Simulation-based procedure for Class Tsunami Fragility Assessment: Using data, data products, software and services within EPOS

Fatemeh Jalayer, Jingren Wu
Department of Risk and Disaster Reduction
University College London (UCL)
Hossein Ebrahimian
Department of Structures, University of Naples Federico II

27th Nov 2024

Multi-hazard and multi-risk assessment for geohazards

27-29 November 2024, Luxembourg

A Forward Probabilistic Framework (PTRA)

Hazard

$\lambda(IM > im)$

IM ***(Intensity Measure)***

e.g., flow depth, momentum flux

Vulnerability

$P_{DS|IM}(DS_i \mid im)$

Fragility Function

DM ***Damage Measure***

e.g., damage states

$G_{DV|DS}(dv \mid DS)$

Consequence Function

DV ***Decision Variable***

e.g., fatalities, loss

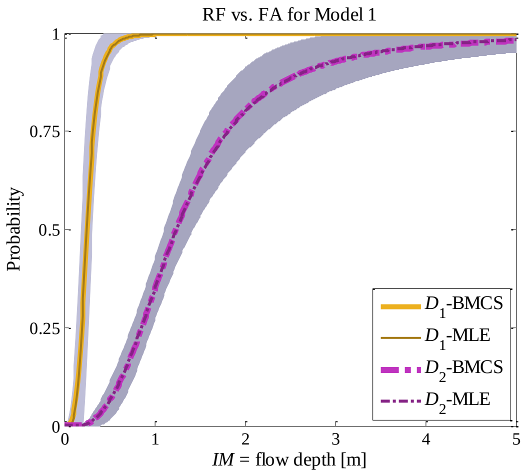
Risk

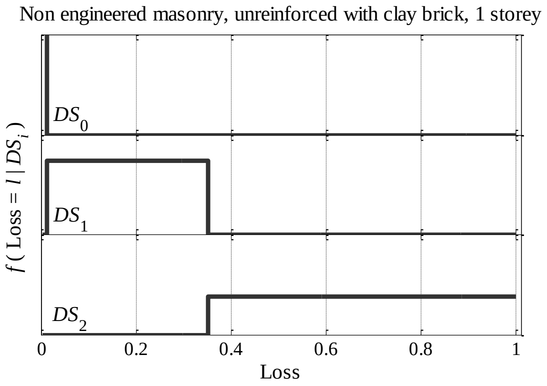
$\lambda(DV > dv)$

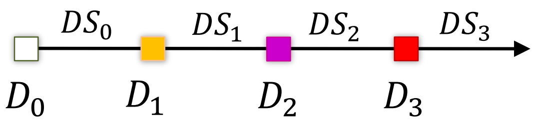
Risk Metrics

e.g., AAL, LEC

Behrens, J., Løvholt, F., Jalayer, F., Lorito, S., Salgado-Gálvez, M.A., Sørensen, M., Abadie, S., Aguirre-Ayerbe, I., Aniel-Quiroga, I., Babeyko, A. and Baiguera, M., 2021. Probabilistic tsunami hazard and risk analysis: A review of research gaps. *Frontiers in Earth Science*, *9*, p.628772.



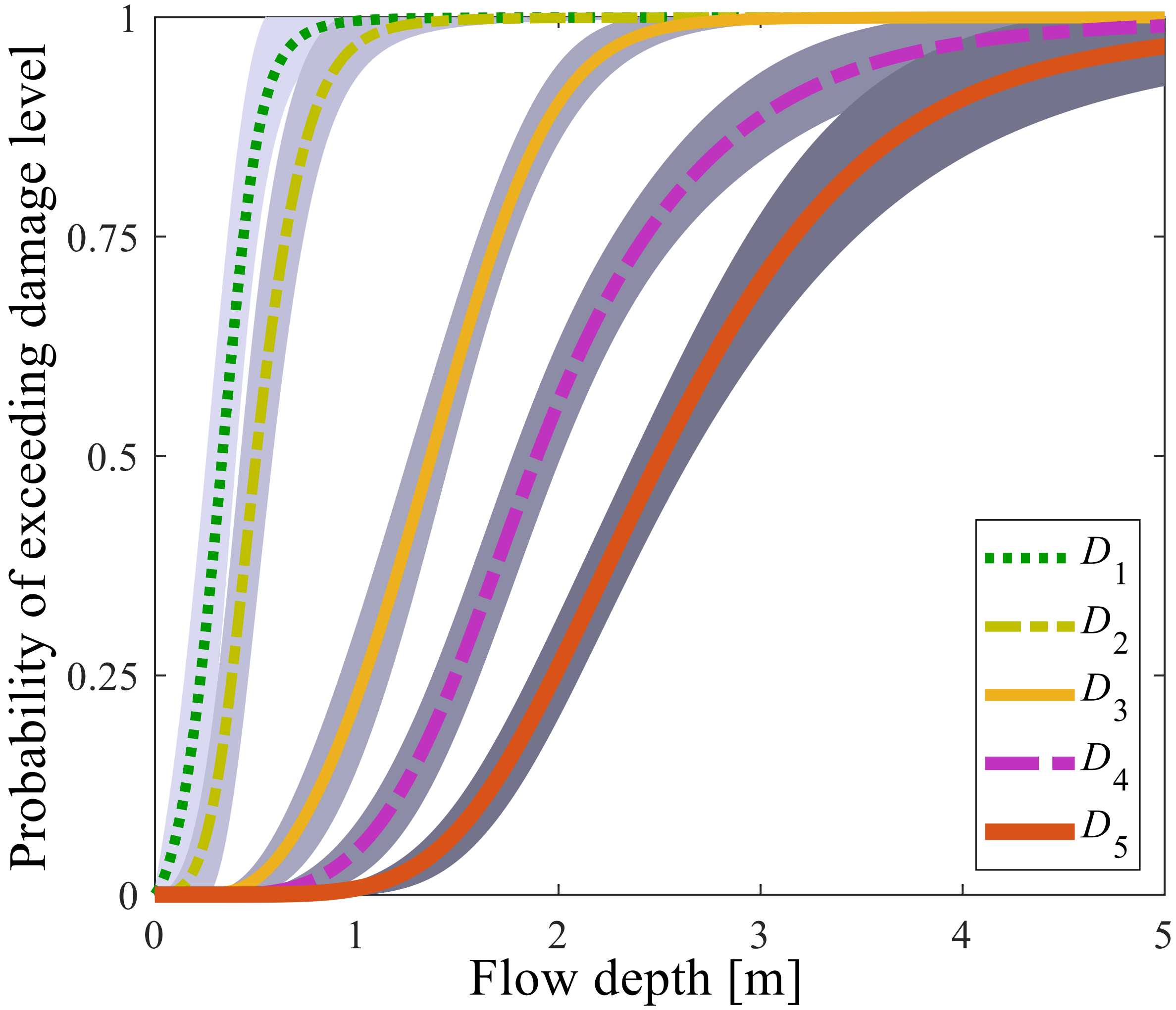




The definition of the fragility

In the context of risk assessment at at regional level, the fragility curve is defined as the probability of exceeding a specific damage level as a function of the intensity measure.

$$P(D > D_i|IM = im)$$



There are some implicit assumptions in the definition of fragility

It is meaningful for a **single system**. It is assumed that with each new event of interest, the system will be “renewed” back to its intact state (D_0).

