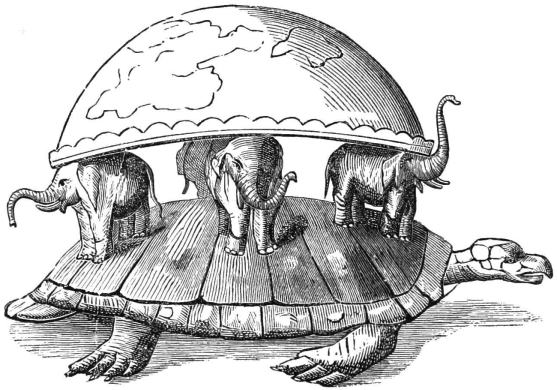
Statistical analysis of the effect of the angle of seismic incidence on probabilistic inelastic seismic demand.

PhD student: Despoina Skoulidou, FEUP
Scientific advisor: Xavier Romão, FEUP



India (Akupara)

Greece (Poseidon)

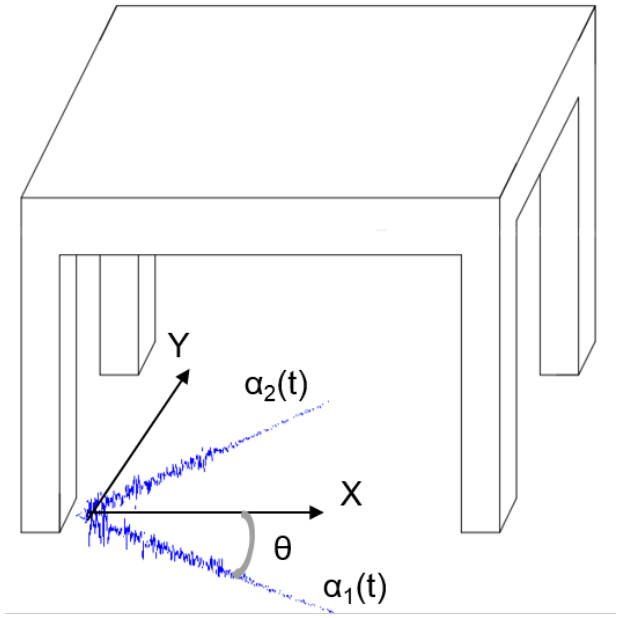
Japan (Namazu)

Genesis of an earthquake in mythology

Introduction: Deterministic vs Probabilistic approach

What is the angle of seismic incidence?

How do we account for it?



Angle of incidence of seismic input {θ}

Traditionally one angle:

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

Deterministic analysis

- Solution for some methods of analysis
- Ongoing research for others methods of analysis

Probabilistic analysis

- Ongoing research
- Effect on seismic risk/losses
- Validation of standard-based procedures

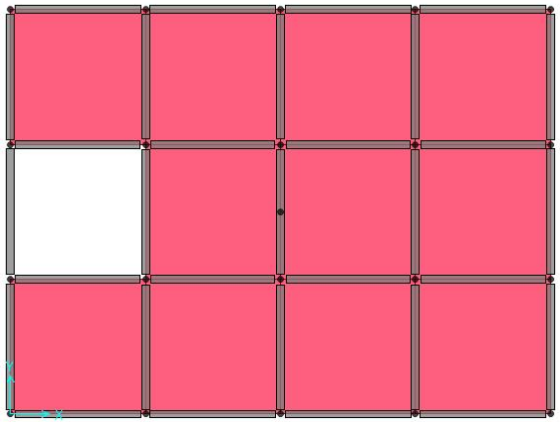
Angle of seismic incidence in NLTHA (probabilistic analysis)

Scope: Analyse the effect of the angle of seismic incidence on the inelastic seismic demand from a probabilistic point of view

