Simplified tools for the risk assessment and classification of existing buildings

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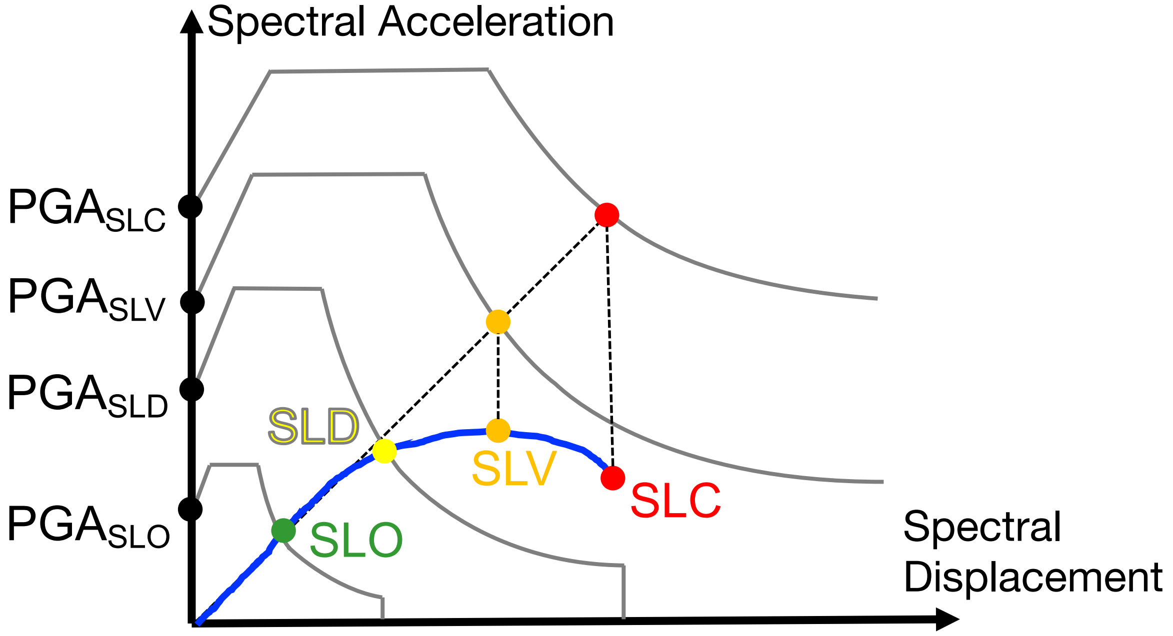
Introduction

- In recent decades, the seismic assessment of existing buildings has developed significantly from traditional objectives focusing on ensuring life-safety of buildings to more advanced metrics considering potential economic losses
- Italy has made notable developments in this regard with the introduction of the so-called Sismabonus seismic risk assessment and classification guidelines
- When scrutinized with respect to more exhaustive risk assessment methods, the simplified approaches adopted within *Sismabonus* may possess some limitations and drawbacks
- With some modest adjustments and modifications, these simplified methods can be notably improved without any notable penalties in applicability in a practitioner setting

Italian Seismic Risk Classification Guidelines (*Sismabonus*)

- Perform a pushover analysis on the building and normalise to Sa-Sd
- Estimate the peak ground acceleration (PGA) of the design spectra needed to reach each limit state
- Additionally, estimate the ratio between $PGA_{C,SLV}$ capacity and the actual PGA you would use for a new design ($PGA_{D,SLV}$) to get SI-LS

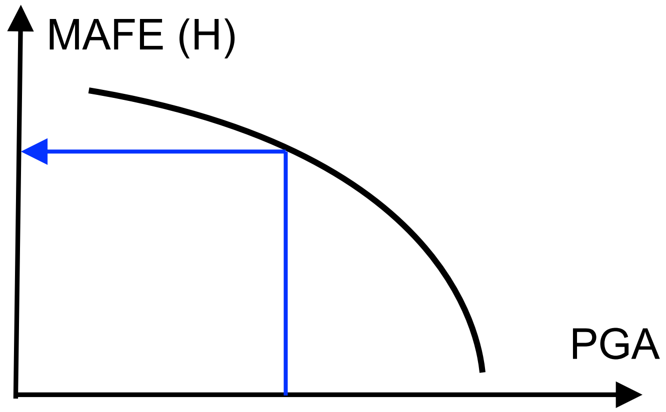


$$SI - LS = \frac{PGA_{C,SLV}}{PGA_{D,SLV}}$$

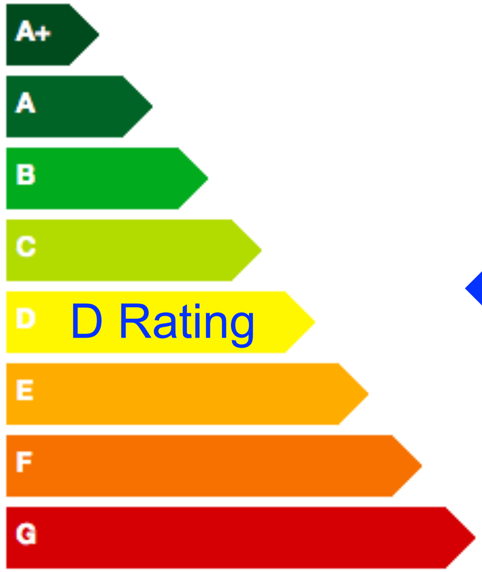
$PGA_{D,SLV}$ = PGA used for design (new design should have *SI-LS* ≥ 1.0)

