# Uncertainty in performance-based analysis of RC buildings due to variability in the ground motion group size and direction

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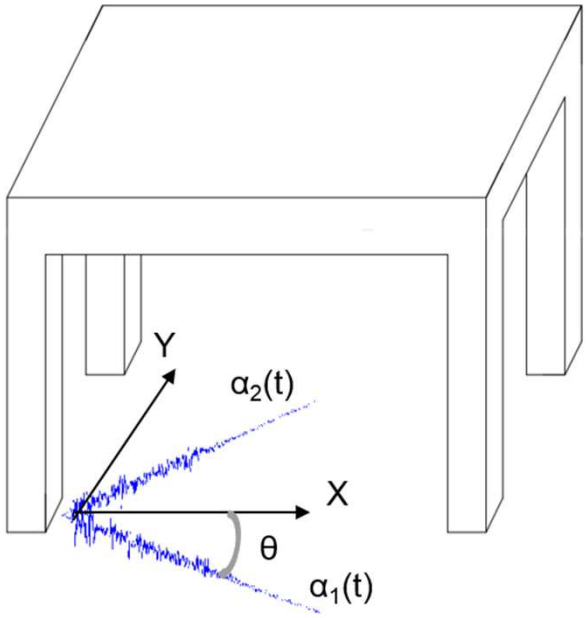
# The angle of incidence of the seismic input

What is the angle of seismic incidence?

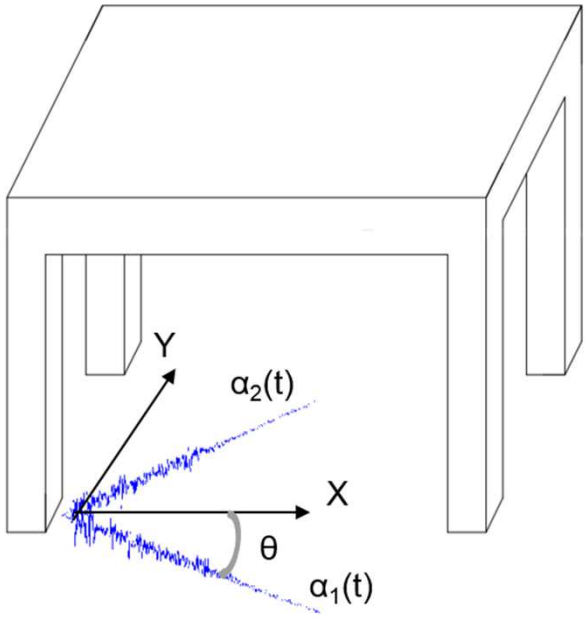



Angle of seismic incidence (ASI) {θ}

# The angle of incidence of the seismic input

What is the angle of seismic incidence?

How do we account for it?

