events




*Amatrice, Italy 2016*

*(Ref: Gallagher Re)*

*Emilia-Romagna, Italy 2012*

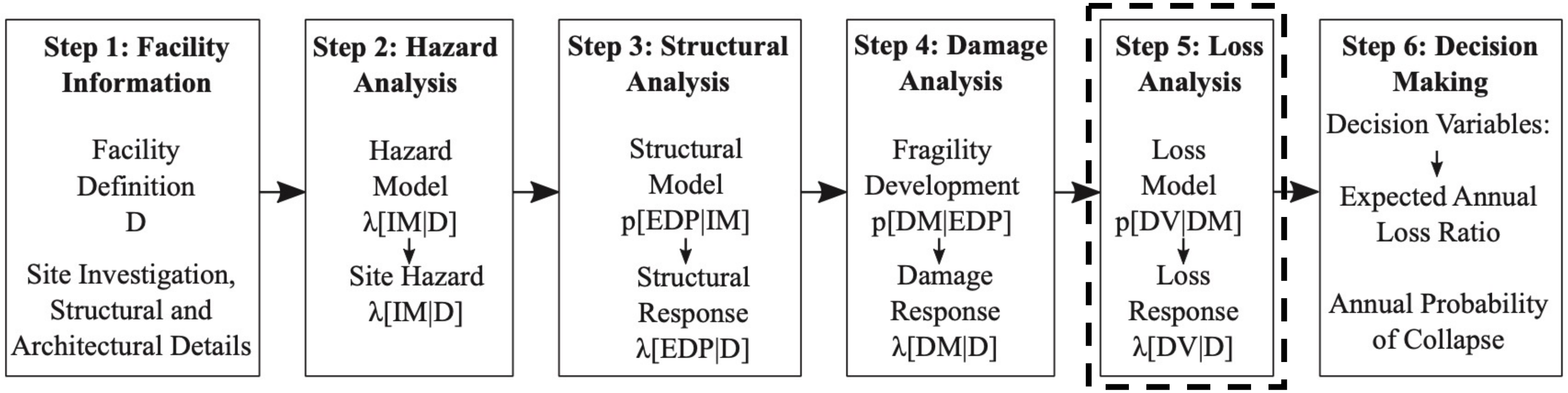
*(Ref: NY Times)*

*Umbria-Marche, Italy 1997*

*(Ref: Corriere della Sera)*

# Introduction

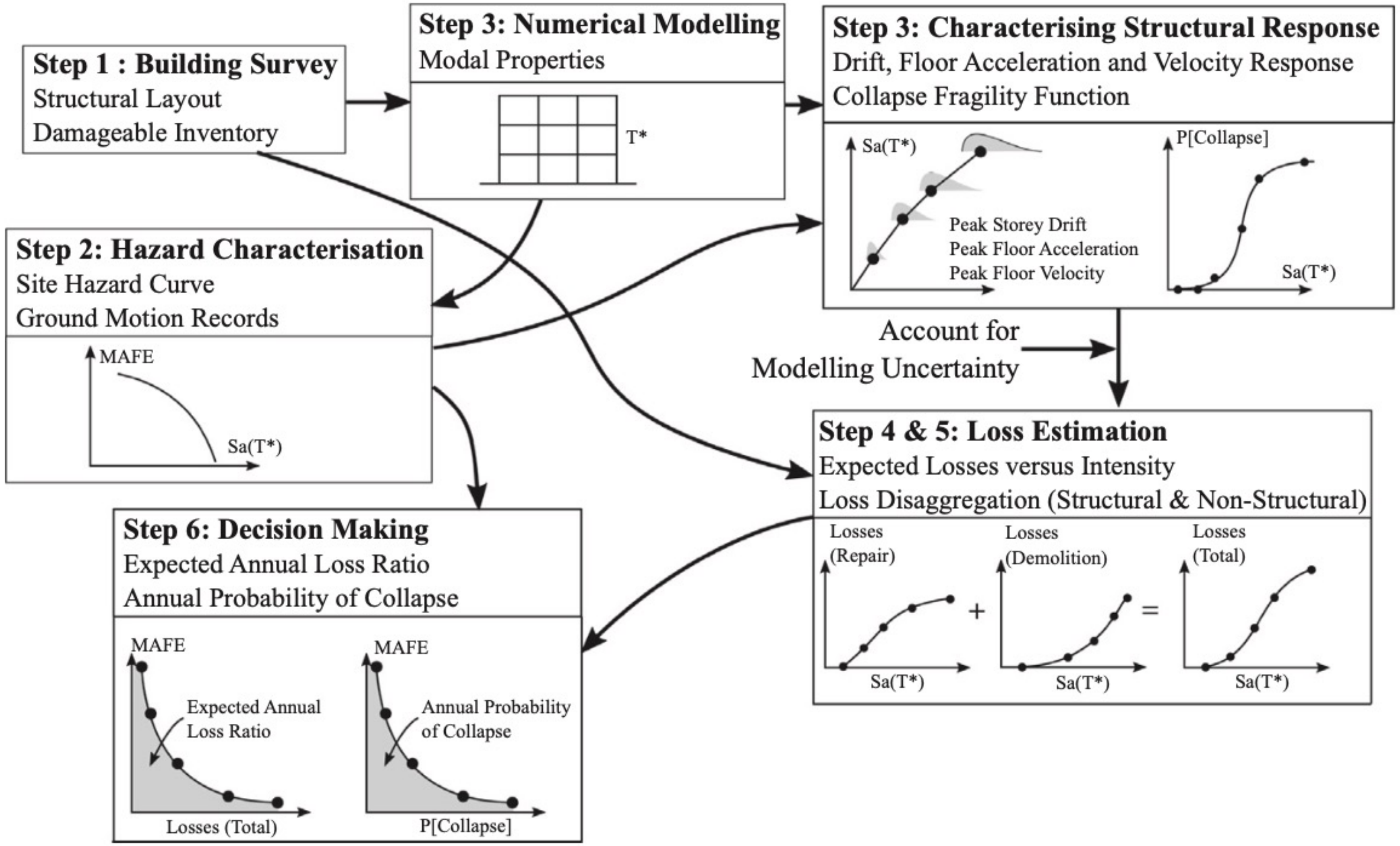
- Urgent need for risk classification methodologies for informed decision-making to carry out building tagging and prioritization of retrofitting actions
- Performance-based earthquake engineering (PBEE) requires the accurate quantification of four main components: hazard, vulnerability, risk and loss
- Loss assessment is becoming a more common instrument in the seismic performance assessment of existing structures
- Different approaches exist with varying degrees of complexity