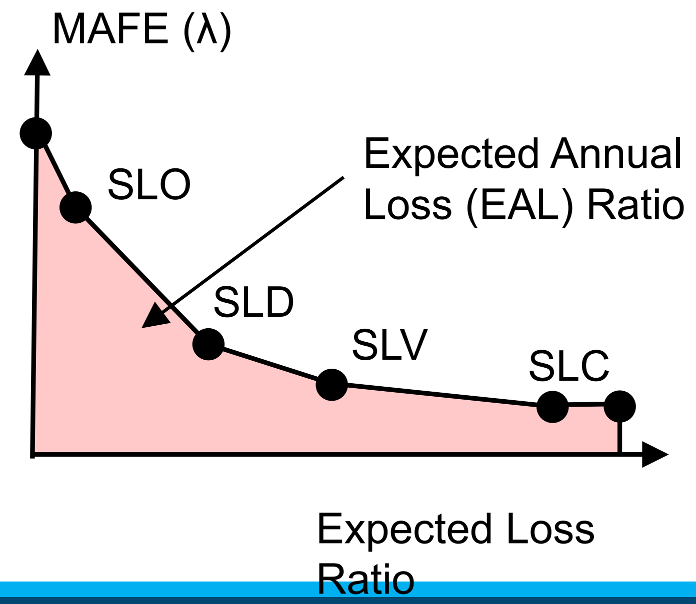
Italian Seismic Risk Classification Guidelines (*Sismabonus*)

- Knowing the PGA for each limit state, the MAFE is computed from the hazard curve
- The limit states are given and the EAL is computed as the area under the loss curve
- Overall ranking is more critical of two



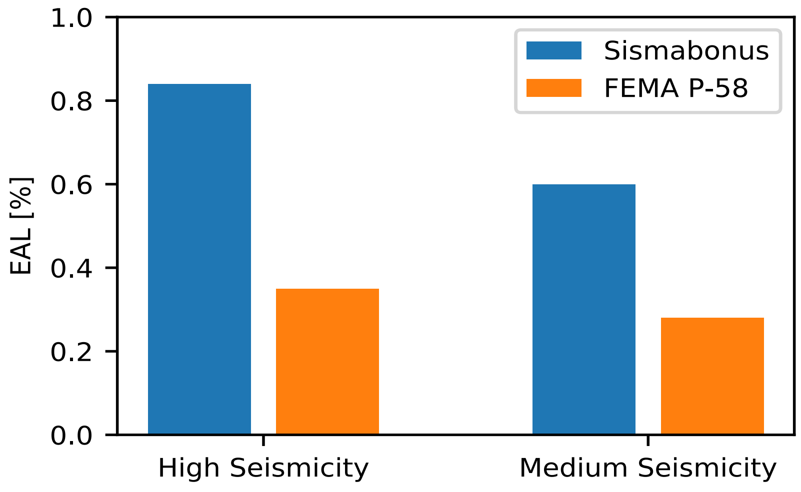
EAL Range	Life Safety Index	
EAL ≤ 0.5%	100% < IS-V	A+
0.5% < EAL ≤ 1.0%	80% ≤ IS-V < 100%	A
1.0% < EAL ≤ 1.5%	60% ≤ IS-V < 80%	B
1.5% < EAL ≤ 2.5%	45% ≤ IS-V < 60%	C
2.5% < EAL ≤ 3.5%	30% ≤ IS-V < 45%	D
3.5% < EAL ≤ 4.5%	15% ≤ IS-V < 30%	E
4.5% < EAL ≤ 7.0%	IS-V < 15%	F
EAL ≤ 7.0%		G





Possible limitations – expected loss

- O'Reilly *et al.* (2018) assessed a case study school building at two locations in Italy using the rigorous approach outlined in FEMA P-58 and *Sismabonus*
- The life safety index was the governing criteria
- EAL computed using *Sismabonus* was much higher than those computed following the rigorous approach
- The overall trends remain the same
- Suggests that the general method is still a good indicator of relative performance, but may need further refinement