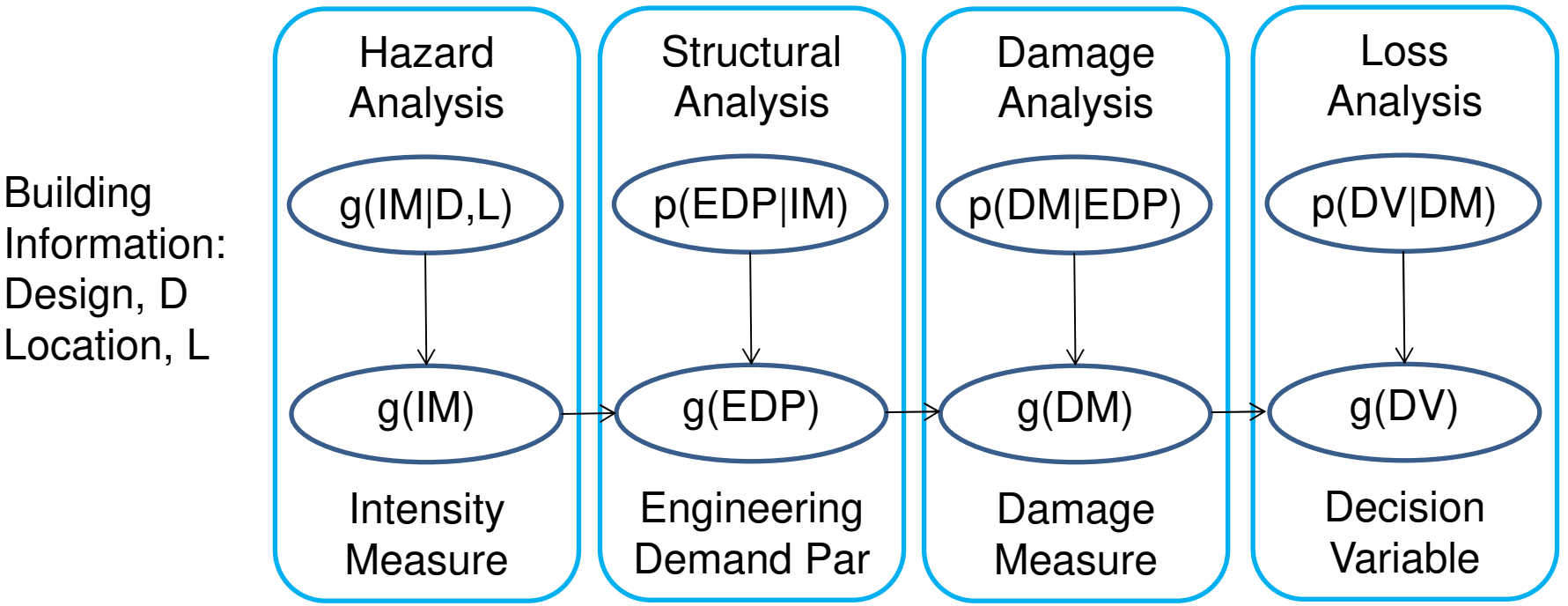



Angle of seismic incidence (ASI) {θ}

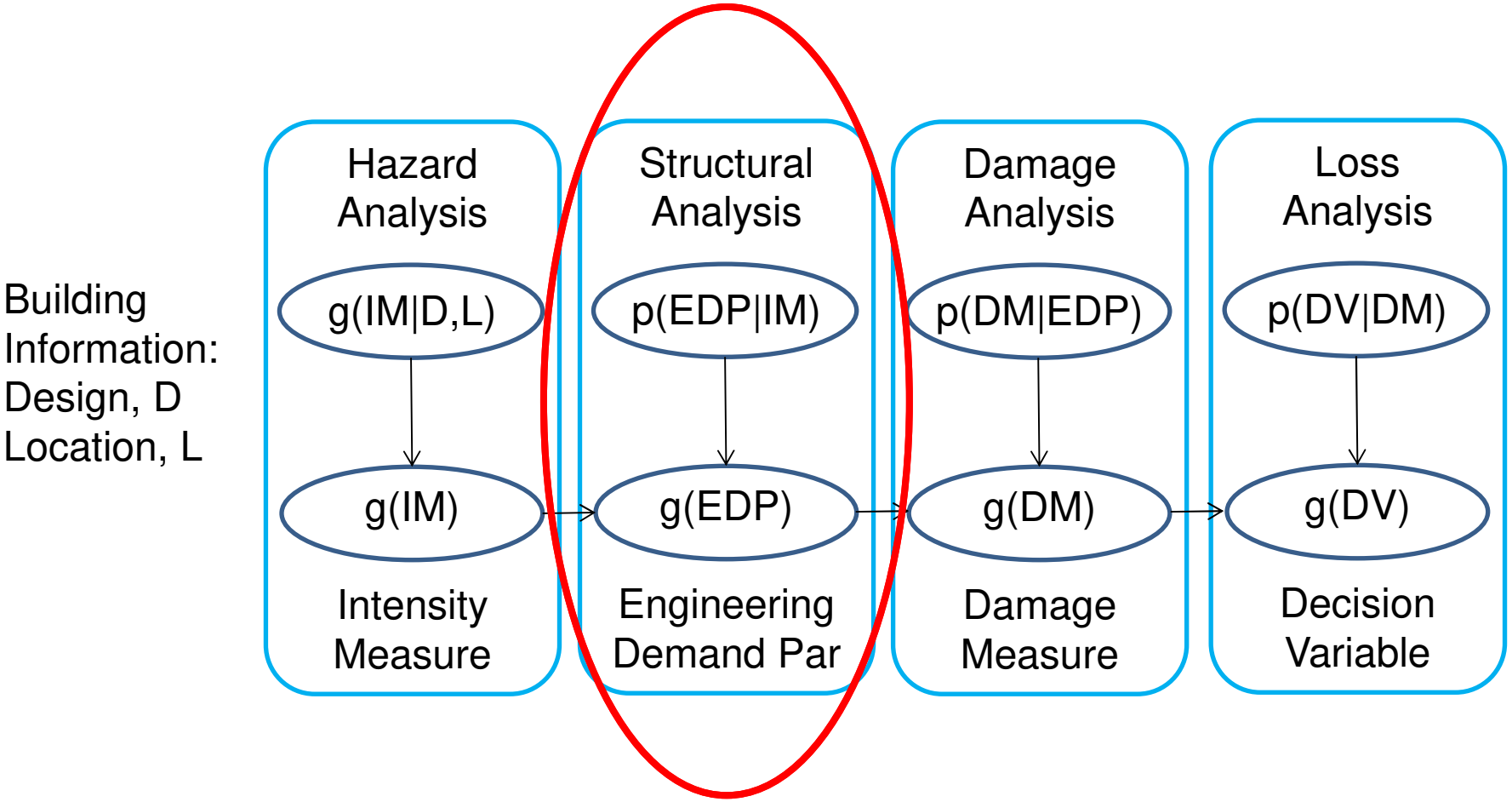
Traditionally one angle:
θ = 0° and $\alpha_1(t)$ // X, $\alpha_2(t)$ // Y

However, is it adequate??

# Probabilistic approach – PEER-PBEE framework



# Probabilistic approach – PEER-PBEE framework



# Probabilistic approach framework

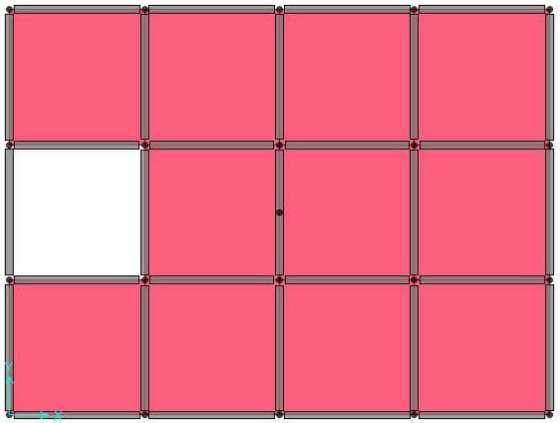
Objective: Effect of the ASI and of the Ground Motion group size on the different stages of the PBEE-PEER methodology: Structural, Damage and Loss analysis.

How:

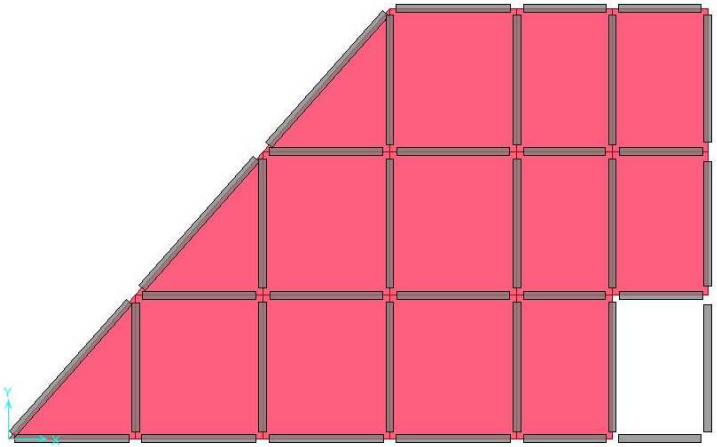
- Analysis of six 3D RC structures (regular and irregular in-plan, different number of storeys), located at a benchmark site.
- Nonlinear time history analysis with reference group of 40 GMs applied along 12 ASIs.
- Reduced sizes of GM groups: 10, 15 ,20, 25, 30, 35. (Regrouping procedure).
- Reduced number of ASIs: 1 to 11.
- Examine the effect of the reduced information, induced by the different of number of ASIs and GMs, on the EDP and its propagation to Collapse risk and Expected Annual Loss

