International Workshop on Advances in Assessment and Modeling of Earthquake Loss

TURKISH NATURAL CATASTROPHE INSURANCE POOL

International Workshop on Advances in Assessment and Modeling of Earthquake Loss, which is organized by the TCIP, will bring the insurance industry players, international reinsurance and modeling companies, government agencies and universities on November 4–5, 2019 in Istanbul, Hotel Wyndham Grand Levent.

EMPIRICAL FRAGILITY AND VULNERABILITY OF REGIONAL BUILDING STOCKS IN EUROPE

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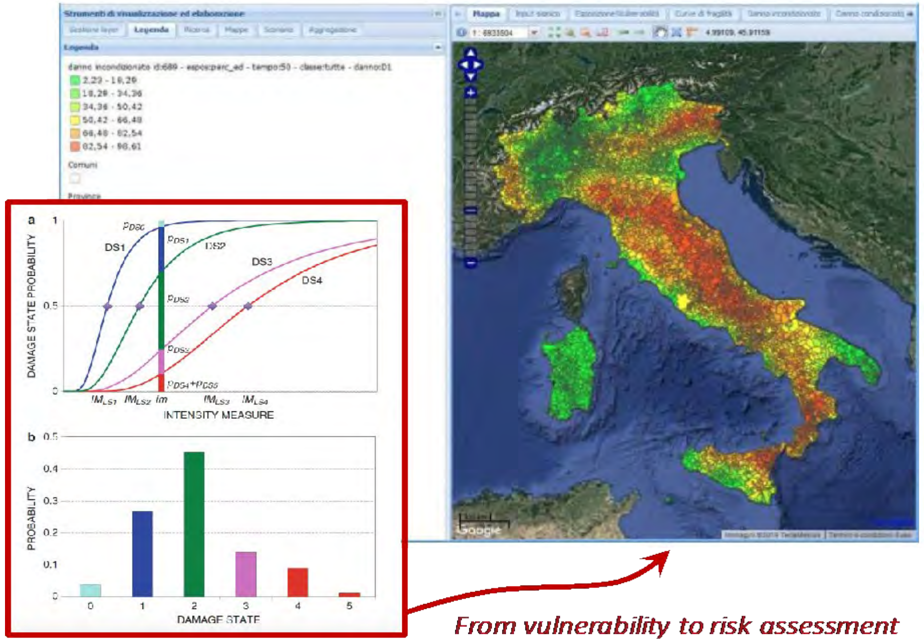
OUTLINE OF THE PRESENTATION

FRAGILITY CURVES

What do they represent?	Vulnerability as a component of seismic risk and loss assessment
What do they depend on?	Involved dispersions & influence on results of seismic risk analysis
How are they obtained?	Overview of methods & focus on macroseismic and empirical ones
How can they be used?	Practical issues & application to the Italian seismic risk assessment



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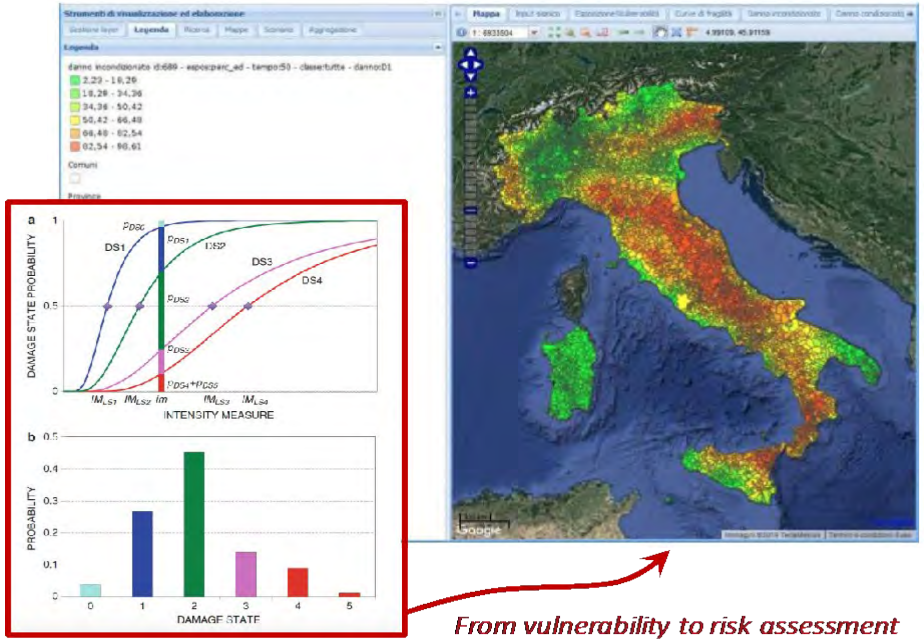