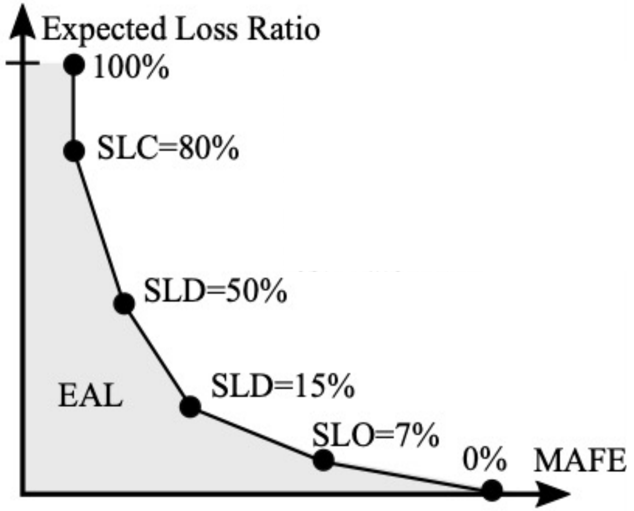


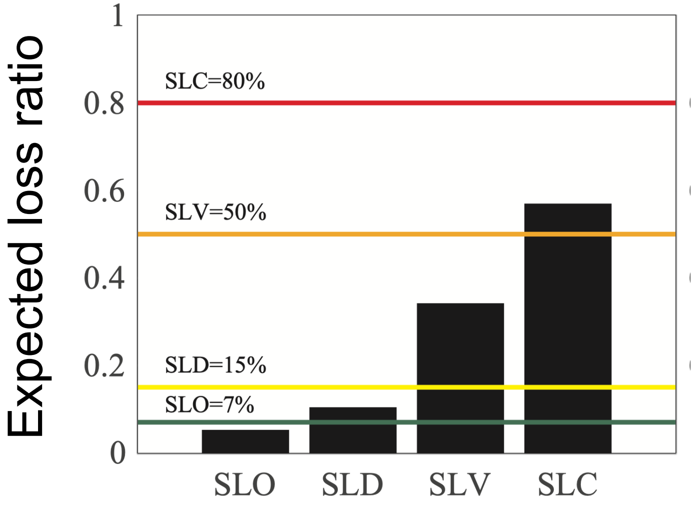
Site Location	High	Medium
EAL	0.84%	0.60%
EAL Classification	A	A
IS-V	0.60	0.79
IS-V Classification	C	B
Overall Classification	**C**	**B**
EAL (FEMA P-58)	0.35%	0.28%

O'Reilly, Gerard J., Daniele Perrone, Matthew Fox, Ricardo Monteiro, and Andre Filiatrault. 2018. "Seismic Assessment and Loss Estimation of Existing School Buildings in Italy." Engineering Structures 168 (August): 142–62. https://doi.org/10.1016/j.engstruct.2018.04.056.

Reasons?

- One simplification is the fixed loss ratios for each limit state
- O'Reilly *et al.* (2018) by comparing the expected loss ratio at each limit state from detailed analysis
- Especially the case at the SLO and SLD limit states which are weighted more during the EAL integration
- Another issue that is not currently considered is regarding the building occupancy type (i.e., apartment, school or office building)
- Taghavi and Miranda (2003) highlighted the importance of building occupancy type on the distribution of economic loss



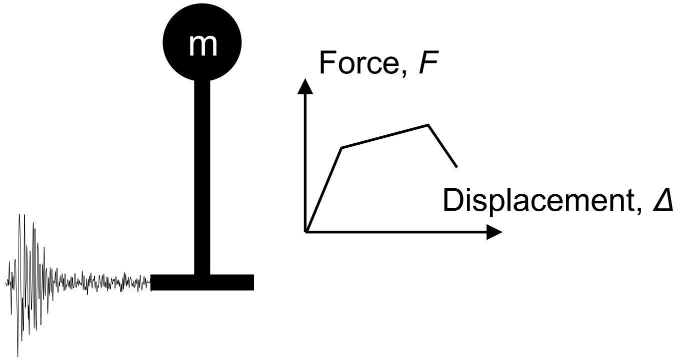


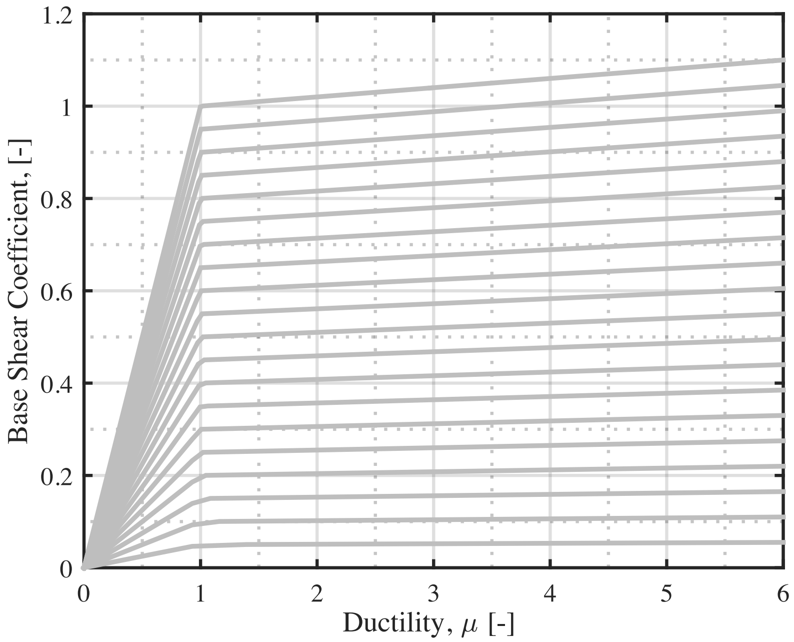
Taghavi, Shahram, and Eduardo Miranda. 2003. "Response Assessment of Nonstructural Building Elements." *PEER Report 2003/05*.