# Structures analysed: Layout

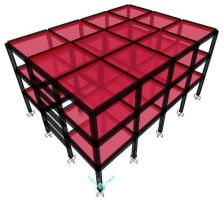
Regular



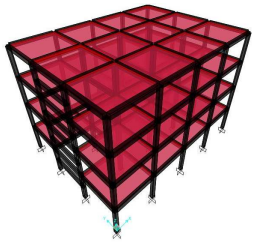
Irregular



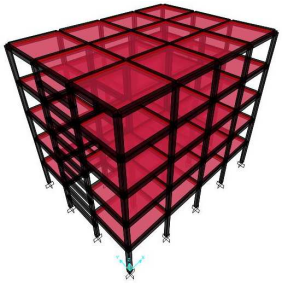
3 storeys



4 storeys



5 storeys

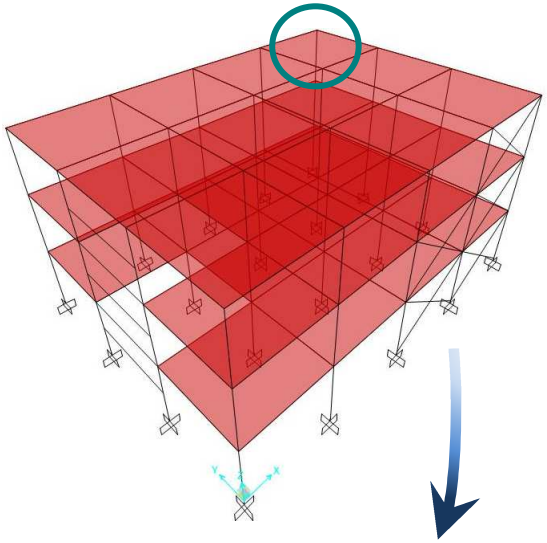


3 storeys

4 storeys

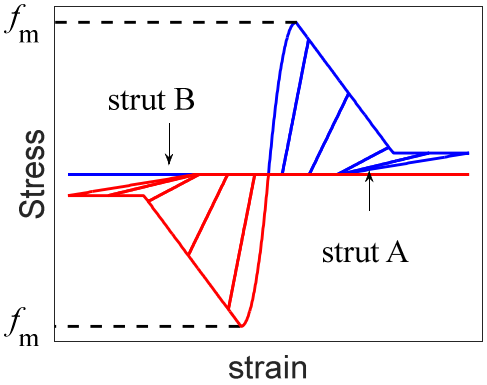
5 storeys

# Structures analysed: Modelling



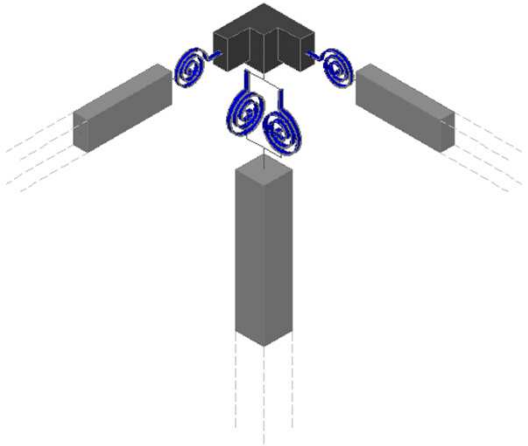
Full/partial infills in peripheral frames

2 struts/infill (compression-only)




Backbone Curve of infill w/wo opening. Dolsek and Fajfar (2008), Panagiotakos and Fardis (1996)

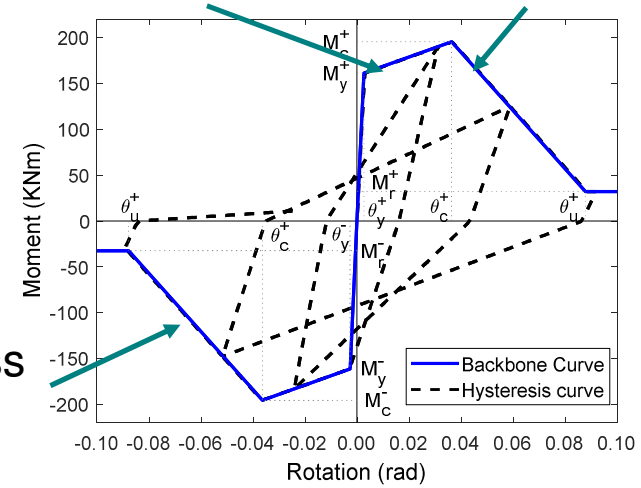
Lumped plasticity model



Stiffness degradation

Strength degradation

Unloading stiffness degradation

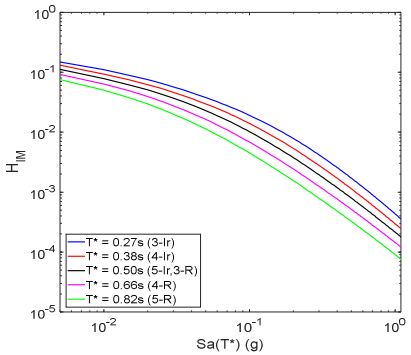



Hysteresis loop. Panagiotakos and Fardis (ACI 2001), Ibarra, L. F., and Krawinkler, H. (2005), Haselton, et al (2008)

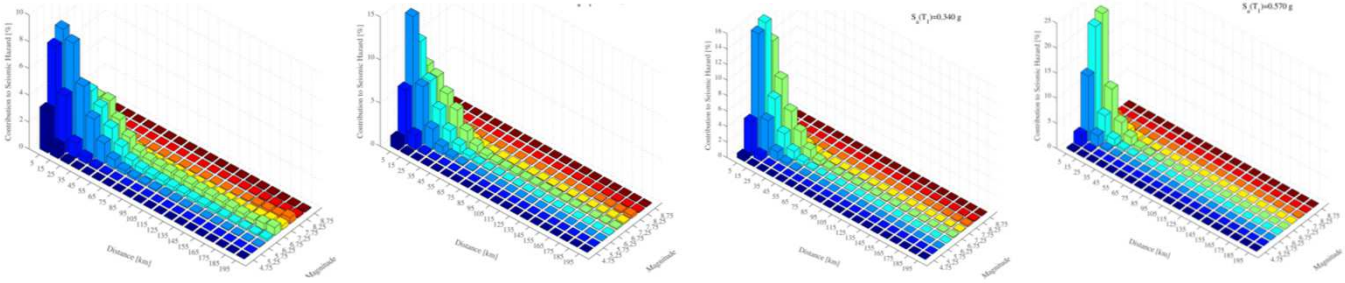
# Ground motion selection

## Location Lisbon, Portugal

### a) PSHA

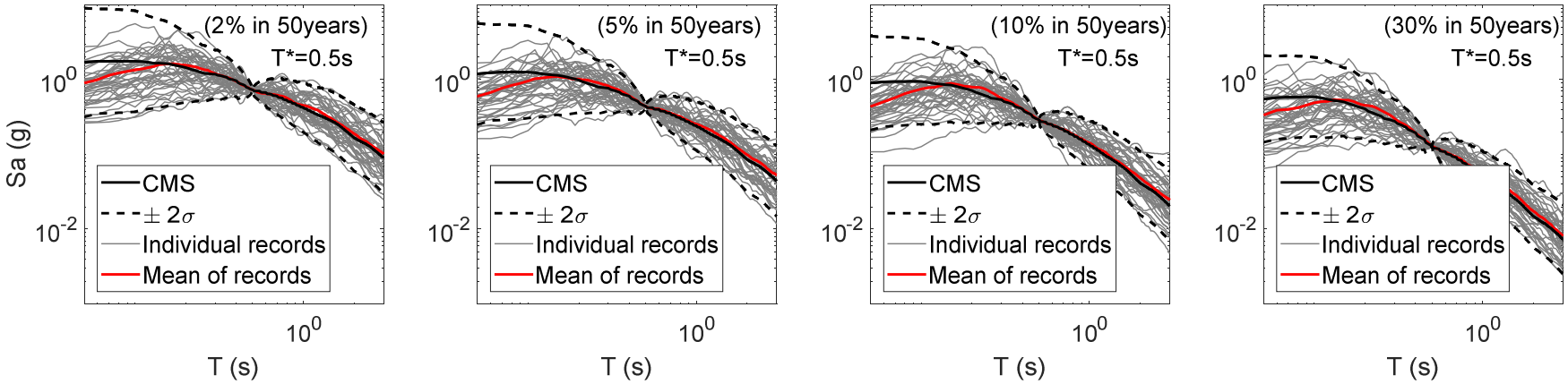



### b) Hazard disaggregation for 4 probabilities of exceedance



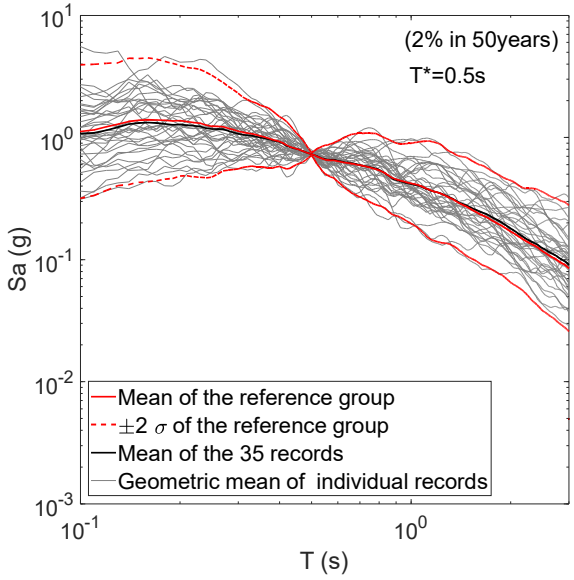
30% in 50 years | 10% in 50 years | 5% in 50 years | 2% in 50 years