From vulnerability to risk assessment

RISK ANALYSIS

HAZARD ASSESSMENT

EXPOSURE & CLASSIFICATION

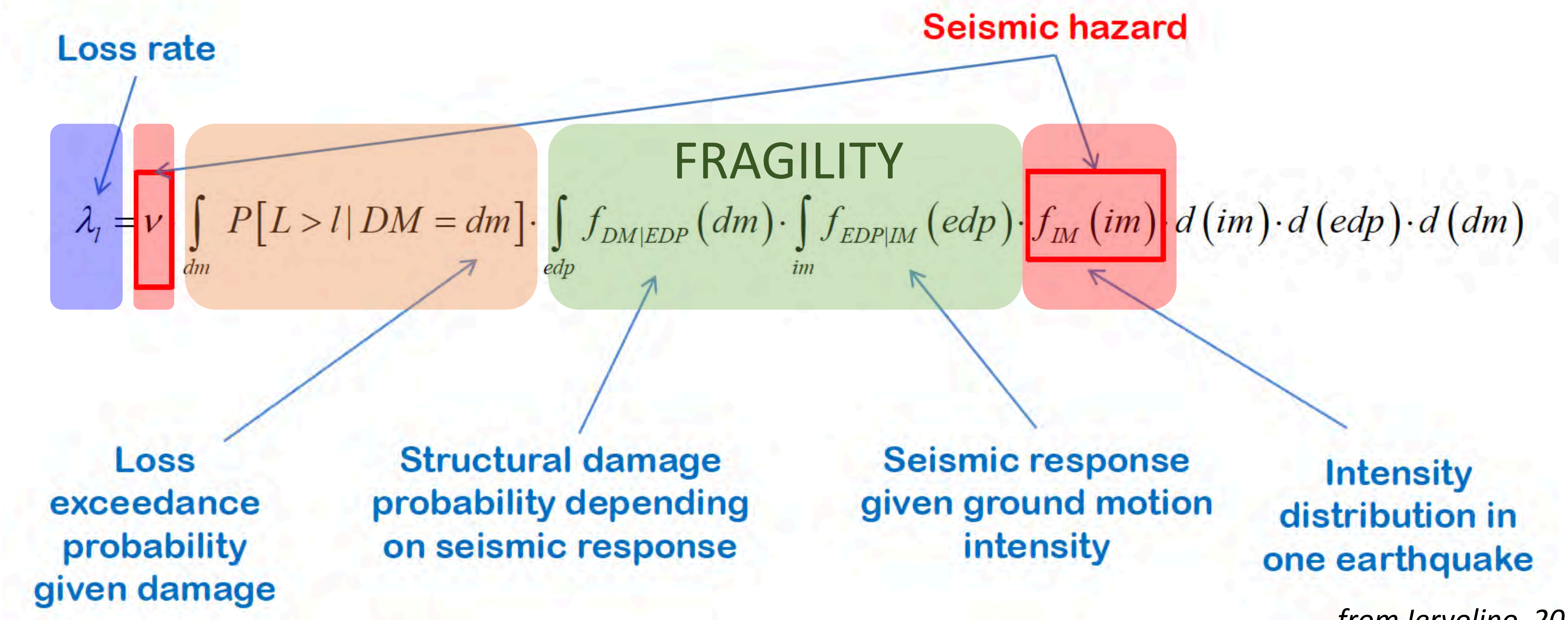
VULNERABILITY & DAMAGE ESTIMATION

LOSS ESTIMATION

The risk analysis at territorial scale is **intrisically probabilistic** (as the PEER-PBA at scale of the single building): it is the result of **convolution of various sources of uncertainties and dispersions**

RISK ANALYSIS – *BASICS*

It represents the **EXPECTED RATE** in a **GIVEN TIME** (e.g. 1 year, 50 years) of possible **LOSSES** (economical, buildings usability, casualties, …) due to the **DAMAGE** occurred **in** the building stock and considering people (**EXPOSURE**) in a **GIVEN AREA** (e.g. the municipality, the region, the whole country) as a consequence of possible seismic events (**HAZARD**)



$$\lambda_l = \nu \int_{dm} P[L > l \mid DM = dm] \cdot \int_{edp} f_{DM|EDP}(dm) \cdot \int_{im} f_{EDP|IM}(edp) \cdot f_{IM}(im) \, d(im) \cdot d(edp) \cdot d(dm)$$

from Iervolino, 2016

RISK ANALYSIS – *HAZARD*

Hazard curve (from PSHA - Probabilistic Seismic Hazard Assessment):
annual probability of exceedance of a selected intensity measure of the earthquake at the given site

UNCONDITIONED

TIME-BASED

Evaluates the loss **in a specified period of time** (e.g. 1 year, 30 or 50 years) considering **all earth-quakes** that could occur in that time period, each one with the specific probability of occurrence

The **time period** depends on the aims of the decision-makers. Assessments based on one year are useful for cost-benefit analysis

CONDITIONED

INTENSITY-BASED

Evaluates the loss assuming the **earthquake intensity** associated to a given return period. In general the design earthquakes consistent with Building Codes are adopted.

Useful for **comparative analyses** by considering RARE and FREQUENT events.

CONDITIONED

SCENARIO-BASED

Evaluates the loss assuming a **shaking scenario**, relative to the area under examination, derived by a **deterministic earthquake**, in terms of **magnitude, epicenter location, etc.**

Useful to support the design of **seismic emergency plan** at municipality scale.

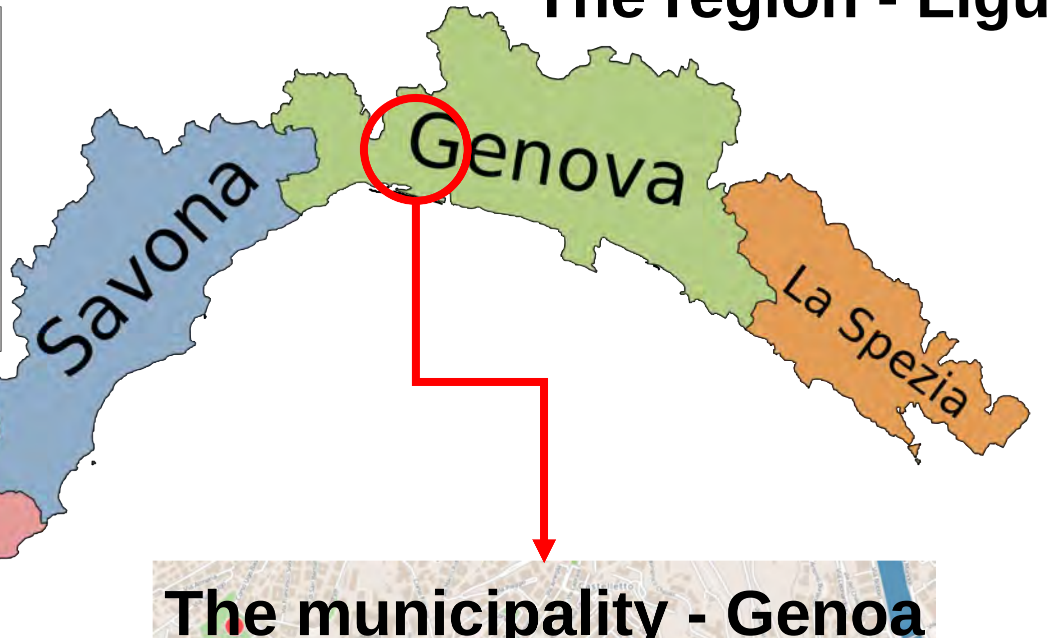
In case of CONDITIONED ASSESSMENT IT IS POSSIBLE ALSO ADOPT THE MACROSEISMIC INTENSITY as INTENSITY MEASURE

according to the notation introduced by FEMA P-58 for performance assessment of buildings

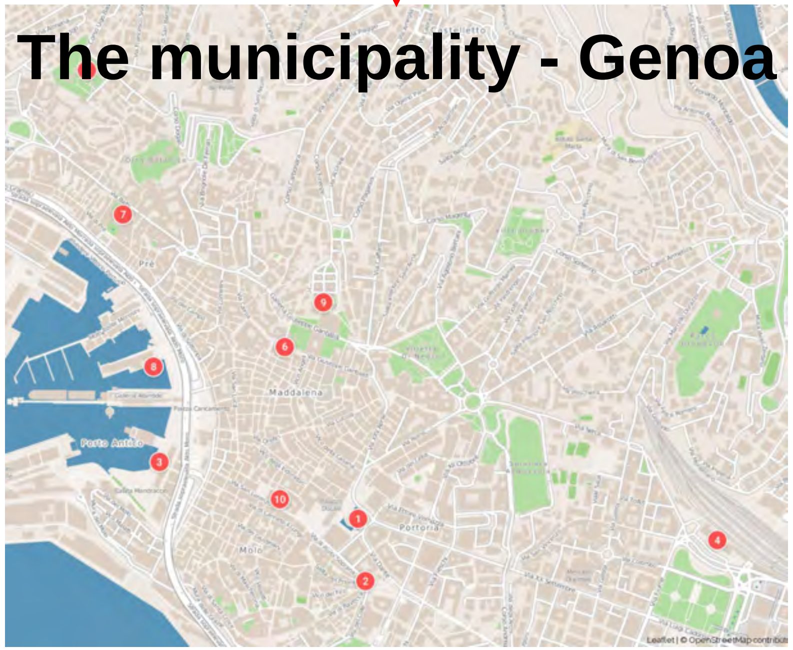
RISK ANALYSIS – *different scales*

The whole country - Italy

The region - Liguria



The municipality - Genoa



RISK ANALYSIS – *EXPOSURE*

Risk analyses at large scale can be referred to:

