18TH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING
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Analytical and empirical fragility functions for regionally assessing non-ductile infilled frames

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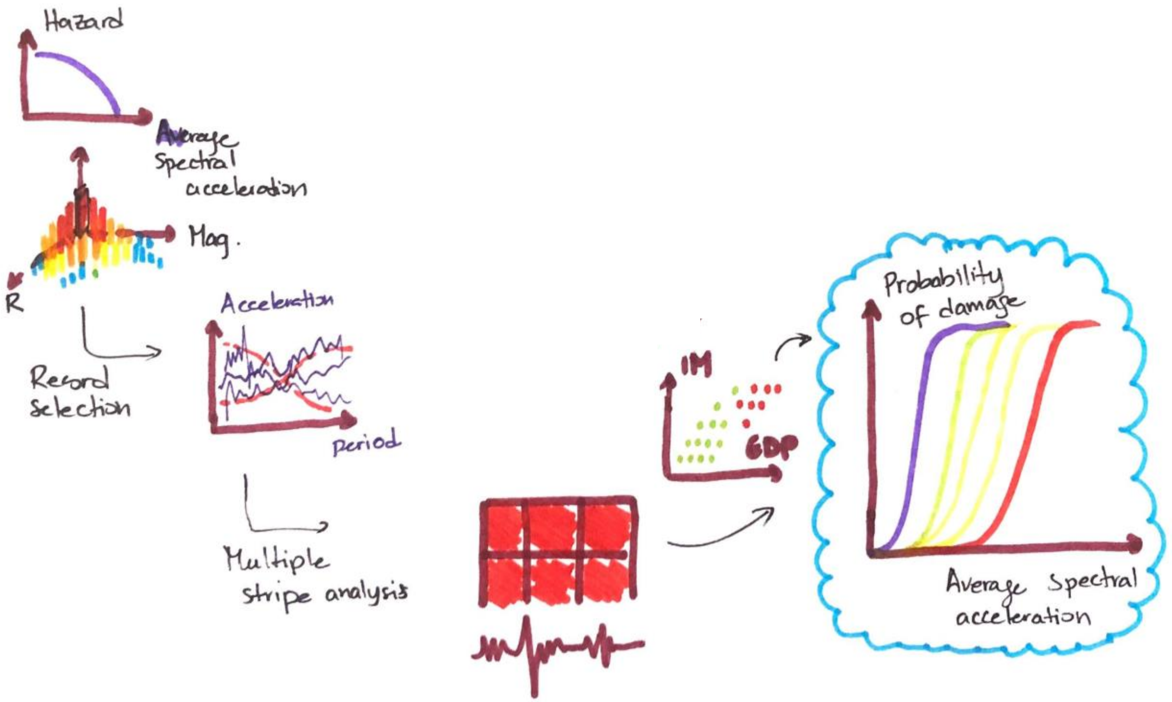
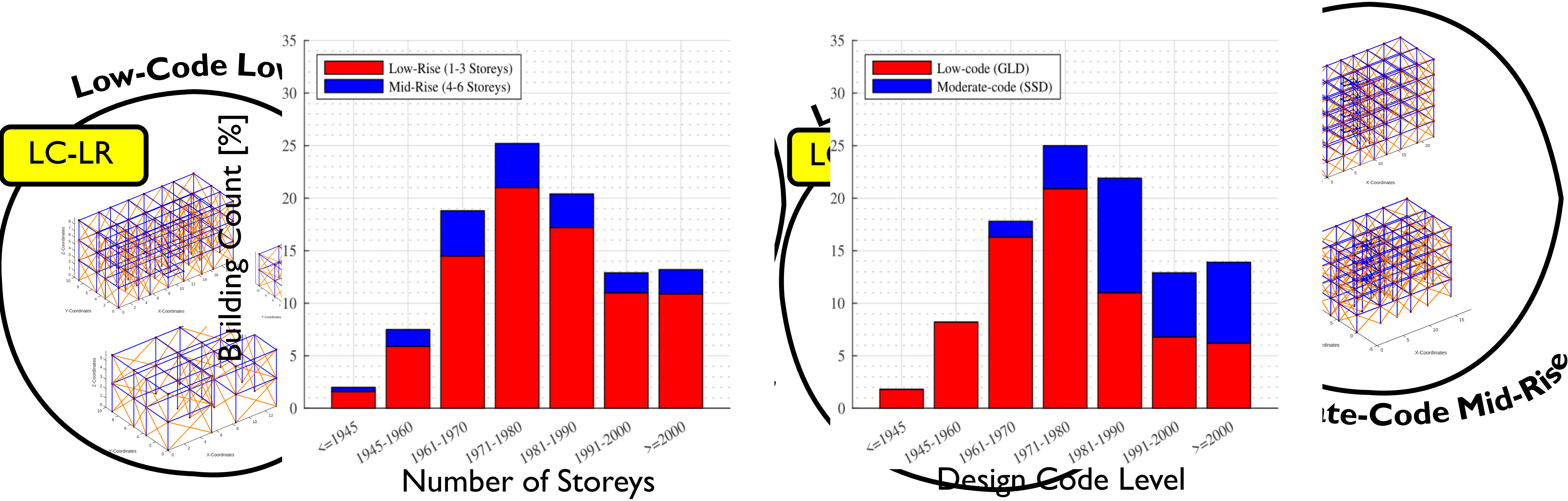
Motivation

- Common practice to develop fragility functions **analytically**
- Use state of the art tools in hazard analysis, ground motion selection and damage characterisation
- Much data has been collected following several earthquake events around the world
- This can be elaborated into **empirical** fragility functions
- How well are we doing when:
  - We compare empirical vs. fragility
  - Integrate recent research developments in fragility analysis



