EGU General Assembly 2020

Developing analytical tsunami fragility functions for Italian coastal communities

from

S.P.O.T. Project

«Potentially triggerable offshore seismicity and tsunamis»

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reluis

Fragility of RC structures under tsunami loading

- Tsunami events are natural disasters that involve entire communities:

- *"The 2004 Indian Ocean tsunami"*

Major damage: Sumatra (Indonesia)

Victims: about 250 000

- *"The 2009 South Pacific tsunami"*

Major damage: Samoa

Victims: about 200

- *"The 2011 Great East Japan tsunami"*

Major damage: Tohoku (Japan)

Victims: about 16 000

Sumatra - 2004

Tohoku- 2011

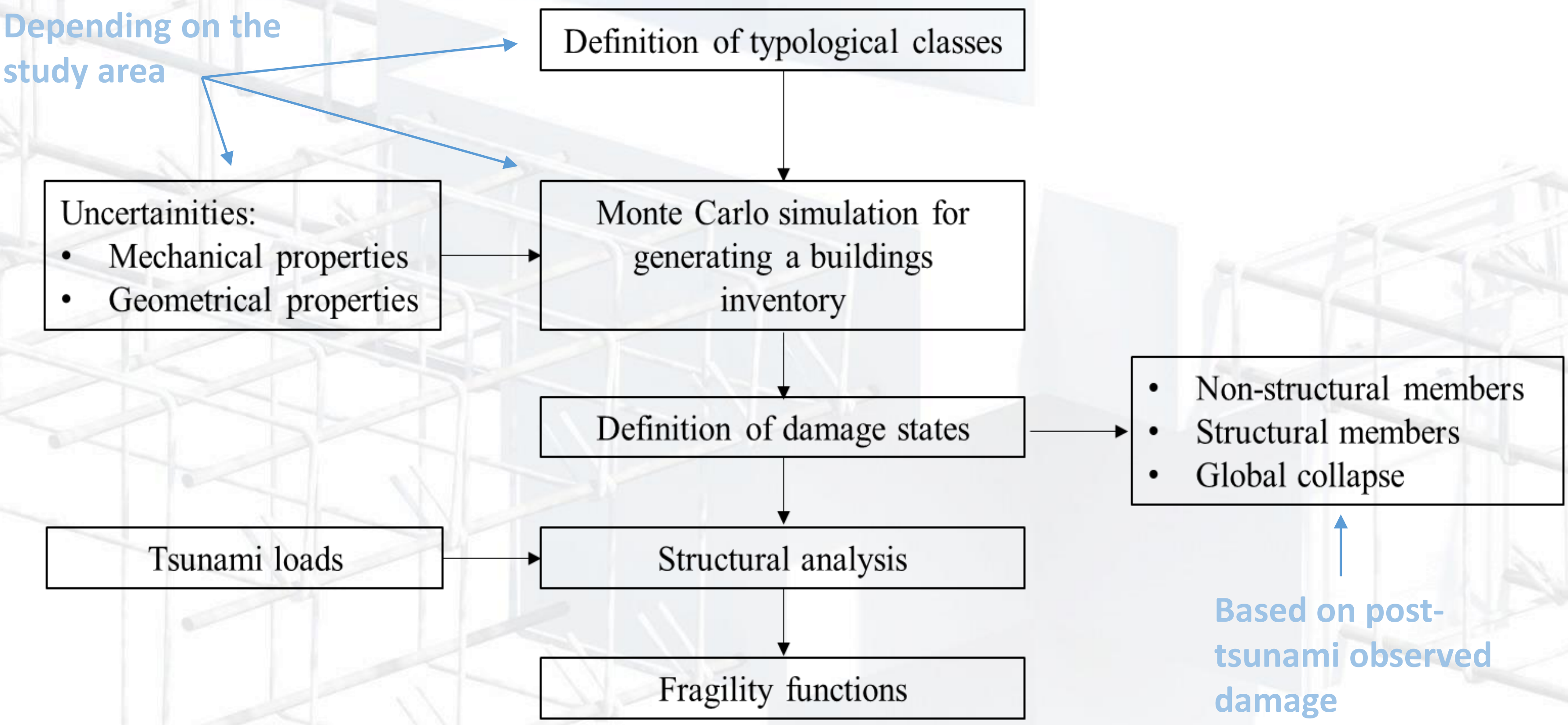
- Tsunamis are a series of fast moving ocean waves generated by natural or anthropic events (***off-shore activities near seismogenic faults***).

