Progetto DPC-ReLUIS 2022-2024 WP4

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

MARS - Seismic Risk Maps (WP4)

Task 4.2 - Hazard: ground shaking maps to support fragility and scenario-based studies

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INTRODUCTION

Seismic fragility curves describe the probability of exceeding a specific **damage level** for a given asset based on a **ground motion intensity measure (IM)**. Their derivation through observational approaches requires two key components: **damage statistics** from post-earthquake surveys and the **ground motion IMs** that caused the damage at each building location (e.g., from **ShakeMaps**). Estimating ground motion from observed damage is challenging due to the limited availability of strong-motion stations. As a result, ShakeMaps may lack constraints or be unavailable.

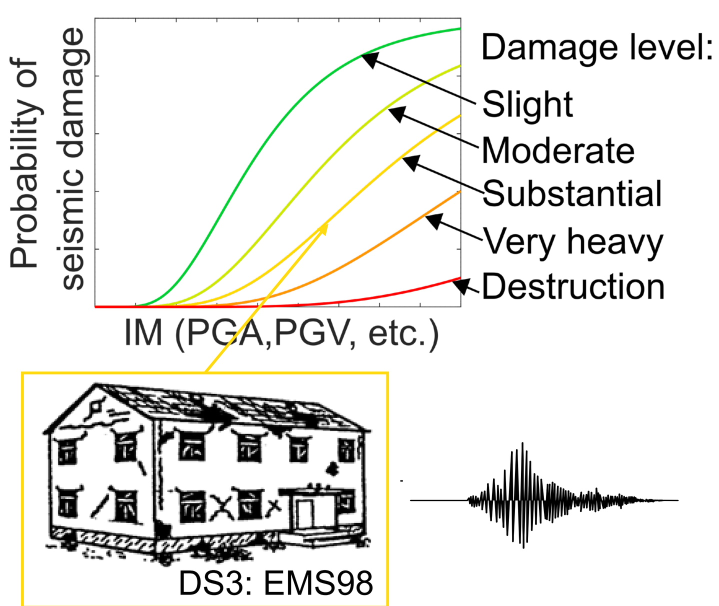

Figure 1. Definition of fragility curves.

Recent advances in **physics-based simulations (PBS)** of **3D** seismic **wave propagation** have improved their ability to realistically estimate earthquake ground shaking and variability. By solving the **elastodynamics** equation, PBS generates ground motion **time histories** that account for **fault rupture**, **propagation path**, and regional **geo-morphological** characteristics.