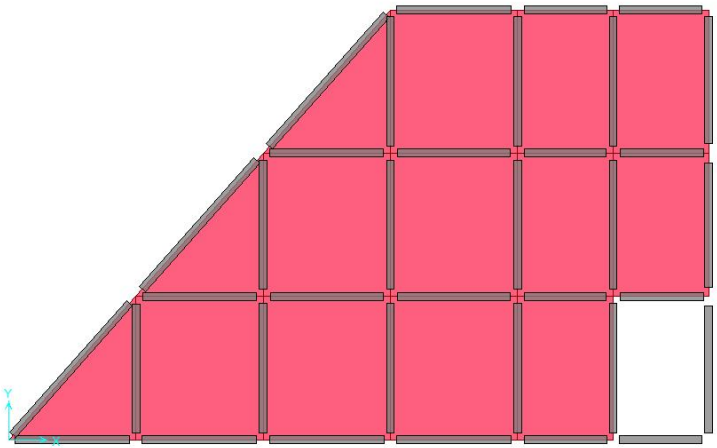
How:
- Analysis of six 3D RC structures (regular and irregular in-plan, different number of storeys)
- Bi-directional ground motion records compatible with a spectrum (EC8 or CMS)
- Nonlinear time history analysis with the ground motions applied along 12 angles of seismic incidence
- Statistical analyses of the results