Why Class Fragility?

Short of detailed building-to-building level information, class fragilities are useful for loss analysis at the regional (portfolio) level.

The concept of fragility curve for a class

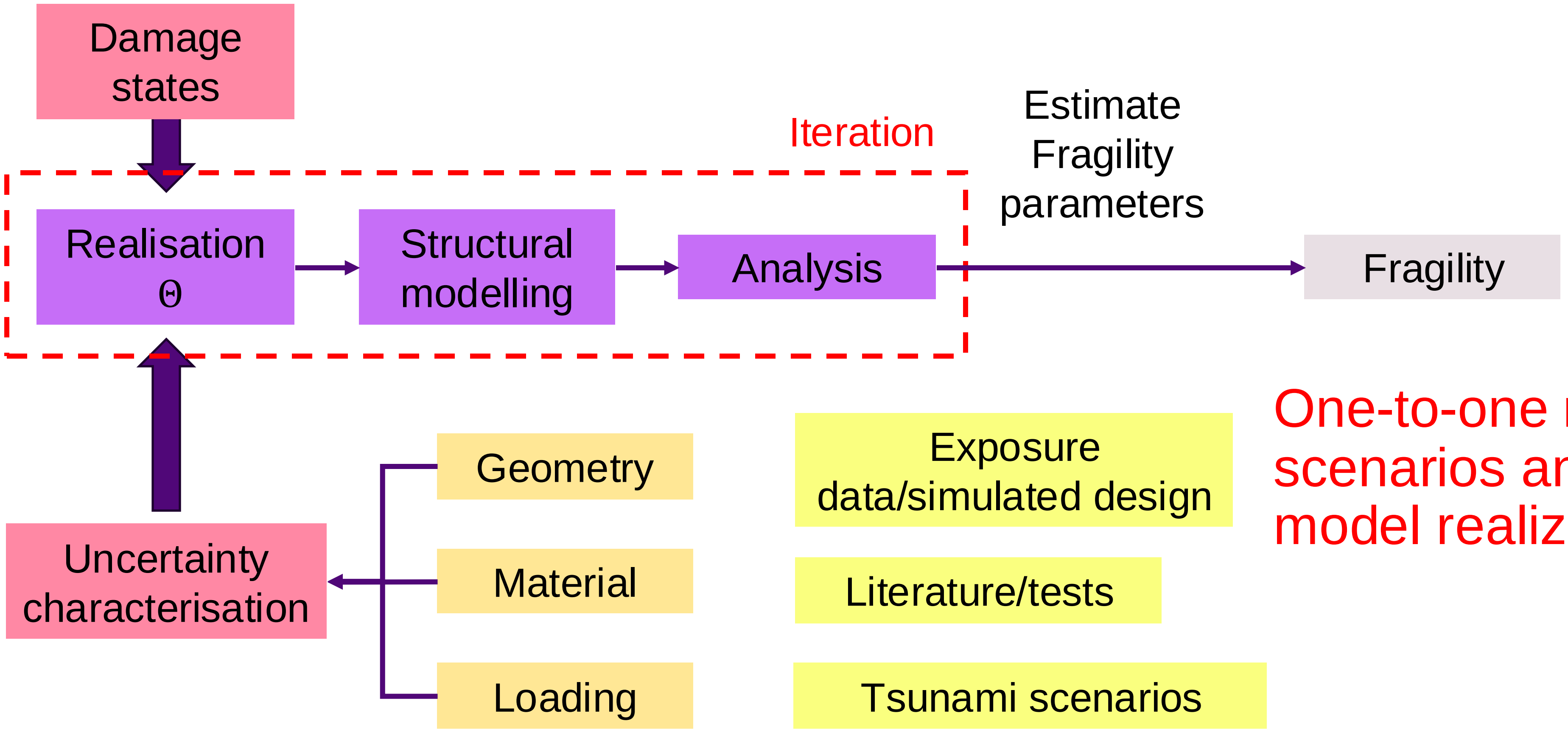
The fragility curve for a class can be derived by assuming that the portfolio of buildings in a class is replaced by an "average" representative building.

The dispersion in the class fragility curve, in theory, should consider the:

(1) Variability in the "events" (e.g., tsunamis, earthquakes) given the intensity measure;

(2) The building-to-building variability within the class;

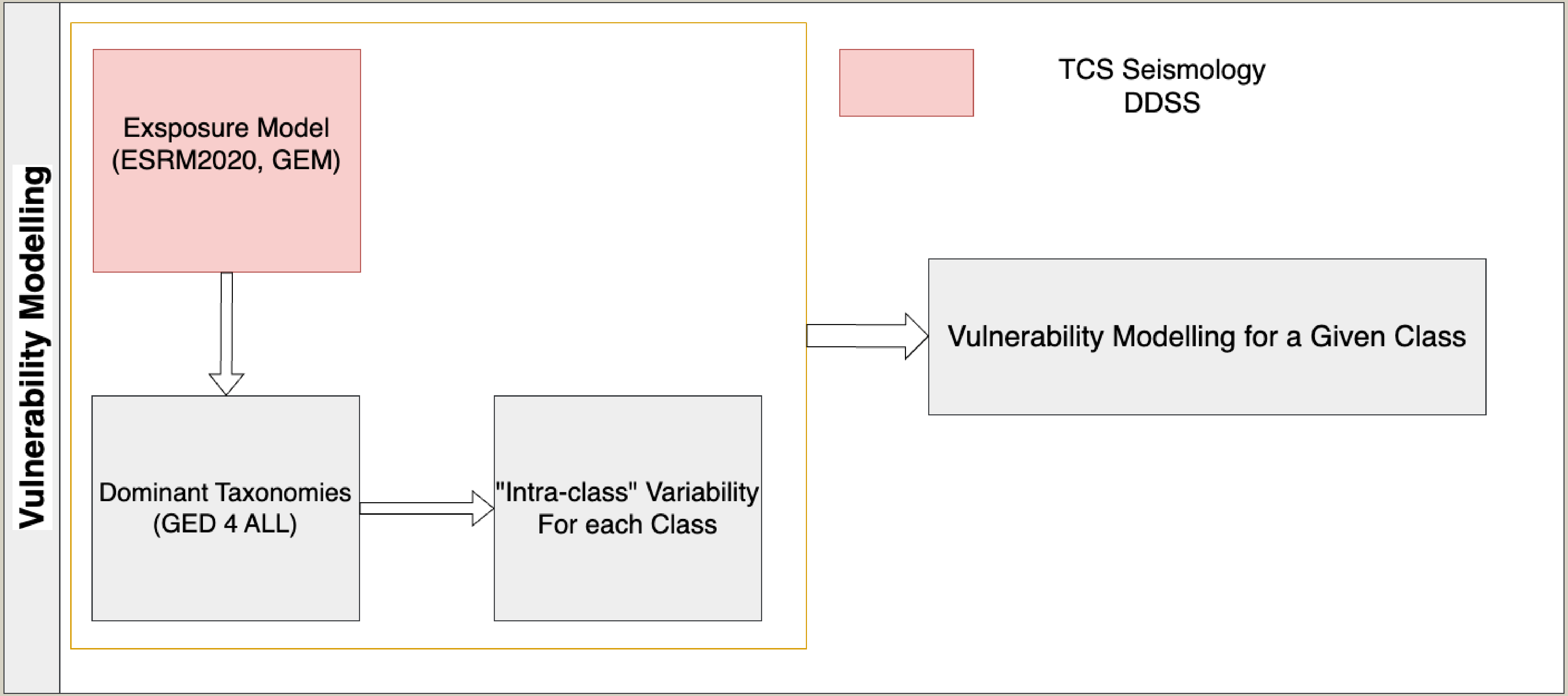
Class Fragility Analysis using Small-sample MC Simulations



