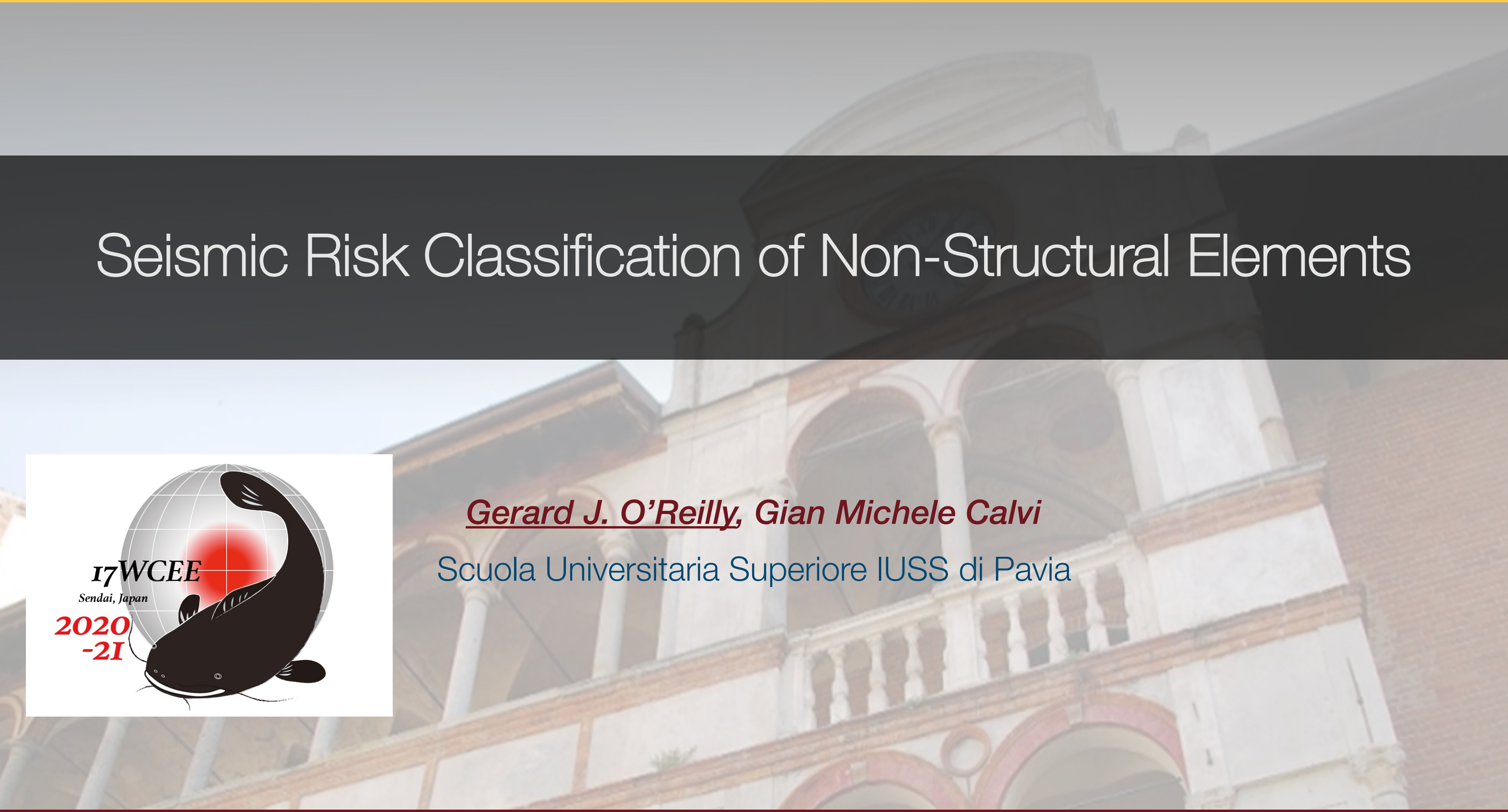

Seismic Risk Classification of Non-Structural Elements

17WCEE
Sendai, Japan
2020
-21

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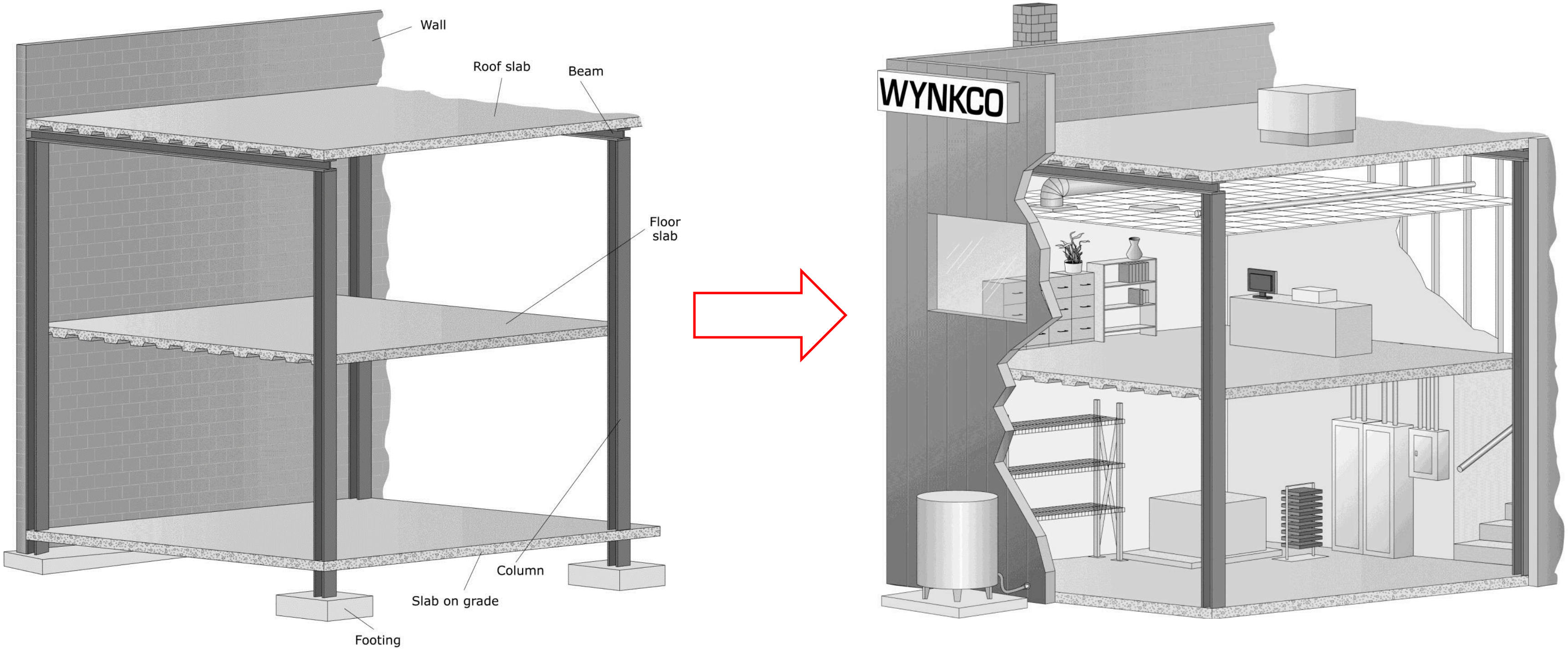
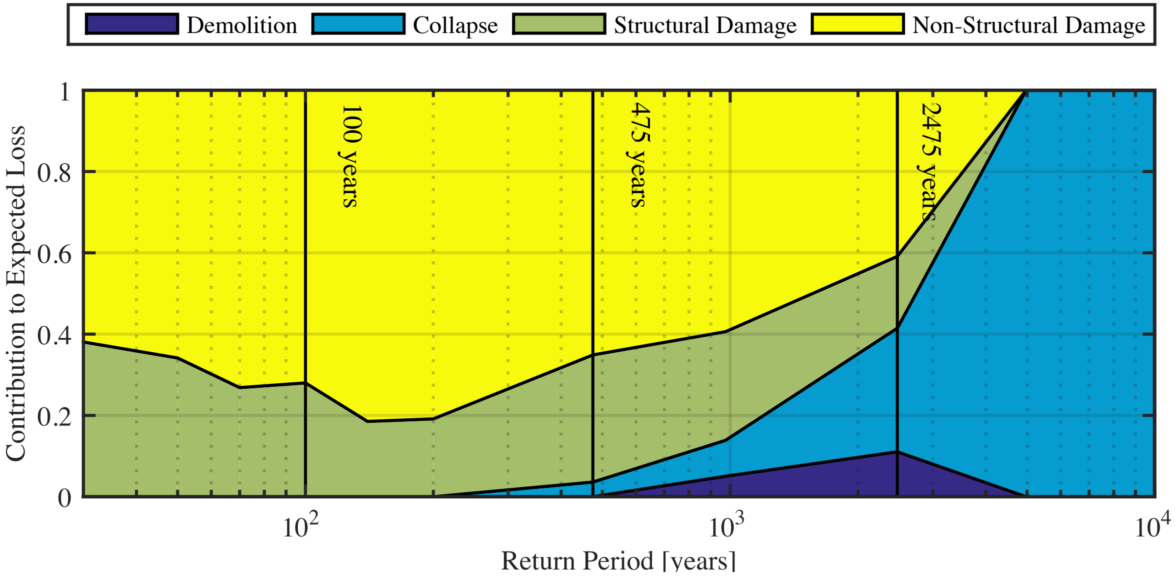
Non-Structural Elements

- Components that do not form part of a building's structural load-bearing system, but are in any case subjected to shaking and deformations during earthquakes are referred to as non-structural elements (NSEs)
- Typically not analysed by structural engineers and may be specified by architects, mechanical engineers (e.g. HVAC