Towards improved response quantification of existing infilled RC frames

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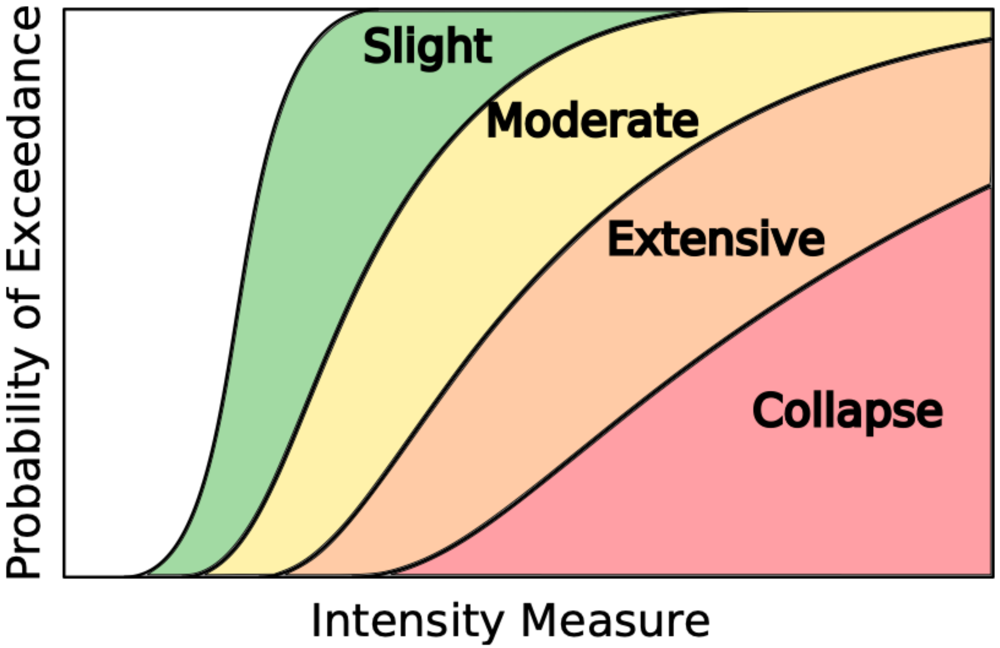
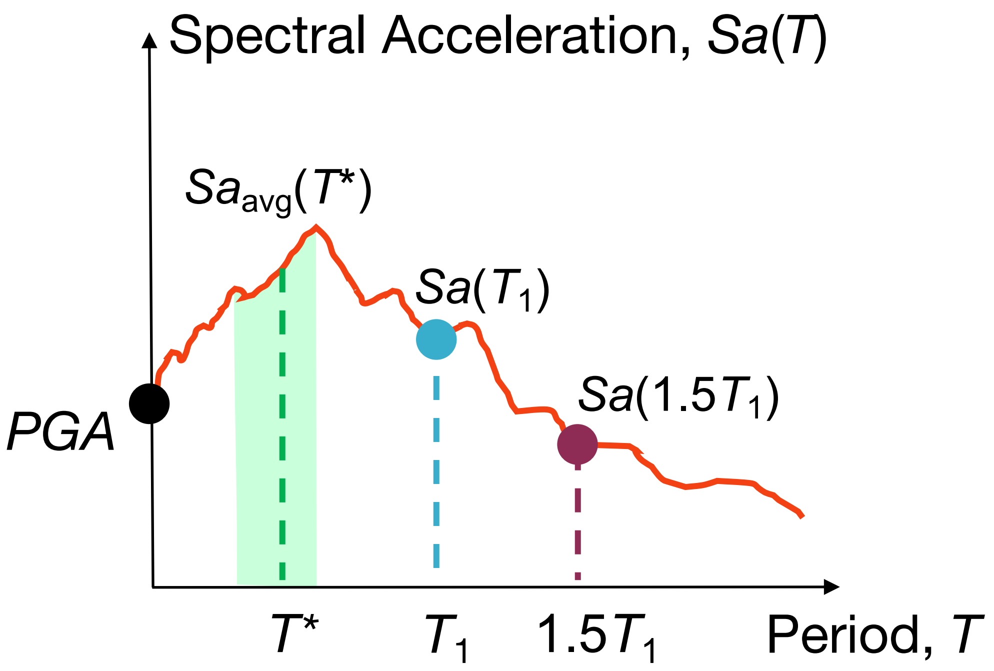
Introduction

- When assessing existing structures, the probabilistic distribution of response (i.e. fragility function) is quantified using some form of seismic intensity measure (IM)
- IMs are usually defined in terms of ground shaking characteristics and a structure's dynamic properties