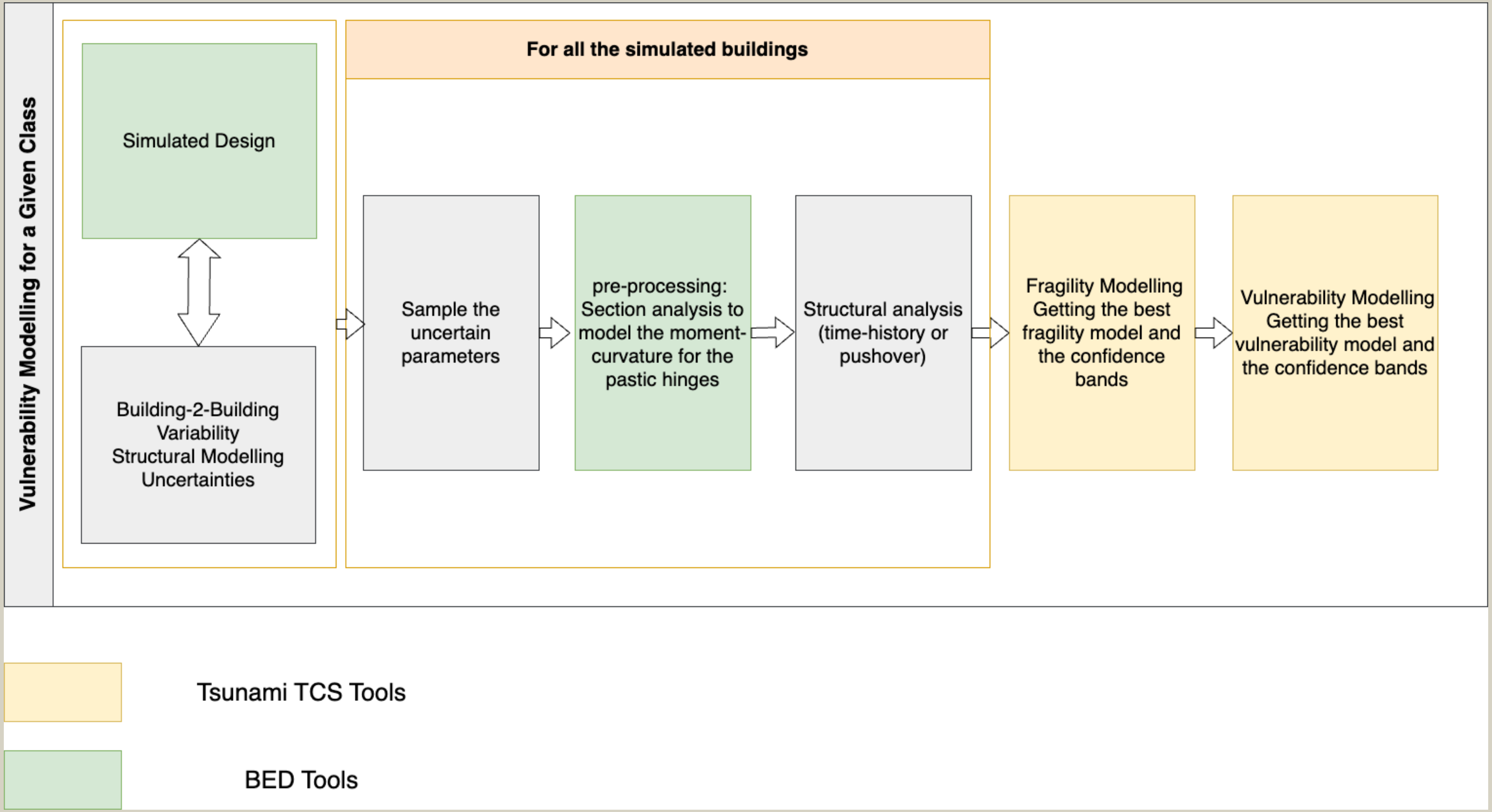
One-to-one matching of scenarios and structural model realizations.

Simulations are used to estimate the fragility parameters and not the of extremes, therefore, even a small-sample (in the order of 50-100) Monte Carlo Simulation could work.