- **building stocks** characterized by data **aggregated in sub-areas –** *typical of the assessment on residential buildings that are present in the area under investigation*
- **buildings portfolio** characterized by a **group of single structures –** *typical of the assessment on strategic buildings in the area (e.g. schools, strategic buildings, …)*

The analysis of the exposure is functional to define the vulnerability, therefore:

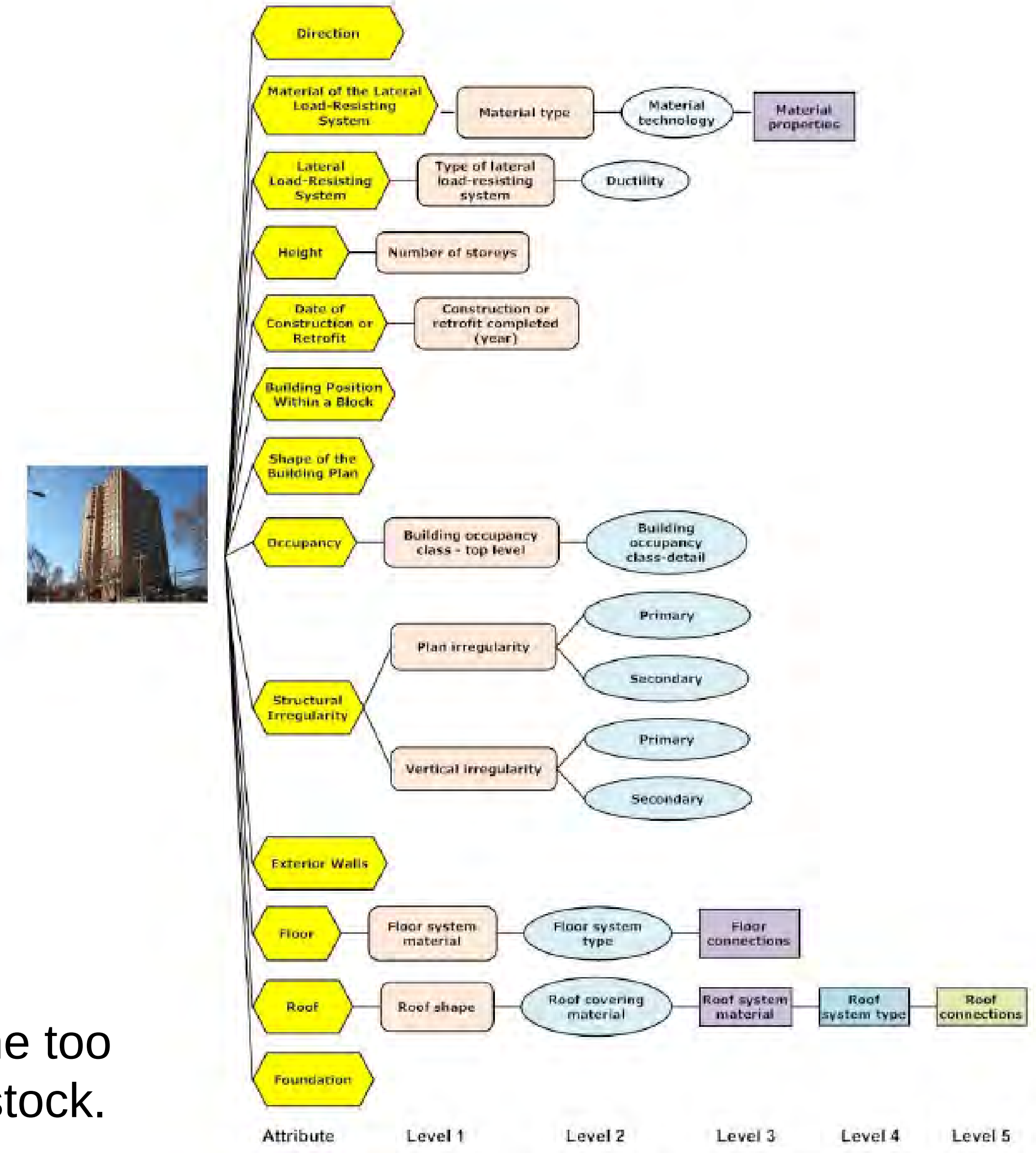
- **Taxonomy**: aimed to define the attributes that influence the vulnerability
- **Classification**: grouping of buildings for which it is assumed the same behavior (using the taxonomy tags, you may end up with a huge number of classes, and it is not straightforward that their behavior is really different)
- **Inventory**: taxonomy and classification must take into account the available information

GEM Building Taxonomy Version 2.0

GEM Technical Report 2013-02
Version: 1.0.0
Date: November 2013

LIST OF 13 ATTRIBUTES

1. Direction
2. Material of the lateral load-resisting system
3. Lateral load-resisting system
4. Height
5. Date of construction or retrofit
6. Occupancy
7. Building position within a block
8. Shape of the building plan
9. Structural irregularity
10. Exterior walls
11. Roof
12. Floor
13. Foundation system



Building classes (combination of tags) may become too many and should be completed in describing the stock.

CLASSIFICATION OF RESIDENTIAL BUILDING STOCK IN ITALY FROM CENSUS DATA

ISTAT - Census of the population

Information available at municipality level, disaggregated in terms of:

Exposure:

- **Population**
- **# of buildings, # flats and size**

Vulnerability:

- **Type (material):**
  - Masonry, Reinforced concrete, other
- **Building height:**
  - Low 1-3, Medium 3-5, High >5
- **Age of constrcution:**
  - < 1919, 1919-1945, 1946-1961, 1962-1981, 1982-1991, >1991

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

EUCENTRE
FOR YOUR SAFETY.

Italian seismic risk maps by **IRMA Platform**

DPC/ReLUIS Project 2019-2021

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
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reluis

- **CARTIS – Inventory of building typologies**
  Coordinator: Giulio Zuccaro
- **MARS – Seismic Risk Maps and Damage Scenario**
  Coordinators: Sergio Lagomarsino and Angelo Masi

Regionalization of fragility curves:

- Identification of sub-regions in which buildings have similar characteristics, by means of sample surveys on small areas, but statistically representative.