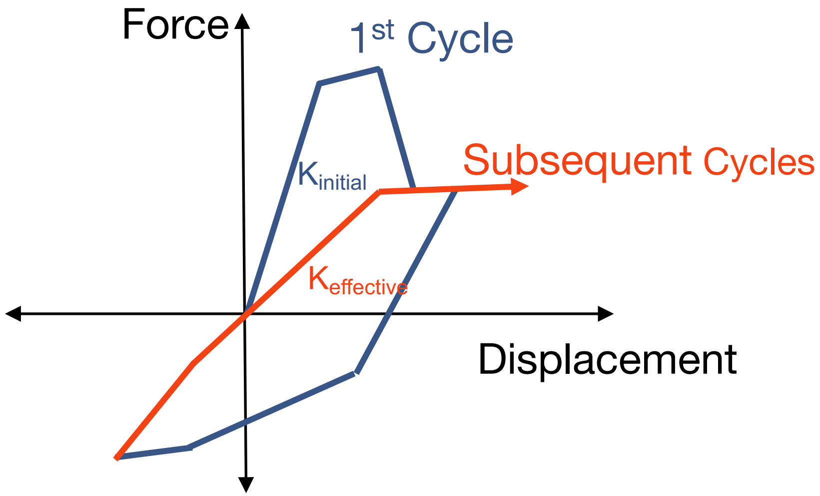
Intensity measures

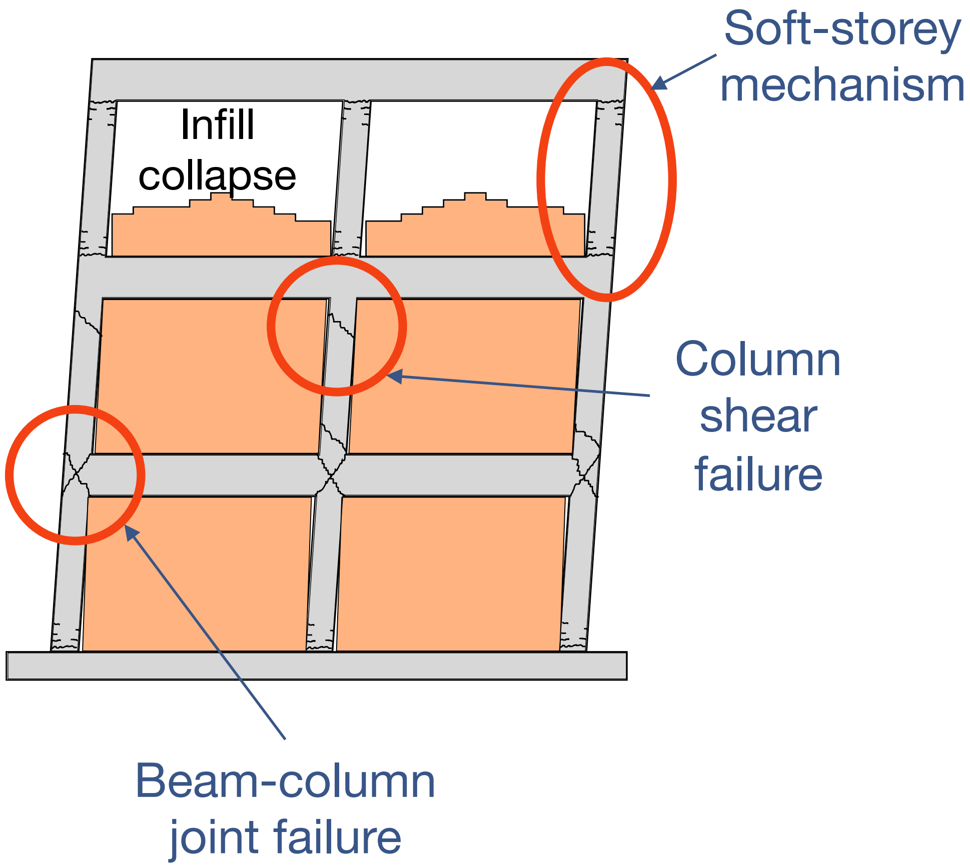
- Peak ground acceleration (*PGA*) remains a firm favourite in regional studies due to its simplicity and easy of applicability
- Spectral acceleration at the first mode of vibration, $Sa(T_1)$, is a popular choices for buildings given its physical meaning
- $Sa(1.5T_1)$ has been shown to be a better choice of IM for collapse assessment
- Another addition is the average spectral acceleration, $Sa_{avg}(T^*)$ which considers the geometric mean of values within a range around T^*
- Two questions:
  - Which IM should we use?
  - How to know what *T* value to use?



Existing RC frames with infills

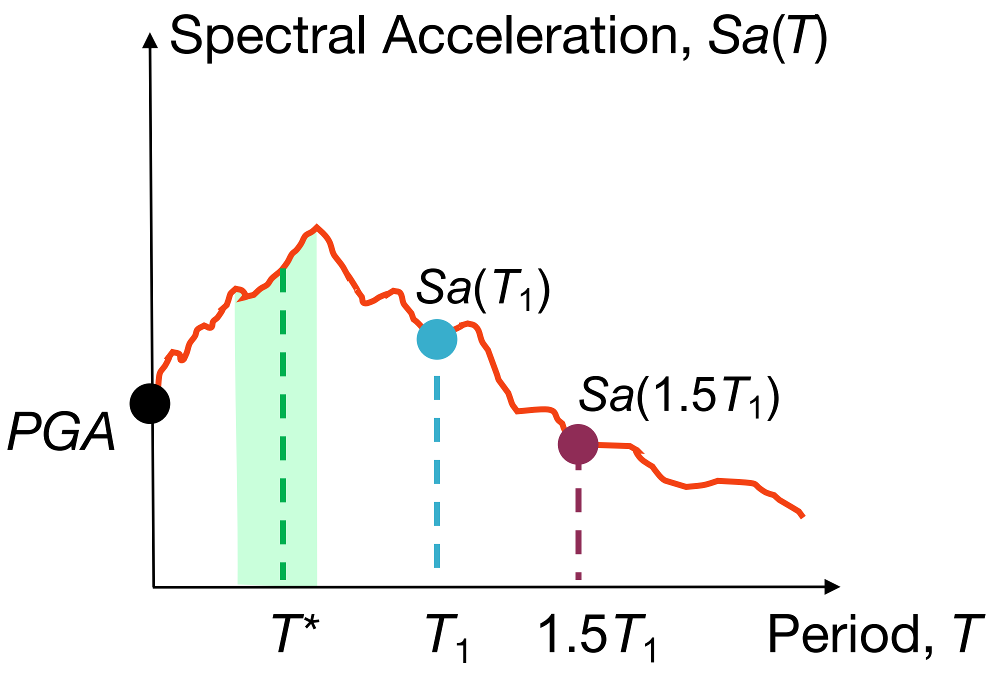
- Reinforced concrete (RC) buildings with masonry infill panels are a common typology in the Mediterranean area
- Increased stiffness and relative brittleness of these panels notably modifies structural behaviour, especially in older buildings where no seismic design provisions were utilised