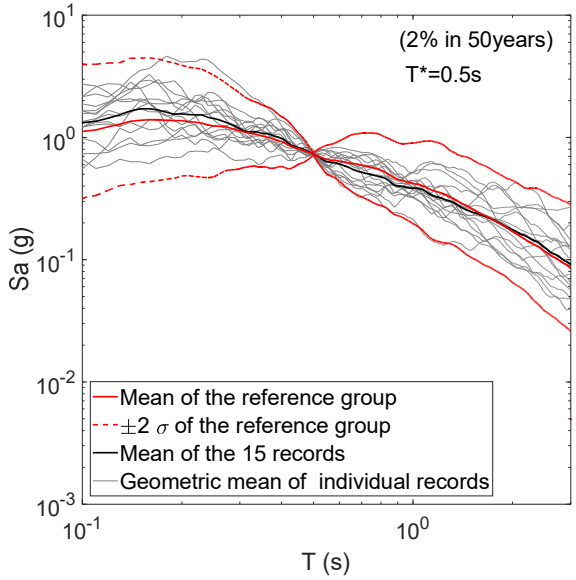
### c) CMS (Baker JW (2010)) 40 pairs of GMs



# Ground motion regrouping procedure

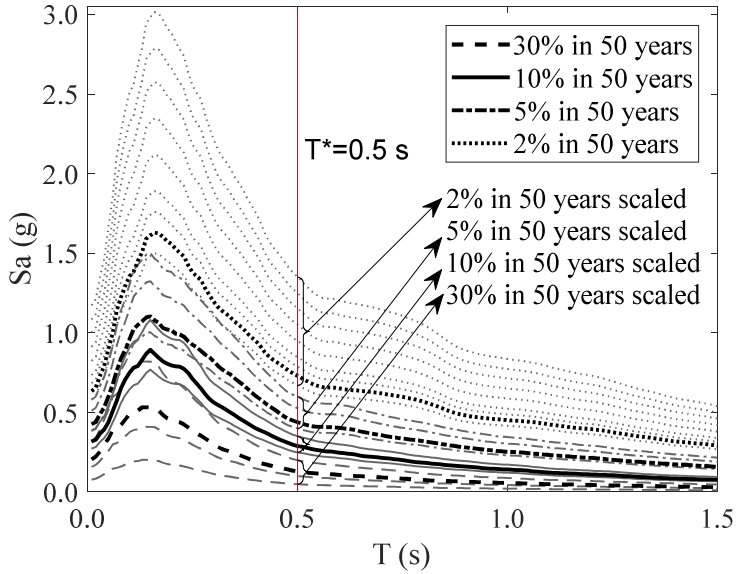
- Each GM group of size 40 is regrouped into GM groups of size: 10, 15 ,20, 25, 30 and 35.
- Regrouping criteria consistent with the initial selection to ensure compatibility with the seismic scenario.
- Total number of 100 groups are created for each combination of a certain GM group size and number of ASIs (1-12).



# Structural Analysis: Probabilistic demand model

Multiple-stripe analysis with 20 intensities (Jalayer & Cornell, 2009)




- ✓ 40 GM pairs compatible with CMS
- ✓ 12 ASIs [0° 165 °] steps of 15 °
- ✓ 20 intensities
- ✓ 6 buildings

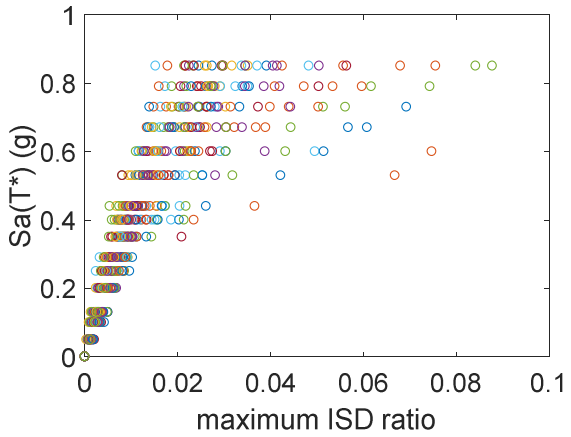
100 groups for each combination size (35, …10) with ASI (1, …12).

EDPs:

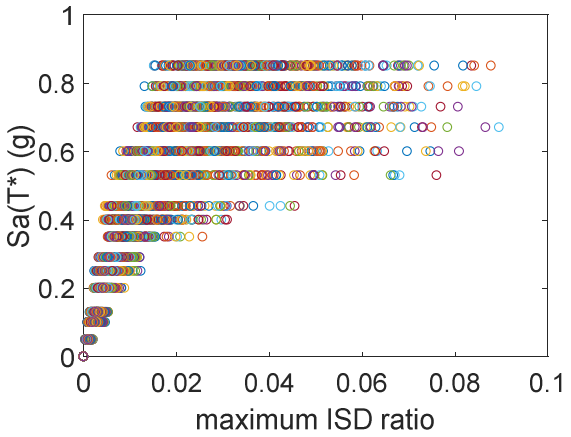
(ISD)
(PFA)
(RD)