Across EPOS TCS's: Analytical Class Fragility Assessment



Across EPOS TCS's: Analytical Class Fragility Assessment

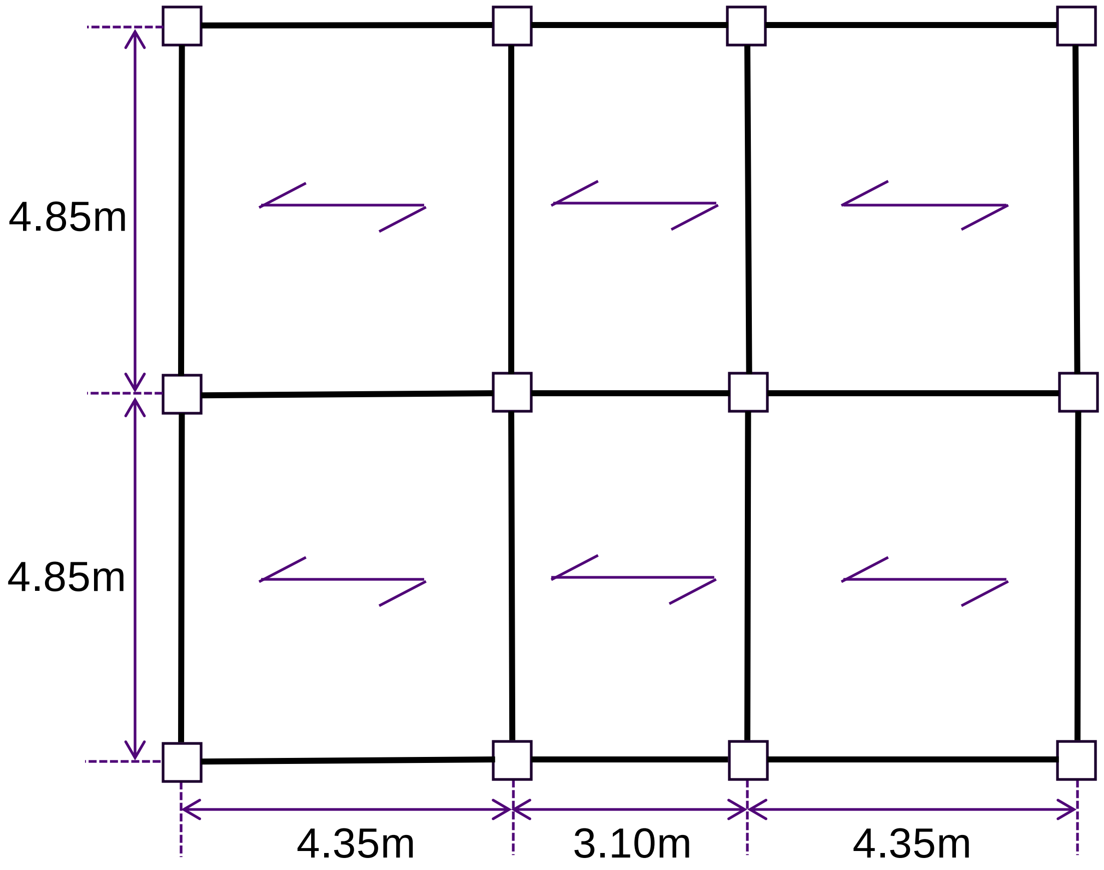


Example: Archetype Building

Taxonomy: CR_LFINF-CDL-0_H2
Building type selected based on the exposure model of Catania, Italy.
Designed by the **simulated design** package:

- Geometry
- Details of reinforcement
- One-way slab
- High construction quality
- Concrete strength f_{ck} = 14 MPa
- Steel yield strength f_{syk} = 400 MPa

Storey Height:
Ground floor = 2.9 m
Upper floor = 2.65 m



Damage States (ESRM 20)

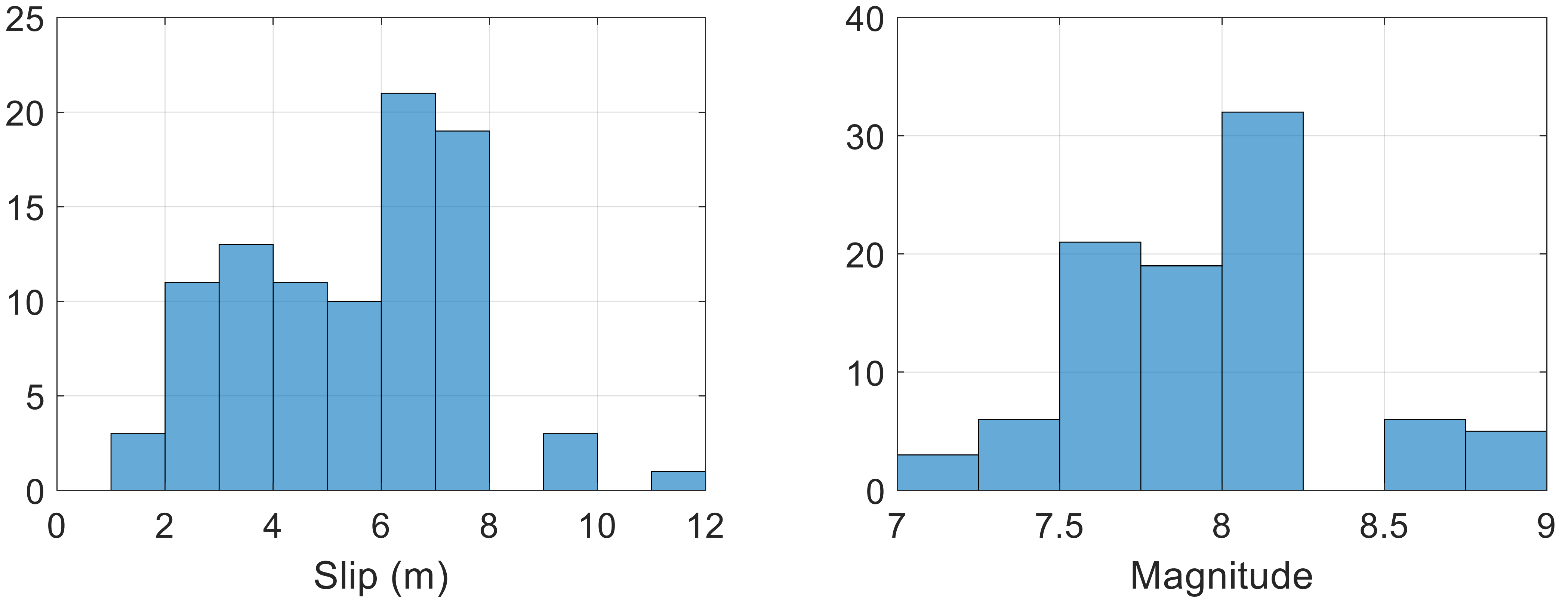
	Classification	Threshold
DS0	Slight	$\theta_{\mathrm{DS0}} = 0.75\theta_{\mathrm{y}}$
DS1	Moderate	$\theta_{\mathrm{DS1}} = 0.5\theta_{\mathrm{y}} + 0.33\theta_{\mathrm{c}}$
DS2	Extensive	$\theta_{\mathrm{DS2}} = 0.25\theta_{\mathrm{y}} + 0.67\theta_{\mathrm{c}}$
DS3	Complete	$\theta_{\mathrm{DS4}} = \theta_{\mathrm{c}}$

θ_{y} = yield rotation
θ_{c} = rotation at 20% strength drop

Crowley, H., Dabbeek, J., Despotaki, V., Rodrigues, D., Martins, L., Silva, V., Romão, X., Pereira, N., Weatherill, G. and Danciu, L., 2021. European seismic risk model (ESRM20). *EFEHR Technical Report*, *2*.