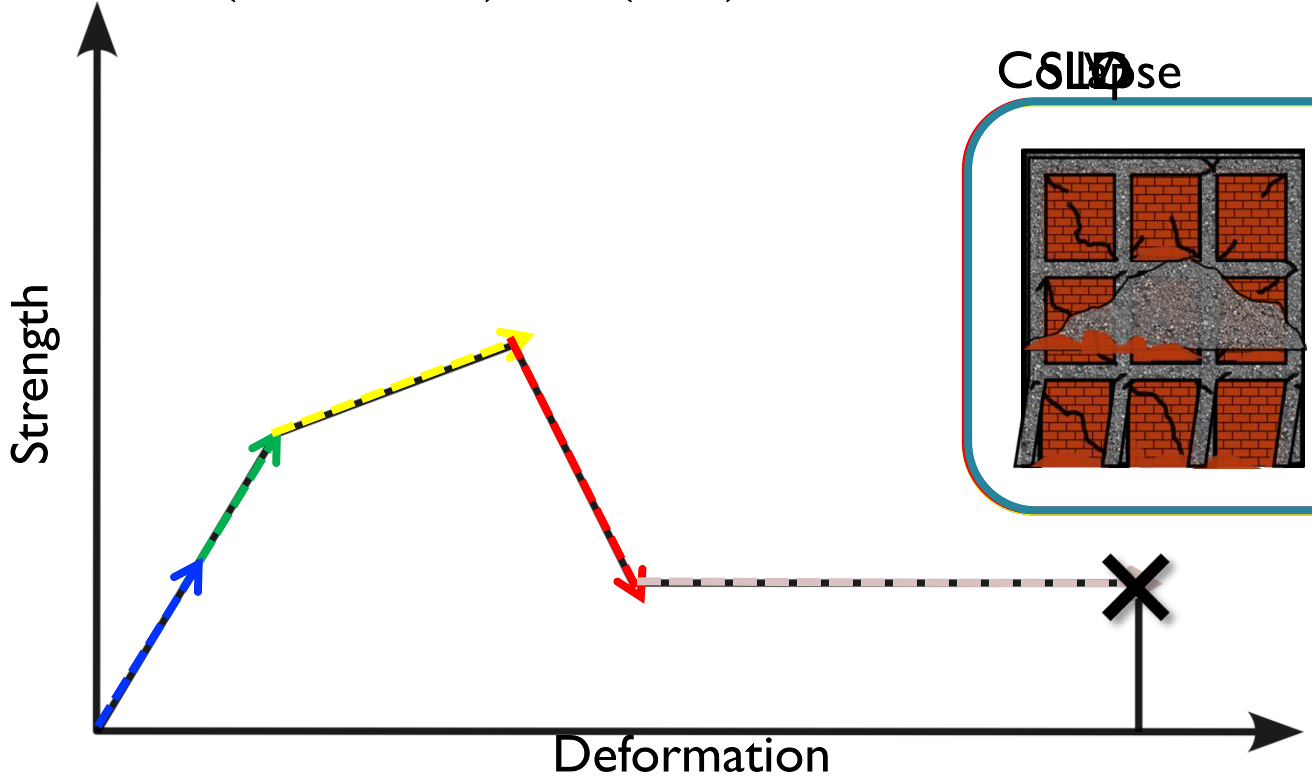
Definition of Building Classes

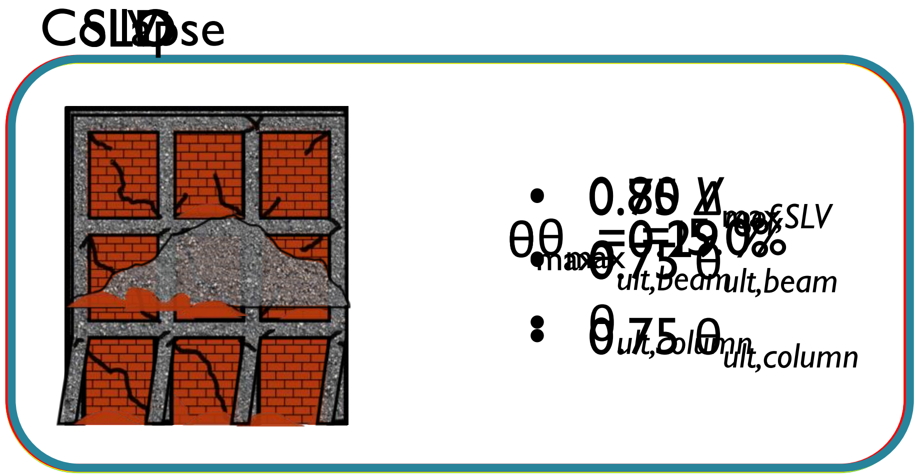
- The definition of a building class is a key step towards assessing seismic risk.
- Building classes must be defined using building attributes relevant to seismic vulnerability



Definition of DSs Thresholds

- A hybrid definition of the damage state thresholds was considered
  - Serviceability Limit States (SLO and SLD): Kurukulasuriya *et al.* (2022)
  - Ultimate Limit States (SLV and SLC): NTC (2018)





- *Kurukulasuriya et al. (2022) Investigation of seismic behaviour of existing masonry infills through combined cyclic in-plane and dynamic out-of-plane tests, 9th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering Methods in Structural Dynamics and Earthquake Engineering*

Analytical-Empirical DS Harmonisation

Quantitative Damage States

Norme Tecniche Per Le Costruzioni (2018)

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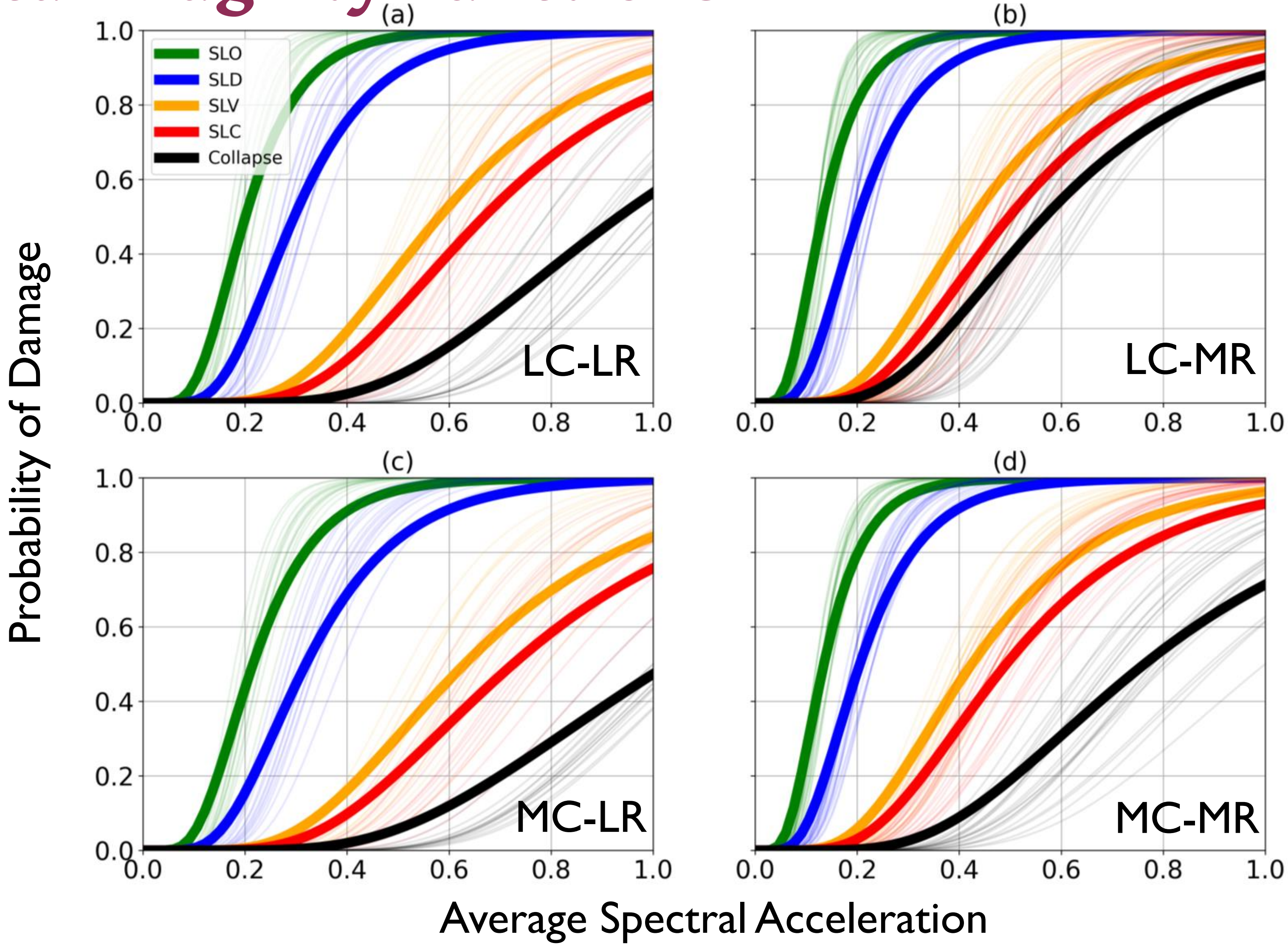
Qualitative Damage States