Some issues arise

- Two questions:
  - Which IM should we use?
  - How to know what *T* value to use?
- In infilled RC frames, there can be abrupt changes in stiffness and strength due to local infill panel failure and subsequent non-ductile mechanisms
- Identifying a good *T* becomes difficult
- IMs like $Sa(T_1)$ can be poor and possibly biased response predictors
- This paper explores $Sa_{avg}(T^*)$ for RC buildings with masonry infill panels from the perspective of efficient and unbiased response prediction



Case study building

- A case study 4 storey building designed for gravity loads only, representative of European structures around the 1970s was considered
- Smooth rebars (Aq42) and low concrete grade with allowable stresses were considered
- These matched the provisions used at the time in Italy (Regio Decreto, 1939)

Beams:

Sections: 50x30cm
ρ_L: 0.21-0.41%
ρ_V: 6mm@150mm

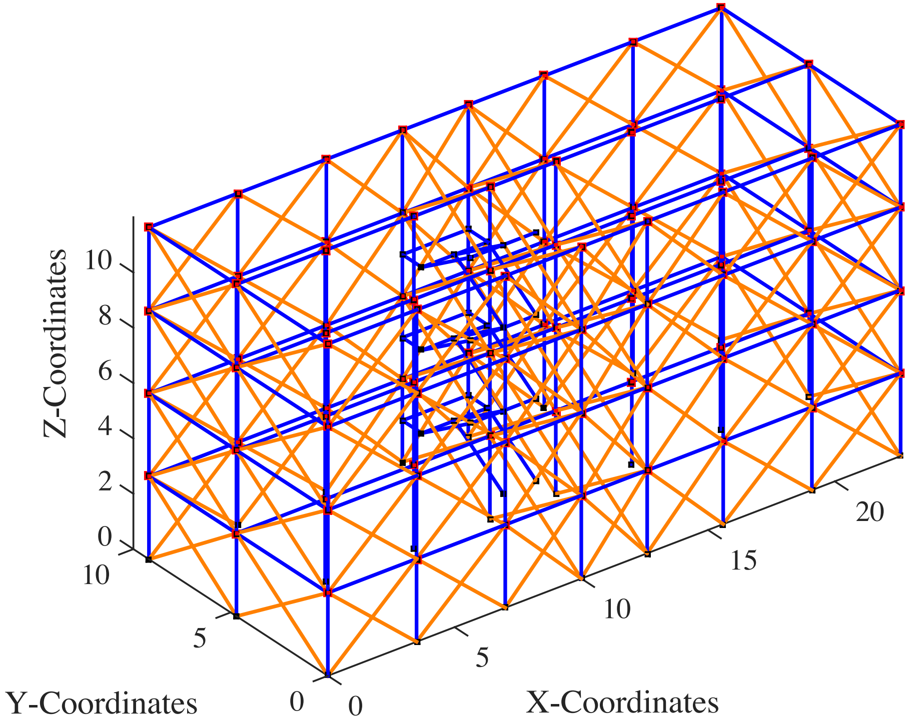
Columns:

Sections: 40x40cm at ground
35x35cm elsewhere
ρ_L: 0.75-0.89%
ρ_V: 6mm@200mm

Regio Decreto. 1939. “Norme per l’esecuzione delle opere Conglomerato cementizio semplice od armato - 2229/39.” Rome, Italy.

Numerical modelling in OpenSees

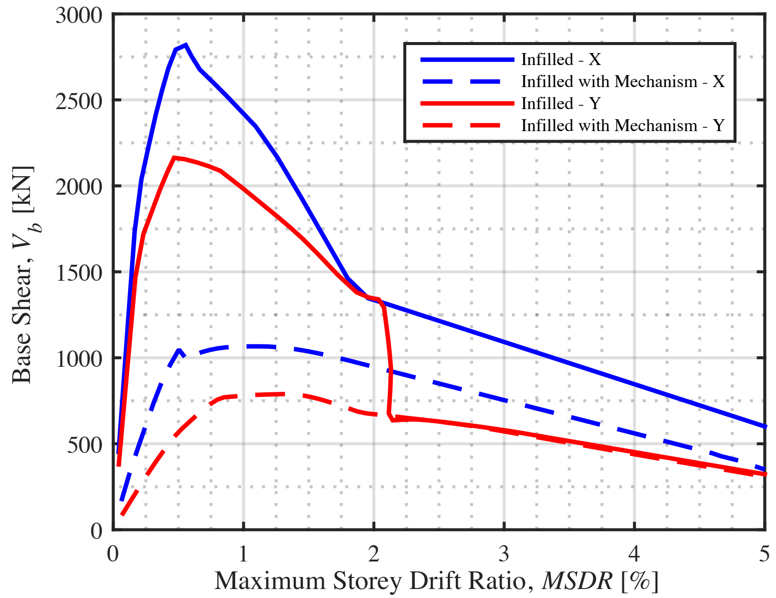
- A 3D lumped plasticity model was developed in OpenSees
- The modelling approach of O'Reilly and Sullivan (2019) for non-ductile infilled RC frames was followed
- Beam-column elements were modelled with bi-directional flexural sections with an internal elastic element behaviour with cracked section properties
- The shear capacity of RC elements was modelled using shear springs
- Beam-column joints were modelled to account for insufficient joint reinforcement and smooth bars with end-hooks