# Existing loss assessment methods

| Methodology | Requirements | Complexity Level |
|---|---|---|
| Component-Based Approach (FEMA P-58) | • Detailed numerical model<br>• Definition of damageable inventory (i.e. quantities, costs, fragilities)<br>• Probabilistic seismic hazard assessment and hazard-consistent record selection<br>• Nonlinear time-history analysis (i.e. MSA)<br>• Quantification of peak seismic demands (i.e. PSD, PFA) and residual deformations ∀ IML<br>• Quantification of collapse fragility<br>• Analysis via PACT software | • High |
| Italian Risk Classification Guidelines, Sismabonus (Cosenza *et al.*) | • Detailed numerical model<br>• Static pushover analysis<br>• Structural performance characterization through the ”life-safety index” obtained via code-based methods (e.g. N2 method)<br>• Quantification of seismic losses through EAL obtained via prescribed set of damage-to-loss ratios | • Moderate |

# Component-based approach (FEMA P-58)



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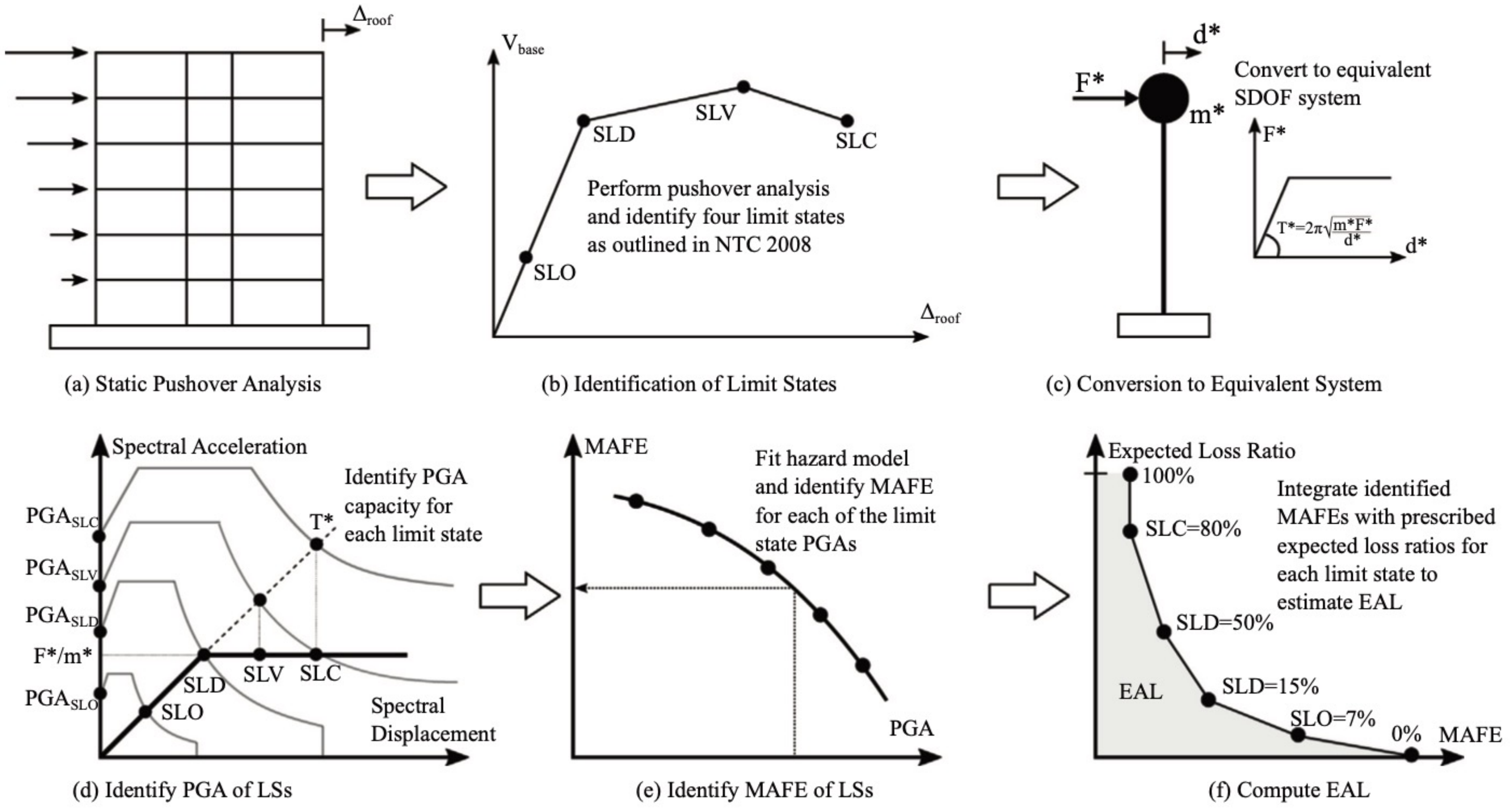
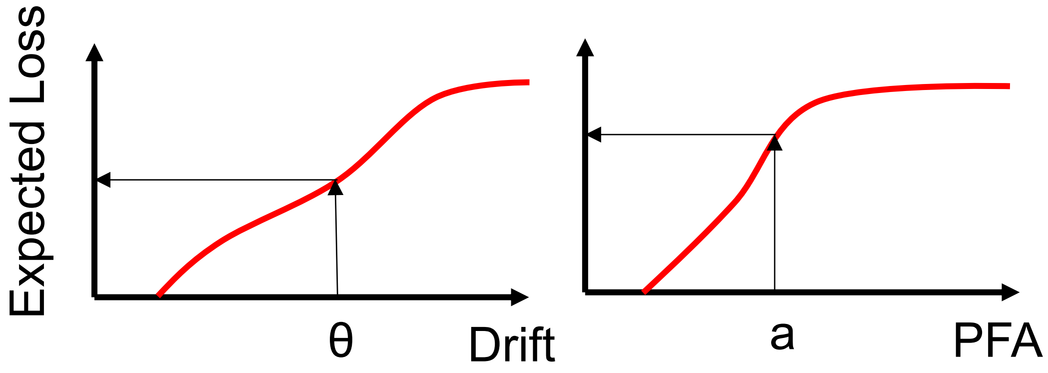
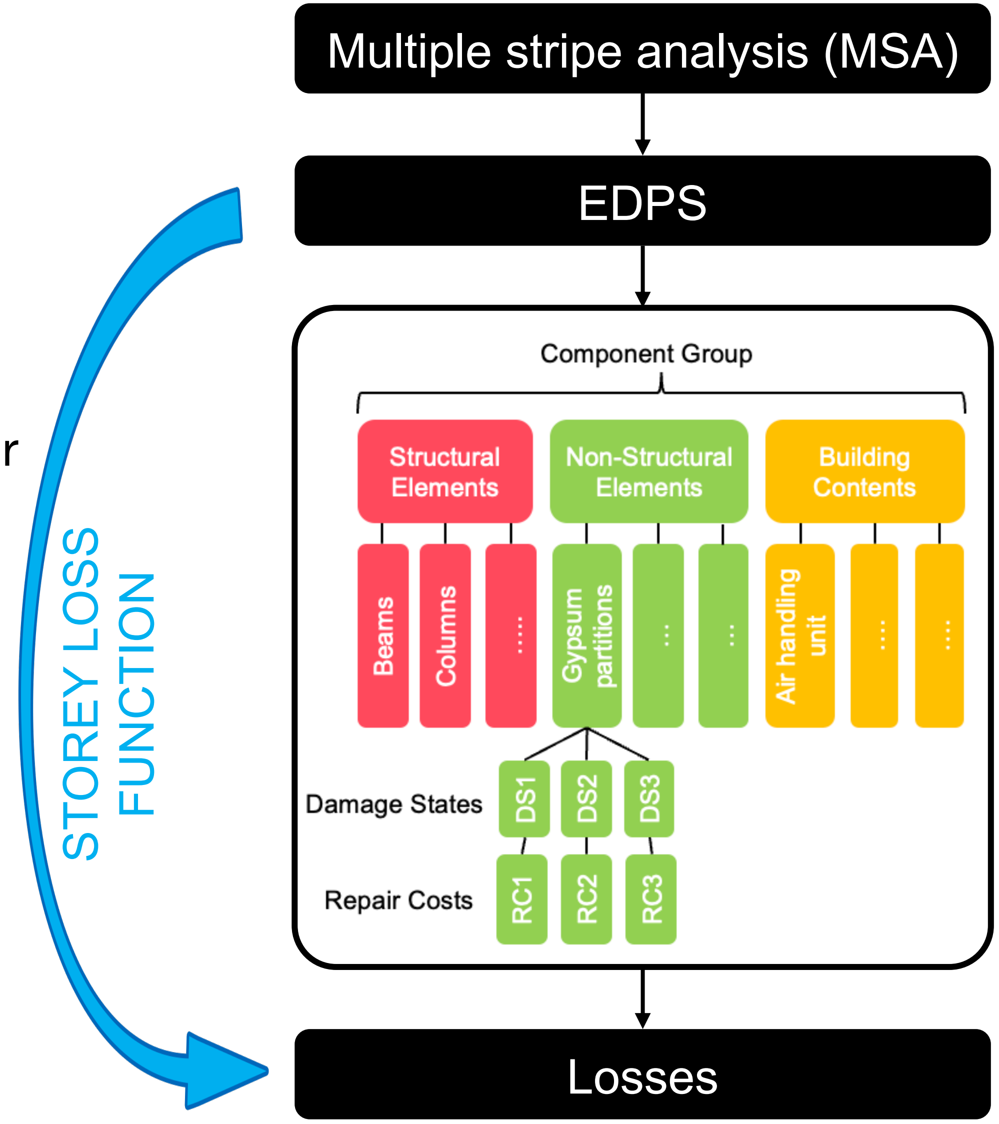
# Italian Risk Classification Guidelines (*Sismabonus*)