systems and plumbing for larger buildings), electrical engineers, or interior designers (contents)



Significance of NSE performance

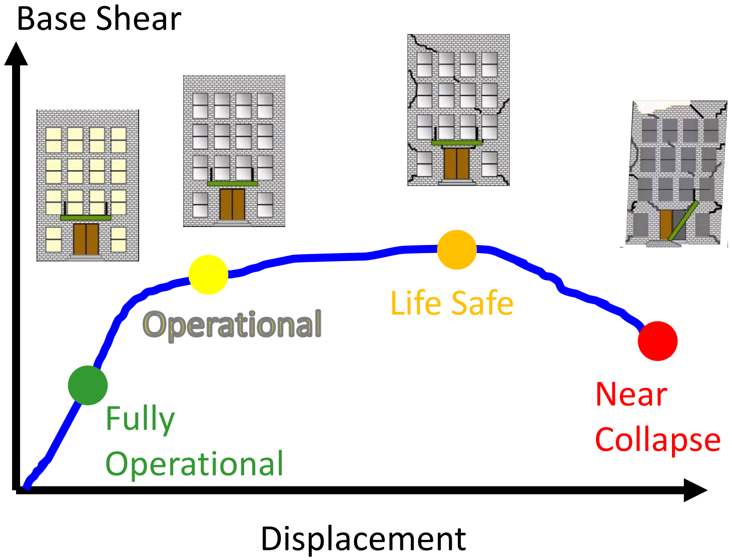
- Past earthquakes have highlighted damage to NSEs, which may be due to design codes’ approach to ensuring the satisfactory seismic performance of buildings at ultimate limit states and avoid loss of life through global collapse

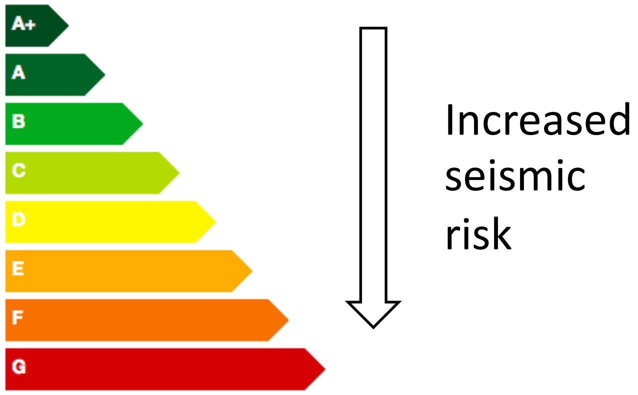


- For a typical school building in Italy, they have been shown to represent the majority (>60%) of the direct monetary losses induced at lower return periods.