O'Reilly, Gerard J., and Timothy J. Sullivan. 2019. "Modeling Techniques for the Seismic Assessment of the Existing Italian RC Frame Structures." Journal of Earthquake Engineering 23 (8): 1262–96. https://doi.org/10.1080/13632469.2017.1360224.

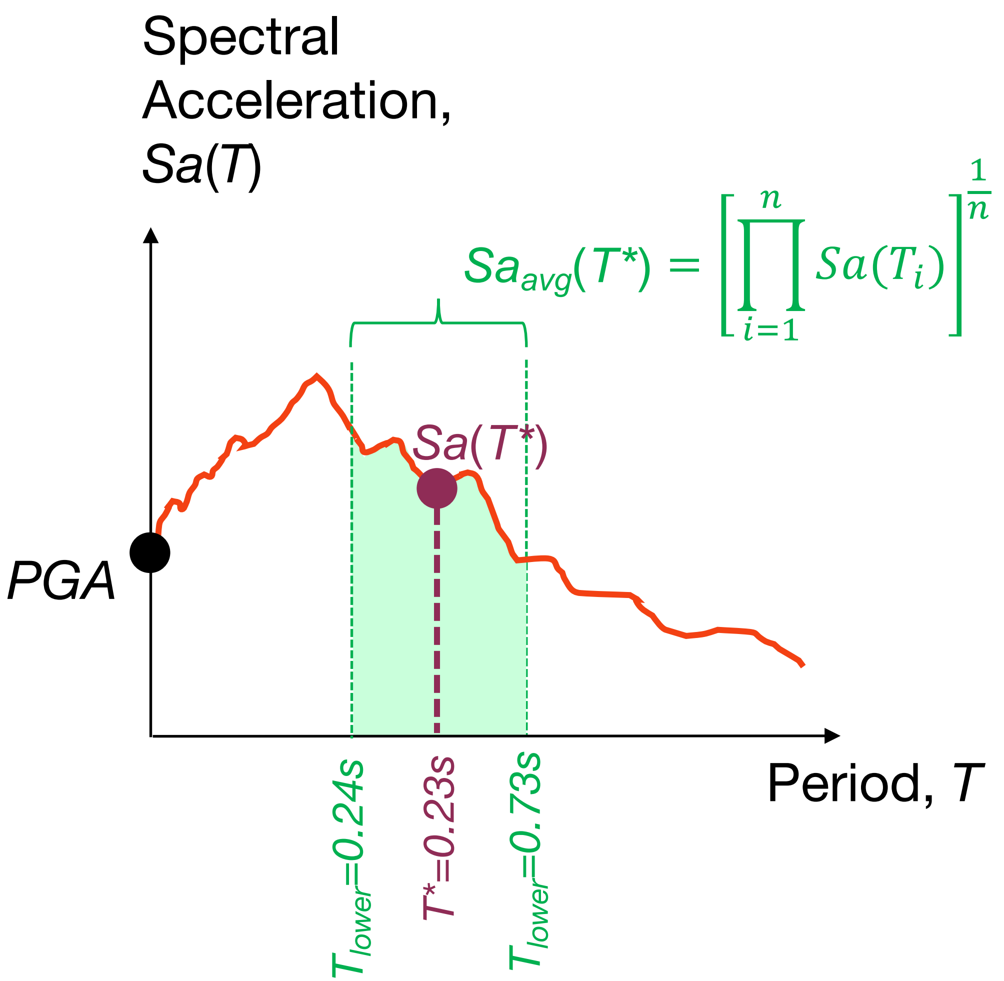
Static pushover analysis

- A pushover analysis shows the non-linear behaviour and brittle behaviour of the structure
- The increased lateral strength and stiffness due to the presence of masonry infills are clear
- Also plotted is the same structure modelled with no infill panels at the storey where the infill collapse mechanism would be expected to form
- This is anticipated to be representative of the hysteretic behaviour of the building during subsequent cycles following the local collapse of infills at one or more storeys
- The sudden drop in lateral capacity in the Y-direction at a drift of just over 2% corresponds to a brittle shear failure caused by the short column effect due to the addition of stairs



Intensity measures

- Three IMs were examined:
  1. *PGA*
  2. $Sa(T^*)$
  3. $Sa_{avg}(T^*)$
- T^* was computed as the arithmetic mean of the X and Y direction first mode periods as (0.22+0.24)/2 = 0.23s
- For $Sa_{avg}(T^*)$, a period range $[T_{lower}, T_{upper}]$ with a spacing of 0.1s was utilised.
- This was defined following the recommendations of $[1.2T_2, 3T_1]$ for non-ductile infilled RC frames in O'Reilly (2021) as [0.24s, 0.73s]



O'Reilly, Gerard J. 2021. "Limitations of Sa(T1) as an Intensity Measure When Assessing Non-Ductile Infilled RC Frame Structures." Bulletin of Earthquake Engineering 19 (6): 2389–2417. https://doi.org/10.1007/s10518-021-01071-7.