- Empirical fragility functions have been built after major tsunami events, but these functions cannot be used for estimating vulnerability of other coastal communities

- In a quantitative risk-assessment framework, the proper estimation of existing buildings fragility under tsunami loading is of paramount importance for predicting the potential impact of tsunami events in coastal areas.

Fragility of RC structures under tsunami loading

- **Framework for developing analytical fragility functions at community level**



Definition of damage states

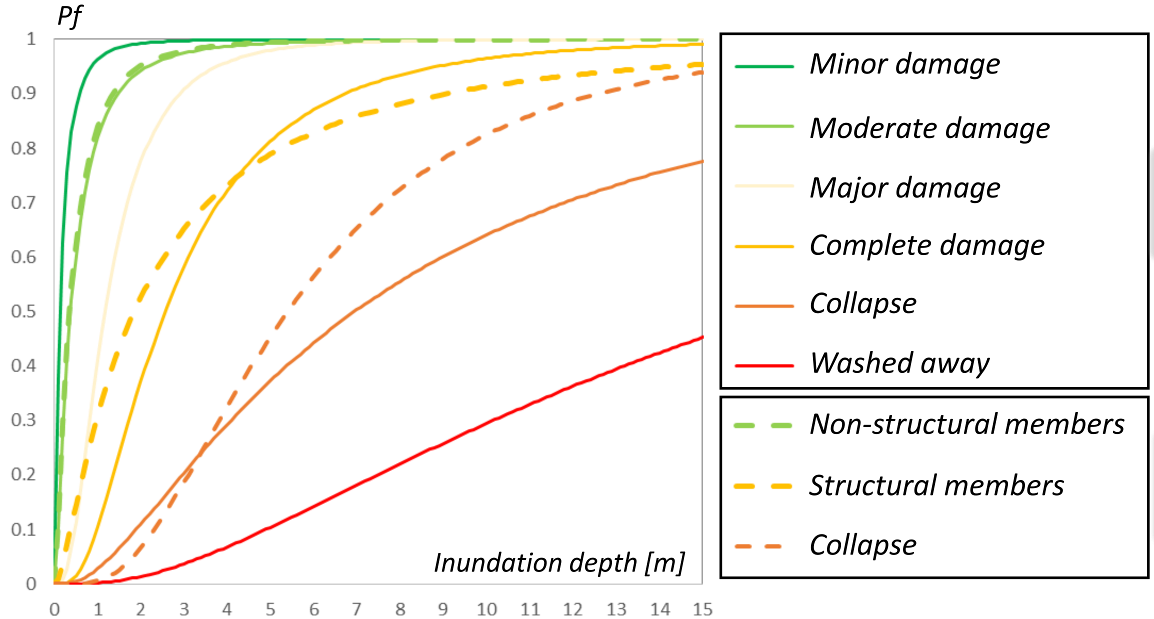
Post-tsunami observed damage

- *Non-structural components*
  - *Infills*
- *Structural members*
  - *Columns Shear walls*
  - *Slabs*
- *Entire structure*
  - *Soft-story mechanism*
  - *Overturning*

Reference:
“Tohoku Investigation of Structural Damage and Development of the ASCE 7 Tsunami Design Code for Buildings and Other Structures” G. Chock
“Tsunami loadings on structure. Review and analysis.” H. Yeh, R.Barbosa, H. Ko, J. Cawley
“Experimental modeling of extreme hydrodynamic forces on structural models” T. Al Faesly, D. Palermo, I. Nistor, A. Cornett