Significance of NSE performance

- In addition to losses, life safety risks due to falling objects or increased downtime due to leaking pipes, for example, are likely outcomes.
- Given that the ultimate behaviour of a structure is the design code focus and the approximate nature of the design for NSE restraints, it is not easy to obtain the actual margin of safety for a building's NSEs
- In Italy, the seismic risk of buildings may be classified by different ratings using the *Sismabonus* guidelines
- With such guidelines, the quantification and classification of seismic risk for existing buildings can be carried out in a ***clearer and more straightforward manner***, fostering an improved way demonstrate how to improve the seismic resilience of buildings
- This type of approach is proposed here for NSEs





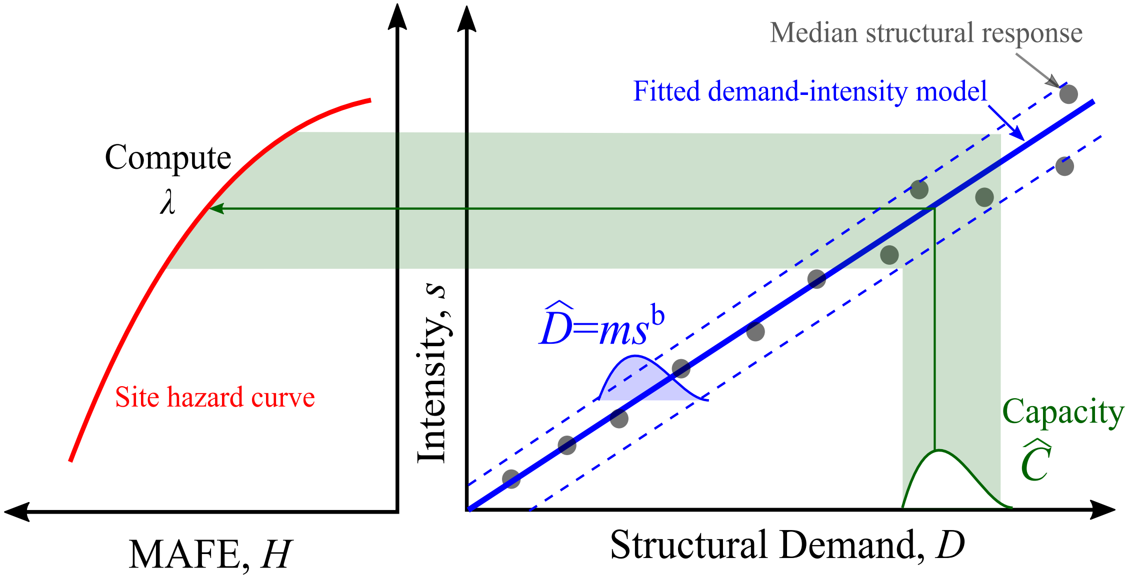
Types of NSE risk

Type of Risk	Description	Example
Life safety (LS)	Could anyone be hurt by this NSE in an earthquake?	School building
Property loss (PL)	Could a large property loss result due to the loss of this NSE?	Warehouse
Functional loss (FL)	Could the loss of this NSE cause an outage or interruption to the functionality of this building?	Civil protection building

- A classification scheme for NSEs could focus much more on mitigating the immediate impacts and consequences due to the failure of certain NSEs on the building, its functionality and its occupants
- FEMA E-74 describes a differentiation among NSEs and which type of risks they pose

Overview of risk quantification

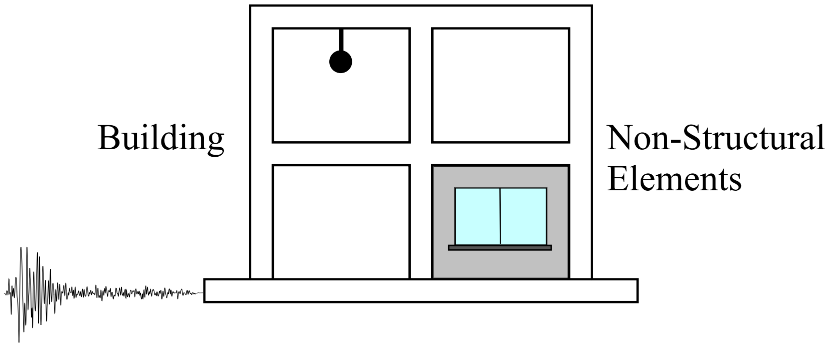
$$\lambda = \int_{0}^{+\infty} P\left[D > C \,|\, s\right] \left|\mathrm{d}H(s)\right|$$