Possible limitations – collapse safety

- Another limitation is the lack of uniformity of risk estimates used to determine the collapse safety of structures
- Several SDOF oscillators were designed for two ductility classes for reinforced concrete (RC) frames
- A site with soil class C in L'Aquila was chosen
- A strength modification factor, ζ, was applied to weaken the overall strength capacity of the SDOF systems and act as a proxy for non-code compliant or existing structures

T = 0.2 – 2s
q = 3.9 and 5.85

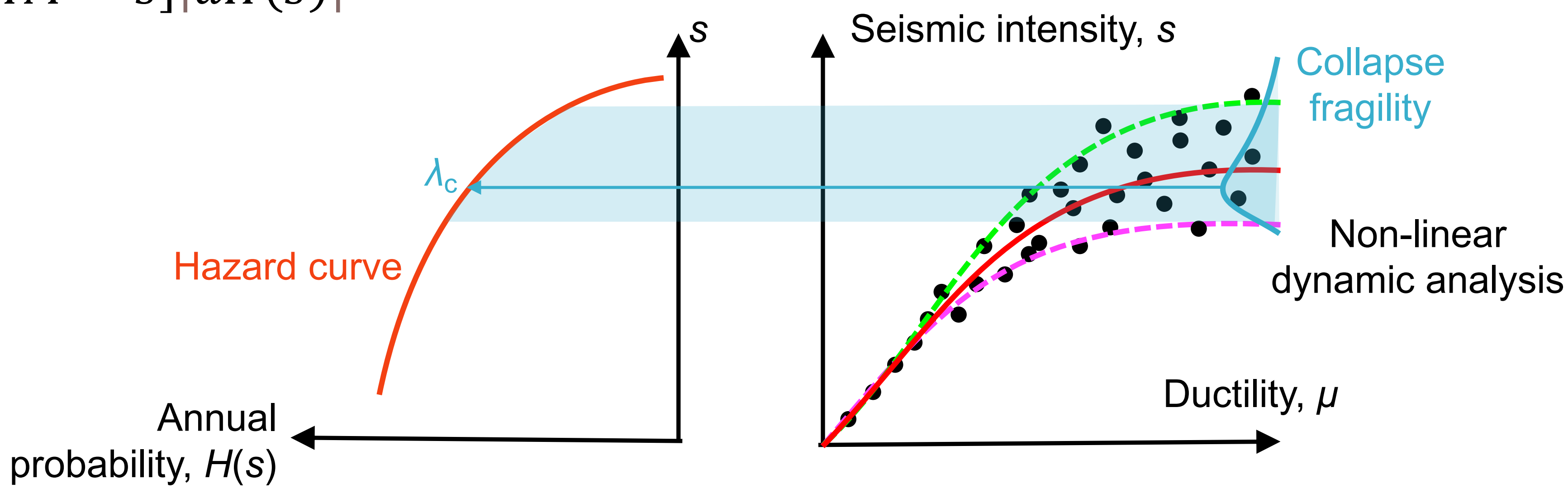




Possible limitations – collapse safety

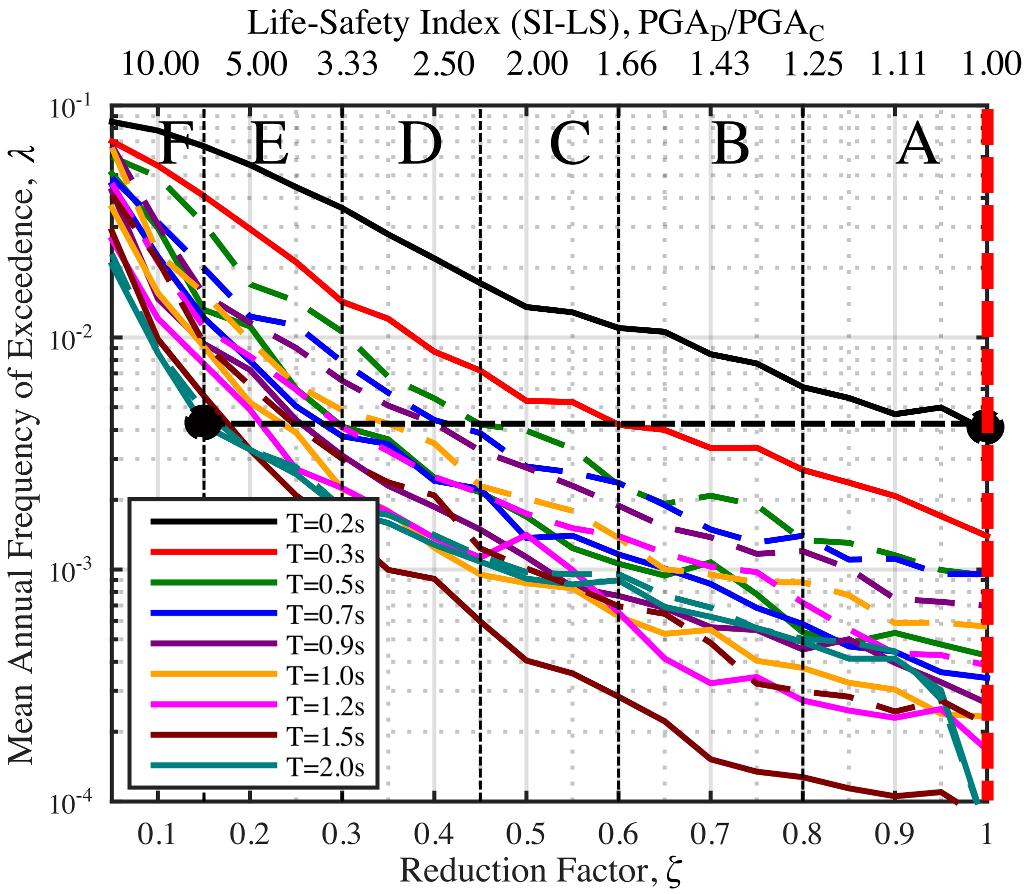
- Multiple stripe analysis was performed using hazard-consistent ground motion records to calculate the risk of failure