# Storey loss functions

- Despite the recent research developments, practitioners must be provided with tools to conduct building-specific loss assessment, **simply** and **accurately**
- The damageable inventory, fragility functions and repair cost functions are known <u>for a given building typology</u>
- Ramirez and Miranda (2009) proposed condensing these steps down to a few functions with **<u>storey loss functions</u>** that link EDP directly to the expected economic loss




*Ramirez, C. M., & Miranda, E. (2009). Building Specific Loss Estimation Methods & Tools for Simplified Performance Based Earthquake Engineering. Blume Report No. 171.*

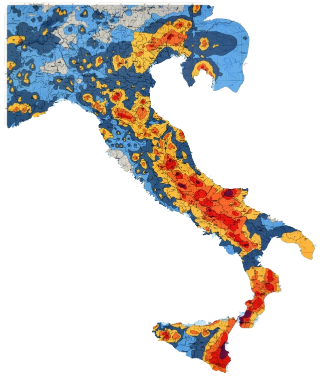
# SLF-Based Approach: PB-Loss

- Pushover-based approach to estimate economic losses intended for practical applications
- PB-Loss is implemented within a previously defined framework for simplified risk estimation (PB-Risk) via seismic hazard and vulnerability approximations
- PB-Loss integrates the recent toolbox developed by Shahnazaryan *et al.* to create user-specific SLFs

# SLF-Based Approach: PB-Loss

- PB-Loss entails:
  1. Characterisation of seismic hazard through PSHA and robust mathematical fitting (i.e. second-order polynomial fit)

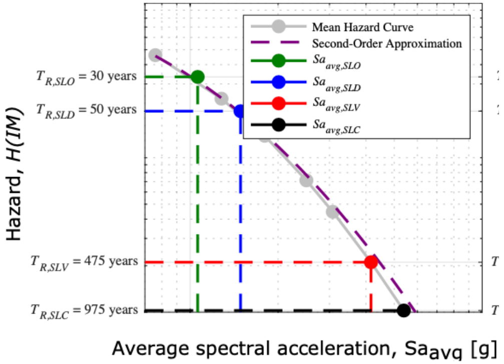
Perform probabilistic seismic hazard assessment at the location of interest (e.g., using *OpenQuake* engine)