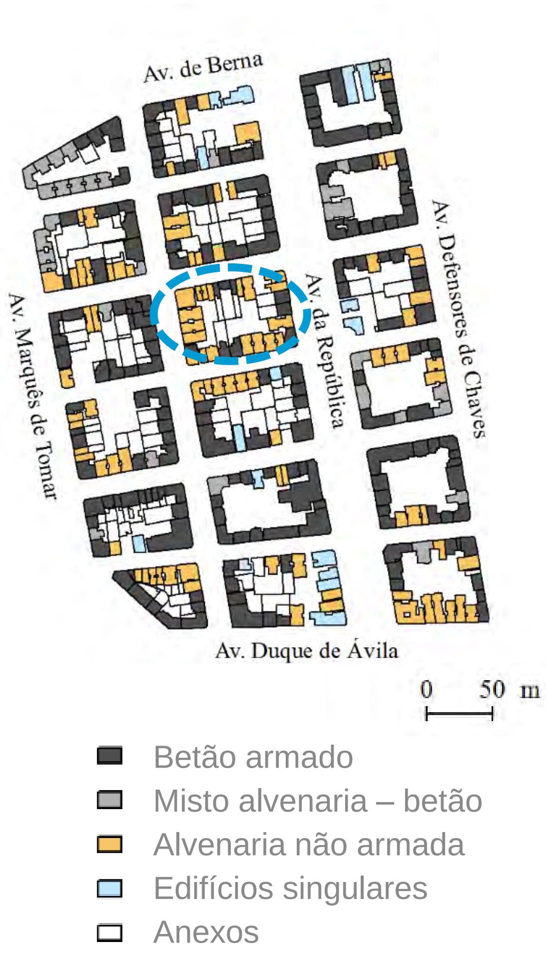
Masonry buildings, age 1919-1945, height 3 to 5 stories

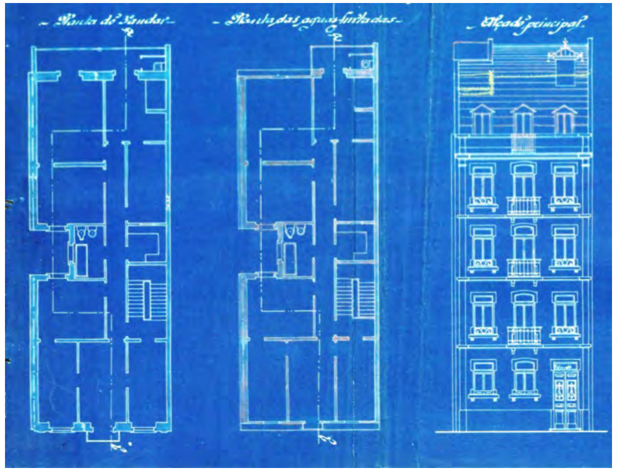
Region	Masonry		Horizontal floors			
	Brick masonry	Stone masonry	Vaults	Timber	Steel	R.C.
Emilia Romagna	95%	5%	15%	40%	40%	5%
Abruzzo	15%	85%	20%	20%	35%	25%

CLASSIFICATION OF THE BUILDING STOCK AT URBAN LEVEL

The case study of GAIOLEIRO buildings in Lisbon between XIX and XX centuries

Avenidas Novas





REF: Simoes et al. (2019) Fragility functions for tall URM buildings around early 20° century in Lisbon. Part 1 & 2. International Journal of Architectural Heritage, online.

CLASSIFICATION OF THE BUILDING STOCK AT URBAN LEVEL

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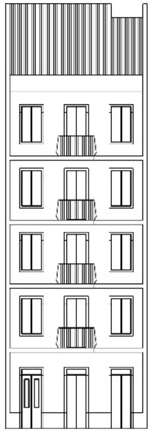
Tipo I