Structures analysed: Layout

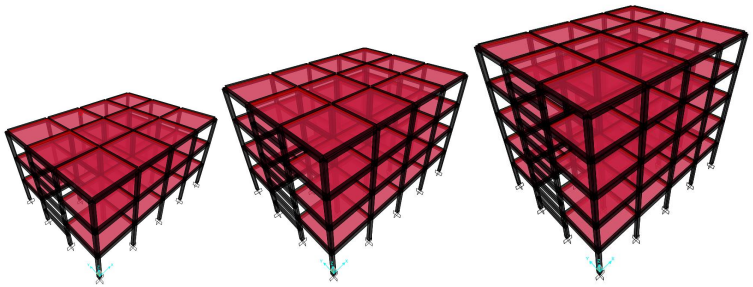
Regular



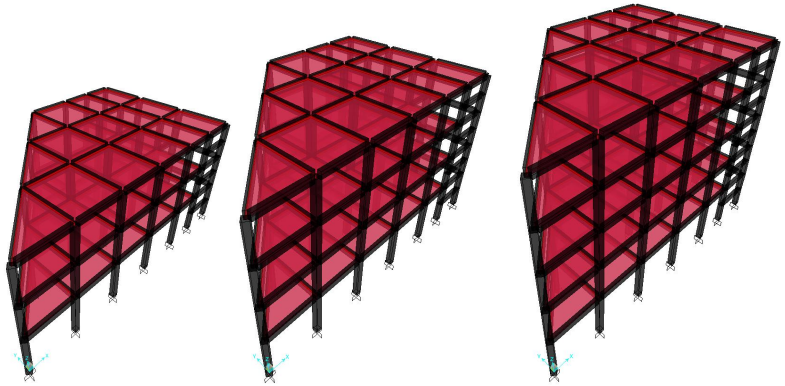
Irregular



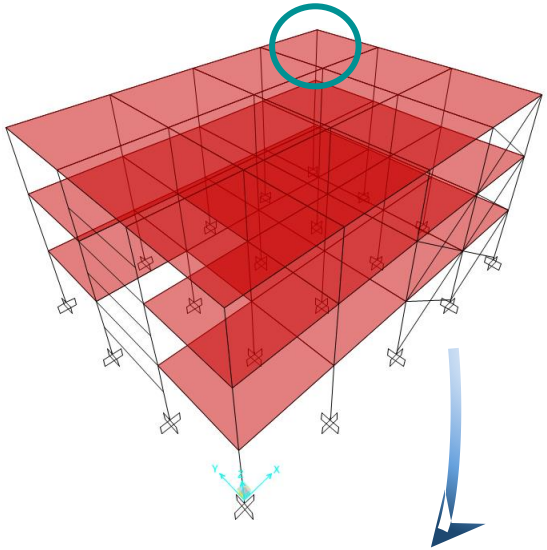
3 storeys 4 storeys 5 storeys



3 storeys 4 storeys 5 storeys

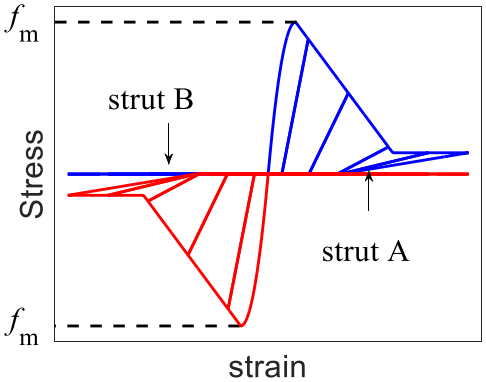


Structures analysed: Modelling



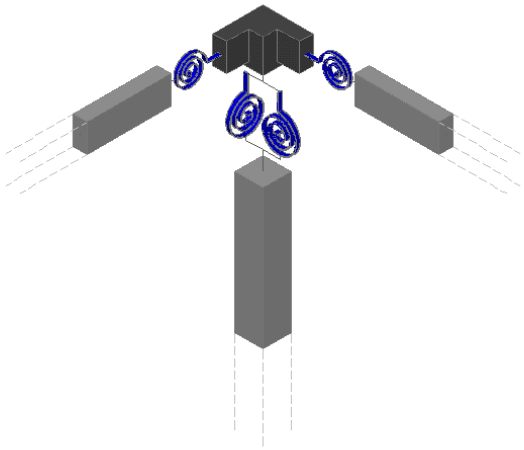
Full/partial infills in peripheral frames

2 struts/infill (compression-only)



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

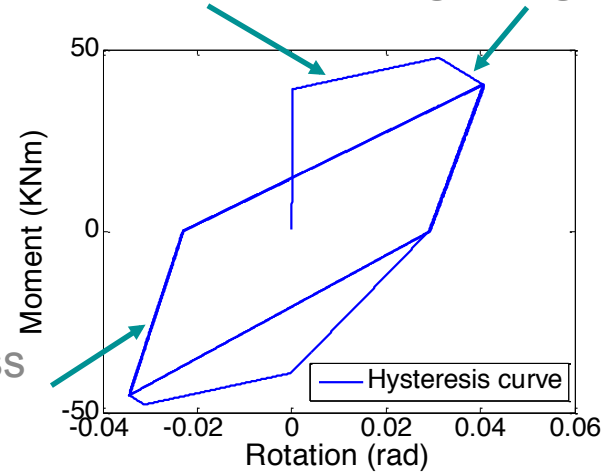
Lumped plasticity model



Stiffness degradation

Strength degradation

Unloading stiffness degradation

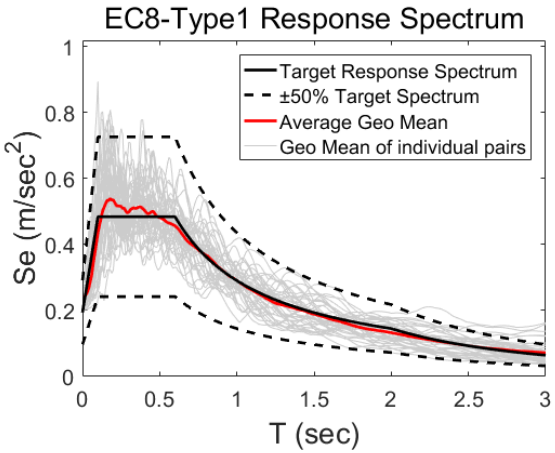


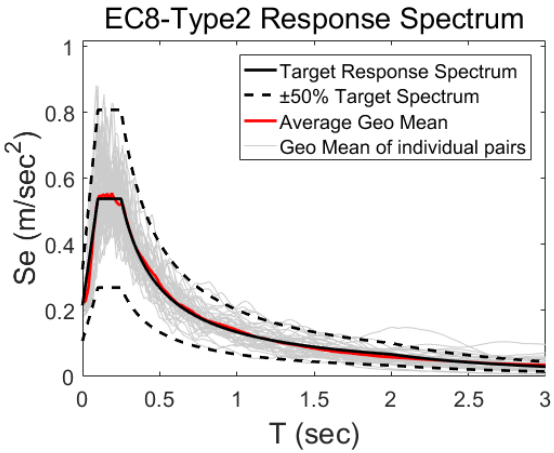
Hysteresis loop. Panagiotakos and Fardis (ACI 2001), Ibarra, L. F., and Krawinkler, H. (2005), Haselton, et al (2008)

Methods of analysis

Two methods of analysis were employed:

1st) Incremental Dynamic Analysis (Vamvatsikos & Cornell 2004)