Hazard analysis and ground motion records

- A case-study site in Campobasso in southern Italy was selected
- Seismic hazard analysis and disaggregation were conducted in OpenQuake for each IM
- Thirty ground motion record pairs were selected and scaled for discrete intensity levels to carry out multiple stripe analysis

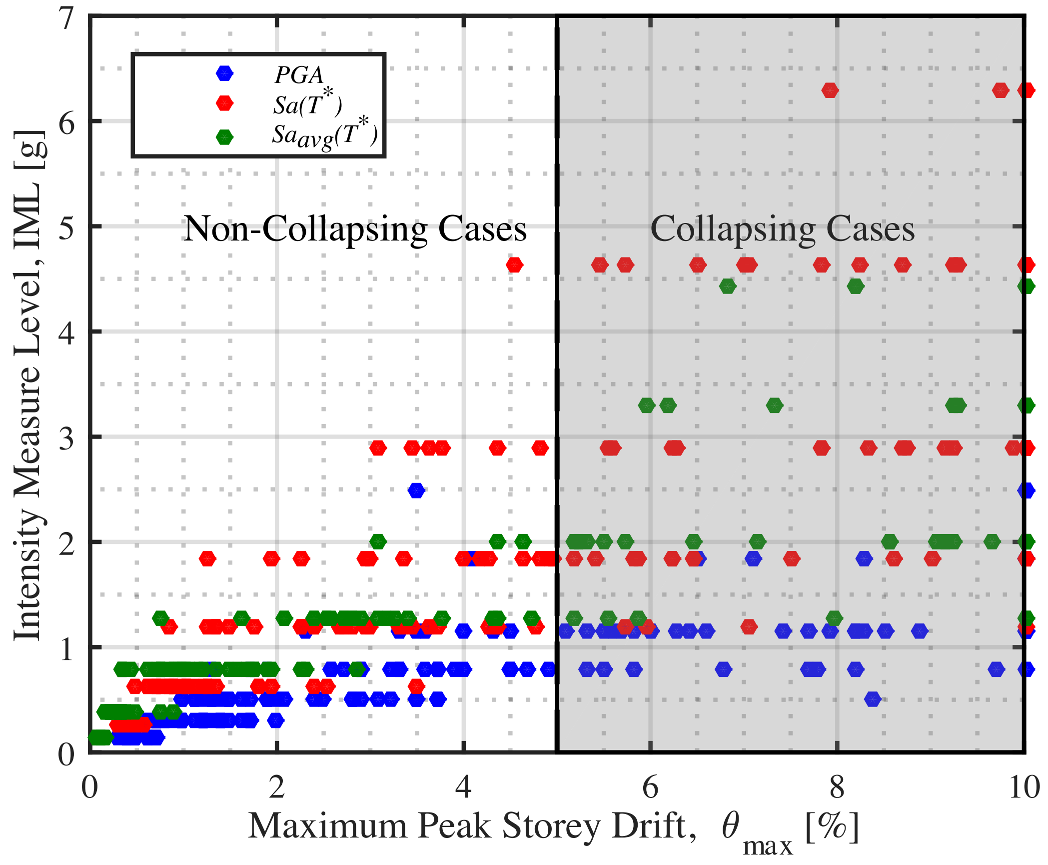
OPENQUAKE
calculate share explore

Multiple stripe analysis

- The engineering demand parameter (EDP) used was the maximum absolute value along the building height of the peak transient storey drifts, with the greater of the X or Y direction being utilised and denoted θ_{max}

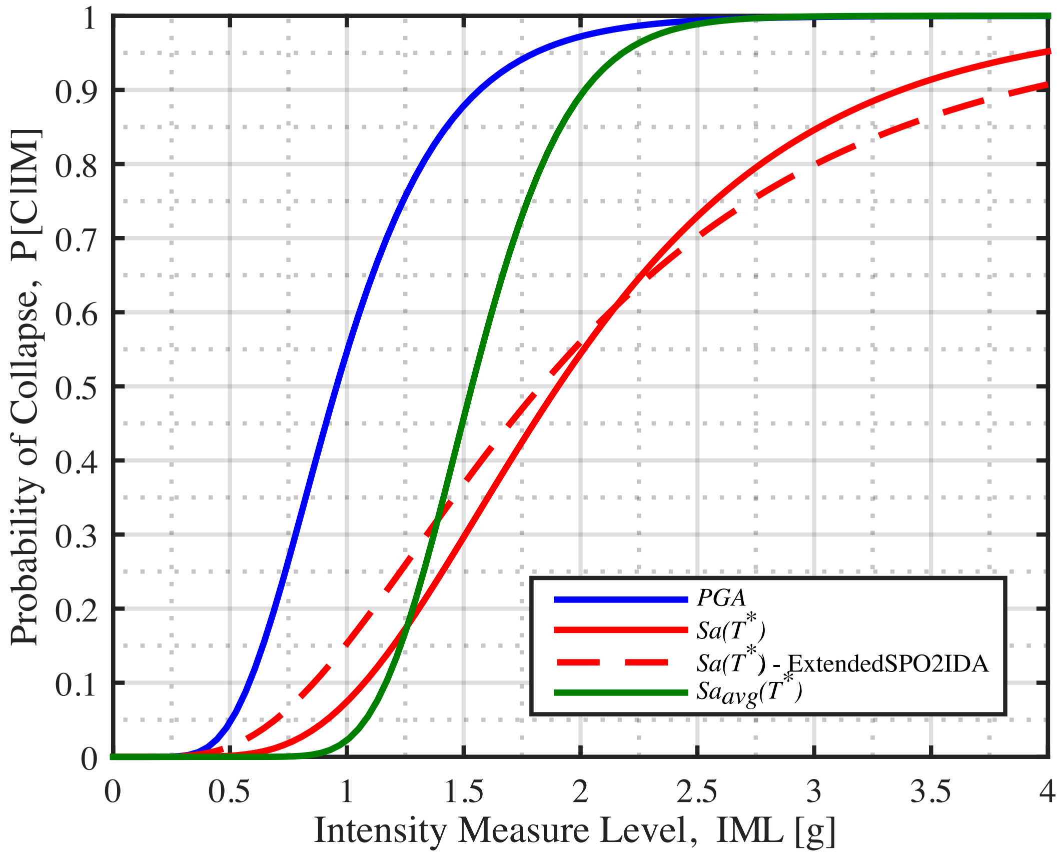
$$\theta_{max} = \max_{\substack{i=X,Y \\ j=1...N \\ t=0..t_{max}}} \left|\theta_{i,j}(t)\right|$$