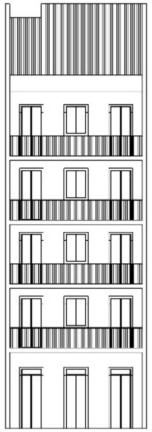
Tipo II

Tipo III

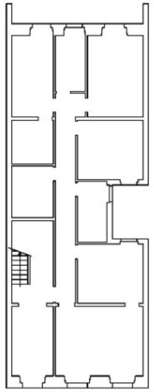
Tipo IV



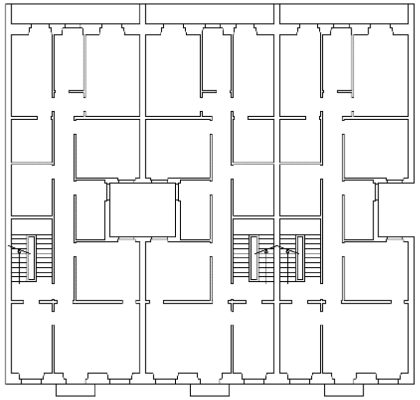
Main Facade



Back Facade



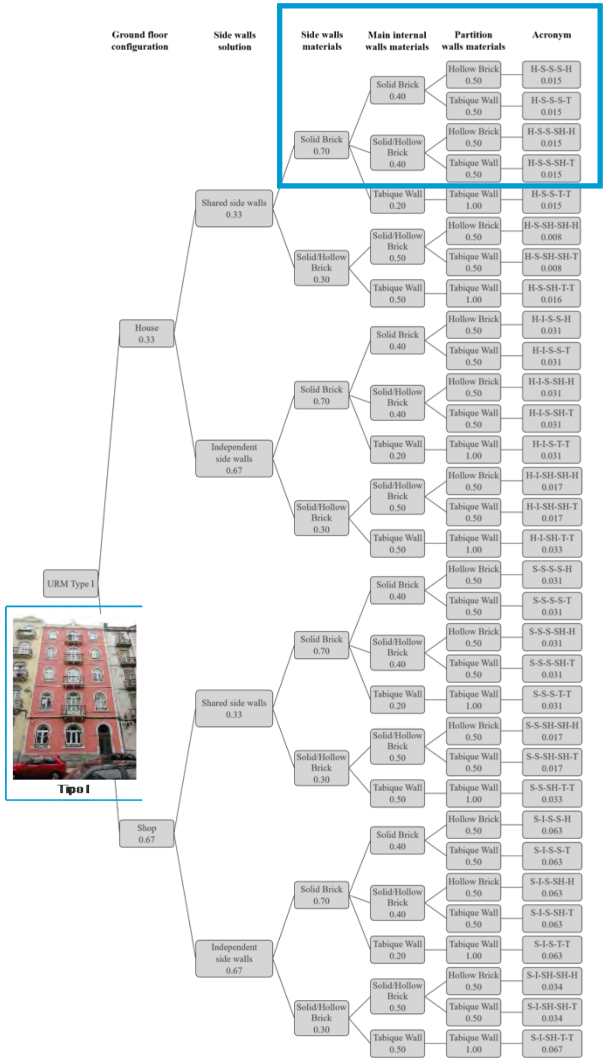
Plan view



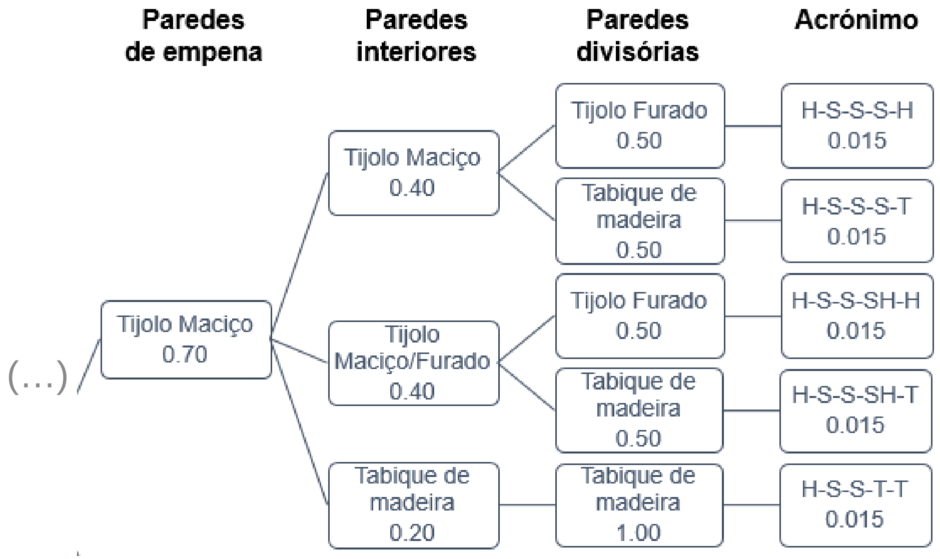
Case of study

REF: Simoes et al. (2019) Fragility functions for tall URM buildings around early 20° century in Lisbon. Part 1 & 2. International Journal of Architectural Heritage, online.

The case study of GAIOLEIRO buildings in Lisbon between XIX and XX centuries



Epistemic Uncertainties: geometry, structural details and materials



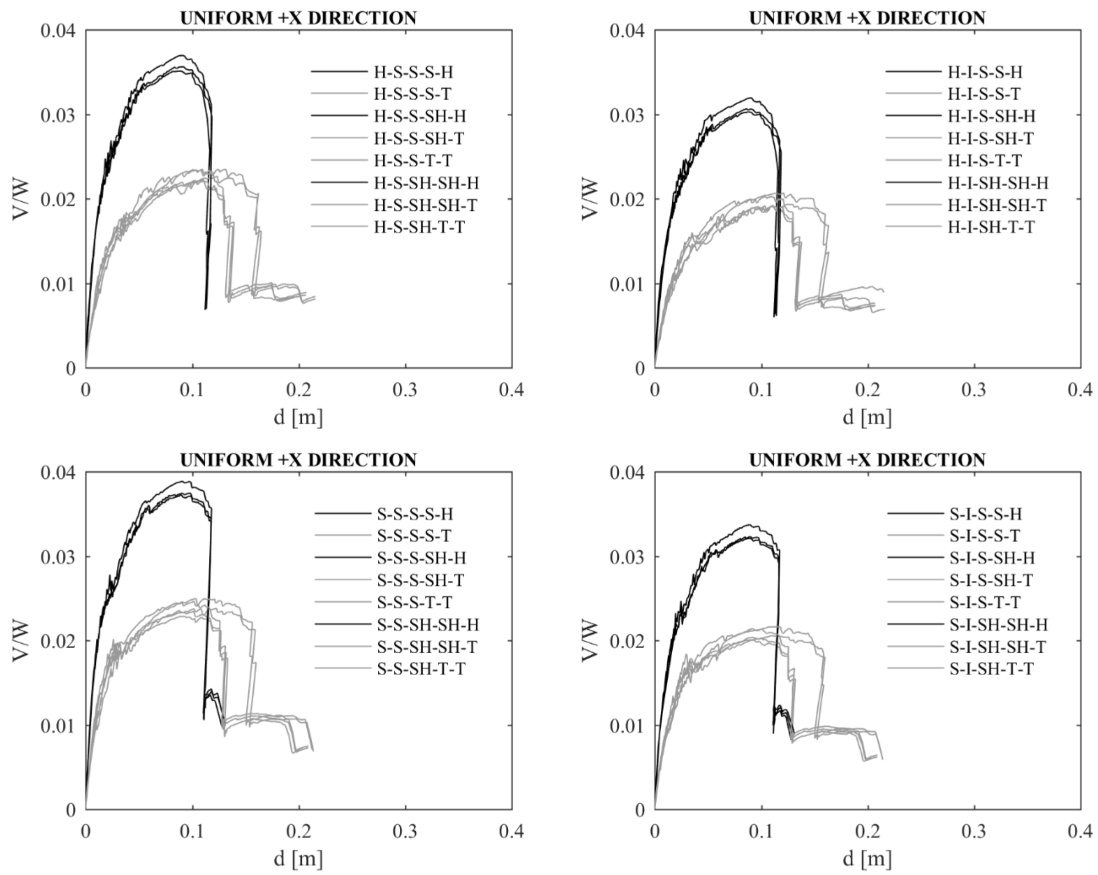
- Configuração R/C: habitação ou comércio
- Solução paredes de empena: meeiras ou independentes
- Paredes de empena: tijolo maciço ou tijolo furado
- Paredes interiores: tijolo maciço ou tijolo furado
- Paredes divisórias: tijolo furado ou tabique de madeira

LOGIC TREE WITH 32 BRANCHES

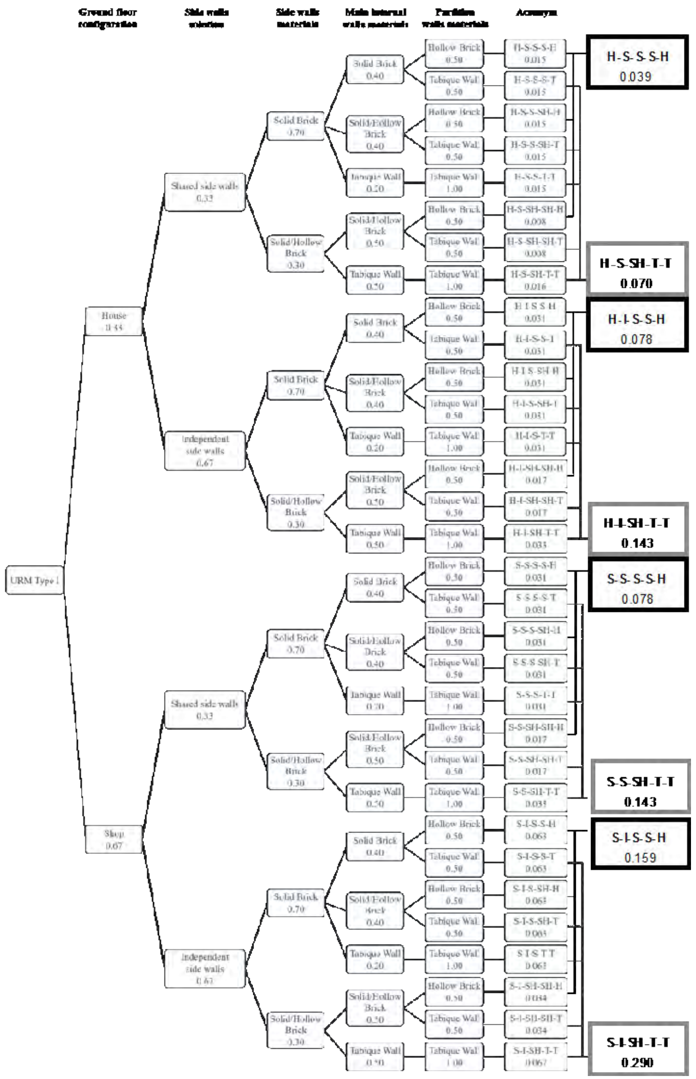
REF: Simoes et al. (2019) Fragility functions for tall URM buildings around early 20° century in Lisbon. Part 1 & 2. International Journal of Architectural Heritage, online.