Get mean *PGA* and $Sa_{avg}$ hazard curves at 30, 50, 475 and 975 years return periods

Apply second-order fit to hazard curves

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



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- PB-Loss entails:
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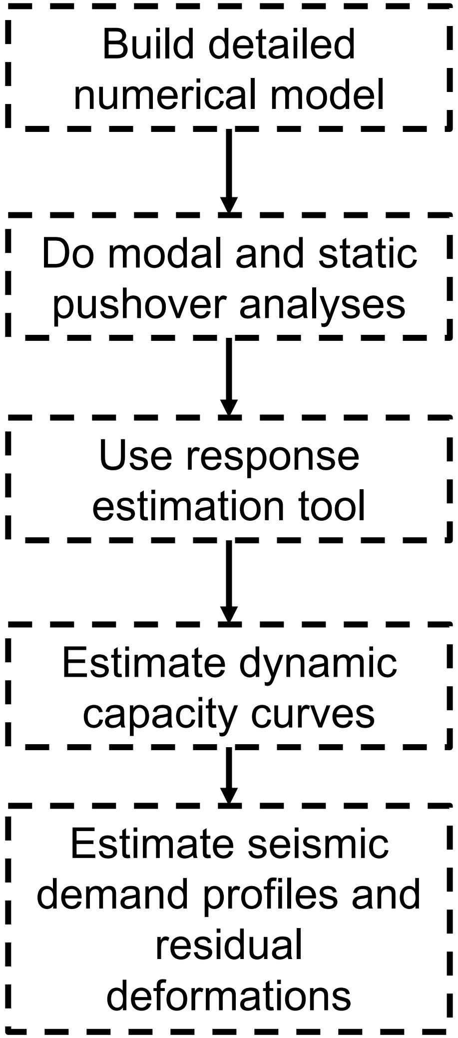
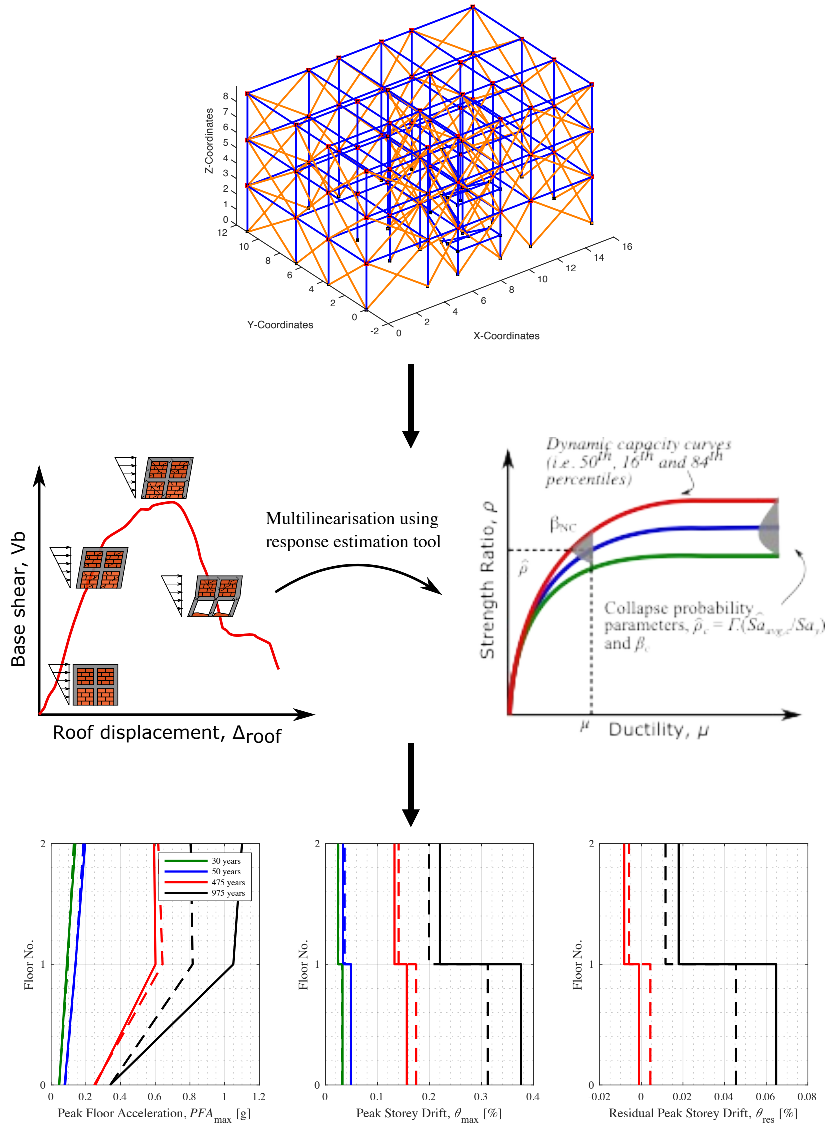
    2. Characterisation of seismic vulnerability through a response evaluation tool that empirically derives the seismic capacity of a given structure through a simple pushover analysis and $\rho$-$\mu$-$T$ relationships