- Cases were separated into collapsing and non-collapsing cases, where collapse indicates a complete loss of lateral capacity, with $\theta_{collapse}$=5% being used



Collapse fragility function

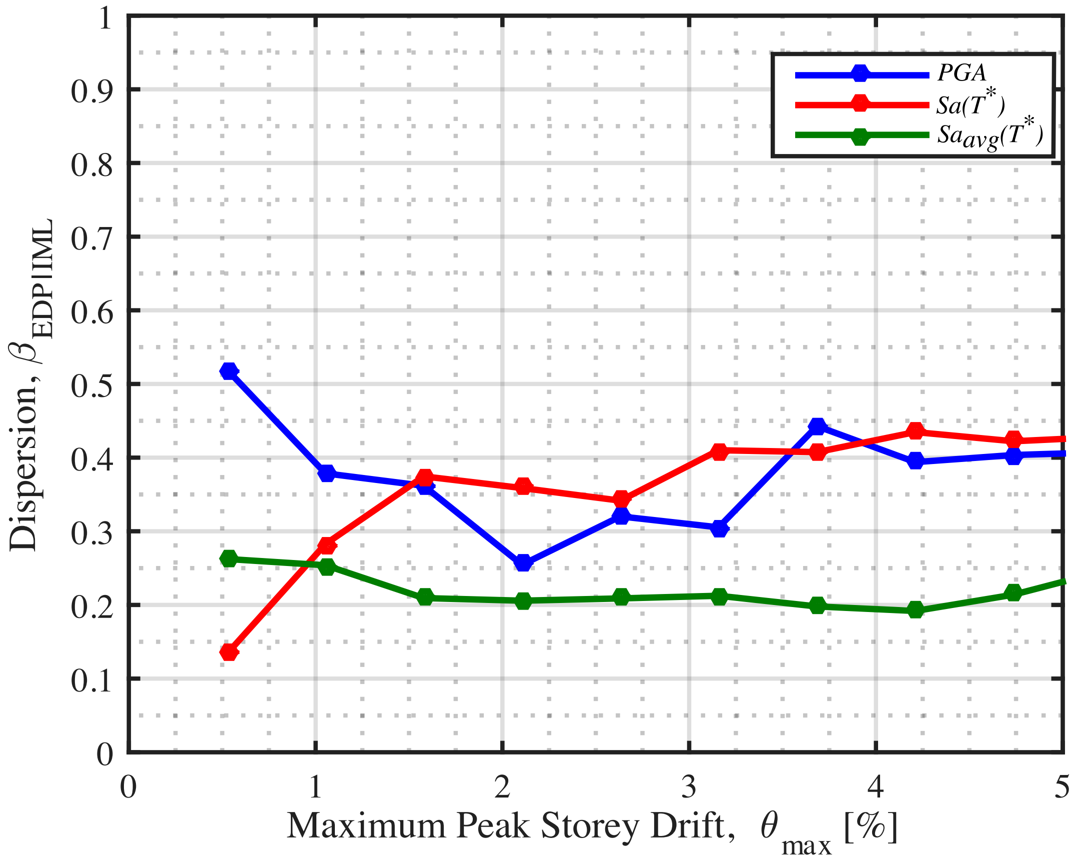
- For each MSA stripe, the fraction of exceedances for a given EDP threshold is counted and a lognormal fragility function is fitted using the maximum likelihood method
- Using the 5% collapse threshold, the resulting fragility function is shown
- Also shown is the collapse fragility obtained via extended SPO2IDA tool (Nafeh et al., 2020) which simply uses the pushover curves and demonstrates a good match



Nafeh, Al Mouayed Bellah, Gerard J. O'Reilly, and Ricardo Monteiro. 2020. "Simplified Seismic Assessment of Infilled RC Frame Structures." Bulletin of Earthquake Engineering 18 (4): 1579–1611. https://doi.org/10.1007/s10518-019-00758-2.