Tsunami Scenarios

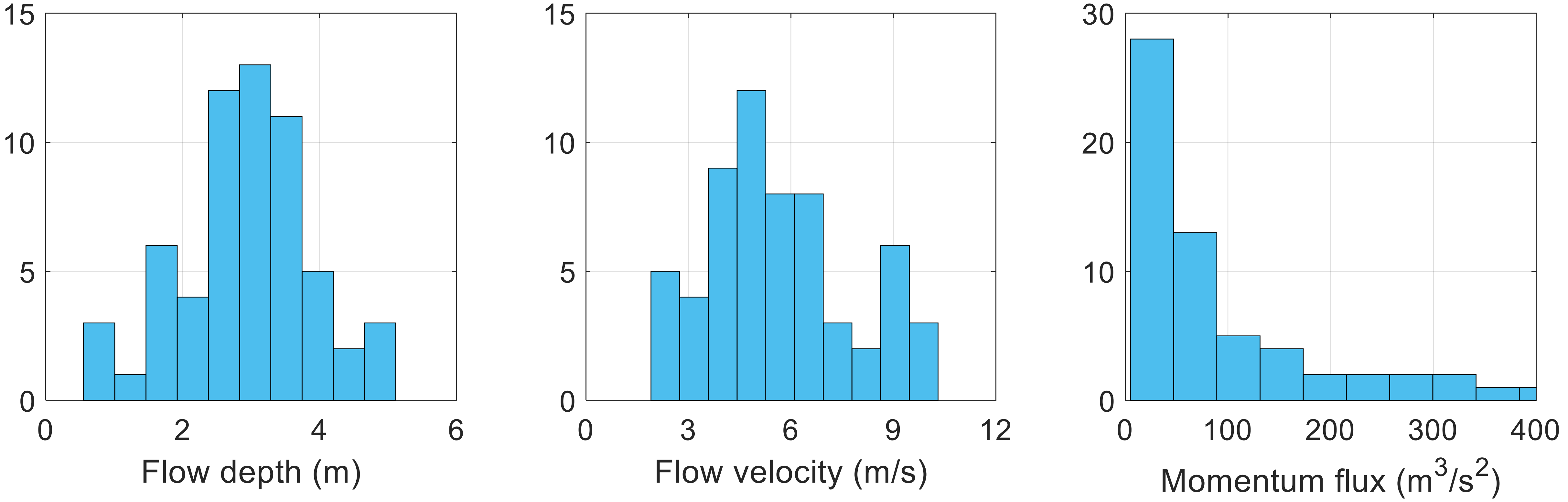
A total of 92 scenarios were generated by INGV, 60 out of which were used for this fragility analysis.



Gibbons, S.J., Lorito, S., Macías, J., Løvholt, F., Selva, J., Volpe, M., Sánchez-Linares, C., Babeyko, A., Brizuela, B., Cirella, A. and Castro, M.J., 2020. Probabilistic tsunami hazard analysis: high performance computing for massive scale inundation simulations. *Frontiers in Earth Science*, *8*, p.591549.

Tsunami Scenarios

A total of 92 scenarios were generated by INGV, 60 out of which were used for this fragility analysis.



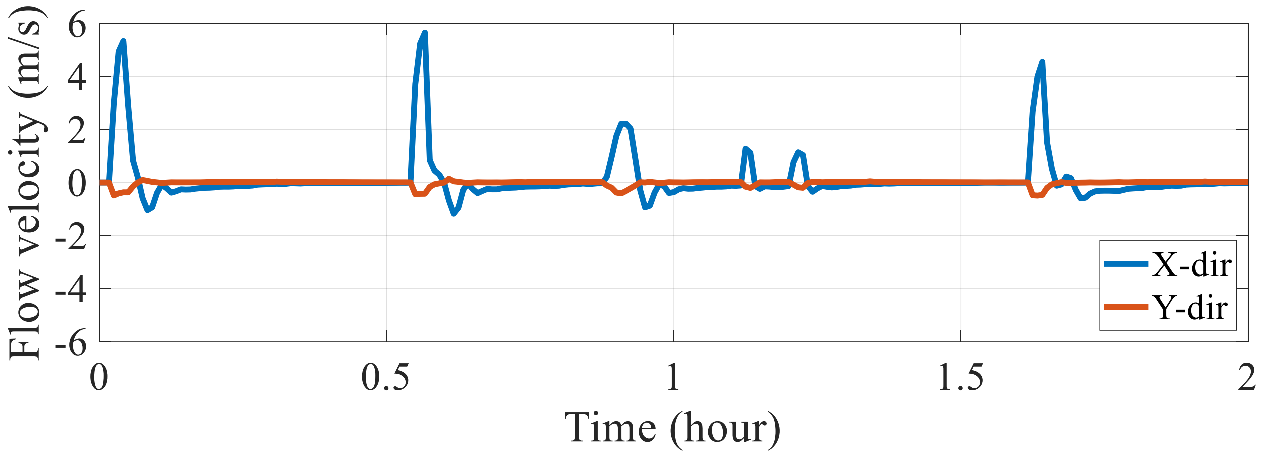
Tsunami Loading

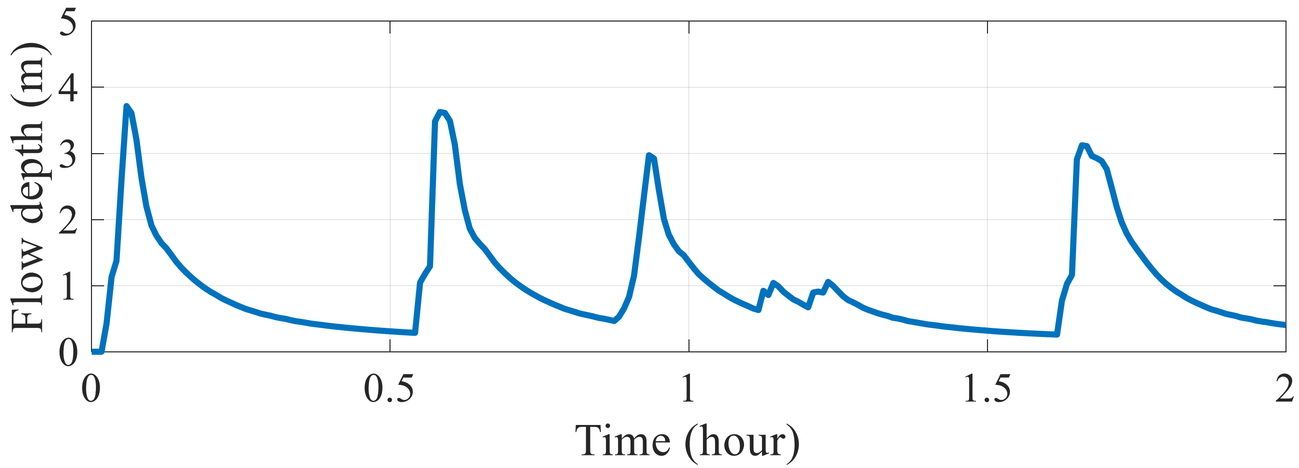
3D nonlinear model built in ***OpenSees***
Tsunami loads include:
- **Hydrostatic** load: $F = \rho g b h$;
- **Hydrodynamic** load: $F = \frac{1}{2}\rho C_{\mathrm{d}} b(hu^2)$;
- Time-history analysis based on the 60 tsunami scenarios (**transient solver**)
- Bi-directional tsunami wave
- Infills assumed to break when the flow depth reach their mid-height