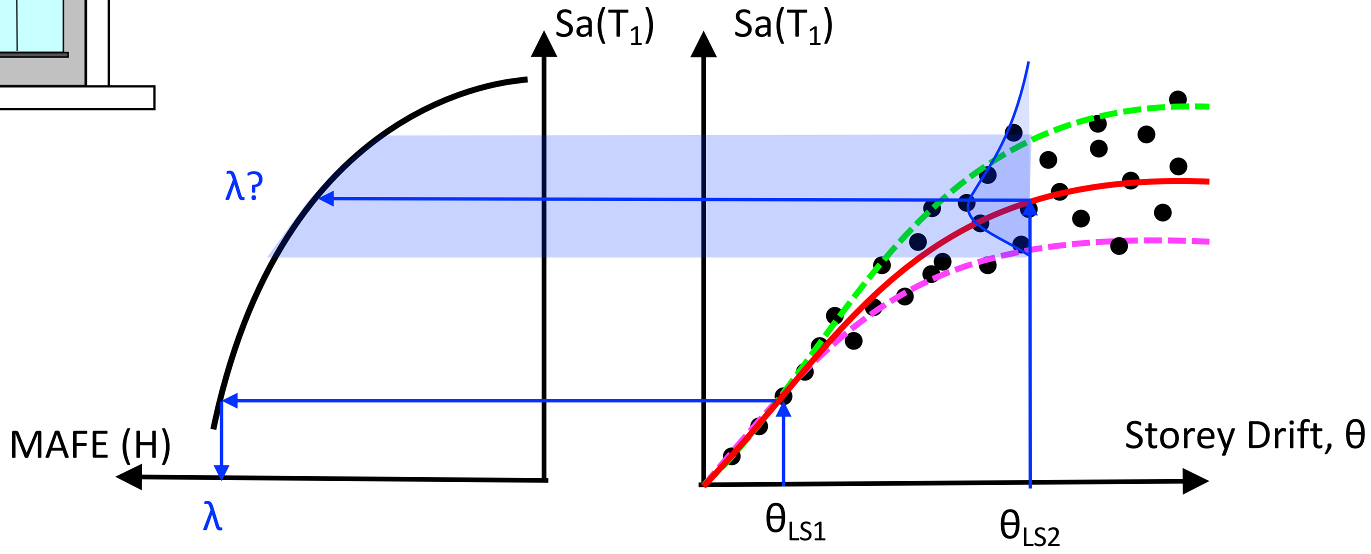
- For a given building, the relationship between structural demand, *D*, and seismic intensity, *s*, is known and is herein termed a *demand-intensity* model
- Knowing this intensity and the site hazard model, the mean annual frequency of exceeding (MAFE) can be computed in a closed-form solution

Overview of risk quantification

- This demand can be a limit state capacity value (i.e. 0.5% storey drift) or the capacity, *C*, of a certain element in the structure; for example, a beam's chord rotation at yield or a NSE's first damage state, both of which have a median capacity and an associated dispersion (i.e. fragility function).
- Cornell et al. [2002] developed a simplified closed-form expression

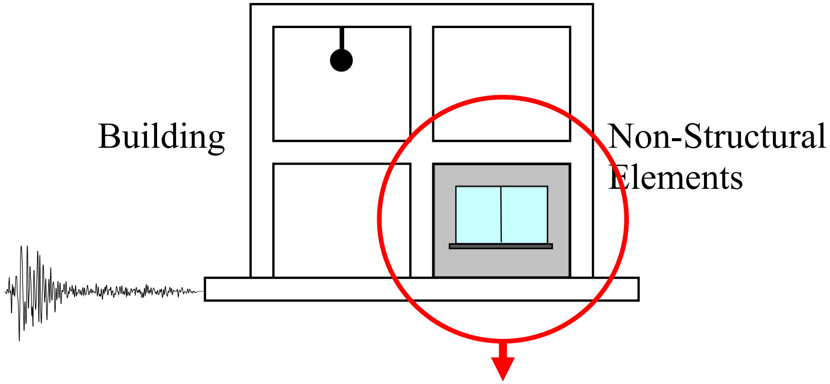


$$\lambda = \overbrace{H\big(\mathrm{Sa}(\mathrm{T}_1)\big)}^{\text{Hazard}}\ \overbrace{\exp[0.5\mathrm{k}_1^2\beta^2]}^{\text{Dispersion}}$$

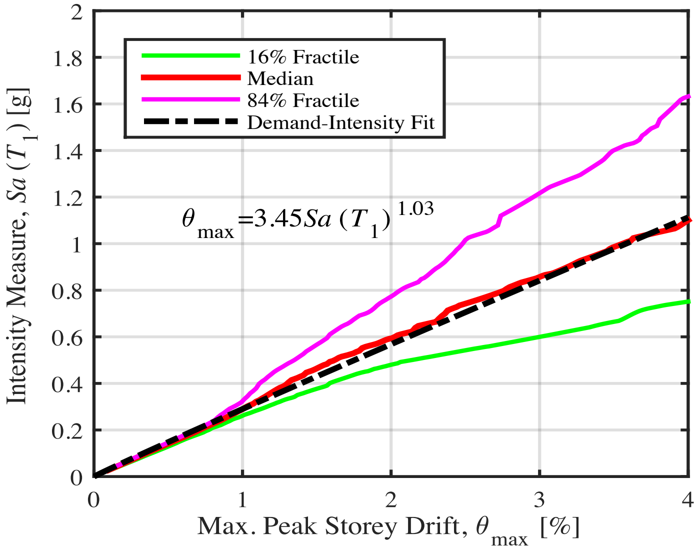


Storey-drift sensitive elements

- The objective is to estimate the MAFE of a certain NSE damage state, whose fragility function is described by a lognormal distribution with median capacity η_C and dispersion β_C
- In terms of demand, the median structural response of a building is predicted using a demand-intensity relationship represented as linear in logspace for storey drift
- Using such a demand-intensity model, Vamvatsikos [2013] derived closed-form expressions to compute the MAFE for MPSD, λ_θ



$$\theta_{max} \approx m_\theta s^{b_\theta}$$

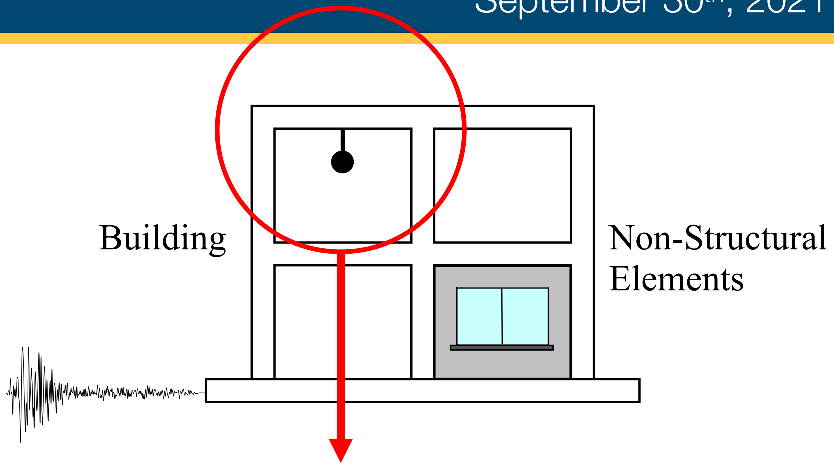


$$\lambda_\theta = \sqrt{\phi'_\theta} k_0^{1-\phi'_\theta} H \left(\left(\frac{\eta_C}{m_\theta} \right)^{\frac{1}{b_\theta}} \right)^{\phi'_\theta} \exp\left[\frac{k_1^2 \phi'_\theta}{2 b_\theta^2} \left(\beta_D^2 + \beta_C^2 \right) \right]$$