$$\lambda_f = \int_{0}^{+\infty} P[f|IM = s]|dH(s)|$$



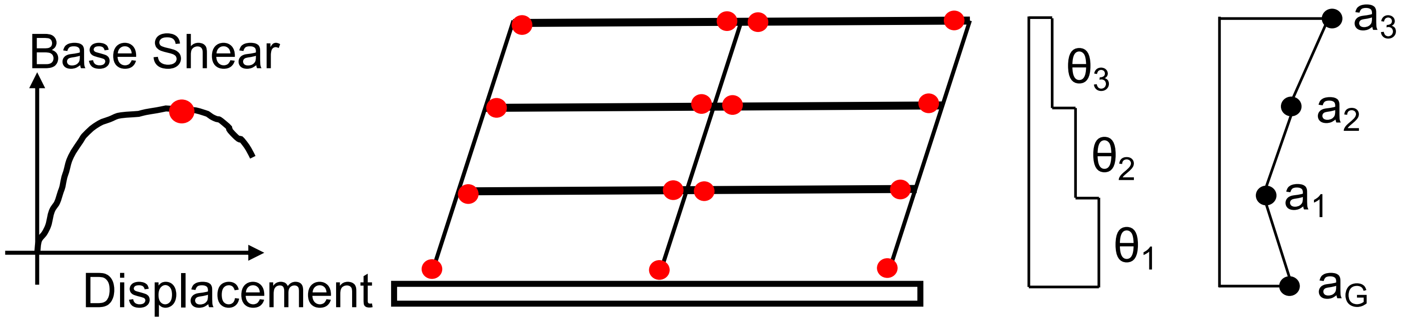
Possible limitations – collapse safety

- The variability between lines shows the inconsistency in risk
- In an ideal world, all lines would coincide
- Notable dispersion in results for code-compliant structures (i.e., *SI-LS* = 1)
- This is well-known as has been shown in projects like RINTC
- Looking horizontally, many different *Sismabonus* risk classes can result for the same λ_{LS} depending on its period and ductility class

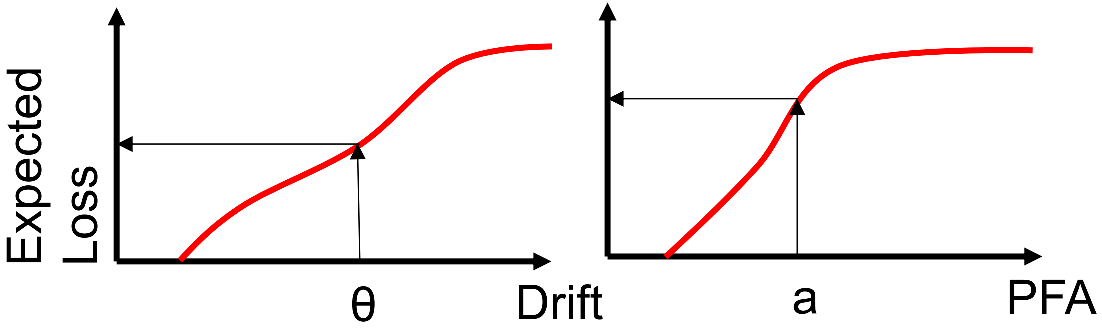


Potential remedies – expected loss

- Performing detailed analyses with individual repair costs and inventory quantities is beyond the scope of most practical application
- Do we really need to use fixed loss ratios for each limit state?