The case study of GAIOLEIRO buildings in Lisbon between XIX and XX centuries

PUSHOVER ANALYSES TO IDENTIFY SIMILAR SEISMIC BEHAVIOUR



➡ **from 32 to 8 branches**

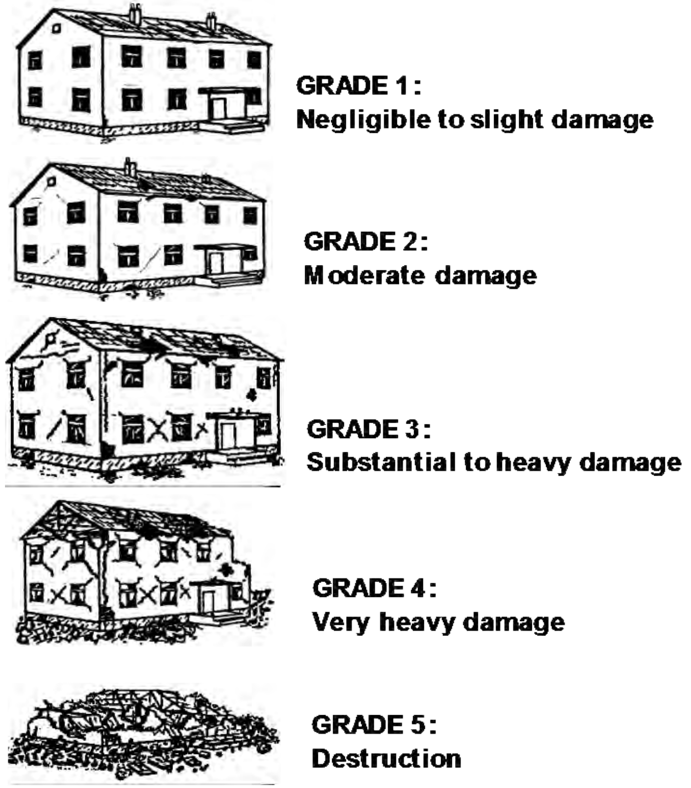


REF: Simoes et al. (2019) Fragility functions for tall URM buildings around early 20° century in Lisbon. Part 1 & 2. International Journal of Architectural Heritage, online.

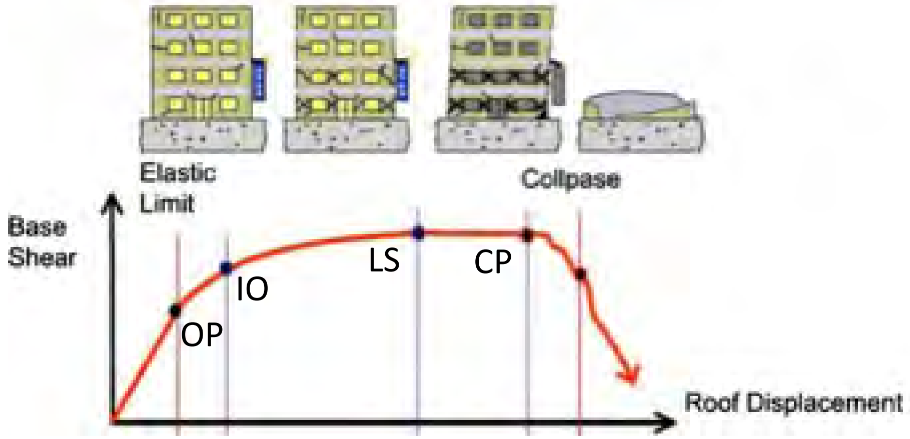
RISK ANALYSIS – *DAMAGE METRIC*

$$\lambda_l = \nu \int_{dm} P[L > l \mid DM = dm] \cdot \int_{edp} f_{DM|EDP}(dm) \cdot \int_{im} f_{EDP|IM}(edp) \cdot f_{IM}(im) \cdot d(im) \cdot d(edp) \cdot d(dm)$$

DAMAGE LEVEL ACCORDING TO EMS 98 (Grunthal 1998)



- Usually, the damage is described in **DISCRETE** terms rather than as a CONTINOUS variable (→ integral becomes a sum)
- The **5 grades** adopted by the EMS 98 scale may be used (the first four are similar to the LSs of seismic codes)
- **DAMAGE LEVELS** are correlated to the EDPs (Engineering Demand Parameters), representative of structural response, and are usually related to PERFORMANCE LEVELS



RISK ANALYSIS – *FRAGILITY*

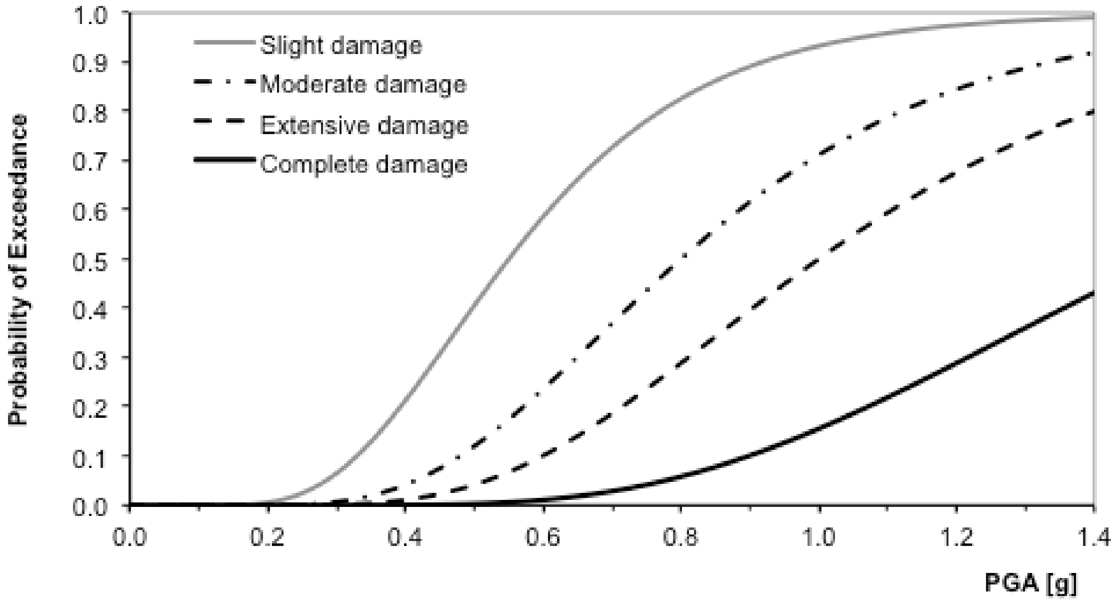
$$\lambda_l = \nu \int_{dm} P[L > l \mid DM = dm] \cdot \int_{edp} f_{DM|EDP}(dm) \cdot \int_{im} f_{EDP|IM}(edp) \cdot f_{IM}(im) \cdot d(im) \cdot d(edp) \cdot d(dm)$$