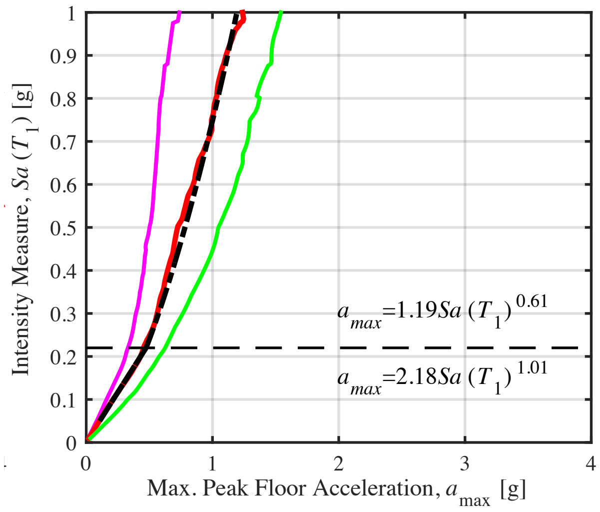
Floor acceleration-sensitive elements

- For acceleration-sensitive elements, the objective is again to estimate the MAFE of a certain NSE damage state
- The maximum of the peak floor accelerations (MPFA), a_{max}, is a demand parameter typically used for acceleration-sensitive components
- MPFA is a quantity that behaves differently to MPSD and begins to saturate with increasing intensity as a result of structural yielding
- O'Reilly and Monteiro [2019] proposed a bilinear demand-intensity model and extended the MAFE calculation for MPFA, λ_a

$$\lambda_a = F_{lower}(s)G_{lower} + [1 - F_{upper}(s)]G_{upper}$$

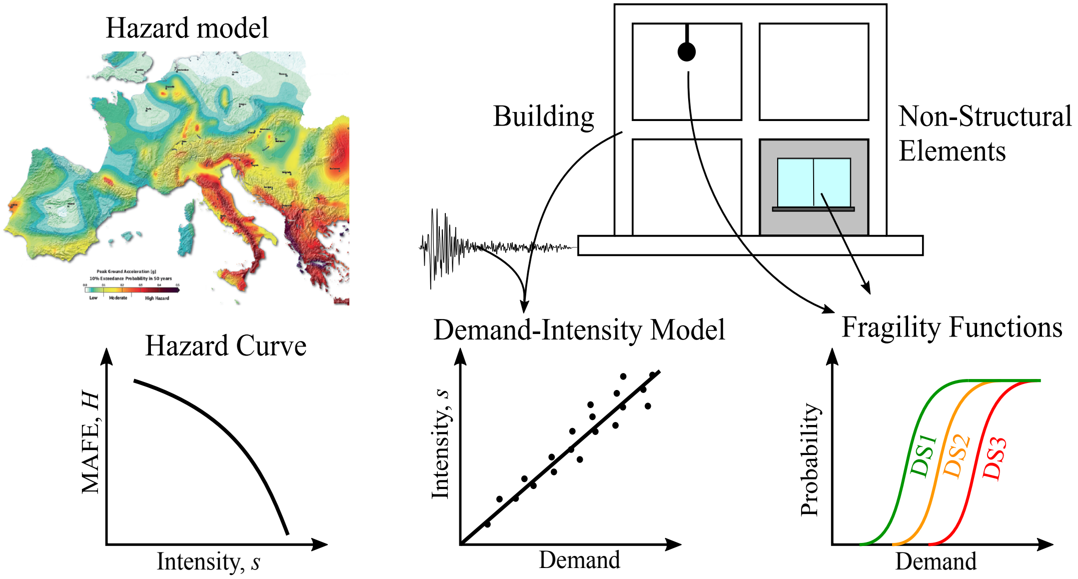


$$a_{max} \approx \begin{cases} m_{a,lower} s^{b_{a,lower}}, & s < s_{lim} \\ m_{a,upper} s^{b_{a,upper}}, & s \geq s_{lim} \end{cases}$$



Quantification of NSE performance

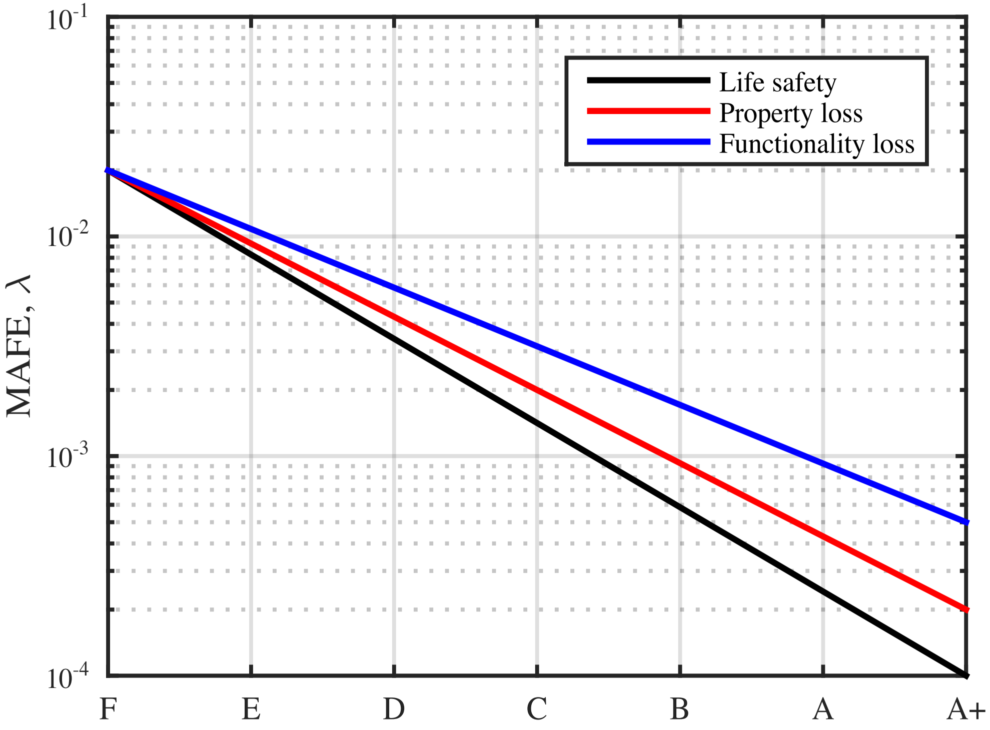
- Based on either λ or T_R, a rating system (e.g. A+, A, B, C etc.) may be defined to classify the NSE performance for a given structural typology and site location
- The input requirements for this would therefore be:
  1. site location and a suitable hazard model
  2. structural typology to characterise its demand-intensity model required for that NSE
  3. fragility of non-structural element
  4. decision framework to assign a risk rating