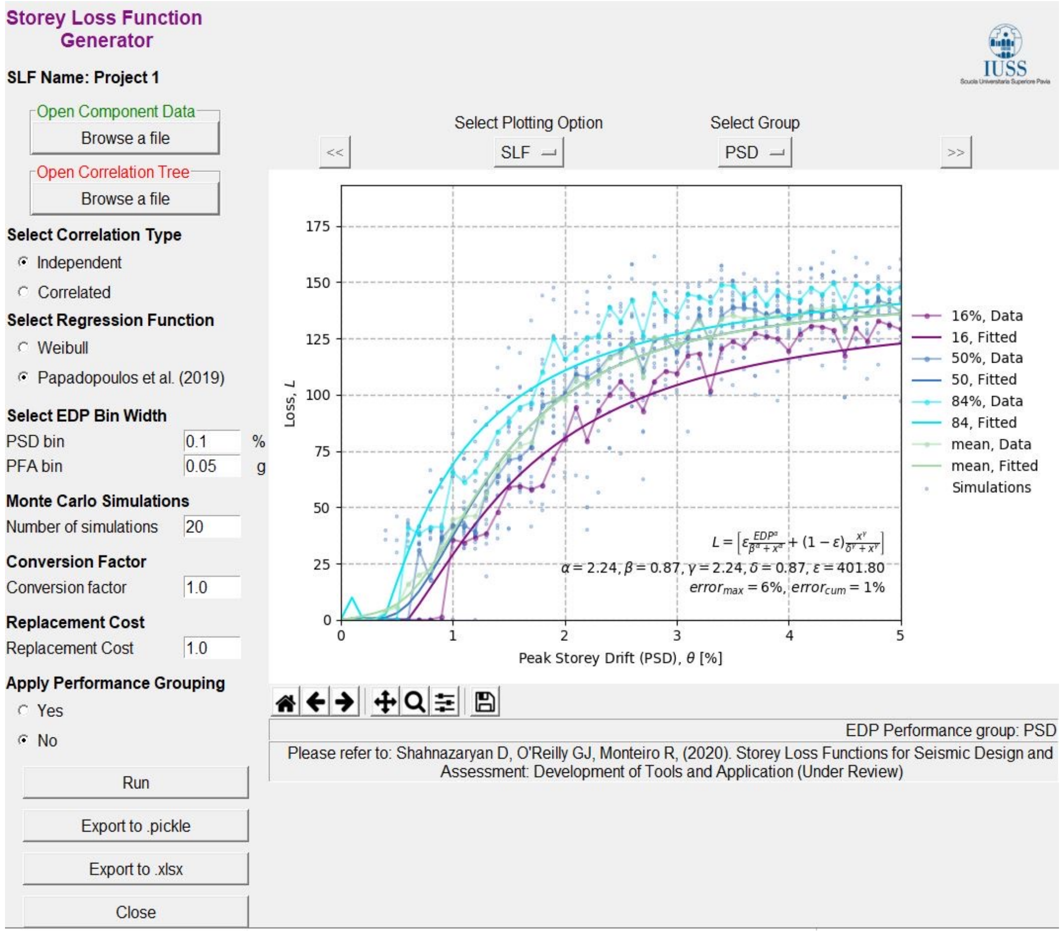
- We could use a more direct approach like storey-loss functions (SLFs) to estimate losses



Potential remedies – expected loss

- SLFs have been mainly implemented in the US
- Shahnazaryan et al. (2021) have developed a toolbox for automated production of SLFs
- It allows quick generation of SLFs and can be easily tailored and personalised for users depending on damageable inventories, repair actions and repair costs

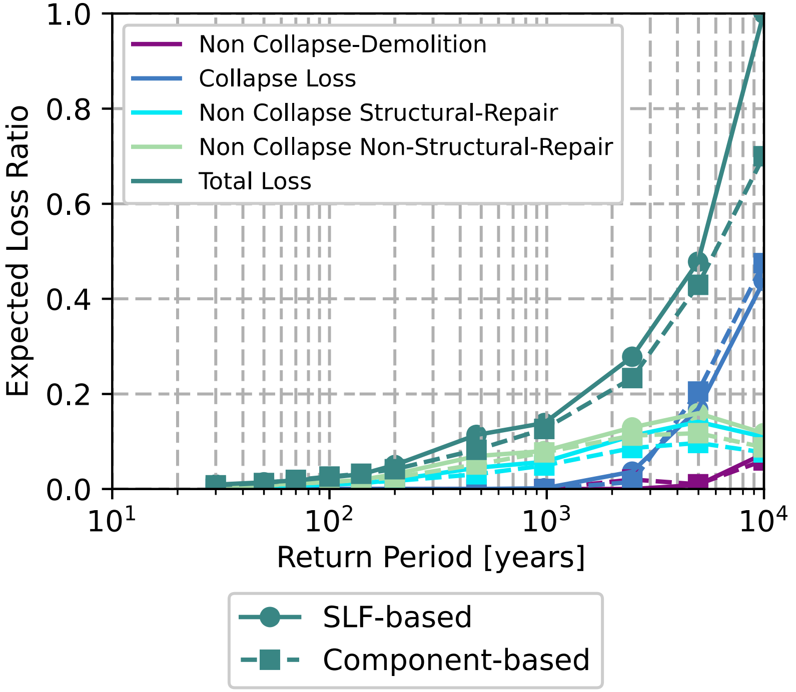
https://github.com/davitshahnazaryan3/SLFGenerator