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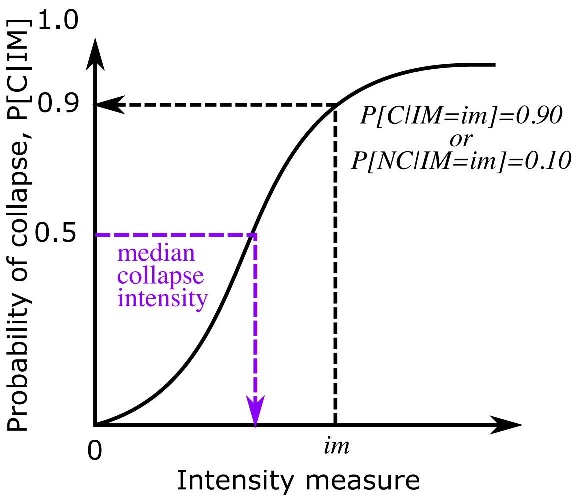
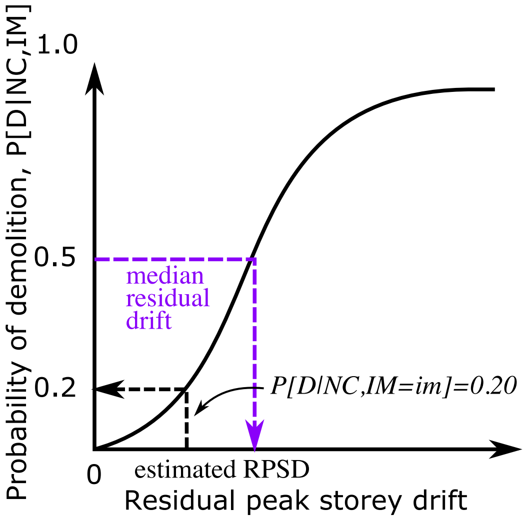
    3. Characterisation of collapse and demolition probabilities



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  3. Characterisation of collapse and demolition probabilities
  4. Calculate collapse risk using the SAC/FEMA IM-based approach

$$\lambda_C = \sqrt{p} k_0^{1-p} [H(\widehat{Sa}_{avg,C})]^p \exp\left[\frac{1}{2} p k_1^2 \beta_C^2\right]$$

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

where $k_0$, $k_1$, $k_2$ are the coefficients of the second-order hazard fit; $H(\widehat{Sa}_{avg,C})$ and $\beta_C$ are the mean annual rate of exceeding the median collapse intensity and the uncertainty associated with the collapse fragility, respectively;

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  3. Characterisation of collapse and demolition probabilities
  4. Calculate collapse risk using the SAC/FEMA IM-based approach
  5. Estimation of direct economic losses accounting for repair, demolition and total replacement (i.e., collapse)

$$E[L_T|IM] = \underbrace{E[L_T|NC \cap R, IM]}_{\text{repair costs from SLFs}} \overbrace{(1 - P[D|NC, IM])}^{\text{probability of no-demolition}} \underbrace{(1 - P[C|IM])}_{\text{probability of no-collapse}} + \overbrace{E[L_T|NC \cap D]}^{\text{demolition costs}} \underbrace{P[D|NC, IM]}_{\text{probability of demolition}} \overbrace{(1 - P[C|IM])}^{\text{probability of no-collapse}} + \underbrace{E[L_T|C]}_{\text{total replacement cost}} \overbrace{P[C|IM]}^{\text{probability of collapse}}$$