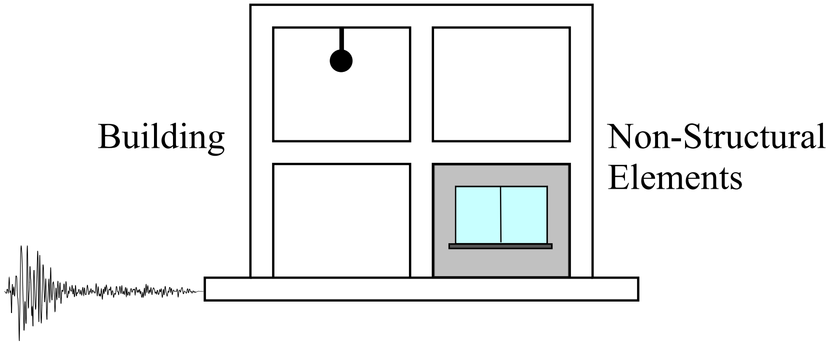
NSE risk classification

- For each risk type, different levels of acceptable MAFE or return periods of failure could be assigned
- For example, the life safety risk could be strictly controlled in buildings with a large concentration of people (e.g. a school or hospital building) but the functionality may be the primary issue to address in a warehouse building
- Establishing these limits is not an easy task and collaborative research is needed to identify suitable values, but it is argued to be a much more thorough and meaningful way to classify and rank the performance of NSEs compared to more typical demand/capacity ratios that current codes employ.

Type of Risk
Life safety (LS)
Property loss (PL)
Functional loss (FL)



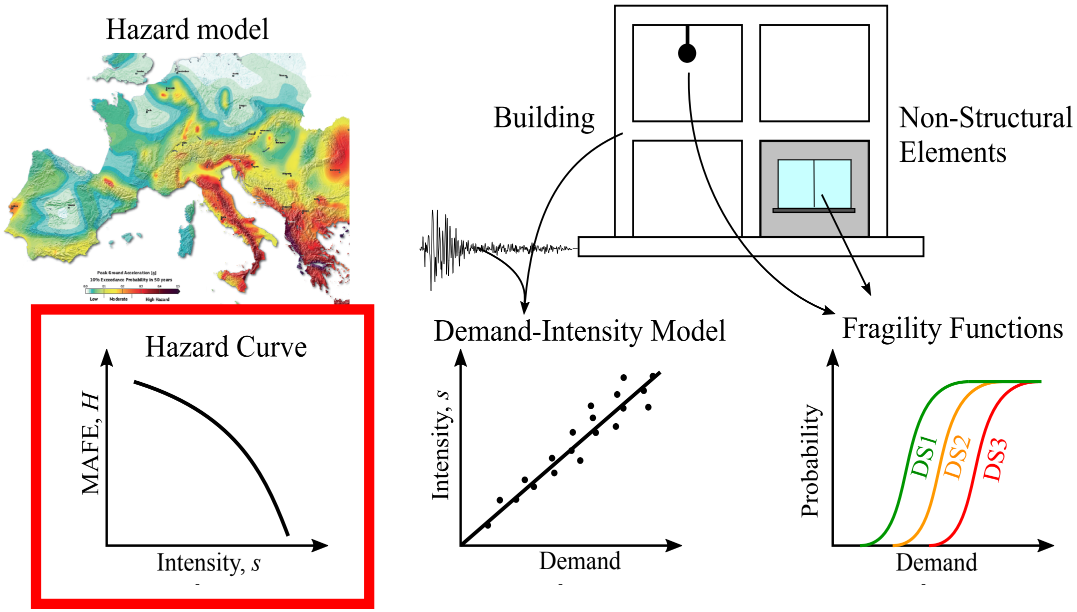
Example application



- Consider a case-study building, whose structural properties are known
- We want to estimate and classify the risk of:
  - Gypsum partition walls located at every storey of the building →
  - Cooling tower located at the roof of the building →

Engineering Demand Parameters	Risk Types
Storey drift sensitive	Property loss (PL)
Floor acceleration sensitive	Functional loss (FL)