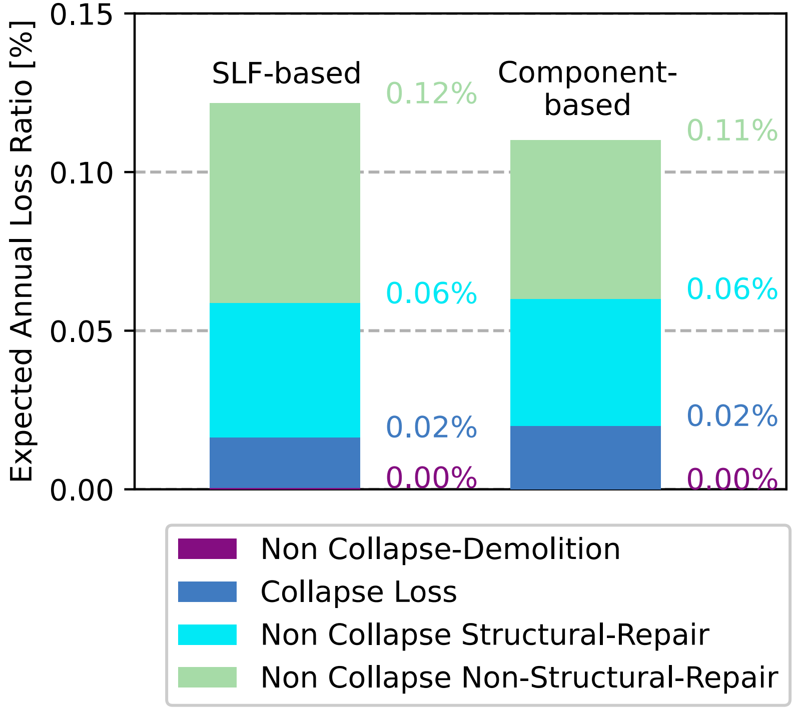


Shahnazaryan, Davit, Gerard J O'Reilly, and Ricardo Monteiro. 2021. "Story Loss Functions for Seismic Design and Assessment: Development of Tools and Application." Earthquake Spectra 37 (4): 2813–39. https://doi.org/10.1177/87552930211023523.

Potential remedies – expected loss

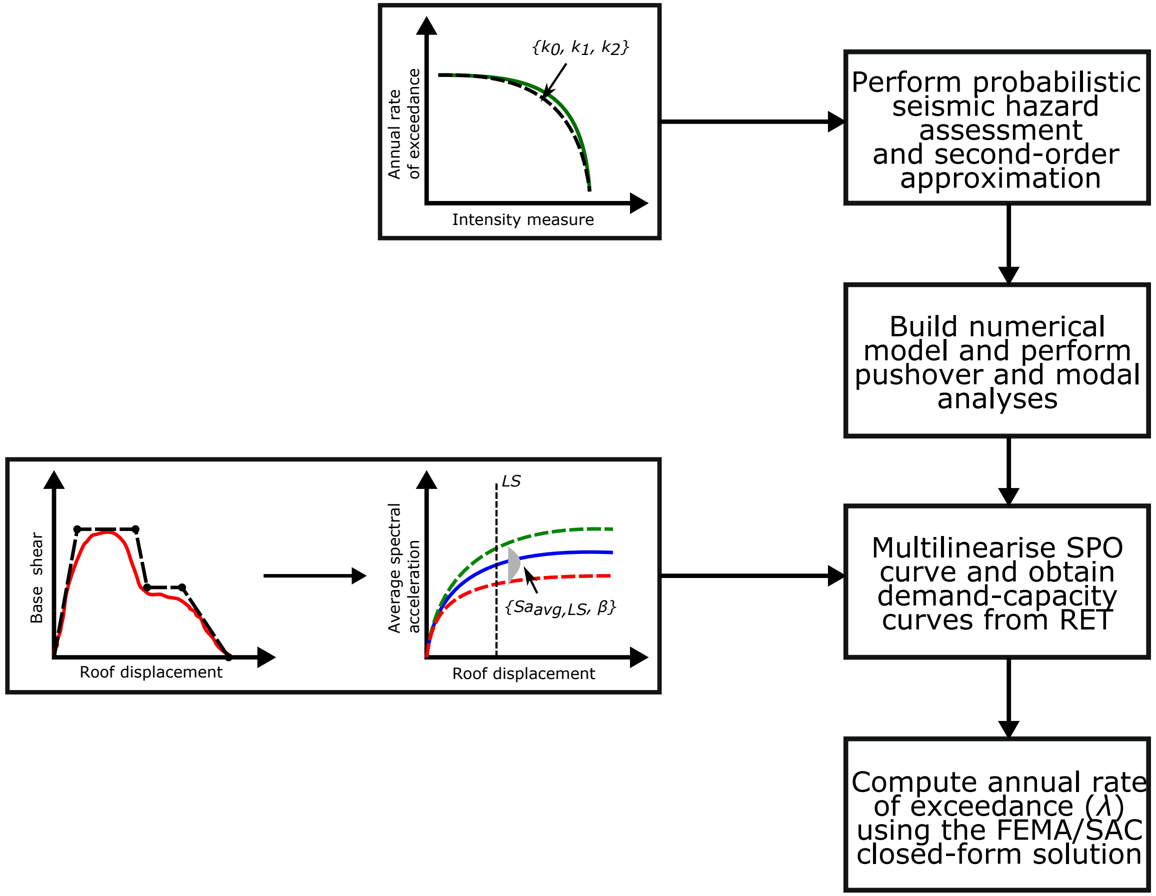
- Application to an RC school building in Italy have shown similar outputs with respect to the more rigorous component-based loss assessment described in FEMA P-58
- Good match in EAL and distribution among different performance groups was observed
- Highlights its applicability for accurate and simple loss assessment