Definition of damage states

- **Empirical fragility functions for RC structures**



2011 Great East Japan

2004 Indian Ocean

Damage classification

2011 Great East Japan

Damage level	Classification	Description	Condition
1	Minor damage	There is no significant structural or non-structural damage, possibly only minor flooding	Possible to be use immediately after minor floor and wall clean up
2	Moderate damage	Slight damages to non-structural components	Possible to be use after moderate reparation
3	Major damage	Heavy damages to some walls but no damages in columns	Possible to be use after major reparations
4	Complete damage	Heavy damages to several walls and some columns	Possible to be use after a complete reparation and retrofitting
5	Collapsed	Destructive damage to walls (more than half of wall density) and several columns (bend or destroyed)	Loss of functionality (system collapse). Non-repairable or great cost for retrofitting
6	Washed away	Washed away, only foundation remained, total overturned	Non-repairable, requires total reconstruction

Non-structural components (damage levels 1–3)

Structural members (damage levels 4–6)

Definition of damage states

- **Definition of damage states for RC frames with masonry infills**

Damage state	Classification	MLIT Empirical definition [21]		Proposed analytical definition	
		NON-STRUCTURAL MEMBERS	STRUCTURAL MEMBERS	NON-STRUCTURAL MEMBERS	STRUCTURAL MEMBERS
DS0	Minor damage	No significant structural or non-structural damage, minor flooding	-	-	-
DS1	Moderate damage	Slight damage to non-structural components	-	Light damage to non-structural components (first cracks)	-
DS2	Major damage	Heavy damage to some infill walls but no damage in columns		Heavy damage to non-structural components (out-of-plane collapse)	
DS3a	Complete damage	Heavy damage to several infill walls and some columns		All the infills at ground storey are collapsed	Light damage to structural members (one half of the steel yielding strain)
DS3b				All the infills at ground storey are collapsed	Heavy damage to structural members (steel yielding strain)
DS4	Collapsed	-	Destructive damage to infill walls (more than half of wall density) and several columns (bend or destroyed)	-	Collapse of the structure (global failure mechanism)
DS5	Washed away	-	Washed away, total overturned	-	-

Tsunami loads on structures

- **Modelling of the tsunami loads for large scale applications**

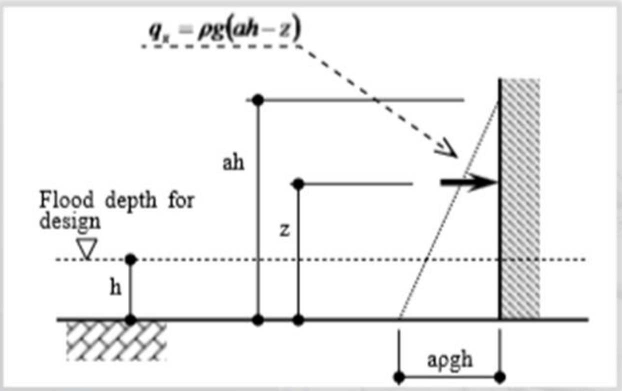
JAPANESE STANDARDS

Simplified approach: **hydrostatic distribution** amplified by ***a*** to account for the **hydrodynamic effects**