Agibilità e Danno nell' Emergenza Sismica

Livello-estensione / Componente strutturale- Danno preesistente		Danno (1) D4 - D5 Gravissimo > 2/3			D2 - D3 Medio Grave > 2/3			D1 Leggero > 2/3			Nullo
		D4 - D5 > 2/3	D4 - D5 1/3 - 2/3	D4 - D5 < 1/3	D2 - D3 > 2/3	D2 - D3 1/3 - 2/3	D2 - D3 < 1/3	D1 > 2/3	D1 1/3 - 2/3	D1 < 1/3	Nullo
		A	B	C	D	E	F	G	H	I	L
1	Strutture verticali	❐	❐	❐	❐	❐	❐	❐	❐	❐	○
2	Solai	❐	❐	❐	❐	❐	❐	❐	❐	❐	○
3	Scale	❐	❐	❐	❐	❐	❐	❐	❐	❐	○
4	Copertura	❐	❐	❐	❐	❐	❐	❐	❐	❐	○
5	Tamponature - Tramezzi	❐	❐	❐	❐	❐	❐	❐	❐	❐	○
6	Danno preesistente	❐	❐	❐	❐	❐	❐	❐	❐	❐	○

		SLV		
		D2-D		
Functionality and usability of the building	Safety and immediate occupancy	Protection of occupants lives and ensurance of safe evacuation	Structural collapse prevention	Structural collapse

Analytical Fragility Functions



Empirical Fragility Functions

- Empirical fragility functions are the end result of convolving two layers of information in combination with robust statistical tools

  - ➢Observed damage to buildings

  - ➢Ground-motion fields (GMFs)

Observed Building Damage

- DaDO: Database of Observed Damage

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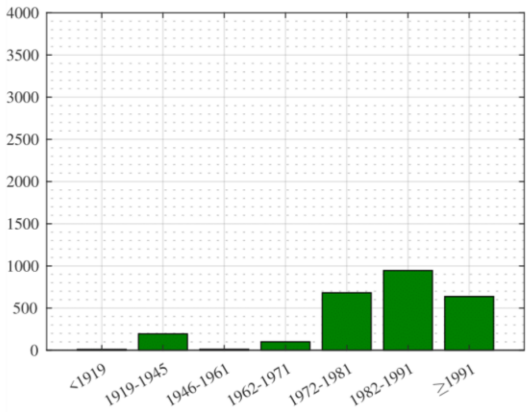
- Friuli 1976
- Irpinia 1980
- Abruzzo 1984
- Umbria-Marche 1997
- Pollino 1998
- Molise-Puglia 2002
- Emilia 2003
- L'Aquila 2009
- Emilia 2012
- Garfagnana-Lunigiana 2013
- Central Italy 2016 - 2017
- Mugello 2019

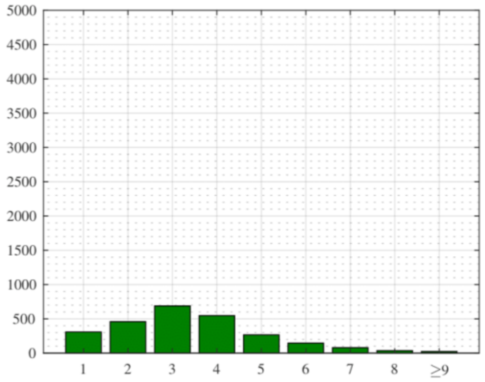
Observed Building Damage

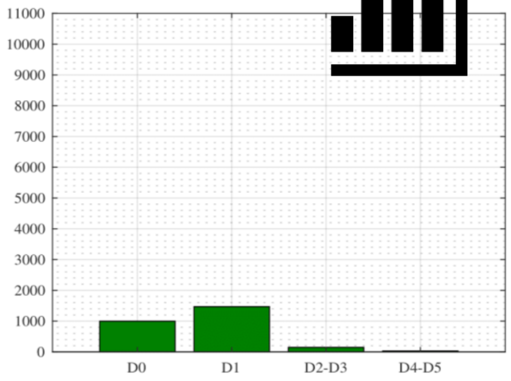
- Building characteristics and spatial distributions (DaDO)

Umbria-Marche 1997 (2164 Buildings)