If the damage is described by a CONTINOUS variable

$$\int_{im} f_{DM|IM}(dm)\, f_{IM}(im)\, d(im)$$

DISCRETE damage variable

$$f_{DM|IM}(dm) = P[dm \geq DM|im] = P[IM_{DM} < im] = \Phi\left[\frac{log\left(\frac{im}{IM_{DM}}\right)}{\beta_{DM}}\right]$$



lognormal fragility curves

FRAGILITY CURVES

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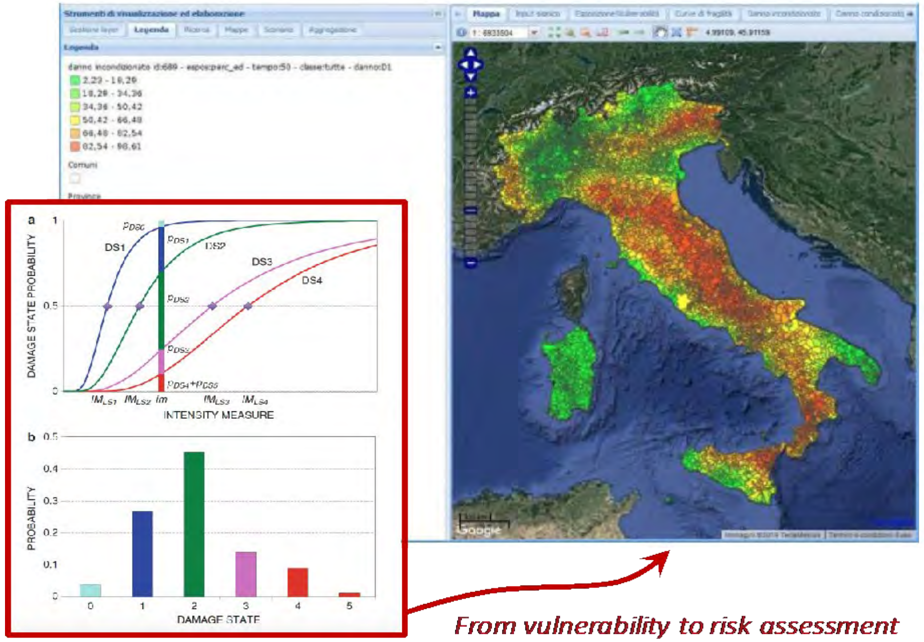


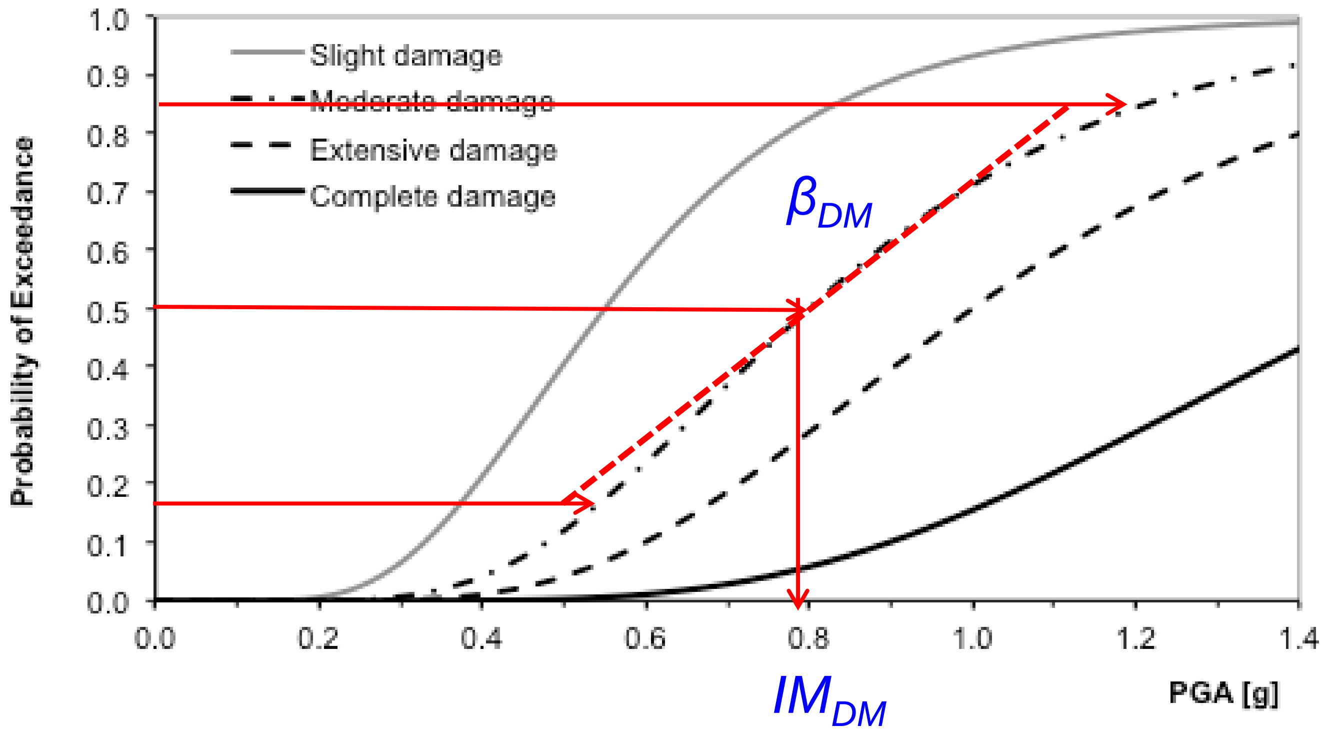
From vulnerability to risk assessment

FRAGILITY FUNCTIONS

The fragility function of a building class gives the probability that a Damage Levels (DM) is reached given a value *im* of the Intensity Measure (IM) :

$$P[dm \geq DM|im] = P[IM_{DM} < im] = \Phi\left[\frac{log\left(\frac{im}{IM_{DM}}\right)}{\beta_{DM}}\right]$$

where: IM_{DM} is the median value of the lognormal distribution of the intensity measure for which the DM is attained and β_{DM} is the dispersion.