$$q_z = \rho\, g\, (a\, \boldsymbol{h} - z)$$

$$Q_z = \rho\, g \int_{z_1}^{z_2} (a\, \boldsymbol{h} - z)\, B\, dz$$

$1.5 \le a \le 3$



- **h = inundation depth**

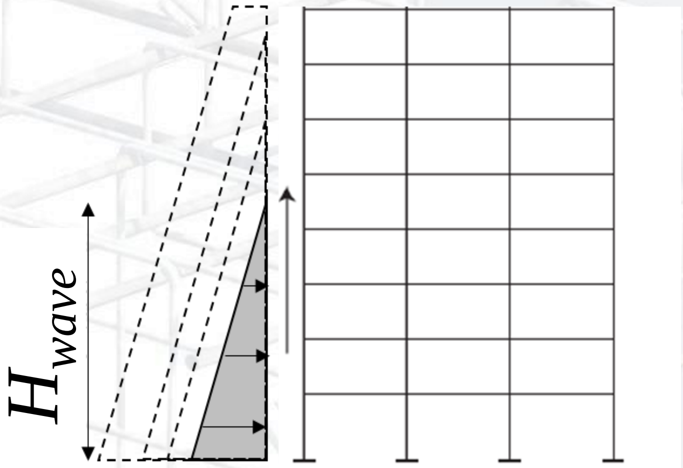
Other components of tsunami-induced loads on structures, such as buoyancy, scour and debris impact, have negloected in this preliminary study

Structural analysis for tsunami loading

- **Structural analysis methodology for assessment under tsunami loading**

VDPO: Variable Depth Pushover Analysis

Hydrostatic + Hydrodynamic actions



$$q = \rho g H_{wave} L$$

- ✓ Force controlled
- ✓ Step-by-step increasing inundation depth **h**

ρ = *sea water density*

g = *gravitational acceleration*

$$H_{wave} = \mathbf{a}h \ \text{ with } \ \mathbf{a = 1.5 - 3}$$

L = *impacting surface* ➡ *Function of the behaviour of external infills*

➢ Simple mechanics-based models for calculating the tsunami inundation depth associated to the achievement of each damage state have been developed to avoid FEM analysis.

Reference:
"Fragility assessment of a RC structure under tsunami actions via nonlinear static and dynamic analyses" C. Petrone, T. Rossetto, and K. Goda

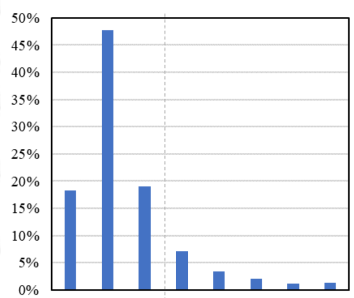
Application to Italian coastal communities

- **Definition of typological classes for Italian coastal communities**

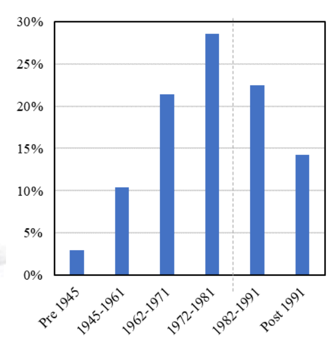
  ✓ Six typological classes have been defined for Italian residencial RC buildings based on the following attributes:

Age of construction:	**Before 1980**	**Before 1980**	**After 1980**
Structural design:	**Gravity loads**	**Seismic loads**	**Seismic loads**
	• **Low rise (1-3 storey)**	• **Low rise (1-3 storey)**	• **Low rise (1-3 storey)**
	• **Medium rise (4-6 storey)**	• **Medium rise (4-6 storey)**	• **Medium rise (4-6 storey)**