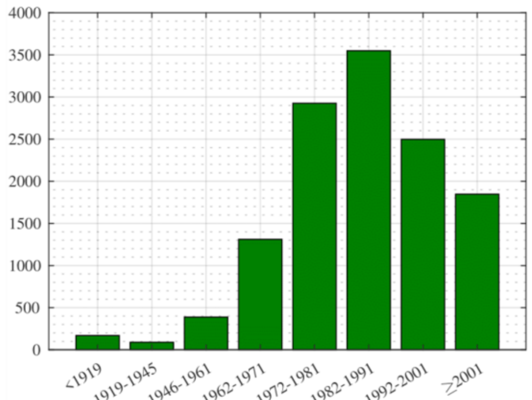
Building Count

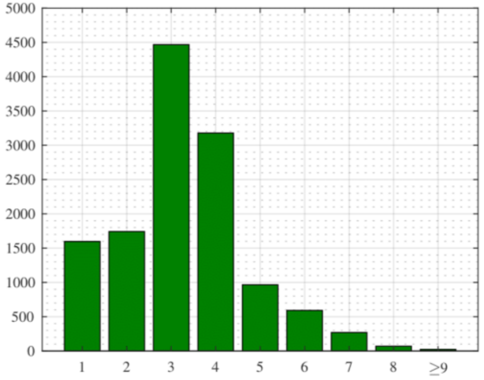


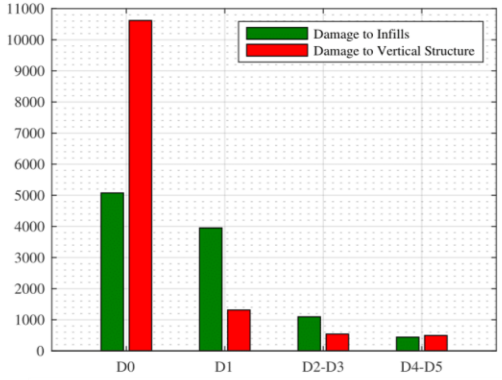


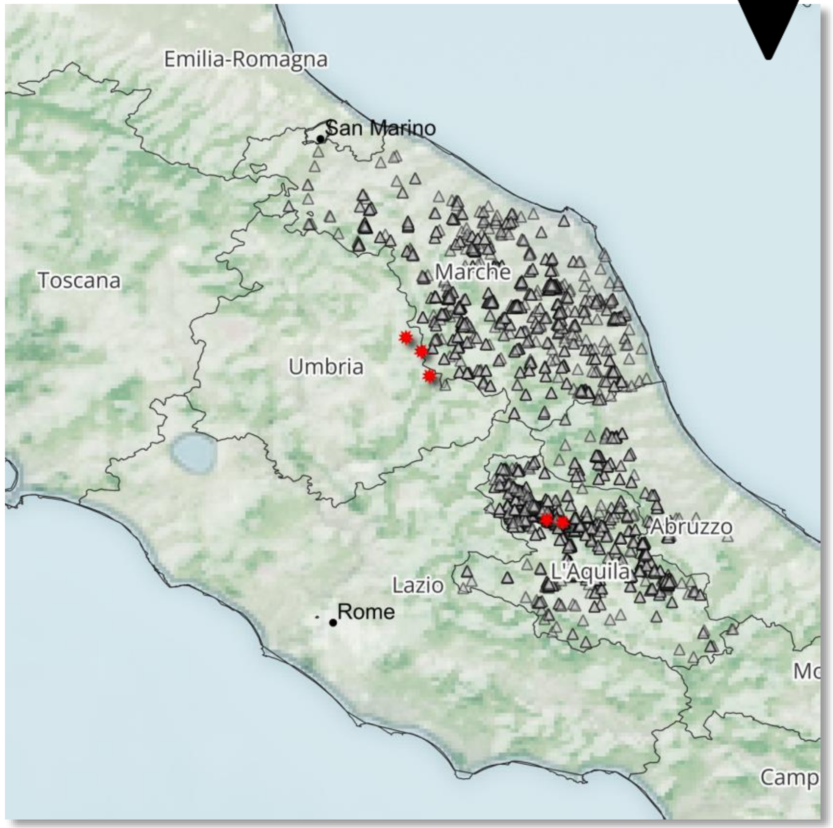


L'Aquila 2009 (8502 Buildings)









Period of Construction

Number of Storeys

Damage States

Inspected Building Locations

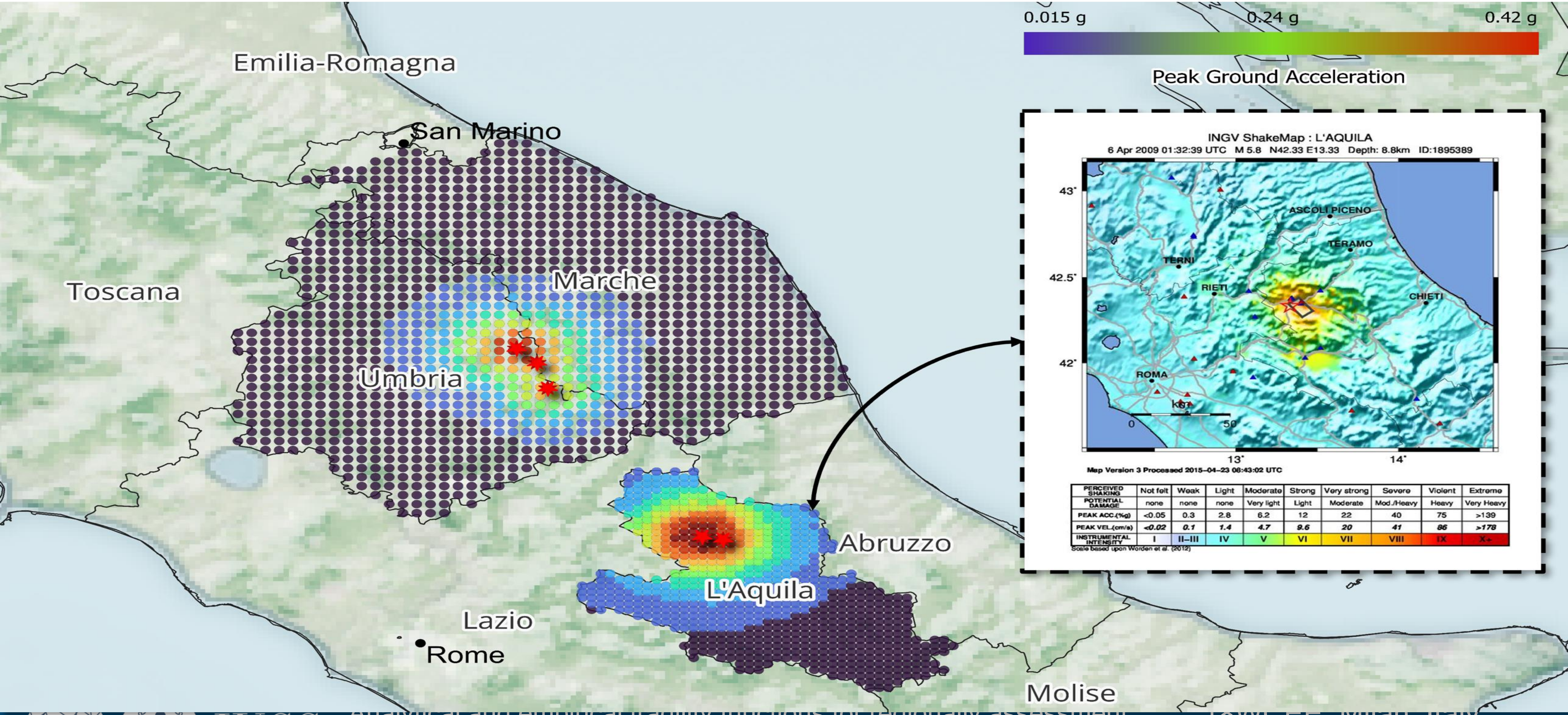
Ground-Motion Fields

- Physically realistic ground-motion fields are a combination of:
  - Handling of ground-motion models (GMMs) for the estimation of spectral intensities (Bindi *et al.* 2011) and indirect approach highlighted in Kohrangi *et al.* 2018 to estimate Sa_{avg} values and the total associated uncertainty
  - Conditioning of GMMs on seismic station data (ITACA) to account for "ground-truth" in the within-event uncertainty (Engler *et al.* 2022)
  - Spatial correlation to consider the spatial dependence in the joint probability distribution function of an intensity measure given a rupture scenario
  - Cross-correlation between IMs to consistently sample ground-shaking intensities from a GMM distribution over multiple IMTs and preserving the spectral shape properties