3D nonlinear model built in ***OpenSees***

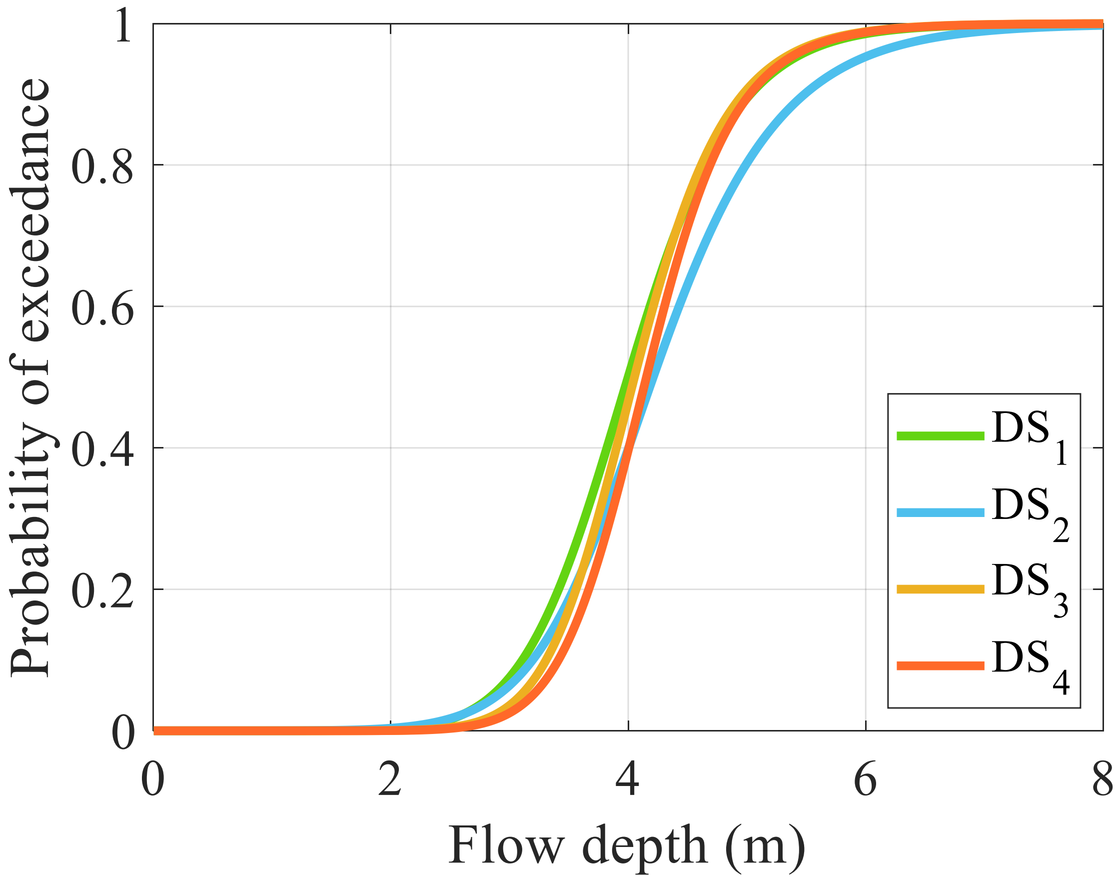
Tsunami loads include:

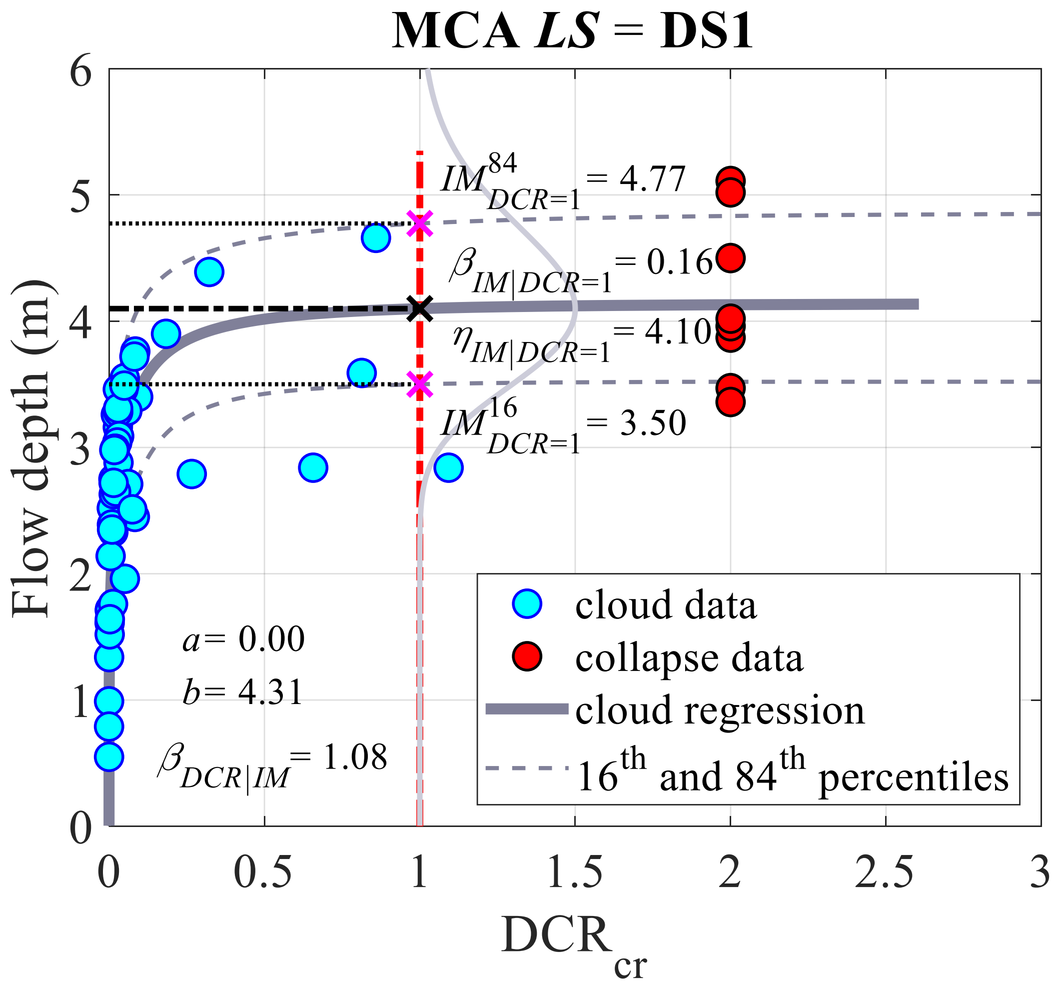
- **Hydrostatic** load: $F = \rho g b h$;
- **Hydrodynamic** load: $F = \frac{1}{2}\rho C_{\mathrm{d}} b(hu^2)$;
- Time-history analysis based on the 60 tsunami scenarios (**transient solver**)
- Bi-directional tsunami wave
- Infills assumed to break when the flow depth reach their mid-height