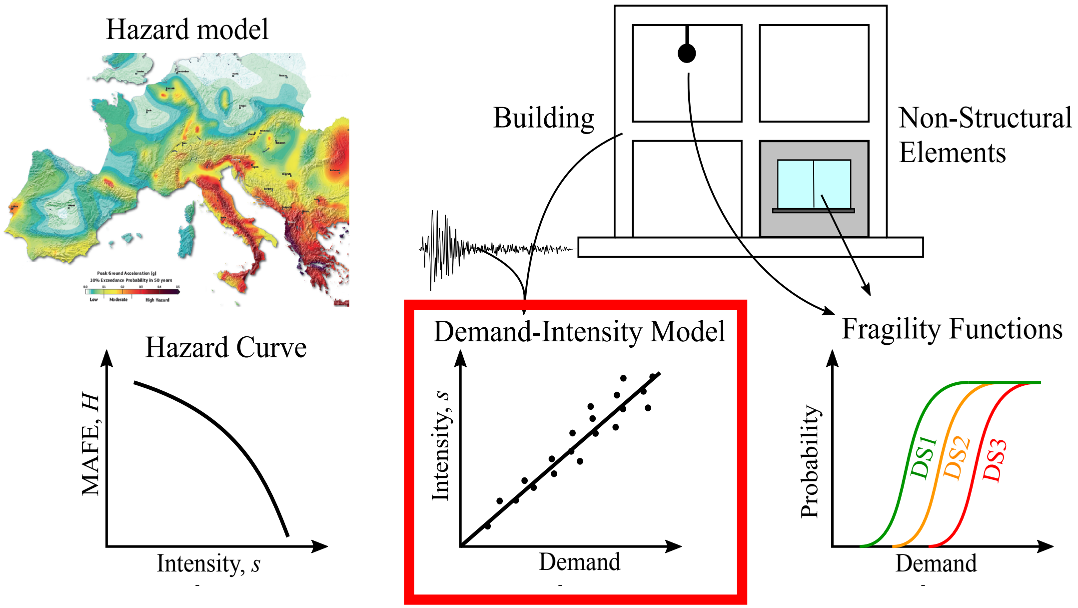
Example application



Hazard

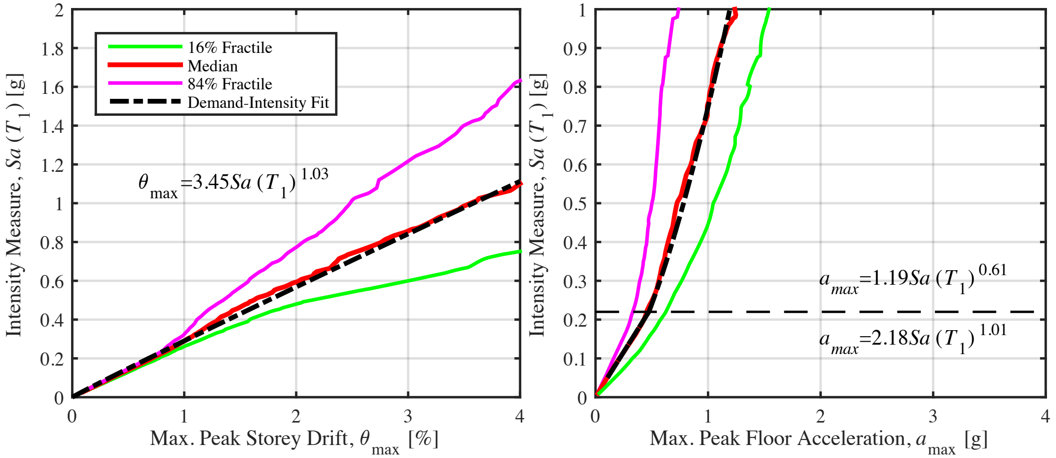
- Site location is known and the hazard curve parameters needed for the MAFE computation are described by the coefficients k_0 = 7e-4, k_1 = 2.0 and k_2 = 0.3

Example application

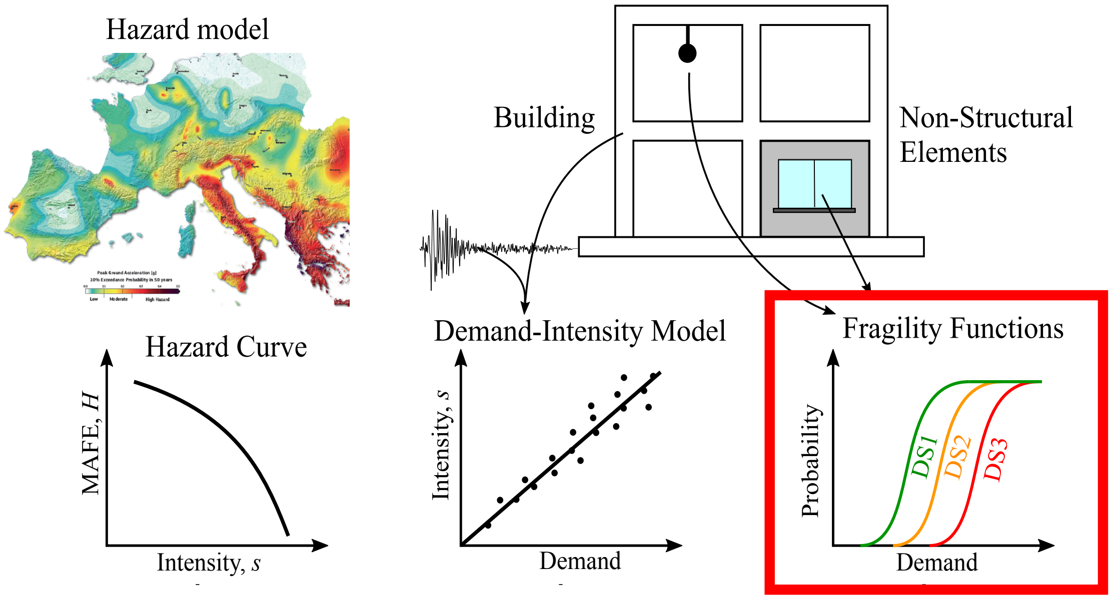


Demand-intensity

- IDA results of the RC frame structure for both MPSD and MPFA, where the fitted demand-intensity models are also shown