https://github.com/gem/oq-engine/tree/master/openquake/hazardlib/

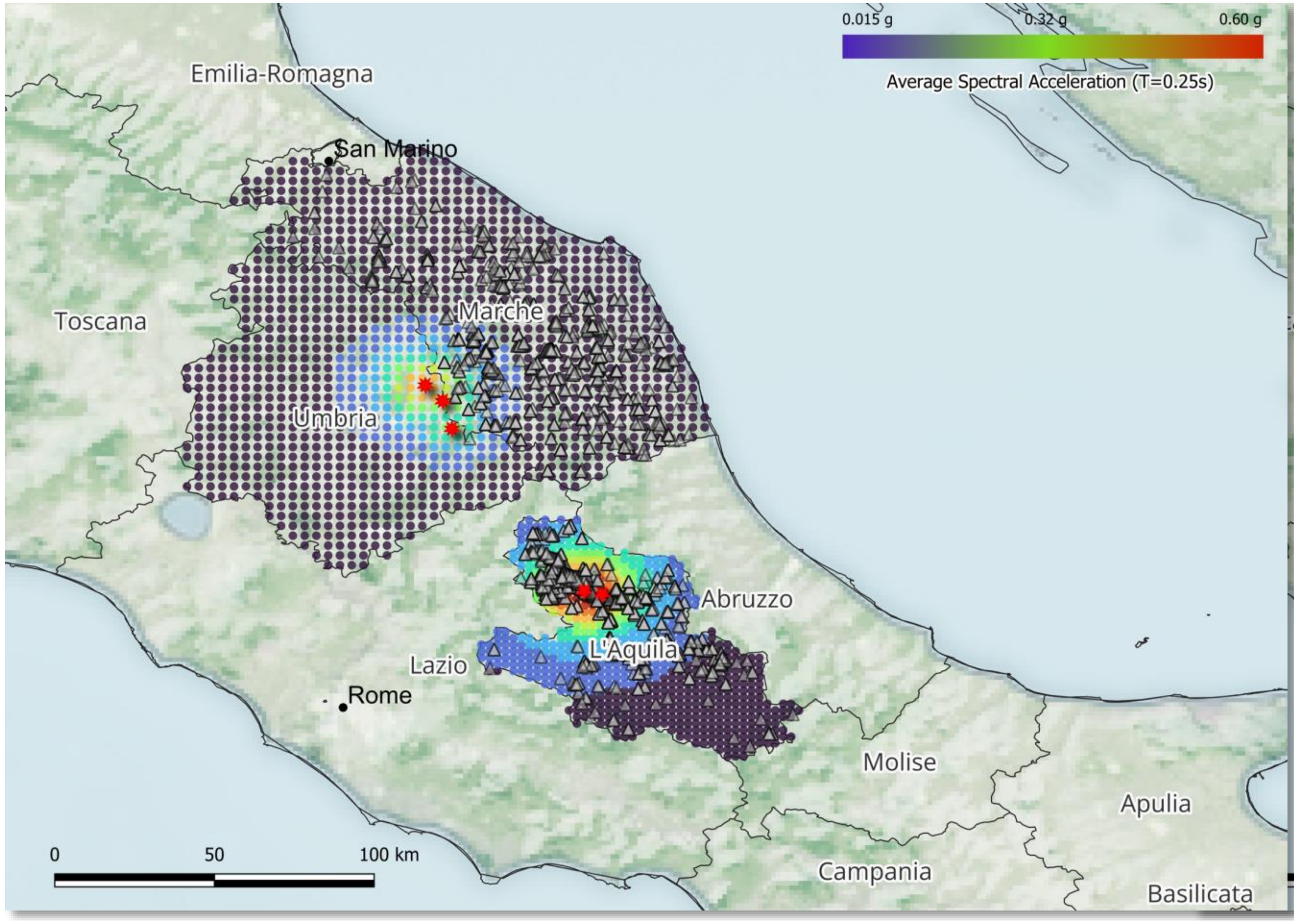
- *Bindi, D., Pacor, F., Luzi, L. et al. Ground motion prediction equations derived from the Italian strong motion database. Bull Earthquake Eng 9, 1899–1920 (2011). https://doi.org/10.1007/s10518-011-9313-z*
- *Kohrangi, M., ... Bull Earthquake Eng 16, ... (2018). https://doi.org/10.1007/s10518-017-...*
- *Jayaram, N. and Baker, J. W. (2009), Correlation model for spatially distributed ground-motion intensities. Earthquake Engng. Struct. Dyn., 38: 1687–1708. https://doi.org/10.1002/eqe.922*
- *Daniel T. Engler, ... Eric M. Thompson, Kishor S. Jaiswal; Partitioning Ground Motion Uncertainty When Conditioned on Station Data. Bulletin of the Seismological Society of America 2022; 112 (2): 1060–1079. doi: https://doi.org/10.1785/0120210177*