# Stripes of EDPs

3-storey regular 40 GMs 1 ASI

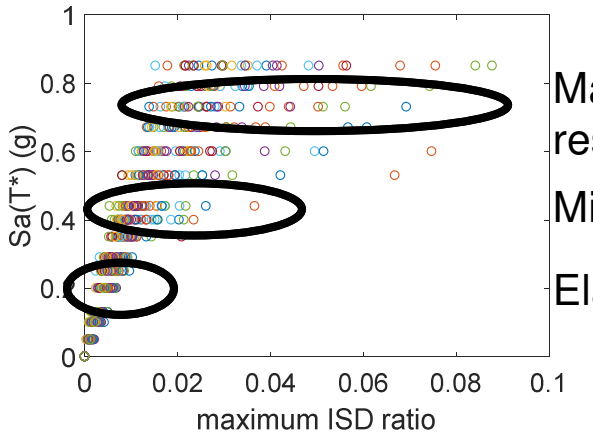



3-storey regular 40 GMs 12 ASIs



# Stripes of EDPs

3-storey regular 40 GMs 1 ASI

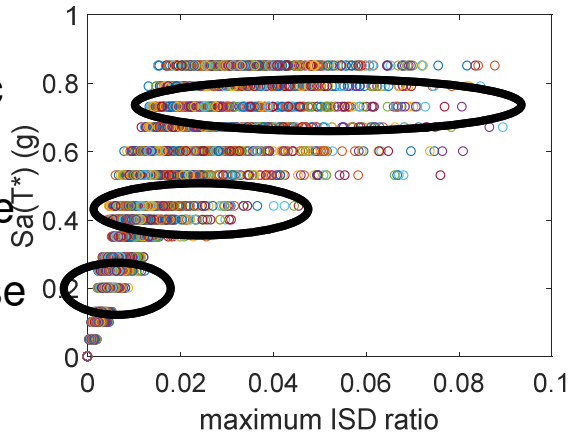



Mainly inelastic response

Mixed response

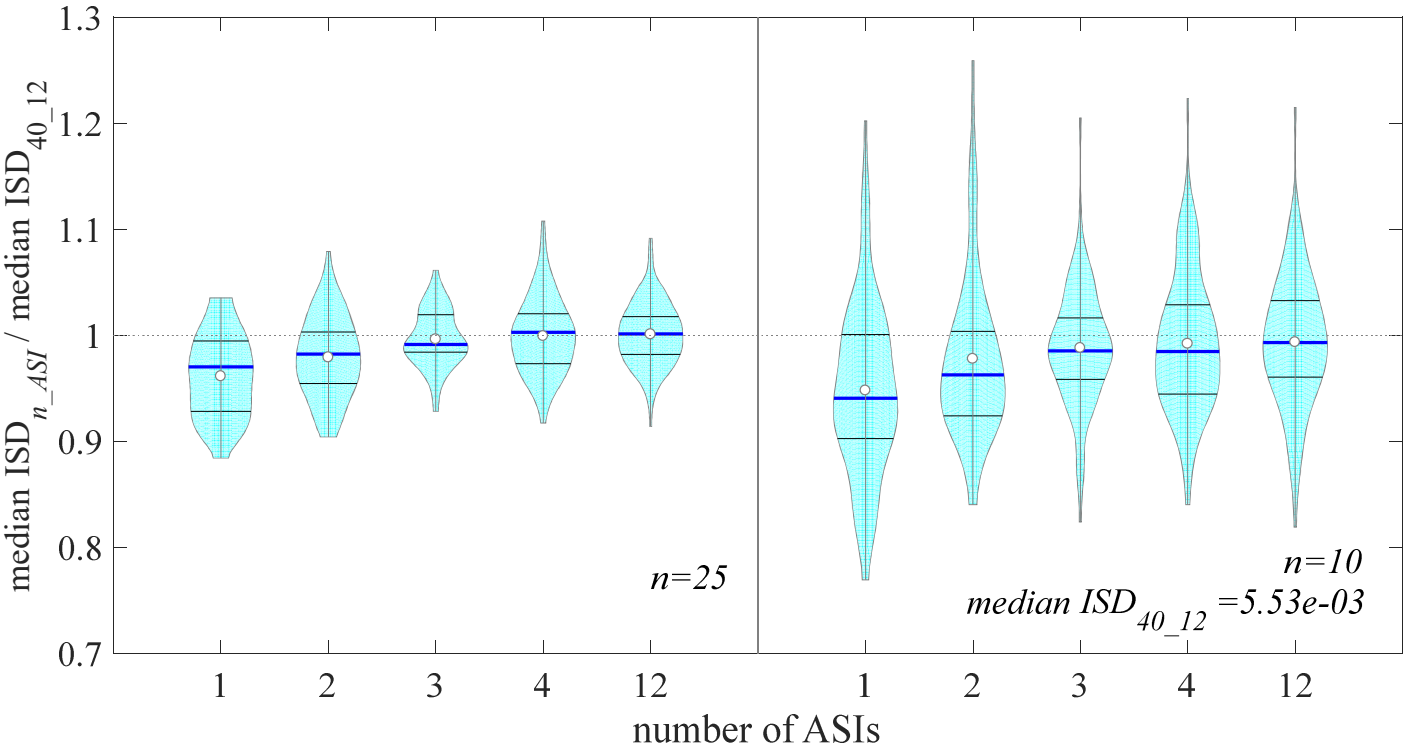
Elastic response

3-storey regular 40 GMs 12 ASIs



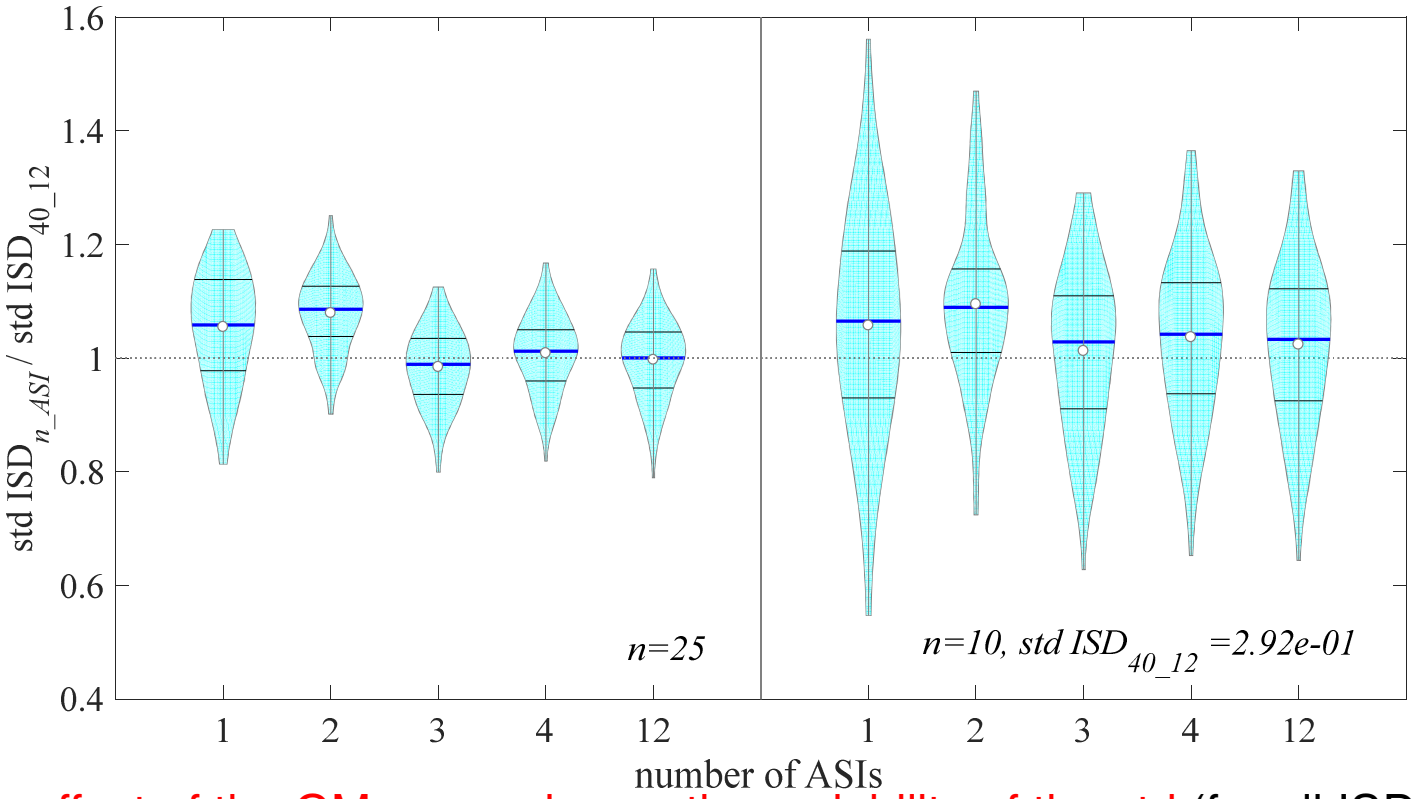

- ✓ The effect of the ASI and the GM group size on the empirical demand
- ✓ Three descriptive statistics (central tendencies and dispersion) of the empirical demand distribution of EDPs at selected Intensity Levels
- ✓ 100 statistics for each *size_ASI* combination

# Empirical Demand – Central tendencies




- ✓ Large effect of the GM group size on the variability of the median (for all ISD, RD and PFA). It governs the variability (observed when all 12 ASIs are used)
- ✓ Slightly larger variability when only 1 ASI is used, which decreases when 2-3 ASIs are used. Negligible variability with 4 or more ASIs.
- ✓ Shift of the distribution when only 1 ASI is used, effectively corrected with at least 2 ASIs.