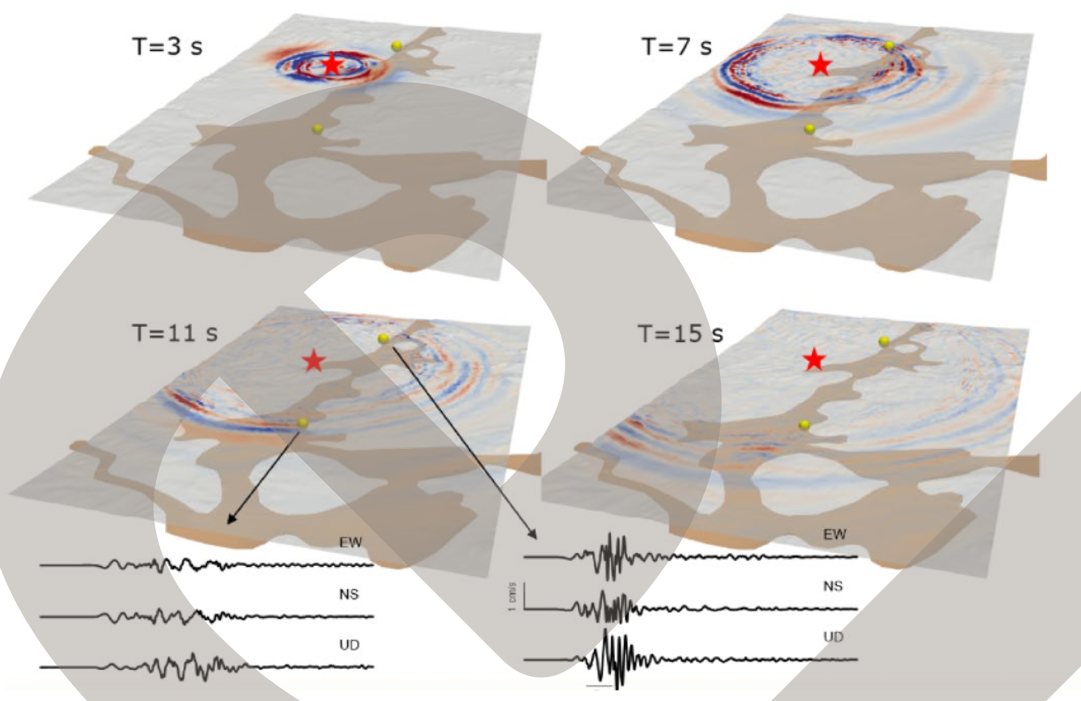

Figure 2. 3D PBS of ground shaking (from Smerzini & Pitilakis 2012).

VALIDATION OF PBS: 2009 L'AQUILA EARTHQUAKE (MW6.2)

In Rosti et al. (2023), the ground shaking fields obtained from 3D PBS, through the spectral element code SPEED (Mazzieri et al. 2013), were successfully exploited to derive observational fragility curves for several **masonry** and **RC** building typologies representative of the Italian building stock.