Ground-Motion Fields Validation

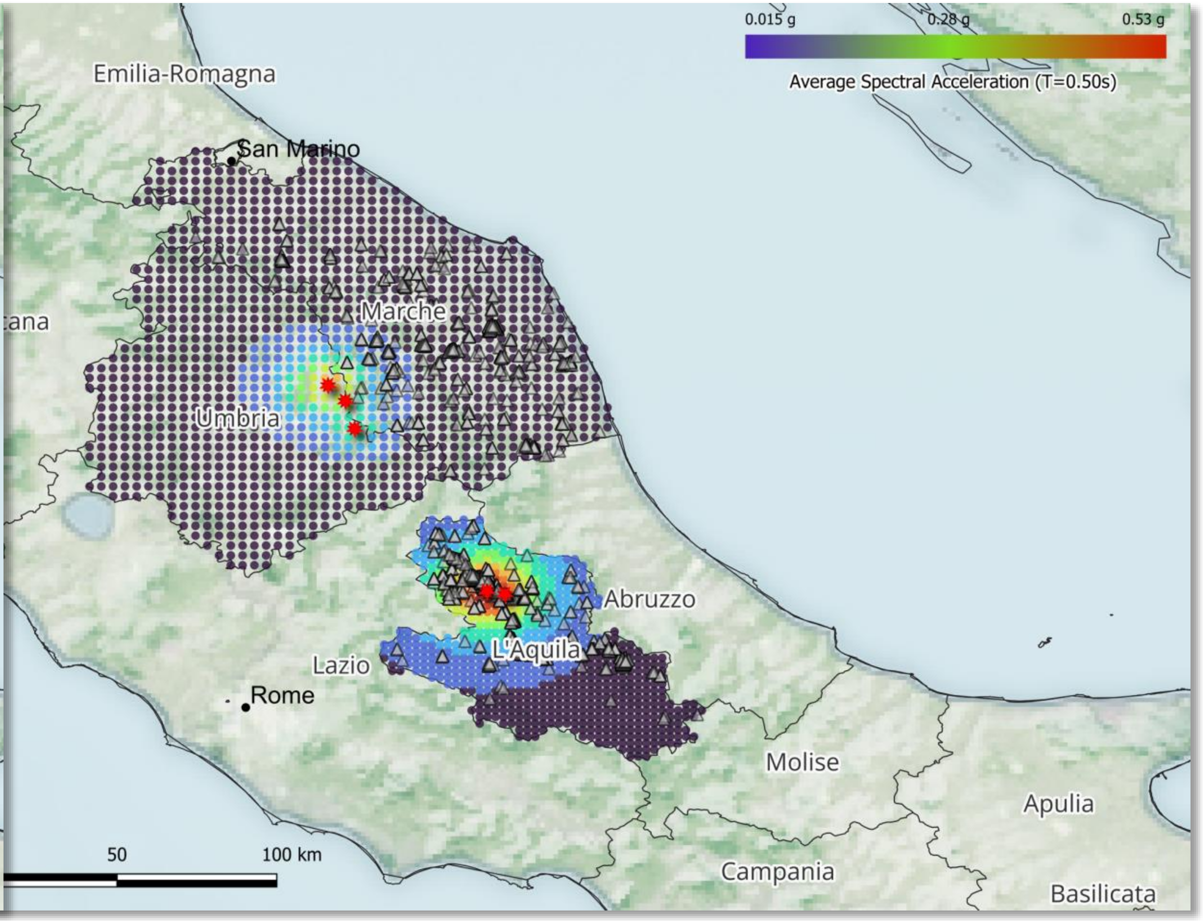


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Sa_{avg}–based Ground-Motion Fields

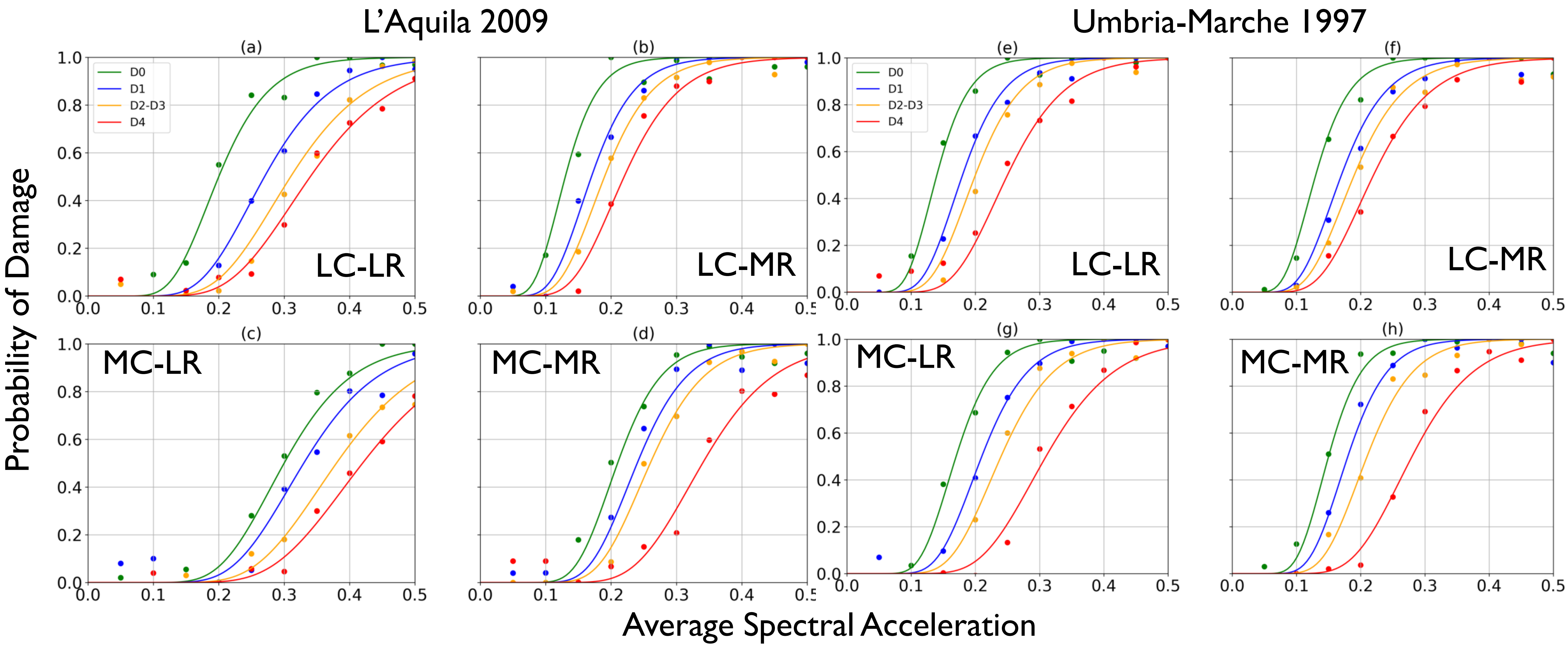


Sa_{avg} (0.25s)-based GMFs for Low-Rise Buildings



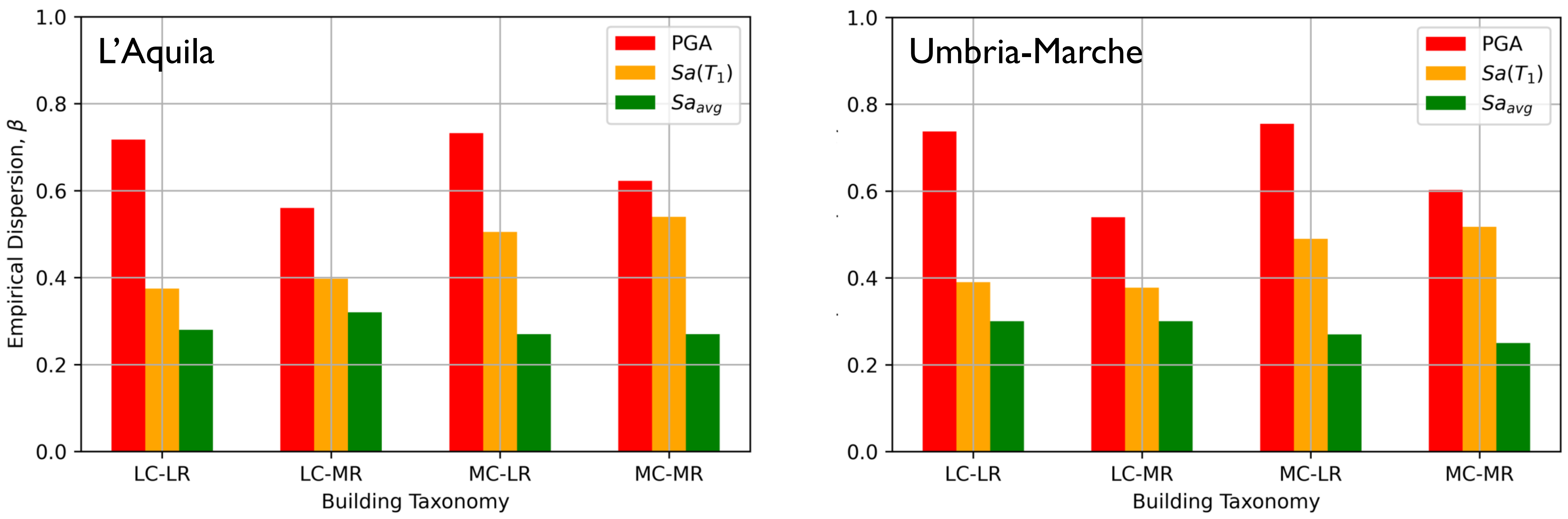
Sa_{avg} (0.50s)-based GMFs for Mid-Rise Buildings