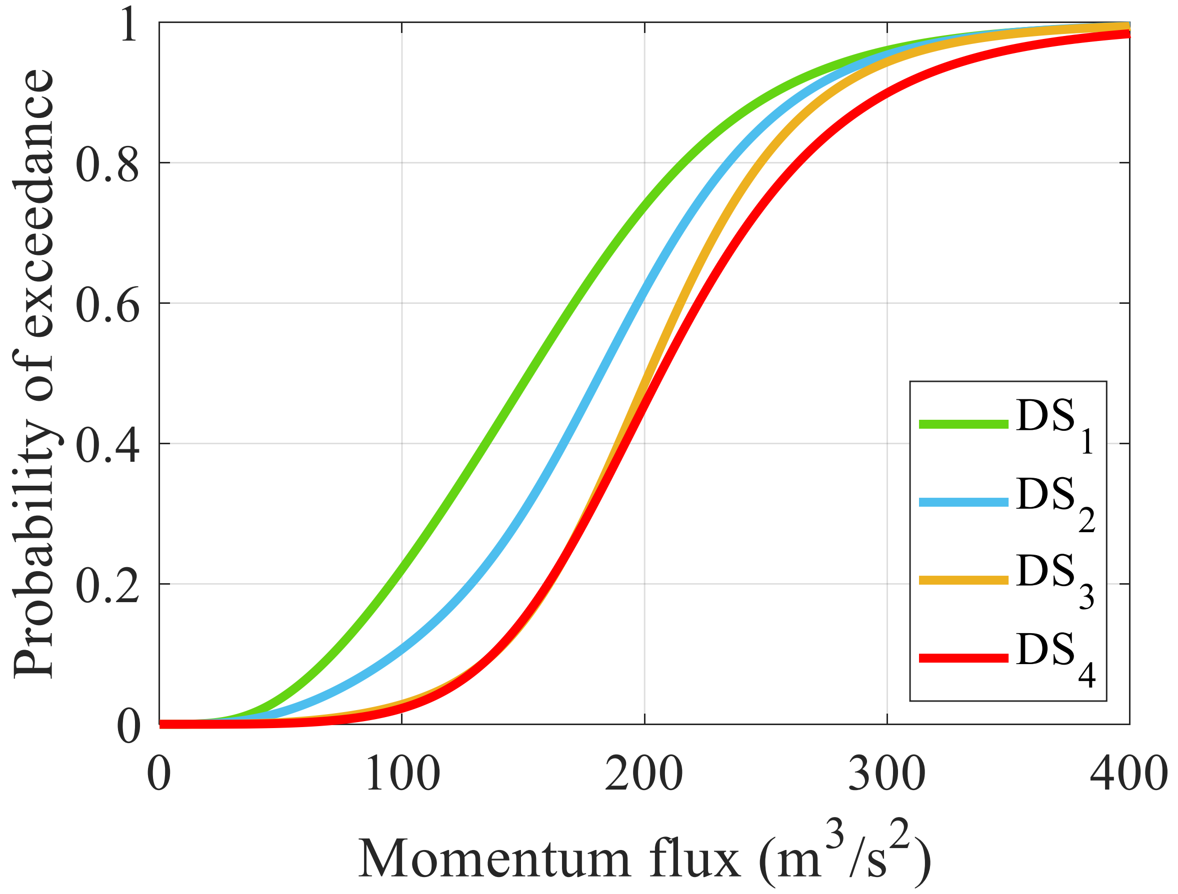
Tsunami Fragility: Flow Depth Modified Cloud Analysis (MCA)