Fragility dispersions

- Performing the same operation for a range of EDP or θ_{max} values shows the fragility function dispersion versus EDP, $\beta_{IML|EDP}$
- This is an indicator of the efficiency of the IM
- Initially *Sa*(*T**) appears to have the lowest dispersion, owing to its close relationship to the initial elastic behaviour of the building, but loses its efficiency with increasing drift demand
- *PGA* is seen to be rather high and remains relatively inefficient
- $Sa_{avg}(T^*)$ is initially not the best but is seen to be consistently more efficient than both *Sa*(*T**) and *PGA*



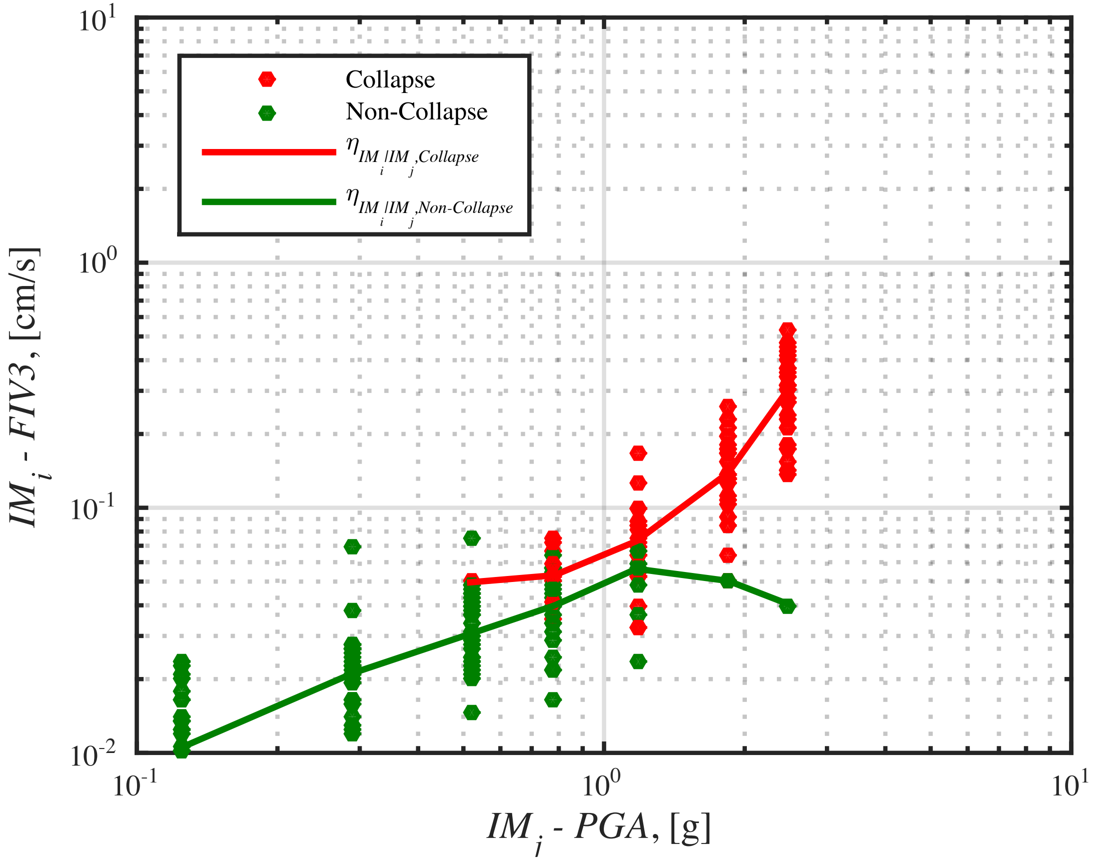
Bias

- Given the observations in IM dispersion, it is of interest to know what the reasons for such a difference may be
- Some dispersion is generally expected for all IMs due to the inherent randomness of ground motions
- For some scenarios, the results obtained using ground motions selected and scaled to a single conditioning IM_j (e.g. $Sa(T^*)$) could also be biased by another IM_i (e.g. ground motion duration)
- The possible bias was evaluated using the velocity-based IM termed filtered incremental velocity, *FIV3* (Dávalos and Miranda, 2019)

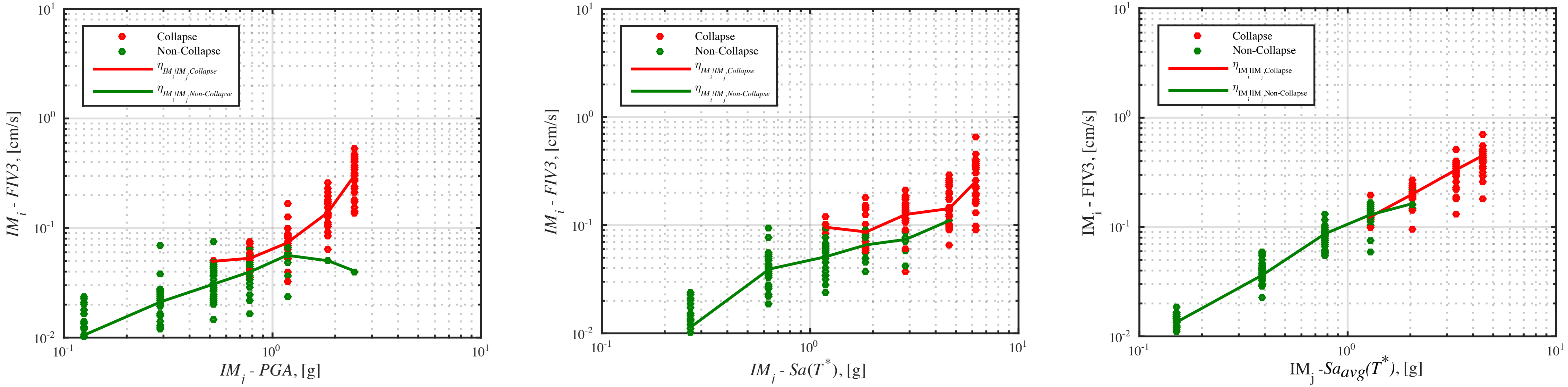
Dávalos, Héctor, and Eduardo Miranda. 2019. "Filtered Incremental Velocity: A Novel Approach in Intensity Measures for Seismic Collapse Estimation." Earthquake Engineering & Structural Dynamics 48 (12): 1384–1405. https://doi.org/10.1002/eqe.3205.