Empirical Fragility Functions



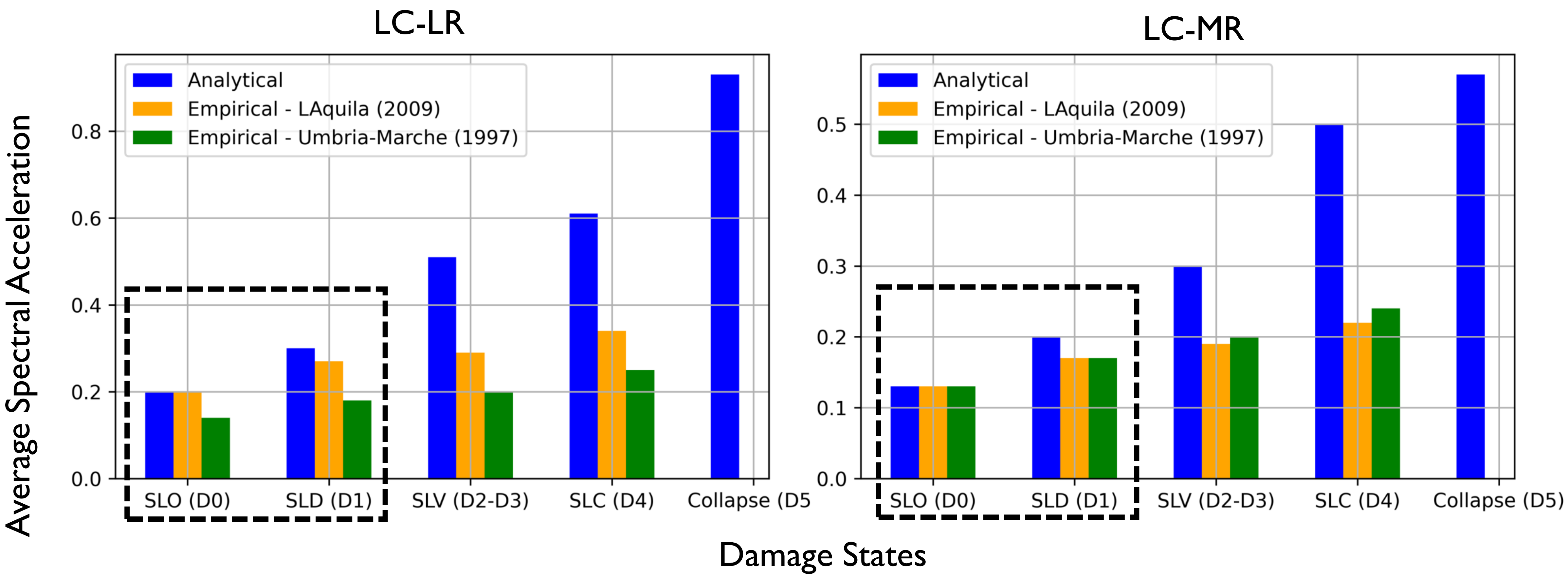
Discussion

- The dispersion values associated with the fitted empirical Sa_{avg}-based fragilities were compared to dispersions considering conventional IMs such as $Sa(T_1)$ and PGA



Discussion

- A good match between analytical and empirical FFs with regards to the serviceability DSs (i.e., operational and damage limitation) was observed, with reasonable errors varying between 0 and 16%.