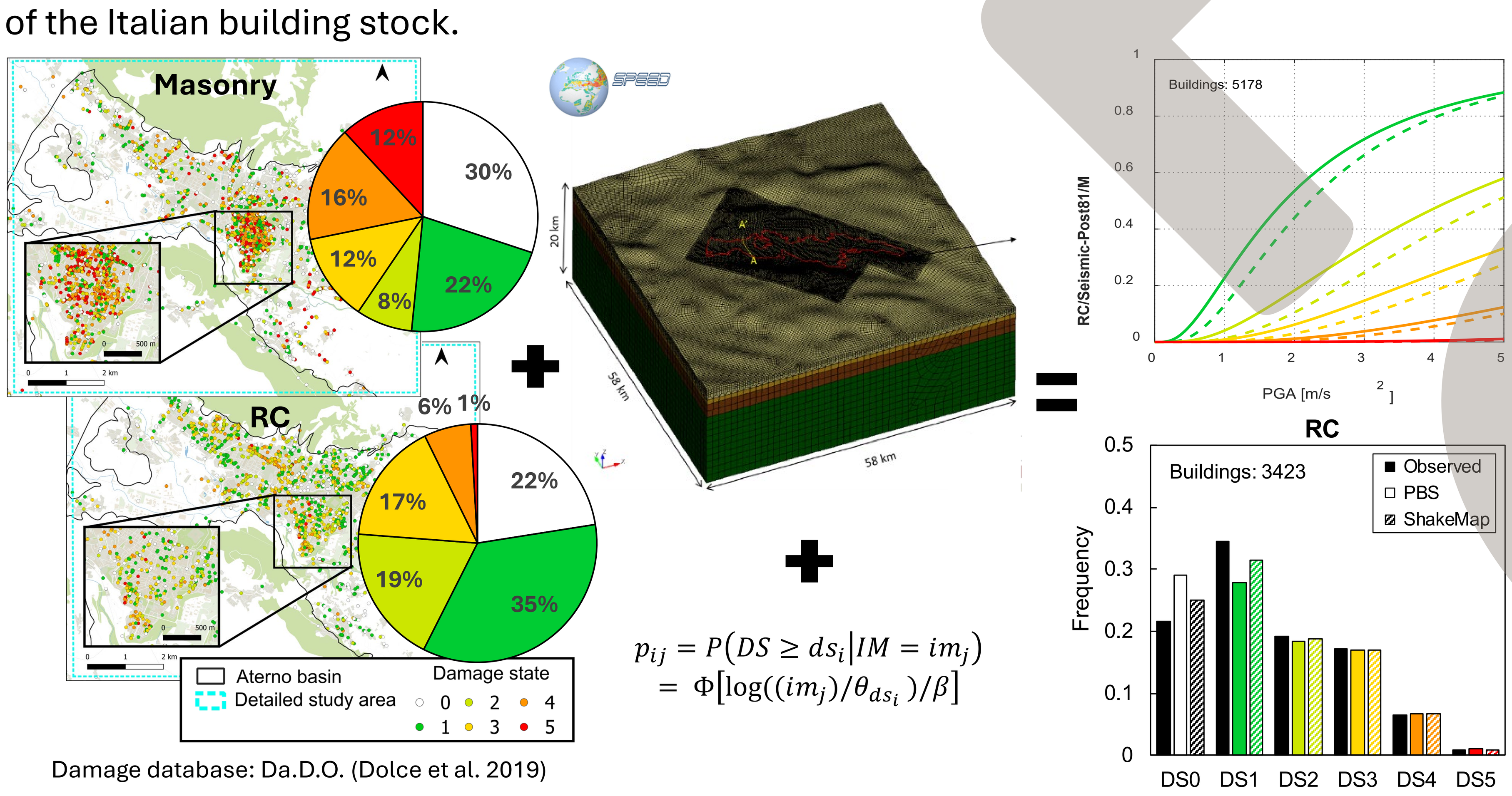

Figure 3. Schematic representation for the derivation of observational fragility curves for the 2009 L'Aquila earthquake.

Such fragility curves, based on Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and weighted mean of spectral acceleration showed **strong agreement** with the curves obtained by employing the available **ShakeMap** and to provide **predictions** of **damage consistent** with post-earthquake observations.