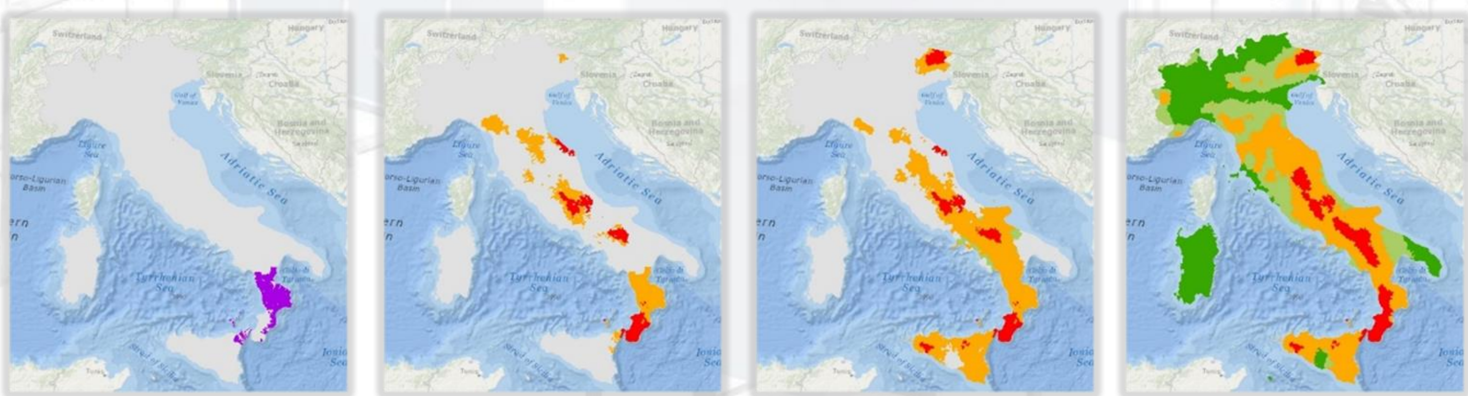
n. storey



Age of construction



Evolution of seismic classification in Italy



1909 1935 1981 2003

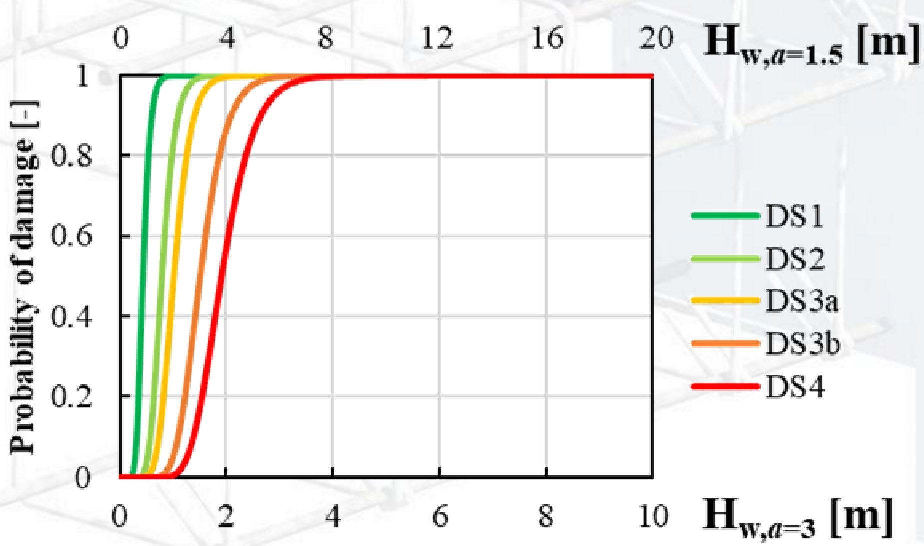
Application to Italian coastal communities