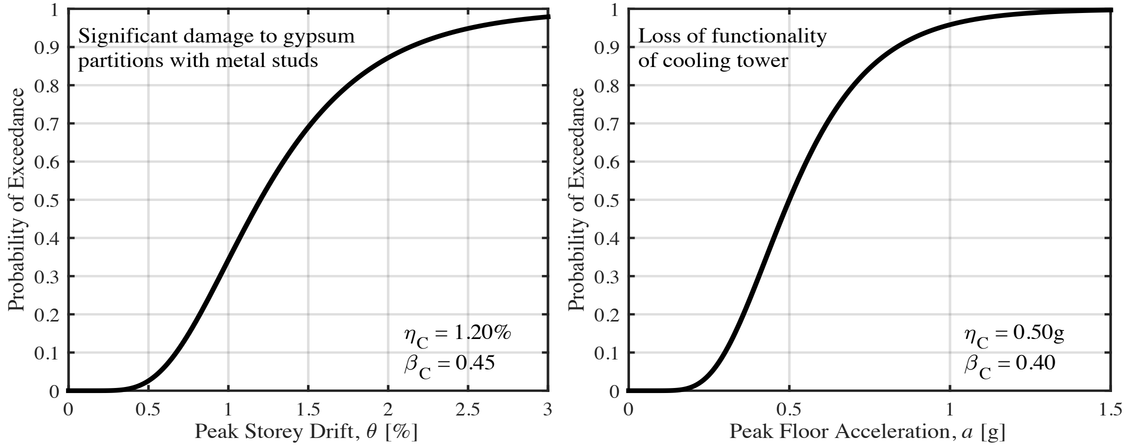


Example application



Component fragility functions

- Illustration of the NSE fragility functions: gypsum partition (left) and cooling tower (right) for the damage states being examined



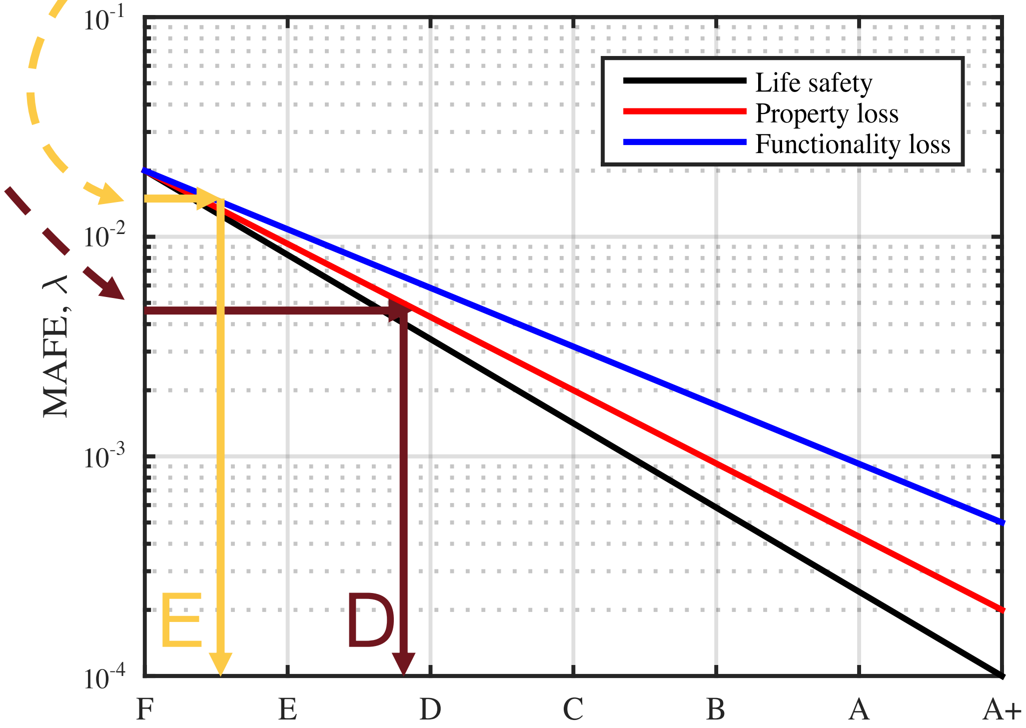
Example application

	Gypsum Partitions	Cooling Tower
Demand-intensity model	$m_\theta = 3.45$, $b_\theta = 1.03$, $\beta_D = 0.30$	$m_{a,lower} = 2.18$, $m_{a,upper} = 1.19$, $b_{a,lower} = 1.01$, $b_{a,upper} = 0.61$, $\beta_D = 0.30$
Site hazard model	$k_0 = 7e\text{-}4$, $k_1 = 2.0$ and $k_2 = 0.3$	
NSE fragility function	$\eta_C = 1.2\%$, $\beta_C = 0.45$	$\eta_C = 0.50g$, $\beta_C = 0.40$
MAFE	$\phi'_\theta = 0.86$	$\phi'_{a,lower} = 0.87$, $\phi'_{a,upper} = 0.71$ $\mu_{lower} = -1.70$, $\mu_{upper} = -1.36$ $\sigma_{lower} = 0.23$, $\sigma_{upper} = 0.35$
	$Sa(T_1) = 0.36g$	$Sa(T_1)_{lower} = 0.23g$, $Sa(T_1)_{upper} 0.24g$
	$H(Sa(T_1)) = 3.97e\text{-}3$	$H(Sa(T_1)_{lower}) = 6.83e\text{-}3$, $H(Sa(T_1)_{upper}) = 6.55e\text{-}3$
	$\lambda_\theta = 4.61e\text{-}3$	$\lambda_a = 1.08e\text{-}2$
Return period	$T_R = 217$ years	$T_R = 92$ years
Rating	D	E

- Computation of the MAFE and risk classification for the significant damage limit state of the gypsum partitions with metal studs and for the loss of functionality limit state of a cooling tower

Example application

	Gypsum Partitions	Cooling Tower
MAFE	$\lambda_\theta = 4.61e\text{-}3$	$\lambda_a = 1.08e\text{-}2$
Return period	T_R = 217 years	T_R = 92 years
Rating	D	E



Conclusions

- A risk classification scheme for non-structural elements (NSEs) has been described, whereby the mean annual frequency of exceeding (MAFE) a given damage state is determined.
- This utilises information from seismic hazard analysis, structural analysis and also NSE behaviour to characterise the performance consistently, while at the same time incorporating the uncertainties involved to be in line with modern performance-based earthquake engineering.
- A classification scheme to rank the performance in a simplified manner similar to the seismic risk classification for buildings *Sismabonus* used in Italy was described.
- While a hypothetical example of what such a scheme may look like was discussed, future work is needed to identify what the acceptable performance limits for such risk types may be.
- An example implementation of the methodology was described for two types of NSE to illustrate its simplified nature.

Thank you