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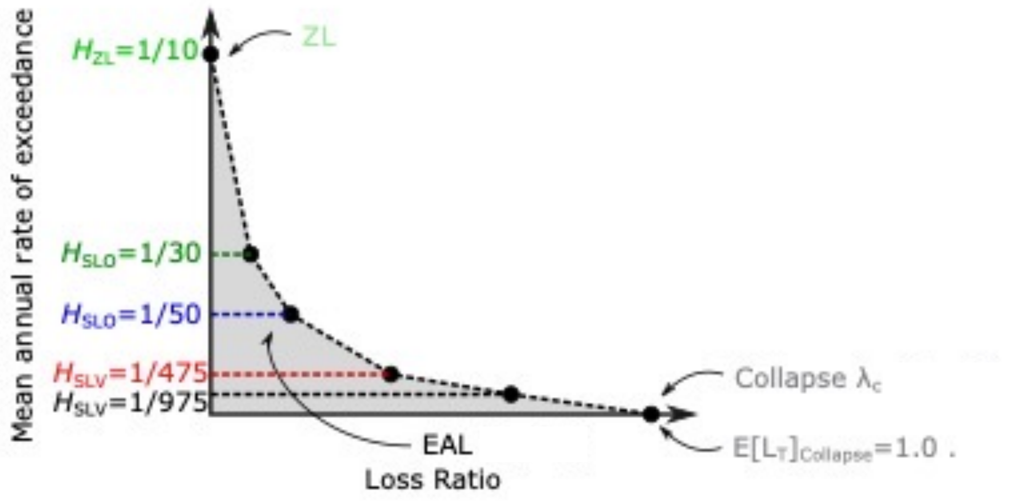
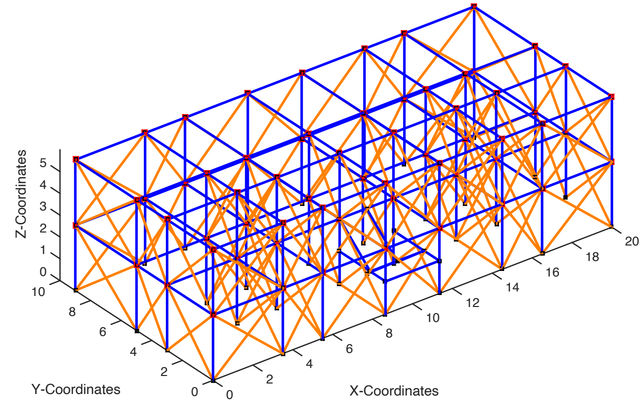
  3. Characterisation of collapse and demolition probabilities
  4. Calculate collapse risk using the SAC/FEMA IM-based approach
  5. Estimation of direct economic losses accounting for repair, demolition and total replacement (i.e., collapse)
  6. Build the loss curve and calculate EAL




$$EAL = \int E[L_T|IM = im] \left|\frac{dH(IM > im)}{dim}\right| dim$$

# Case Study Application

- 70 Archetype non-ductile infilled reinforced concrete buildings (2-6 stories) representative of the southern Mediterranean construction were analysed
- Different plan layouts
- Distinct temporal design considerations