# Empirical Demand – Dispersion




- ✓ Large effect of the GM group size on the variability of the std (for all ISD, RD and PFA). It governs the variability (observed when all 12 ASIs are used)
- ✓ Larger variability when only 1 ASI is used, which decreases when 2-4 ASIs are used.
- ✓ Shift of the distribution when only 1 ASI is used, suggested up to 4 ASIs to effectively correct it..

# Collapse capacity and risk modelling

Capacity modelling: Ultimate chord rotation in a column

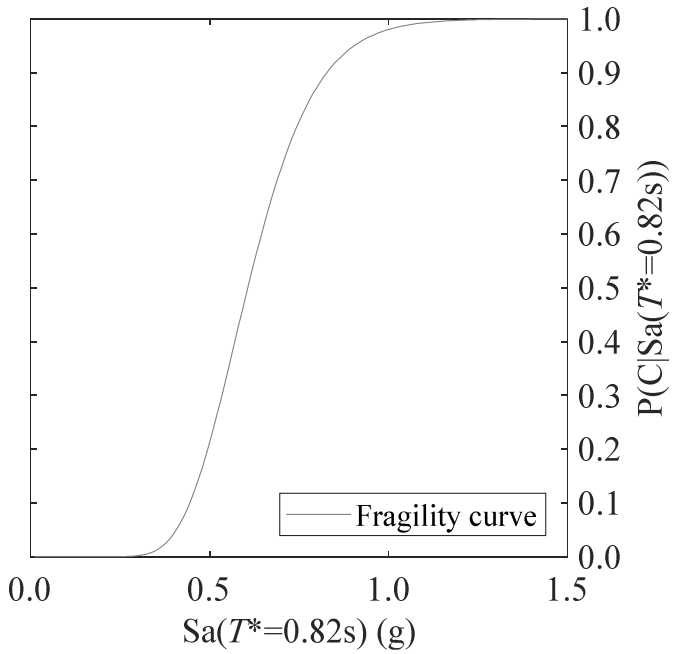
Shear failure in a column

Numerical failure of the model

Probability of collapse:

$$P\left(C|IM=im\right)=\Phi\left(\frac{\log(im/\theta_C)}{\beta_C}\right)$$

1 group of a given combination: GM group size & ASI



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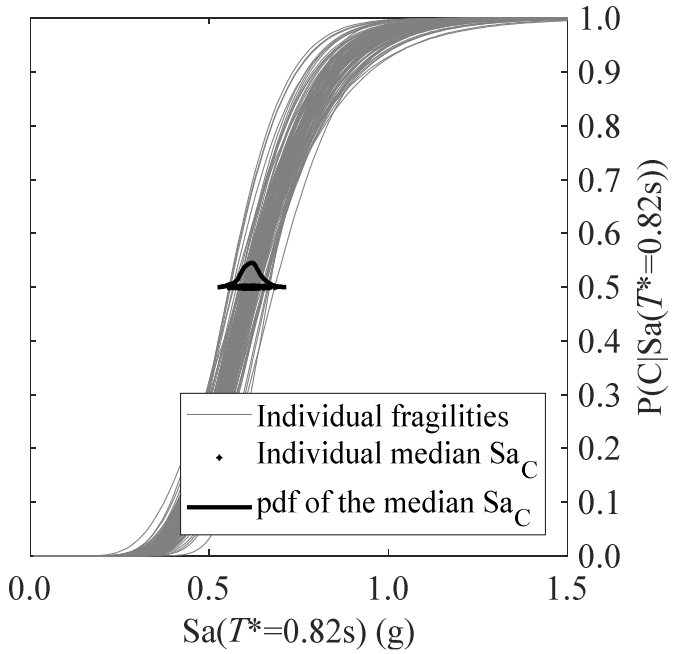
$$P(C|IM=im) = \Phi\left(\frac{\log(im/\theta_C)}{\beta_C}\right)$$

100 groups of a given combination: GM group size & ASI



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Capacity modelling: Ultimate chord rotation in a column

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Numerical failure of the model

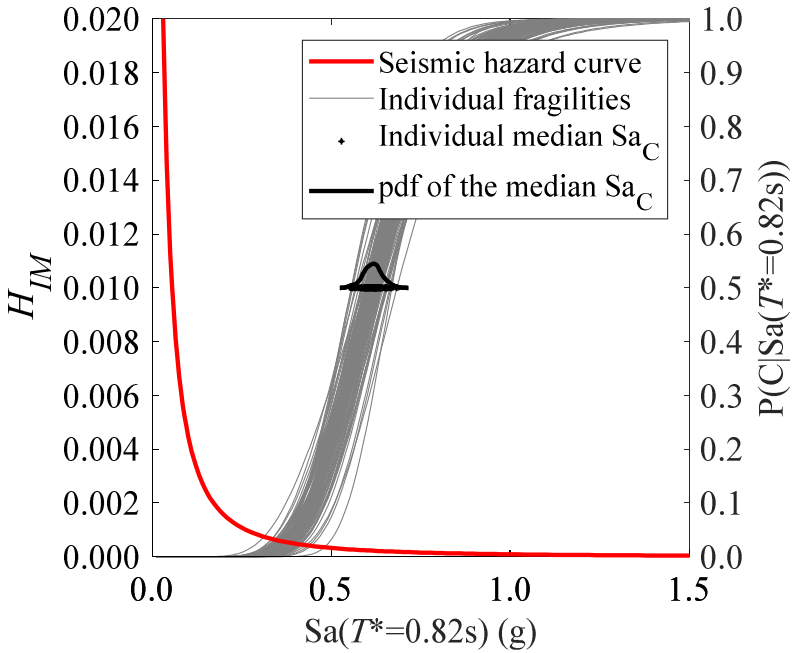
Probability of collapse:

$$\mathrm{P}\left(\mathrm{C}|\mathrm{IM}=im\right)=\Phi\left(\frac{\log(im/\theta_C)}{\beta_C}\right)$$