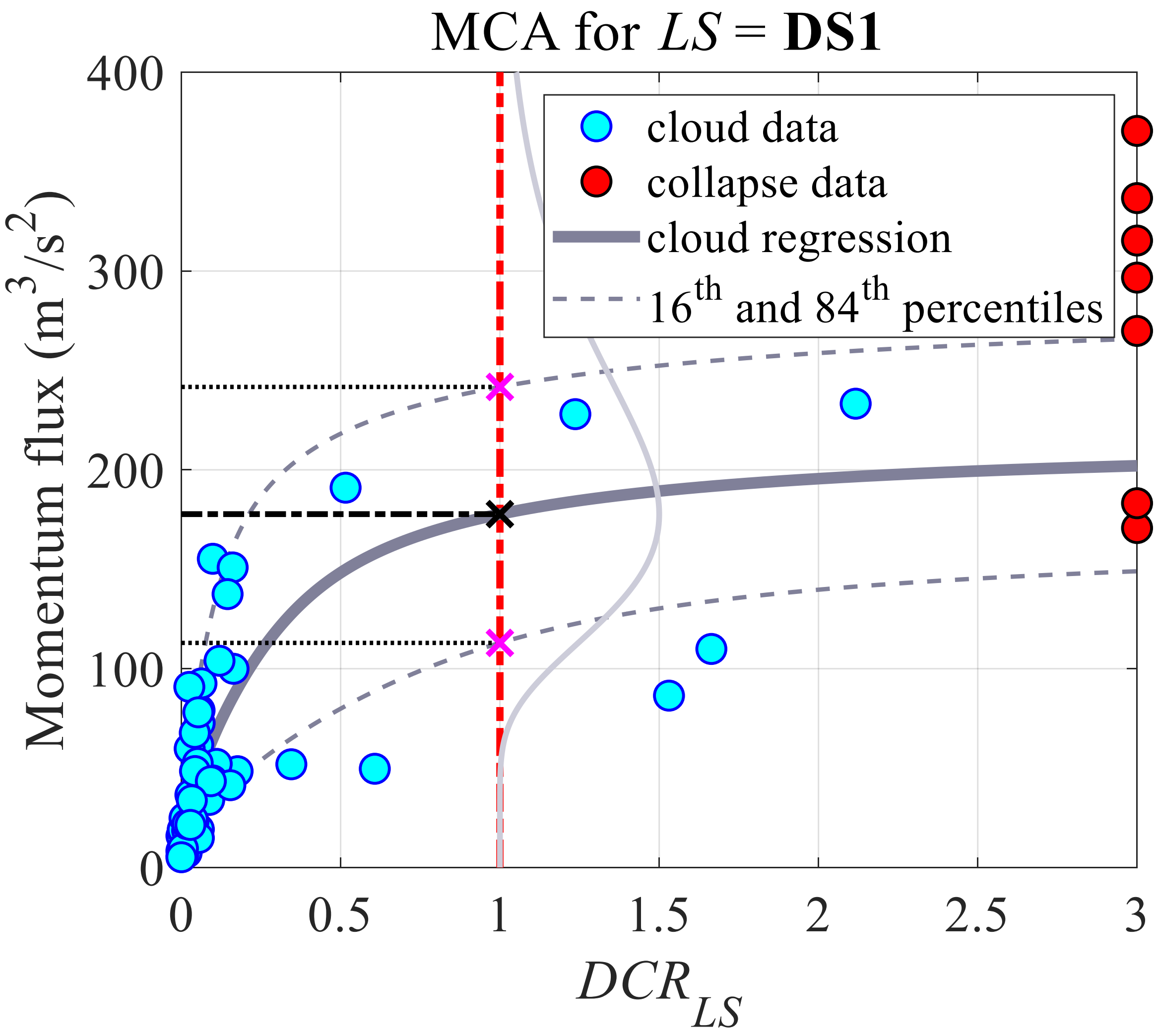




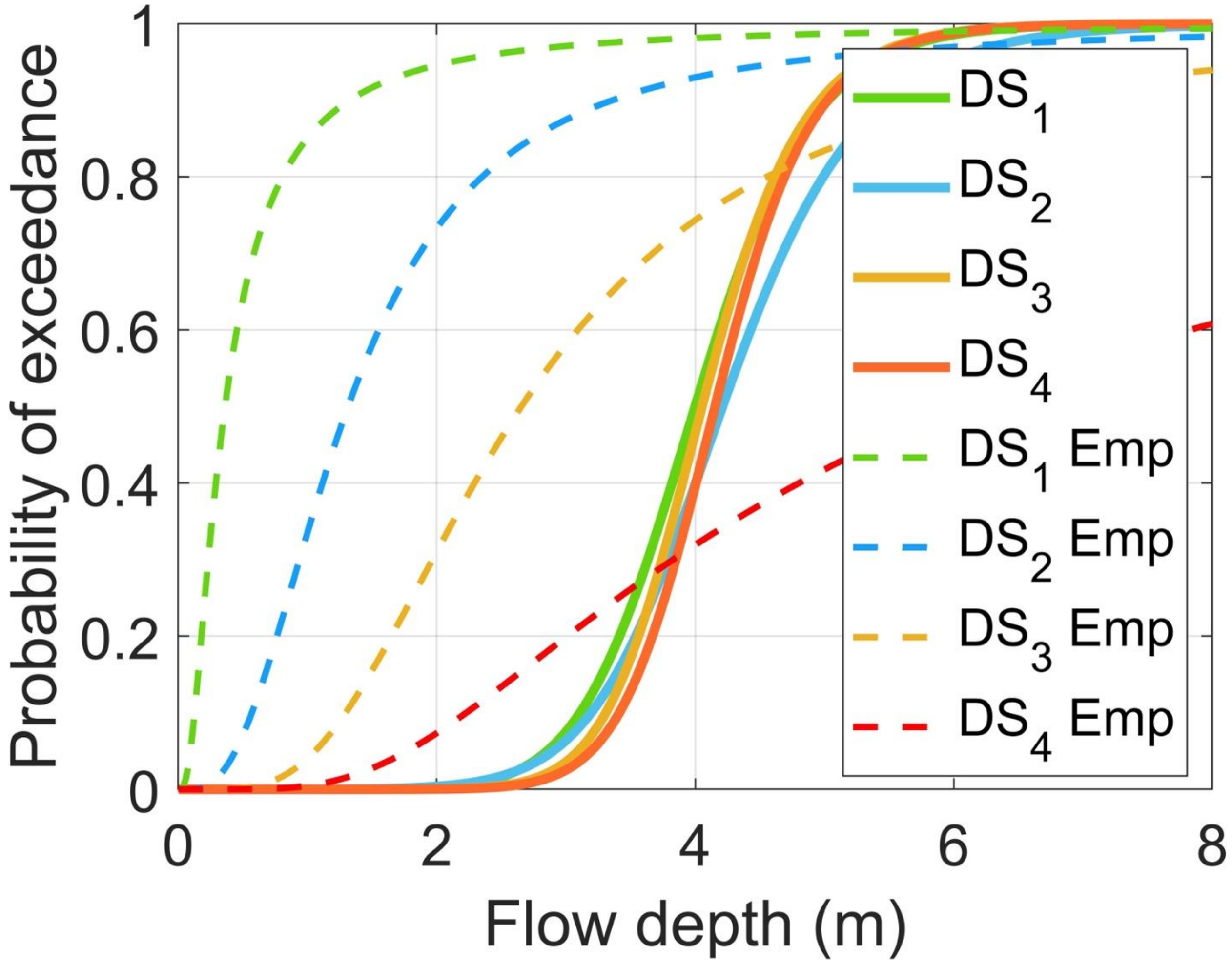
Jalayer, F., Ebrahimian, H., Miano, A., Manfredi, G. and Sezen, H., 2017. Analytical fragility assessment using unscaled ground motion records. *Earthquake Engineering & Structural Dynamics*, *46*(15), pp.2639-2663.

Tsunami Fragility: Momentum Flux





Empirical vs Analytical



Comparisons with Japan 2-storey RC building:

- Damage scales are different
- The analytical curve has no building-to-building variability

Source: European Tsunami Risk Service https://github.com/eurotsunamirisk/etris_data_and_data_products/blob/main/etris_data_products/Fragility_Curves/Japan%202011%20RC%2C%202%20storey_M1.csv

Some take home points

A simulation-based procedure for class fragility assessment.

The models can be sophisticated since small-sample MC simulation is used.

Challenges related to harmony of definitions (taxonomy, damage scale, design, modelling.

Access to ground motion recordings and tsunami inundation simulations.

Importance of detailed exposure models to model building-to-building variability.

Challenges in geolocalising the building classes on the map for simulation purpose (not always available).