Bias

- For each MSA stripe with conditioning IM_j = {PGA, $Sa(T^*)$, $Sa_{avg}(T^*)$}, the corresponding $IM_i = FIV3$ values of each ground motion are plotted via markers on the vertical axis
- This distribution of $IM_i|IM_j$ at each intensity is what indirectly results when selecting ground motions conditioned on IM_j alone
- To examine bias due to $IM_i=FIV3$, the results were segregated based on the collapsing and non-collapsing cases
- The median values were computed and plotted for the non-collapsed $\eta_{IMi|IMj}$ and collapses cases $\eta_{IMi|IMj,collapse}$



Bias



- For *PGA* and *Sa*(*T**), there is a clear distinction between records causing collapse and those not
- This indicates a biasing effect of the velocity-based IMs on *Sa*(*T**) and *PGA*, whereas $Sa_{avg}(T^*)$ did not present such an impact

Summary

- This work has examined the seismic assessment of an infilled RC frame utilising different IMs
- A case study building located in Southern Italy was examined
- Examining the fragility functions:
  - *PGA* was seen to have relatively high dispersion
  - $Sa(T^*)$ showed efficiency initially but gradually became highly disperse
  - $Sa_{avg}(T^*)$ exhibited a relatively low dispersion throughout
- The potential bias caused by the velocity-based characteristics of the ground motions was examined
- In short, if we use *PGA* and $Sa(T^*)$ in our assessments, our results will be dependent on the velocity-based characteristics of the records we use
- If we use $Sa_{avg}(T^*)$, we avoid this problem without much extra effort

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- Wind
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- RA2: Critical Infrastructures
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- RA4: Advanced Technologies

TA User Groups

Total Budget: €11,616,118
Duration: 4 years (01/06/2022 – 31/05/2026)

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- External user groups prepare project proposals in line with the goals of ERIES
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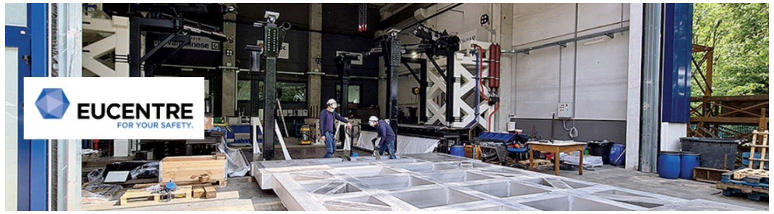
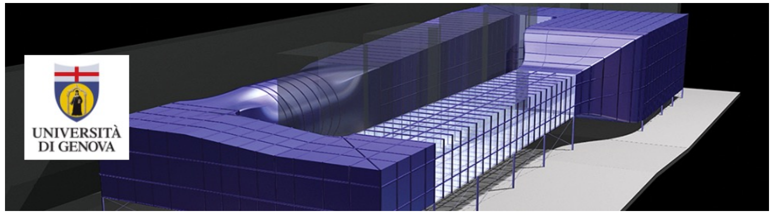
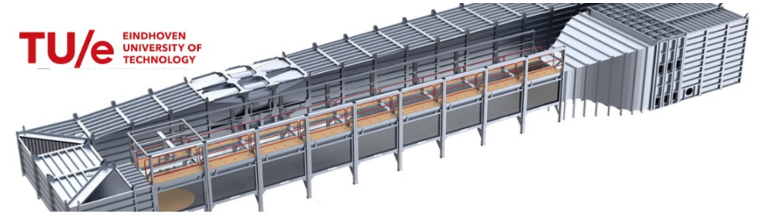
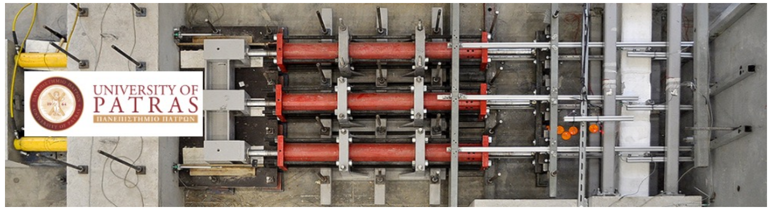
- This means European* users travel to another country and use the research infrastructures made available as part of ERIES
- Cost of experimental testing in addition to travel and accommodation of user groups are covered









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Applications collected and evaluated at cut-off dates:

- 30 Sept 2022
- 1 Jan 2023 (est.)
- 1 Jun 2023 (est.)
- 1 Nov 2023 (est.)

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