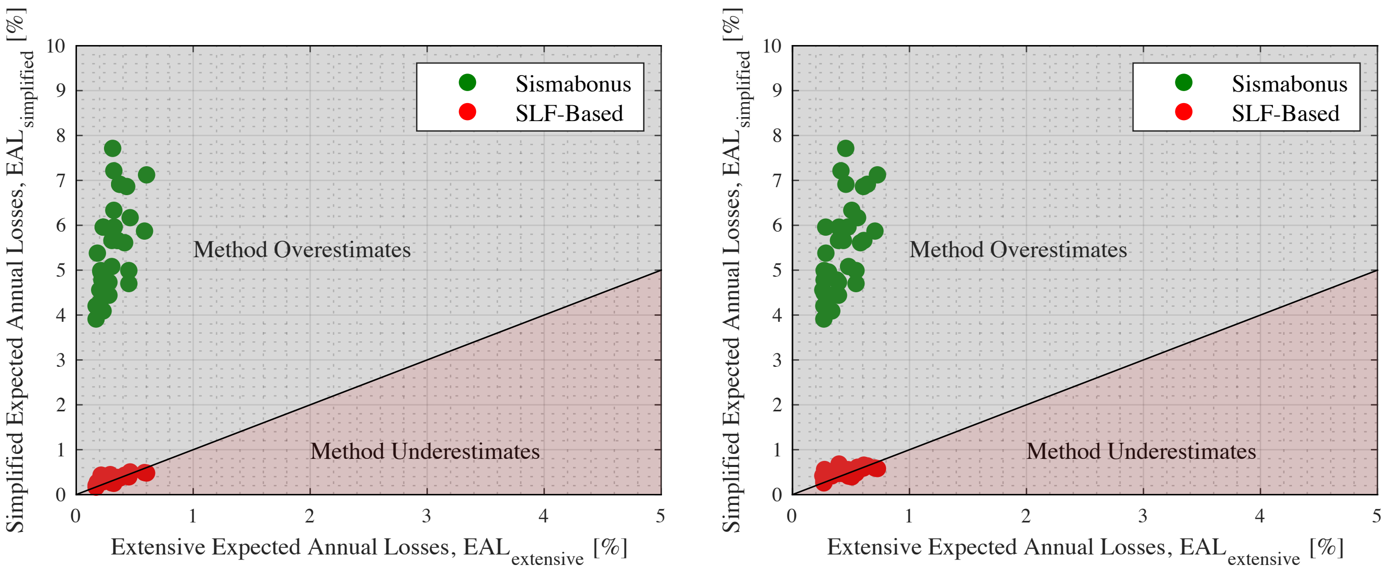



| Archetype Design Consideration | Construction Era | Design Methodology | Design Considerations |
|---|---|---|---|
| Gravity-Load Design (GLD) | Pre-1970s | Gravity Loads + Allowable Stress Method (Royal Decree 2229/39) | • Frames spanning in one direction<br>• Smooth rebars with low yield strength (Aq42, ($\sigma_{all,s} \approx$ 140 MPa)<br>• Concrete with low compressive strength ($\sigma_{all,c} \approx$ 5 MPa)<br>• Poor transverse detailing and low shear reinforcement ratios<br>• Inadequate detailing of beam-column joints |
| Sub-Standard Design (SSD) | 1970s-1980s | Equivalent Lateral Force Method + Allowable Stress Method (L. 1086/71, DM 40/1975, DM 108/1986) | • Frames spanning in one (or both) directions<br>• Deformed rebars with moderate yield strengths (FeB44k, $\sigma_{all,s} \approx$ 260 MPa)<br>• Concrete with moderate compressive strength ($\sigma_{all,c} \approx$ 7.5 MPa)<br>• No consideration for ductile detailing |

# Comparison

| Method | Procedure |
| --- | --- |
| Component-Based Approach (FEMA P-58) | 1. Detailed numerical modelling;<br>2. Definition of building damageable inventory;<br>3. PSHA using $Sa_{avg}$ at L'Aquila, Italy;<br>4. Hazard-consistent ground-motion selection using EzGM toolbox (Ozsarac *et al.*);<br>5. Multiple-stripe analysis using 9 intensity measure level corresponding to return periods of 22-4975 years;<br>6. Post-processing of MSA results for the quantification of seismic demands, residual drifts, collapse fragility;<br>7. Loss-based assessment in PACT;<br>8. Calculate the EAL; |
| Sismabonus (Italian guidelines) | 1. Detailed numerical modelling;<br>2. Static pushover analysis;<br>3. N2 method to determine life-safety index (PGAc/PGAd);<br>4. Calculation of mean annual frequency of exceedance (MAFE) using life-safety index;<br>5. Assembling MAFE vs expected loss ratio (i.e. repair costs/ total replacement cost) curve;<br>6. Calculate the EAL; |
| PB-Loss | 1. Detailed numerical modelling;<br>2. Modal and static pushover analysis;<br>3. PSHA using PGA and $Sa_{avg}$ at L'Aquila, Italy;<br>4. Estimate the seismic demands and collapse fragility using the response estimation tool;<br>5. Calculate the collapse risk using the SAC/FEMA approach;<br>6. Estimate the repair costs using SLFs;<br>7. Calculate the total repair costs;<br>8. Build and integrate under the loss curve to calculate the EAL; |

# Results




- The comparison was carried out in terms of the EAL evaluated from Sismabonus and PB-Loss plotted against component-based assessment taken as benchmark
- Sismabonus significantly overestimates the EAL for all case study buildings due to the high fixed loss ratios (percentage of the total replacement cost) associated with each prescribed limit-states
- PB-Loss yielded relatively good estimates when compared to the component-based approach due to its adaptability in characterising the economic losses related to structural and non-structural damage

# Conclusions

- A novel pushover-based loss assessment (PB-Loss) was developed to address the shortcomings and incorporate many facets currently overlooked in practical loss assessment
- PB-Loss is a relatively fast and simple method for the estimation of direct economic losses offering a high level of accuracy while significantly reducing the demanding computational effort required by extensive methods such as the component-based approach adopted in FEMA P-58
- PB-Loss integrates state-of-the-art robust approximations and assumptions for the representation of hazard , characterization of seismic vulnerability, estimation of seismic risk and evaluation of direct losses corresponding to repair, demolition and collapse
- A comparative case-study application on a large set of archetype numerical models highlighted the robustness of the generalized SLF-based approach (PB-Loss) for evaluating economic losses when compared to the more rigorous component-based approach
- Existing methodologies implemented within national standards such as Sismabonus in Italy were also comparatively evaluated with respect to PB-Loss. Results showed that Sismabonus consistently overestimated the losses with respect to the component-based approach