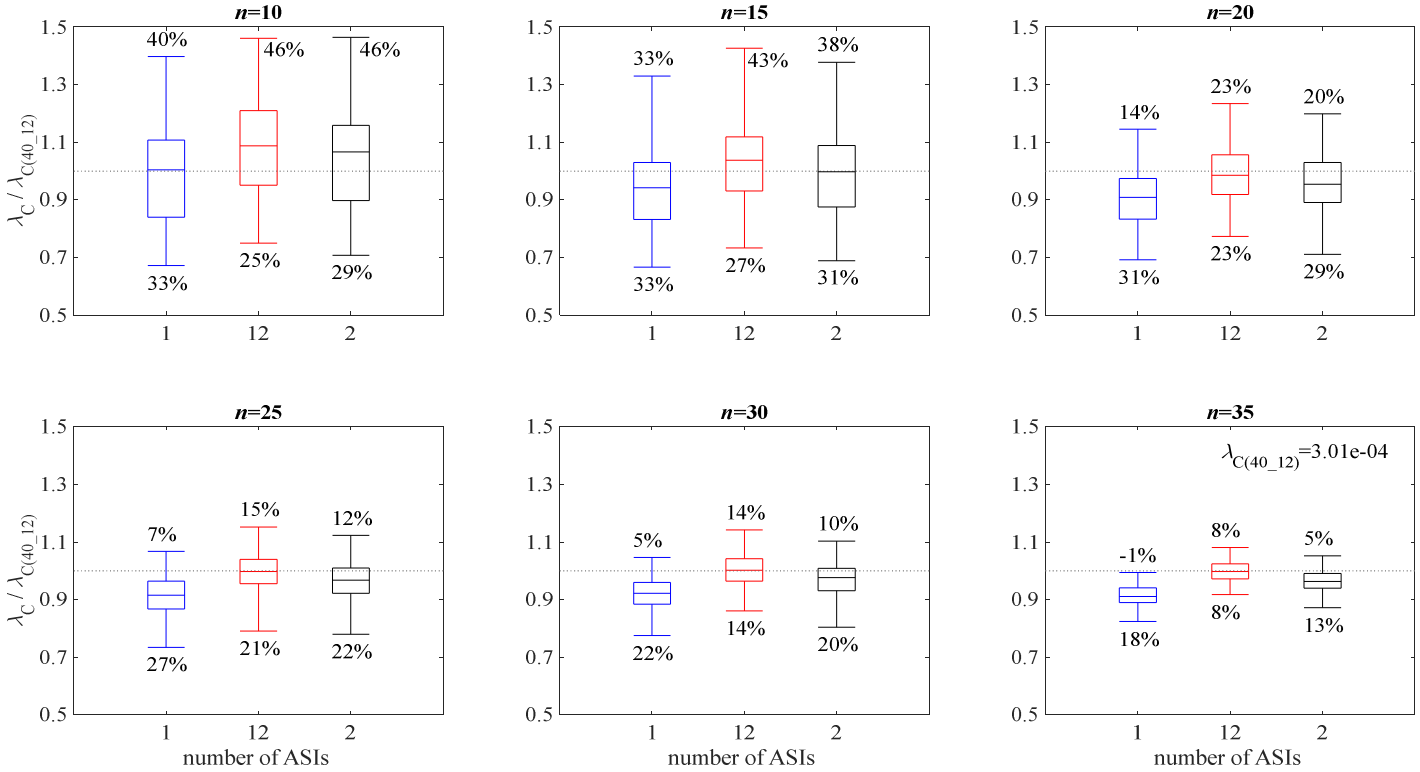
Rate of Collapse (Risk):

$$\lambda_C=\int_0^{\infty}\mathrm{P}\left(\mathrm{C}|\mathrm{IM}=im\right)\left|dH_{IM}(im)\right|$$

100 groups of a given combination: GM group size & ASI



# Collapse risk - Results

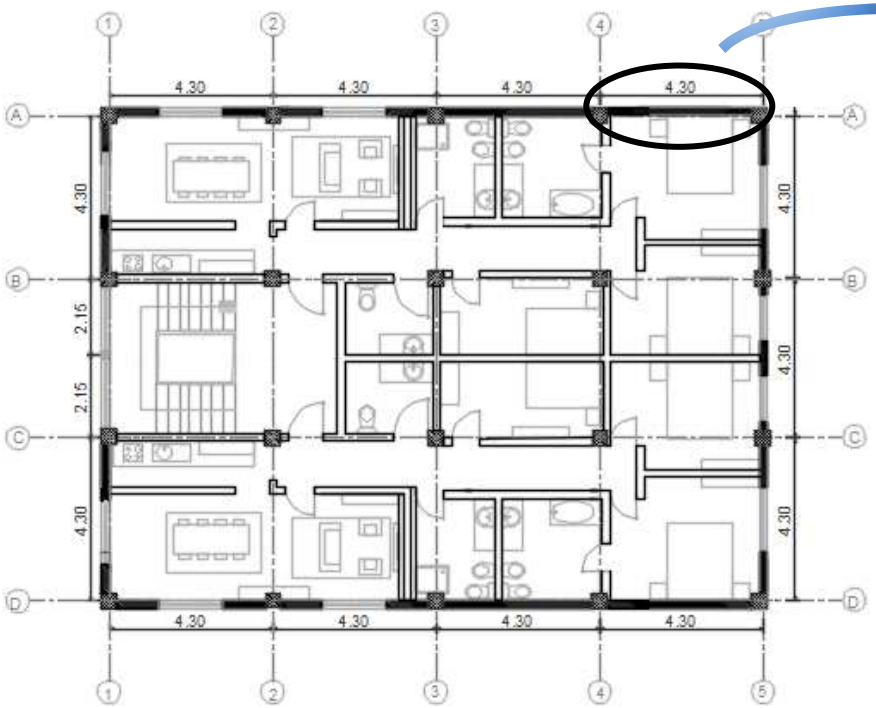


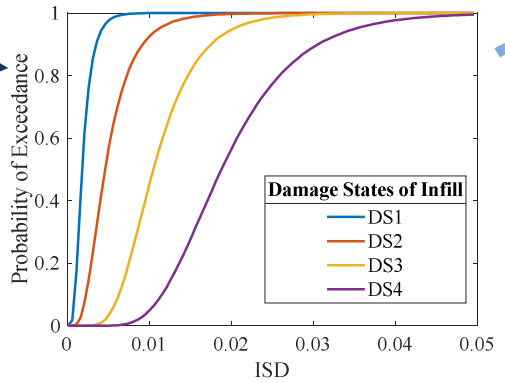

- ✓ Large effect of the GM group size on the variability of collapse risk.
- ✓ Slightly larger variability when only 1 ASI is used, which decreases when 2 ASIs are used.
- ✓ The median collapse risk exhibits bias when only 1 ASI is used, effectively corrected with at least 2 ASIs.
- ✓ Suggestion: 20 GMs along 2 ASIs

# Loss analysis – Modelling of the EAL

Final output of the PEER-PBEE methodology: Decision Variable
Here: Direct economic losses.