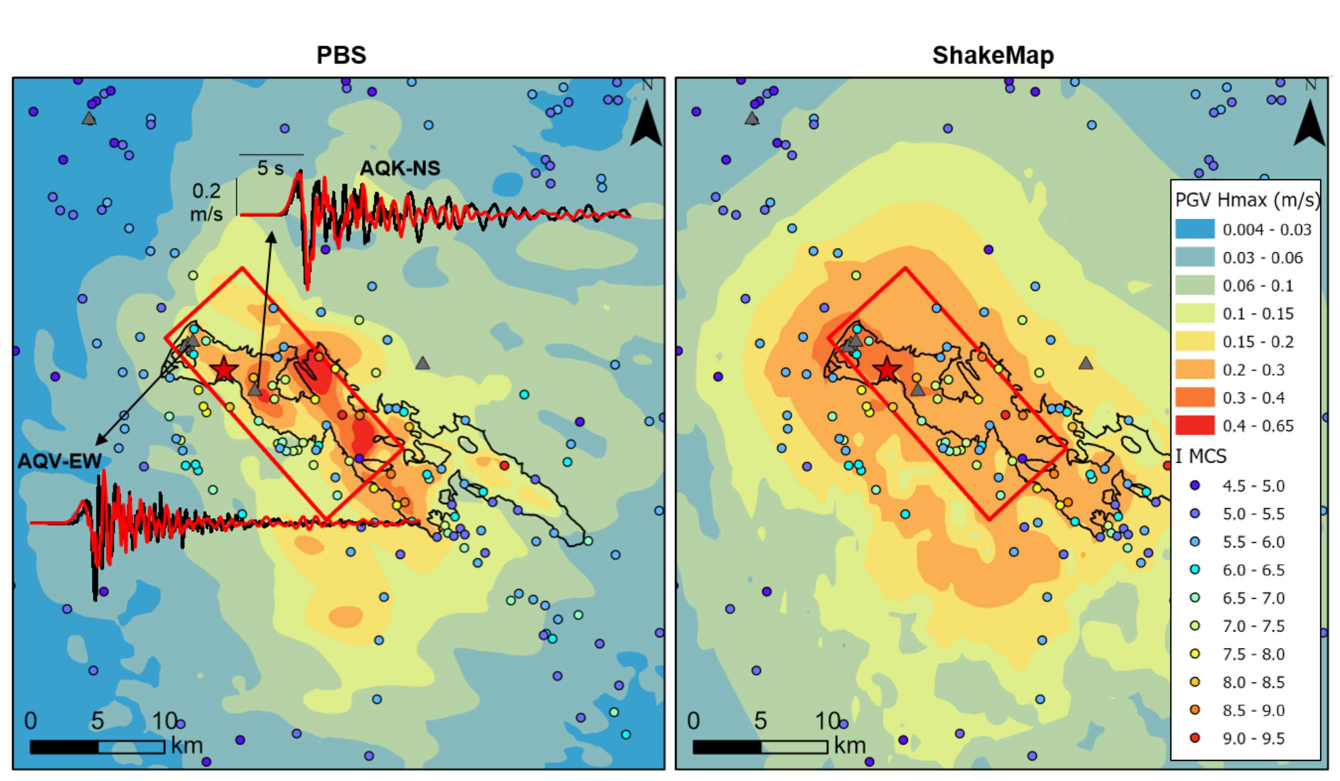

Figure 4. Comparison of the simulated ground motion against ShakeMap and available recordings (from Rosti et al. 2023).

APPLICATION: EXPLORING ALTERNATIVE INTENSITY MEASURES

While ShakeMaps rely on peak ground motion values, PBS generates ground motion time histories and **any desired IM** for specific earthquake scenarios, offering greater flexibility. In Monsalvo (2023) this advantage was exploited to explore the **sensitivity** of fragility curve estimation to various IMs, using damage statistics from Rosti et al. (2023). Fragility curves were developed for a **wider range of IMs**. Two approaches (i.e., **cross-validation** and **mean damage**) were used to identify the **optimal** IM for damage prediction and seismic risk applications (**Figure 5**).