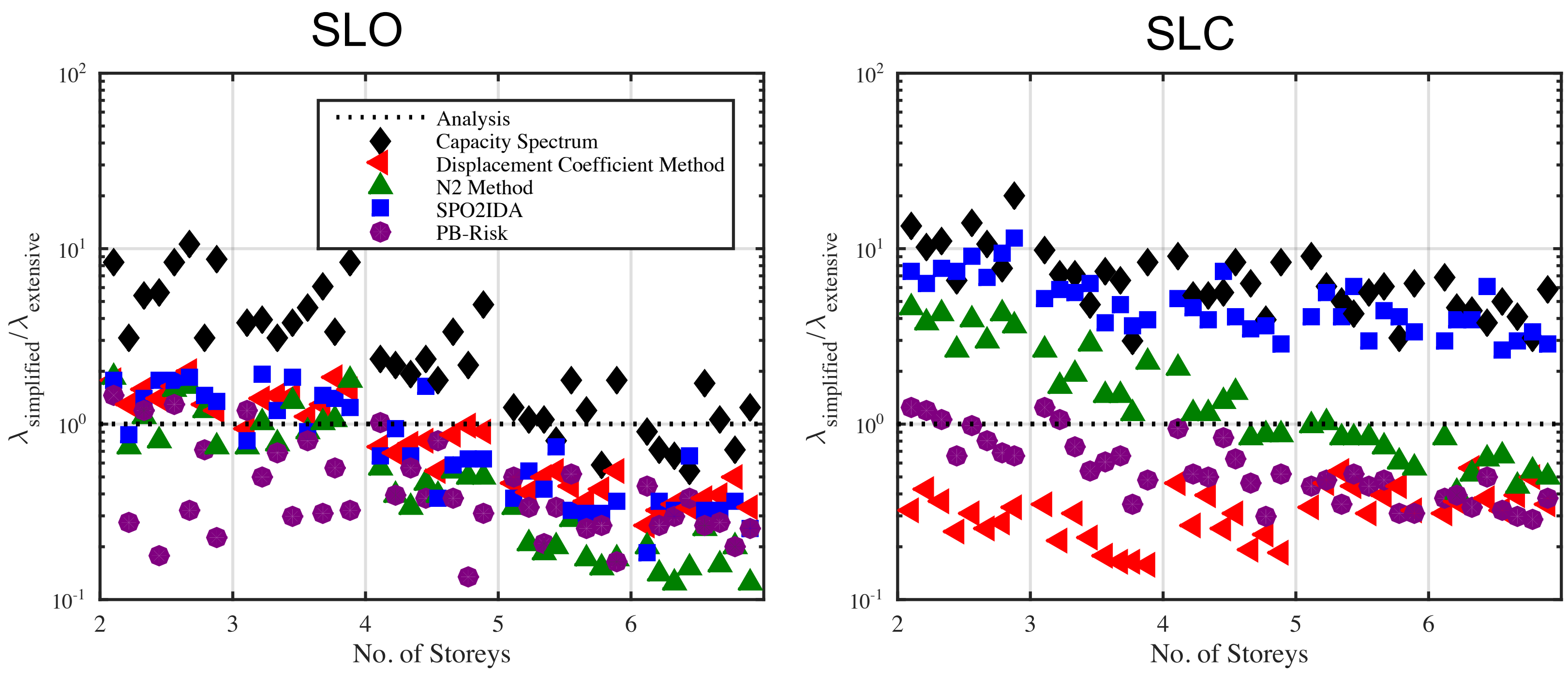
Potential remedies – collapse safety

- A possible improvement for collapse safety is a simple pushover-based methodology *PB-Risk* developed by Nafeh and O'Reilly (2022a)
- It estimates the seismic response using the results obtained from pushover analysis
- It is quick and easy to implement within a practical and code-based setting and could be easily adopted within risk classification guidelines



Potential remedies – collapse safety

- The *PB-Risk* method was scrutinized with respect to other non-linear static procedure methods for infilled RC frames structures
- The results show a notable difference in the risk when compared to detailed non-linear time-history analyses



- Capacity spectrum method (CSM)
- N2 method
- Displacement coefficient method (DCM)
- SPO2IDA

Summary

- Recent years have seen the evolution of seismic risk assessment
- This is especially the case in Italy with the advent of the Sismabonus guidelines
- When scrutinised with respect to rigorous state-of-the-art methods, it can run into some problems
- The overall goal still remains sound and worthwhile
- With some minor adjustments and improvements, the guidelines could be improved greatly and made more tailorable
- This presentation looked at some candidates for this