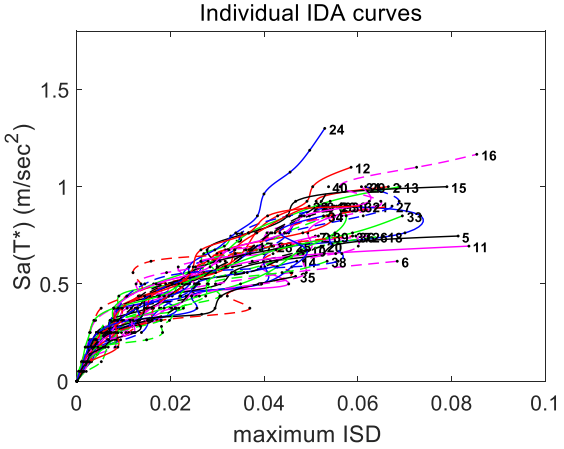
- 40 + 40 ground motion pairs compatible with EC8 elastic spectrum Type 1 and 2
- 12 angles of incidence
- 15 intensities range from elastic response up to collapse
- Total number of NL dynamic analyses:

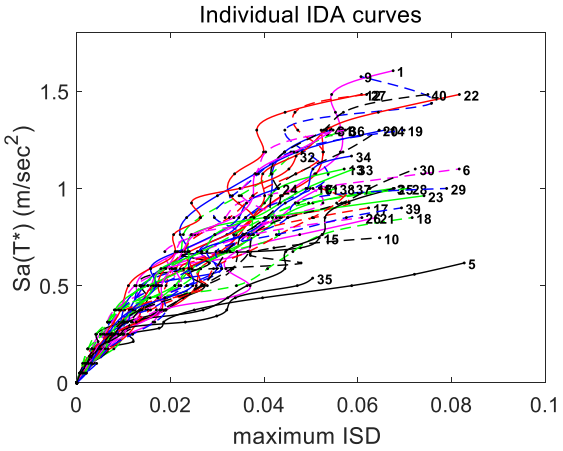
2 (Spec Types) × 40 (GM) × 15 (ints) × 6 (structs) × 12 (angles) = 86.400 NLTHA

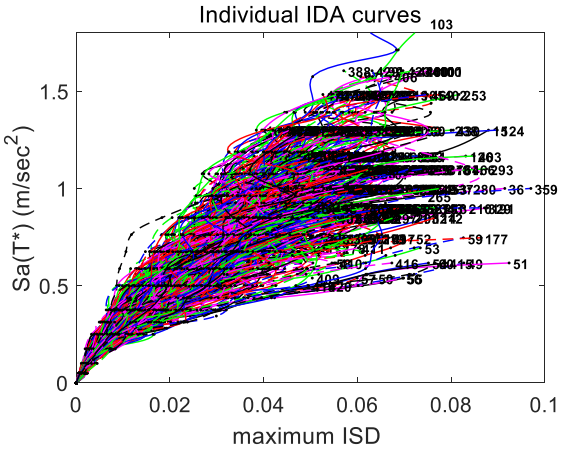
86.400 (analyses) × 15 (mins) = 1296000 mins ~ 2.5 years (with a single core)

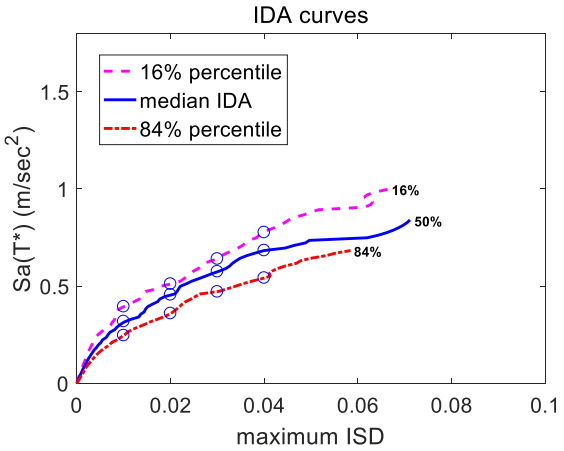
Methods of analysis (preliminary results)

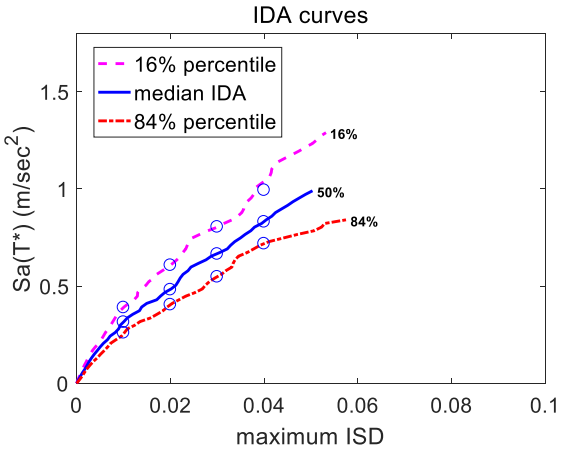
1st) Incremental Dynamic Analysis (Vamvatsikos & Cornell 2004)