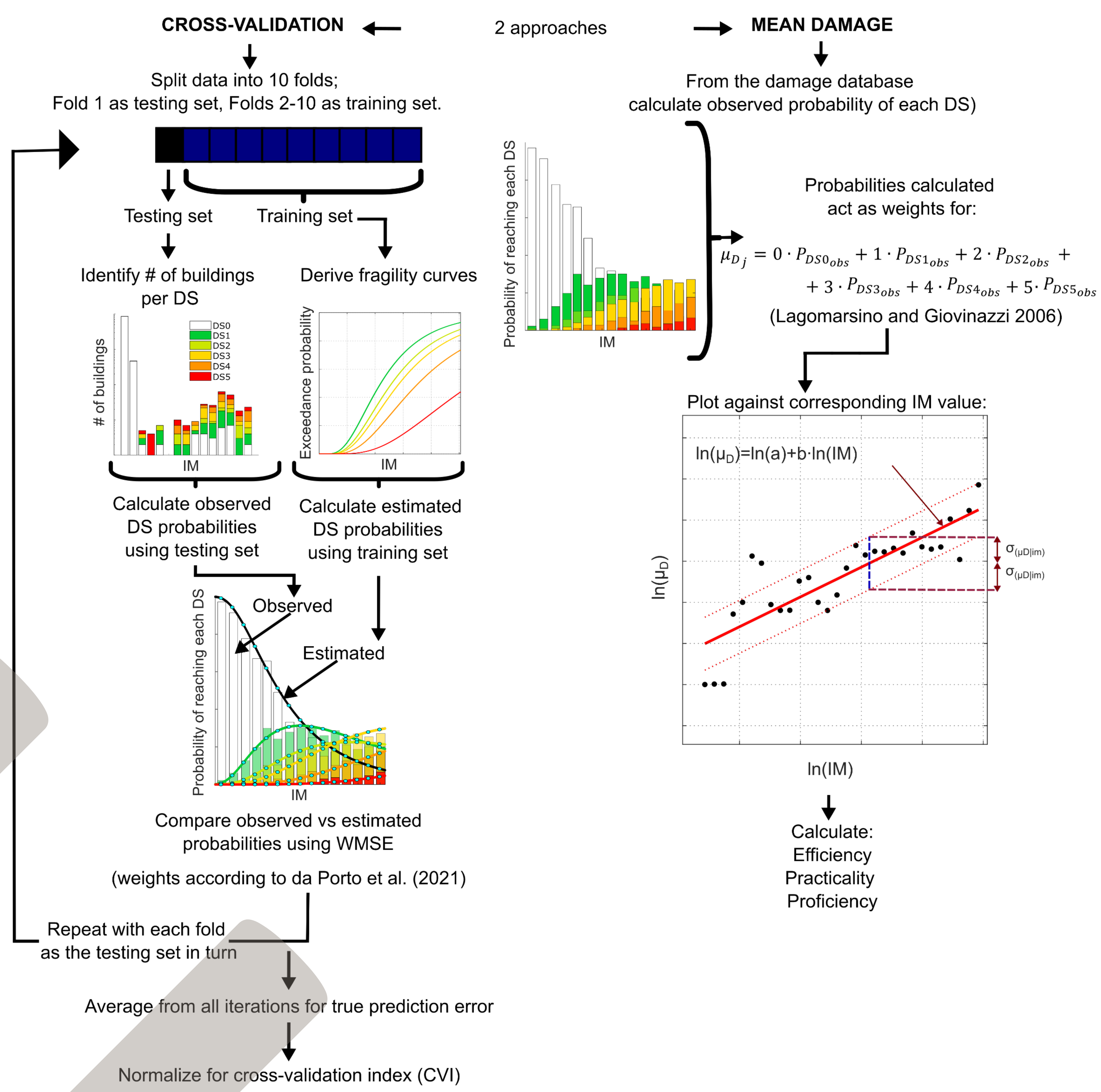

Figure 5. IM's optimality quantification and comparative analysis.

Results highlighted the geometric and weighted means of spectral acceleration to be strongly correlated with building damage, aligning with previous research. Additionally, for both masonry and RC buildings, PGA proved to be a reliable IM for seismic fragility assessment, confirming the usefulness of acceleration-related measures for rigid systems. Finally, among integral IMs, Houster Intensity performed best, while Arias Intensity and Cumulative Absolute Velocity were less effective.

da Porto F, Donà M, Rosti A, et al (2021) Comparative analysis of the fragility curves for Italian residential masonry and RC buildings. Bulletin of Earthquake Engineering 19:3209–3252

Dolce M, Speranza E, Bocchi F, et al (2019) Observed damage database of past Italian earthquakes: the Da.D.O. WebGIS. Bollettino di Geofisica Teorica ed Applicata 60

Lagomarsino S, Giovinazzi S (2006) Macroseismic and mechanical models for the vulnerability assessment of current buildings. Bulletin of Earthquake Engineering 4:415–443

Mazzieri I, Stupazzini M, Guidotti R, Smerzini C (2013) SPEED: SPectral Elements in Elastodynamics with Discontinuous Galerkin: a non-conforming approach for 3D multi-scale problems. International Journal for Numerical Methods in Engineering 95:991–1010

Monsalvo Franco IE (2023) Seismic Fragility Curves With Unconventional Intensity Measures From Physics-Based Simulations. Dissertation, Politecnico di Milano

Rosti A, Smerzini C, Paolucci R, et al (2023) Validation of physics-based ground shaking scenarios for empirical fragility studies: the case of the 2009 L'Aquila earthquake. Bulletin of Earthquake Engineering 21:95–123

Smerzini C, Pitilakis K (2018) Seismic risk assessment at urban scale from 3D physics-based numerical modeling: the case of Thessaloniki. Bulletin of Earthquake Engineering 16:. https://doi.org/10.1007/s10518-017-0287-3