Damageable building inventory



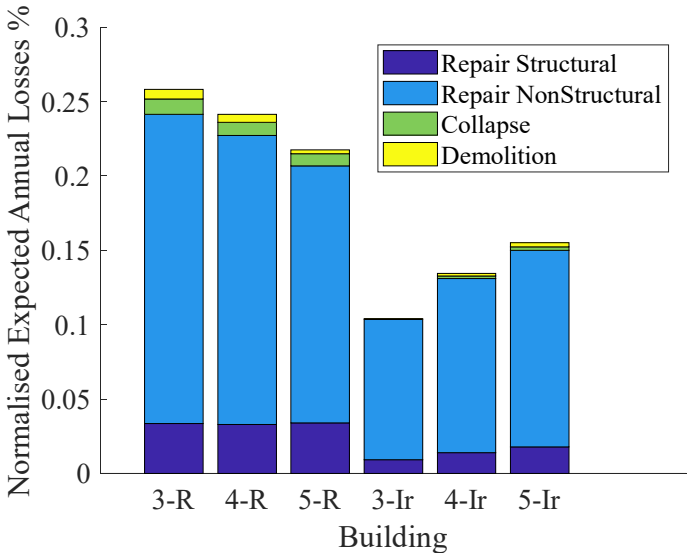

Repair Cost for each DS

$$E(L|IM_m) = E(L|NC \cap R, IM_m)P(NC \cap R|IM_m) + E(L|NC \cap D, IM_m)P(NC \cap D|IM_m) + E(L|C, IM_m)P(C|IM_m)$$

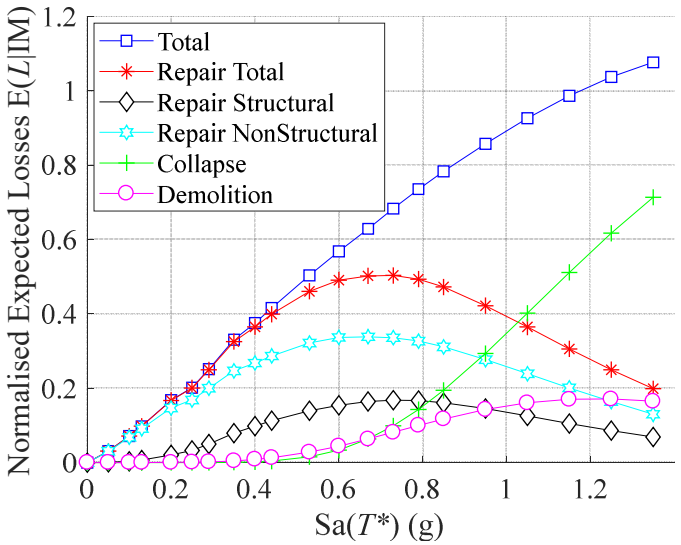
$$EAL = \sum_m E(L|IM_m)\,p(IM_m)$$

# Loss analysis – Results

EAL of reference case *40_12*




Disaggregated losses 3-R




- ✓ 0.10% - 0.26% of the replacement cost.

- ✓ Larger contribution of the repair costs (non-structural components):
  - Repair losses outweigh the other loss components for low-medium intensities
  - Losses due to collapse and demolition are dominant for high intensities

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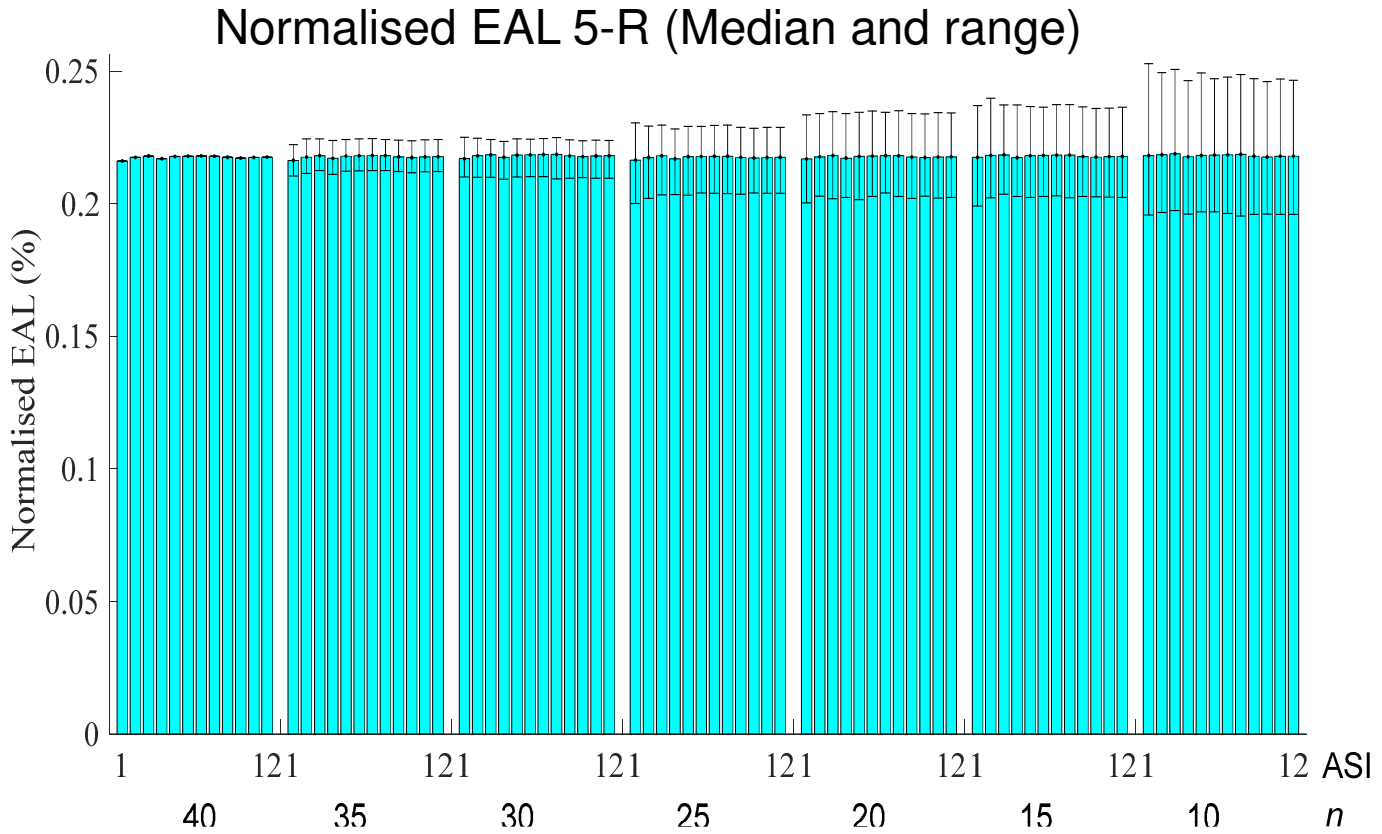
# Loss analysis – Results




- ✓ The effect of the ASI and the GM group size on the median EAL is negligible.
- ✓ Variability of the EAL due to the GM group size.
- ✓ Slightly larger range of the variability when only 1 ASI is used.
- ✓ 1 ASI is adequate, but GM group size should be larger than 10.

# Conclusions and Outlook

The effect of the number of ASIs and of the GM group size was examined in the context of the PEER-PBEE framework:

- The effect of the ASI was seen to decrease when progressing through the stages of the framework. As such:
  - 1 ASI was seen to be adequate to estimate the EAL
  - 2 ASIs were found to be enough to estimate collapse risk and
  - more than 2 ASIs were seen to be necessary to estimate most of the EDP distributions
- The GM group size was shown to have a larger effect, when compared to that of the ASI, and the use of at least 20 GMs was suggested to reduce the variability

# Conclusions and Outlook

- Validation of the conclusions using a wider variety of buildings, including:
  - ✓ Different material properties
  - ✓ Structural systems
  - ✓ Number of stories
  - ✓ Levels of irregularity
  - ✓ Different uses
- Different EDPs (local and global)
- Near field GMs where a specific orientation needs to be considered
- GM selection procedure (e.g. different spectrum)
- Different probabilistic model (e.g. IDA)
- Additional uncertainties (structural modelling, capacity models, cost data)
- Losses related to other sources

Thank you for
your attention!