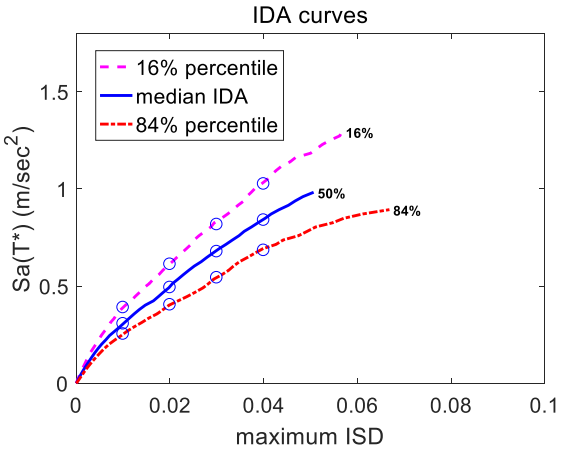












3-storey regular
Type 1, 1 angle/GM

3-storey regular
Type 2, 1 angle/GM

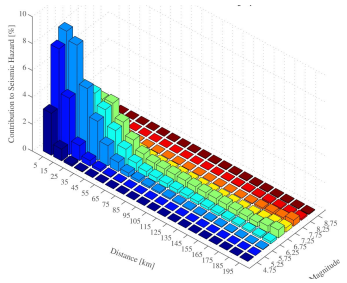
3-storey regular
Type 2, 12 angle/GM

Methods of analysis

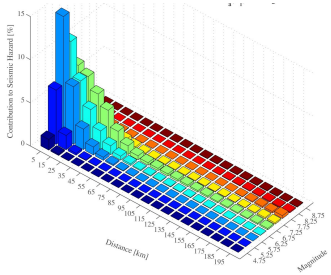
Two methods of analysis were employed:

2nd) Multiple-stripe analysis (Jalayer & Cornell 2009)

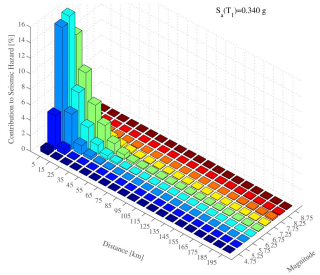
a) Hazard disaggregation of the site (Lisbon) for 4 probabilities of exceedance