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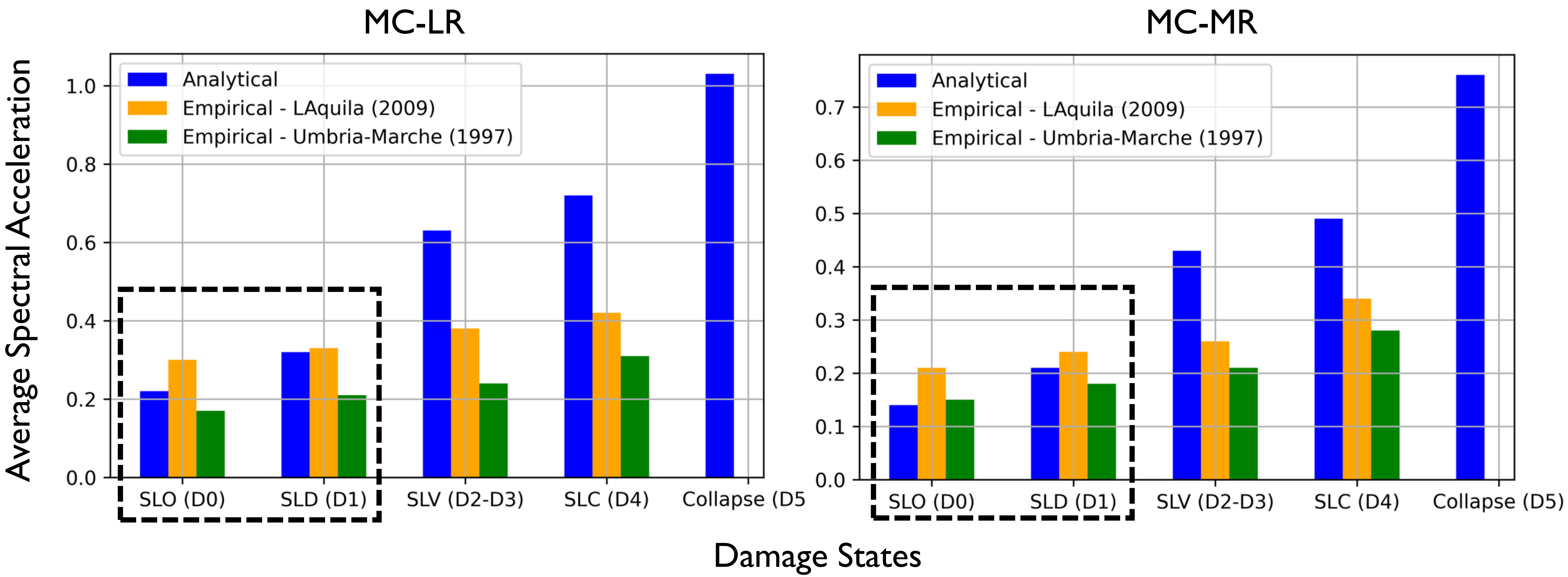
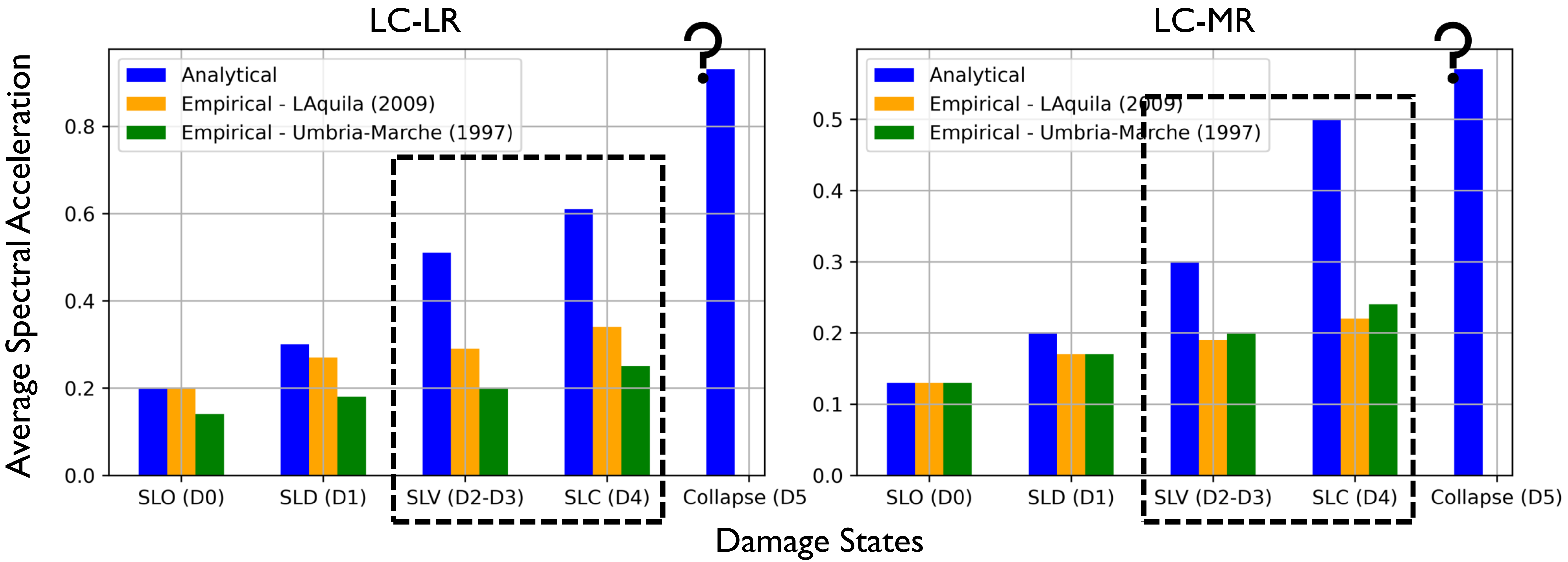


Discussion

- For the life-safety and near-collapse DSs, it can be seen that the analytical FFs tended to consistently overestimate the median intensities with respect to the empirical observations



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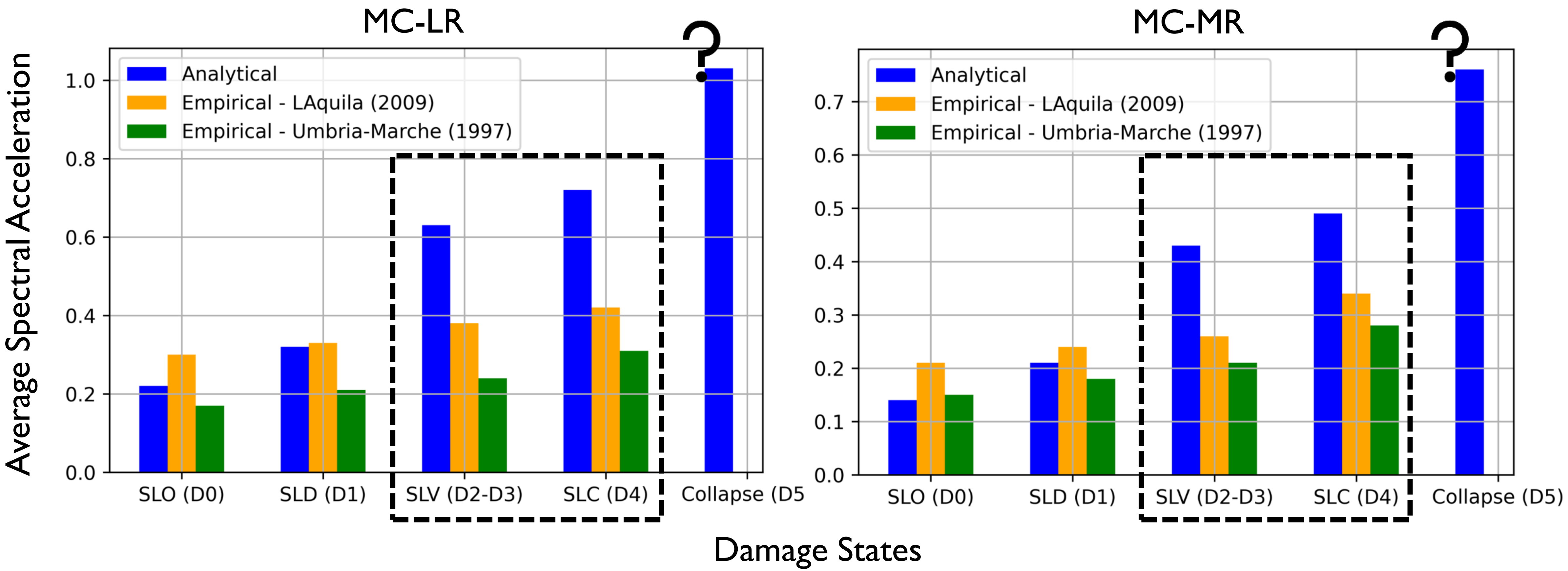

Discussion

- Quality of data particularly for the 1997 Umbria-Marche earthquake sequences, and the AeDES form before 2002:
    - ➢Inability to encompass all potential structural component types;
    - ➢Equal classification of the seismic behaviour among typologies that appeared similar aesthetically

- Damage accumulation in buildings following earthquake sequences
    - ➢Data was collected following the conclusion of EQ sequences
    - ➢Highlights the importance of input energy, hysteretic energy dissipation and proper ground motion record selection to characterise response to mainshock-aftershock sequences

- Uncertainty in the ground-shaking prediction and site conditions (e.g., Vs30)
- Harmonization in the DS definition between Italian code and macro-seismic scales
- Bias in data collection due to the differences in DS perception from one evaluator to another

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Questions?

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