- **Definition of analitycal fragility curves for a buildings invetory**

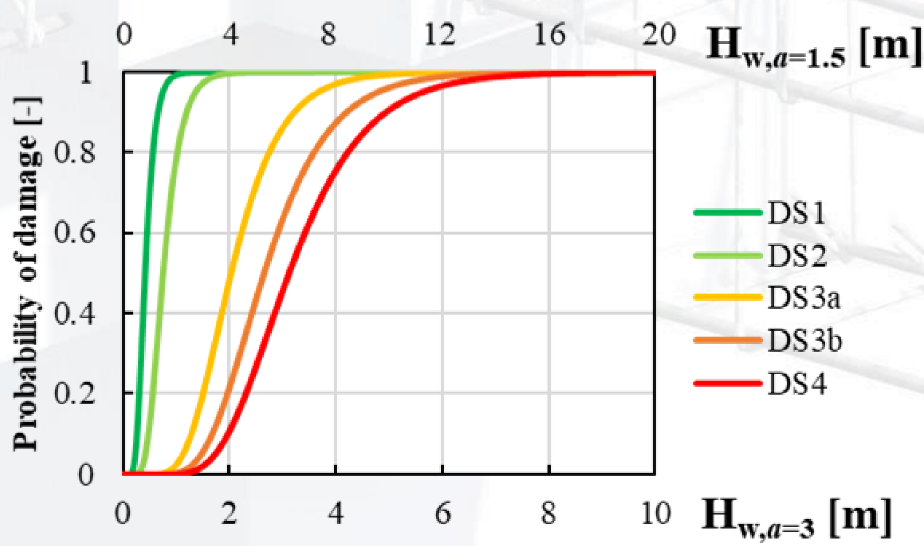
  ✓ An inventory of 100.000 buildings was generated with a Monte Carlo simulation per each typological class

Low rise RC buildings (1-3 storey)

Before 1980 - Gravity



After 1980 - Seismic



Conclusions and future developments

- ✓ The proposed methodology allowed to define analytical tsunami fragility functions at community scale performing very easy calculations for a large number of buildings and avoiding the use of finite-element models;

- ✓ The methodology is generally valid and can be adopted for every coastal community, after the definition of typological classes and of simulated design procedures strictly related to a specific study region;

- ✓ Damage states and related mechanics-based models were specifically developed for RC frames with masonry infills. Future works will expand the proposed methodology to other structural typologies typical of coastal regions.

Further information

S.P.O.T. Project Final Report

Link for download:

https://unmig.mise.gov.it/index.php/it/informazioni/notizie-e-faq/it/198-notizie-stampa/2036109-progetto-spot-pubblicato-il-report-integrato-di-fine-progetto

PROGETTO SPOT - SISMICITÀ POTENZIALMENTE INNESCABILE OFFSHORE E TSUNAMI

Report integrato di fine progetto

Una collaborazione del MiSE, con il supporto tecnico del DPC, con CNR-ISMAR, INGV, EUCENTRE e ReLUIS

Ministero dello Sviluppo Economico
DGISSEG
Antoncecchi I., Ciccone F., Dialuce G., Grandi S., Terlizzese F.

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile
Di Bucci D., Dolce M.

ISMAR
Argnani A., Mercorella A., Pellegrini C., Rovere M., *con la partecipazione dell'Università di Bologna:* Armigliato A., Pagnoni, G., Paparo M.A., Tinti, S., Zaniboni F.

INGV
Basili R., Cavallaro D., Coltelli M., Firetto Carlino M., Lipparini L., Lorito S., Maesano F.E., Romano F., Scarfì L., Tiberti M.M., Volpe M., *con la partecipazione dell'Università di Pavia:* Fedorik J., Toscani G.

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Borzi B., Faravelli M., Bozzoni F., Pascale V., Quaroni D., Germagnoli F.

reluis
Belliazzi S., Del Zoppo M., Di Ludovico M., Lignola G.P., Prota A.

Antoncecchi I., Ciccone F., Dialuce G., Grandi S., Terlizzese F., Di Bucci D., Dolce M., Argnani A., Mercorella A., Pellegrini C., Rovere M., Armigliato A., Pagnoni, G., Paparo M.A., Tinti, S., Zaniboni F., Basili R., Cavallaro D., Coltelli M., Firetto Carlino M., Lipparini L., Lorito S., Maesano F.E., Romano F., Scarfì L., Tiberti M.M., Volpe M., Fedorik J., Toscani G., Borzi B., Faravelli M., Bozzoni F., Pascale V., Quaroni D., Germagnoli F., Belliazzi S., Del Zoppo M., Di Ludovico M., Lignola G.P., Prota A. (2020) - Progetto SPOT - Sismicità Potenzialmente innescabile Offshore e Tsunami. Report integrato di fine progetto.

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