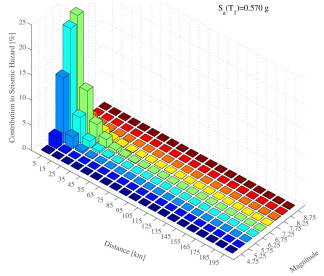
30% in 50 years



10% in 50 years

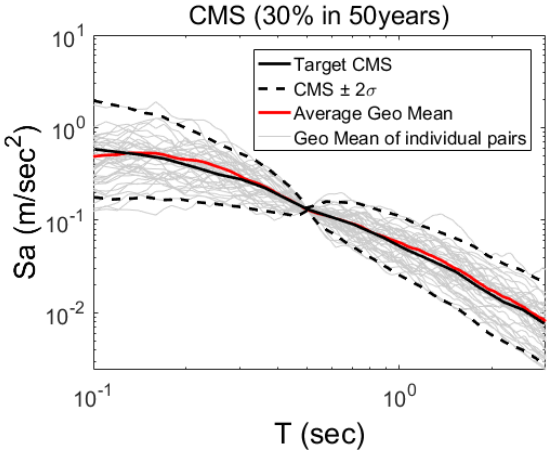


5% in 50 years

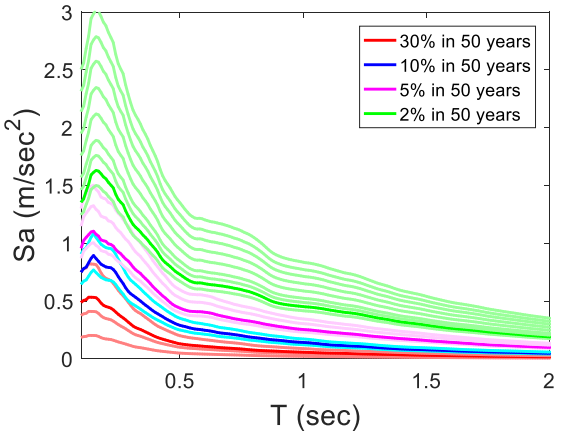


2% in 50 years

b) CMS (Baker JW (2010)) 40 pairs of GMs

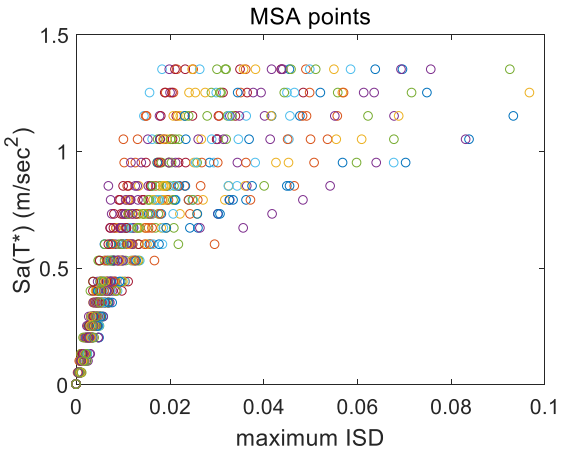


c) CMS scaling. 21 intensities total

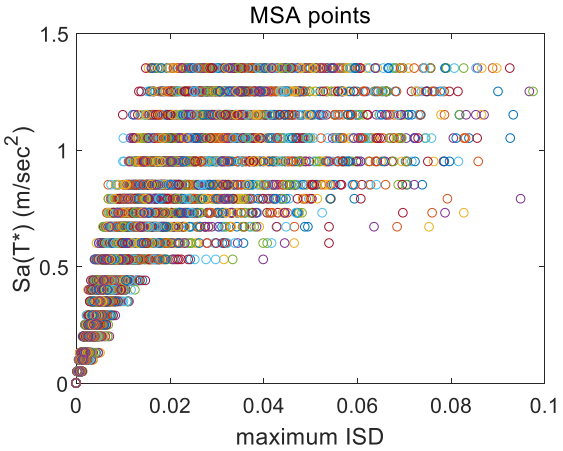


Methods of analysis (preliminary results)

2nd) Multiple-stripe analysis (Jalayer & Cornell 2009)



5-storey irregular
1 angle/GM



5-storey irregular
12 angle/GM

- 40 ground motion pairs compatible with Conditional Mean Spectrum
- 12 angles of incidence
- 21 intensities
- Total number of analyses:

40 (GM) × 21 (ints) × 6 (structs) × 12 (angles) = 60.480 NLTHA

60.480 (analyses) × 15 (mins) = 907200 mins ~ 1.7 years (with a single core)

Post-Processing of the results

The analyses generated a significant amount of results.

How to exploit the results?

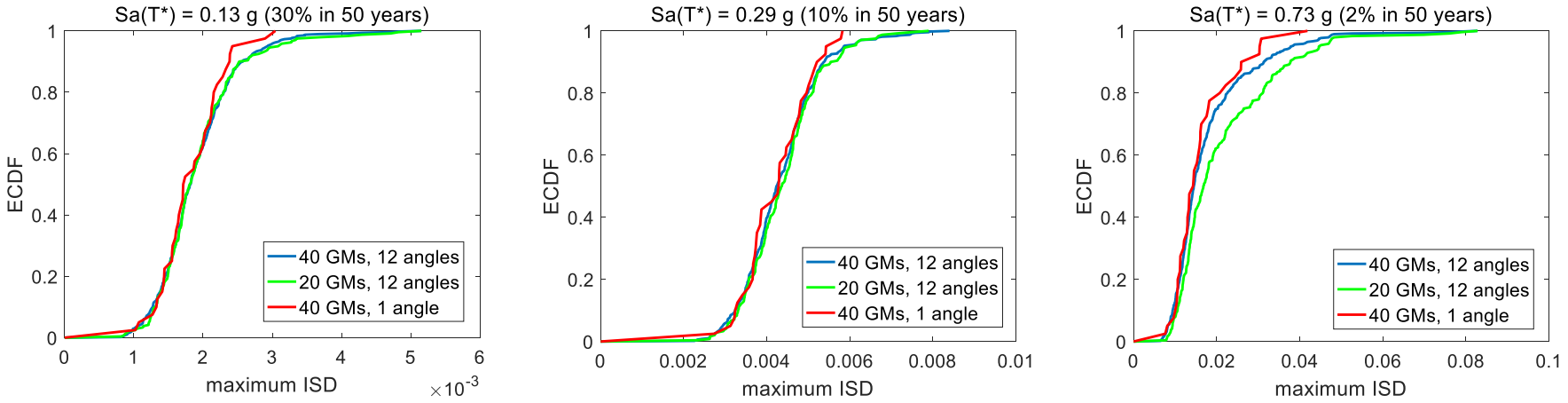
- Probabilistic point of view
  - determine the effect of the angle on seismic demand
  - determine the effect of the angle on the fragility
  - determine the effect of the angle on the expected losses