Damage-informed fragility curves based on post-earthquake observation data

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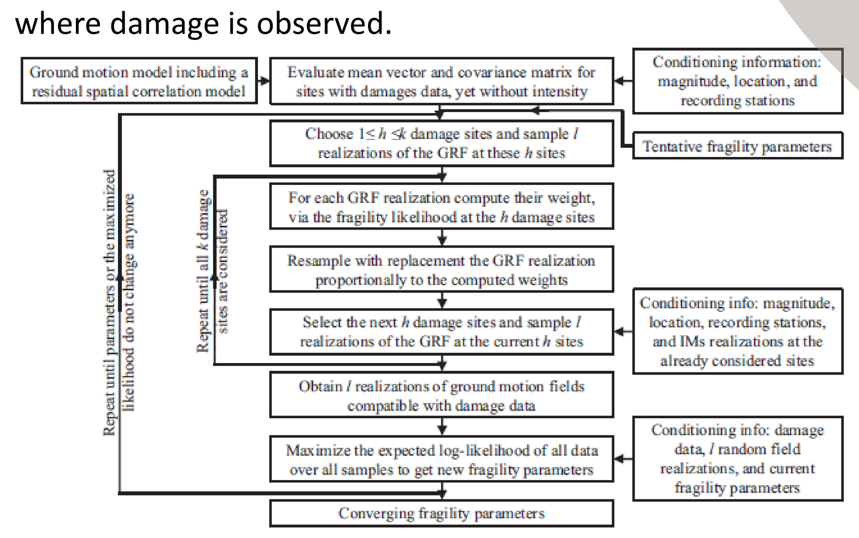
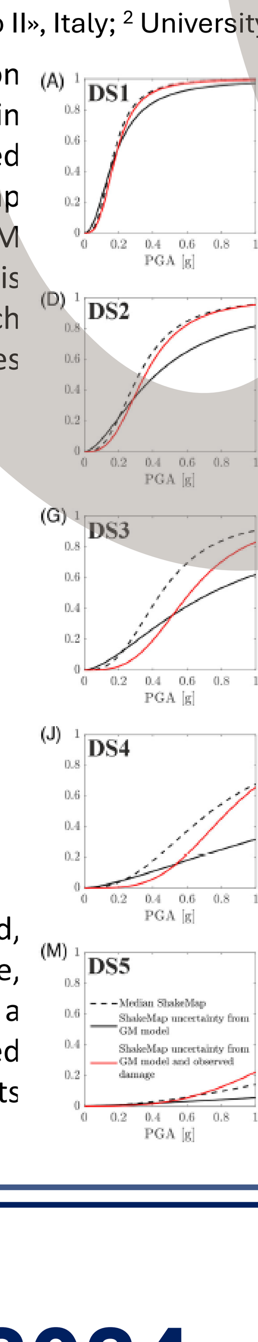
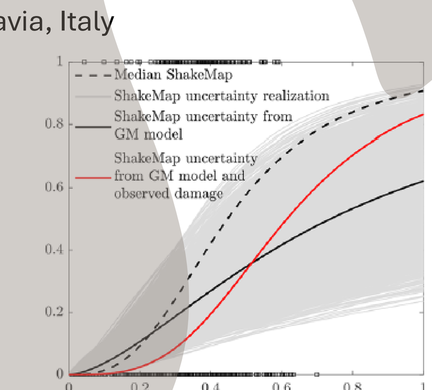
Fragilities based on empirical data require the characterization of the ground motion (GM) intensity at the building sites in the area affected by the earthquake producing the observed damages. This is commonly conducted via ShakeMap estimates which are affected by the uncertainty of the GM model used to characterize it, which is usually neglected. This uncertainty can be reduced by building damage data, which provide information on the shaking intensity at the sites where damage is observed.







Fragilities obtained using different levels of information

Fragility curves obtained considering:
(i) median ShakeMap (dashed black curve),
(ii) uncertainty in ShakeMap only, averaging the parameters from ten thousand GRF simulations (continuous black line),
(iii) effect of the information provided by damage on GM (red curve).

A result of this work is that if this uncertainty is not addressed, also considering the shaking information provided by damage, the estimates of the fragility parameters obtained using a median ShakeMap only can be biased, and a recommended maximum likelihood estimation procedure – which exploits the *expectation maximization algorithm* – is provided.

Iervolino, I., Rosti, A., Penna, A., & Giorgio, M. (2024). Damage-informed ground motion and semi-empirical fragility assessment. *Earthquake Engineering & Structural Dynamics*, *53*(11), 3514-3526.