- Deterministic point of view (further post-processing)
  - validation of standard-based methods of analysis

Post-Processing of the results

For each intensity level (EDP-based) or Limit State (IM-based):

- Take samples of demands (ISD or Sa) using different number of ground motions (green line) and angles of seismic incidence (red line) - reference case: 40 ground motions and 12 angles (blue line).
- Use two-sample statistical tests to evaluate the equality of the distributions.



EDP-based results for the 5-storey irregular building.

Selection and validation of tools to post-process the results

How: Statistical methods to compare the distributions with different number of angles of incidence and different number of ground motions.

Tools: Two-sample statistical tests to analyse the equality of distributions.

Examine if two samples come from the same distribution, without making assumptions for the type of the distribution.

Validation of statistical tests: Perform extensive simulation study to estimate the power of existing tests

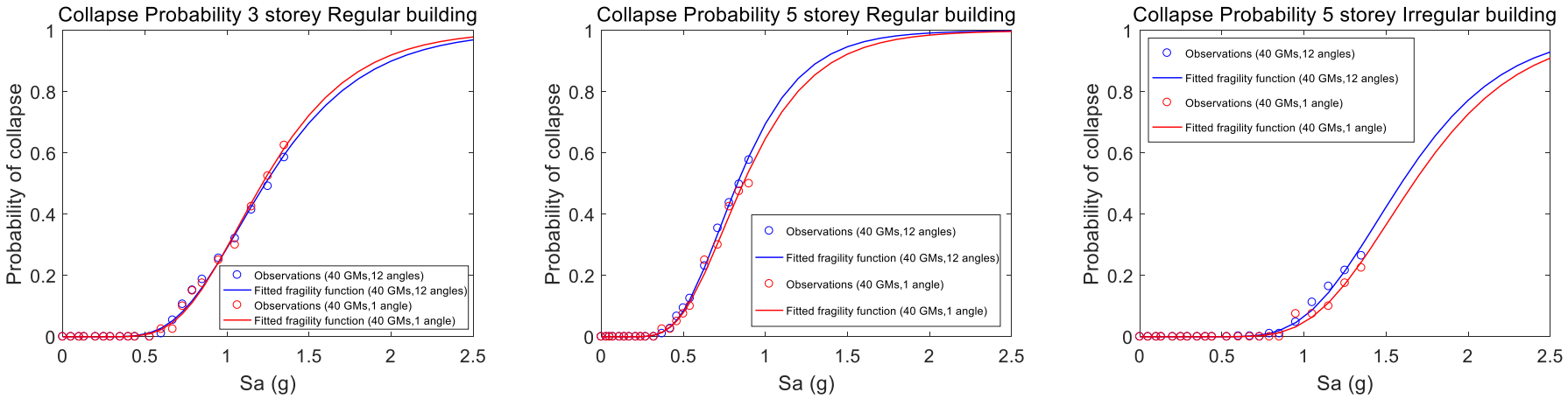
Sample size of both samples	Distribution type	Significance level
(500-400)..	Symmetric	5%
(250-150)..	Asymmetric	10%
(50-7)	Altered Normal	15%

Further Post-Processing of the results

For both IM- and EDP-based.

Samples for different number of ground motions and angles.

- Compare the location of the samples (deterministic analyses).
- Check the family of the distribution (probabilistic analyses).
- Fit a theoretical distribution and compare the parameters (probabilistic analyses).
- Evaluate the effect on economic terms (loss analyses)



Collapse fragilities from MSA results

Concluding remarks

- Effect of the angle of incidence on the seismic demand and fragility
- Effect of the angle of incidence on the expected losses

Significant or not?

- Combination of ground motions and angles of incidence so that the deviations from the reference case become statistically insignificant

- Use the results to validate standard-based approaches

Thank you for your attention

Genesis of an earthquake in mythology. Siberia