For IM different possible choice

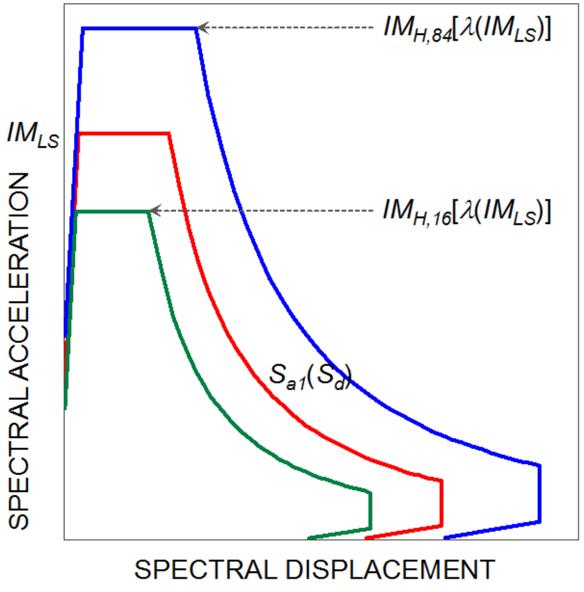
the more IM is effective and the less is β

$$\beta_{DM} = \frac{1}{2}[log(IM_{84}) - log(IM_{16})]$$

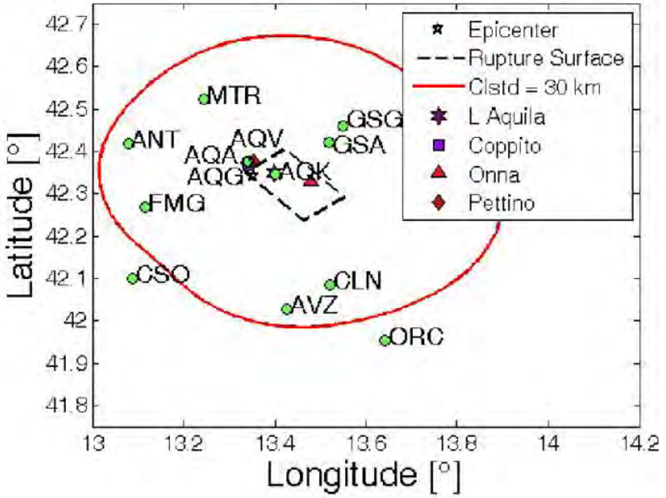
the more the building class is homogenous and the less is β

FRAGILITY FUNCTIONS – *involved uncertainties*

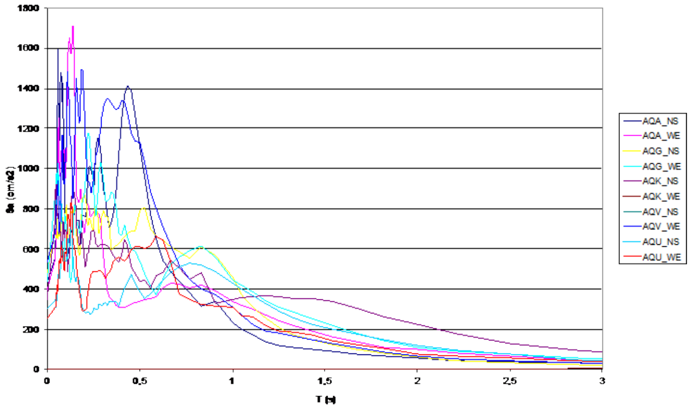
$$\beta_{DM} = \sqrt{\beta^2_{records} + \beta^2_{capacity} + \beta^2_{damage\ level}}$$



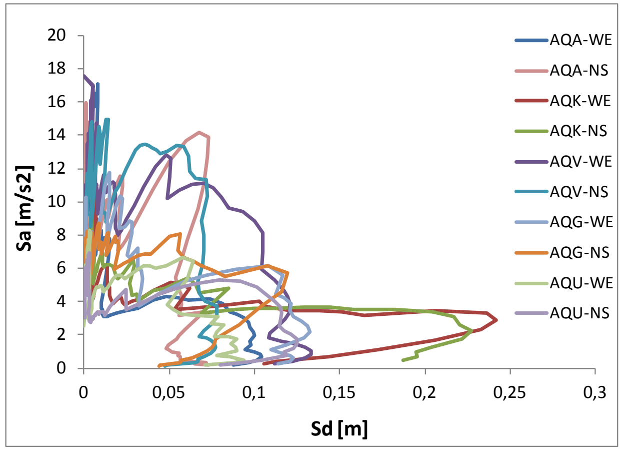
L'Aquila 2009 event – recordings from the 10 available stations on the area

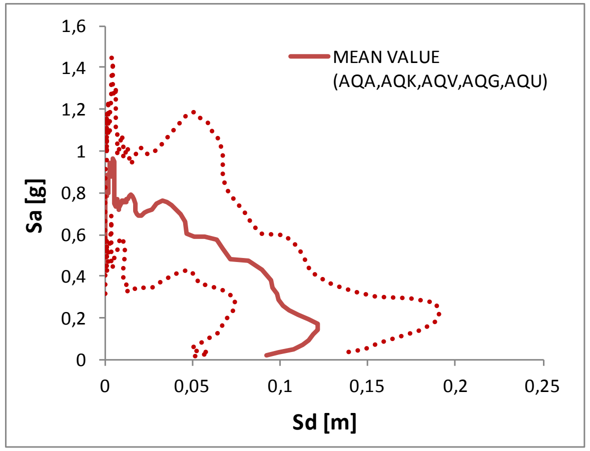


Sa- T acceleration spectrum format



ADRS acceleration spectrum format



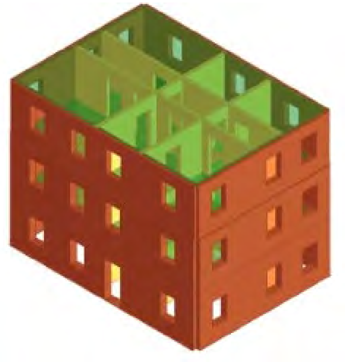


FRAGILITY FUNCTIONS – *involved uncertainties*

$$\beta_{DM} = \sqrt{\beta^2_{records} + \beta^2_{capacity} + \beta^2_{damage\ level}}$$

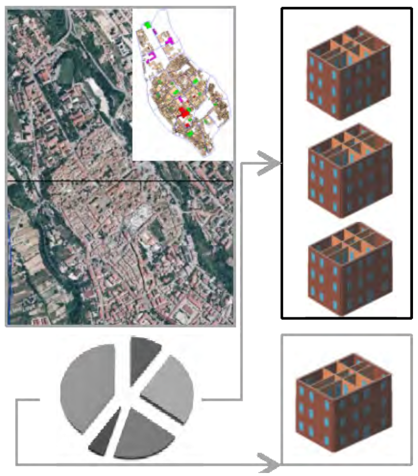
SINGLE BUILDING

Single structure at a given site

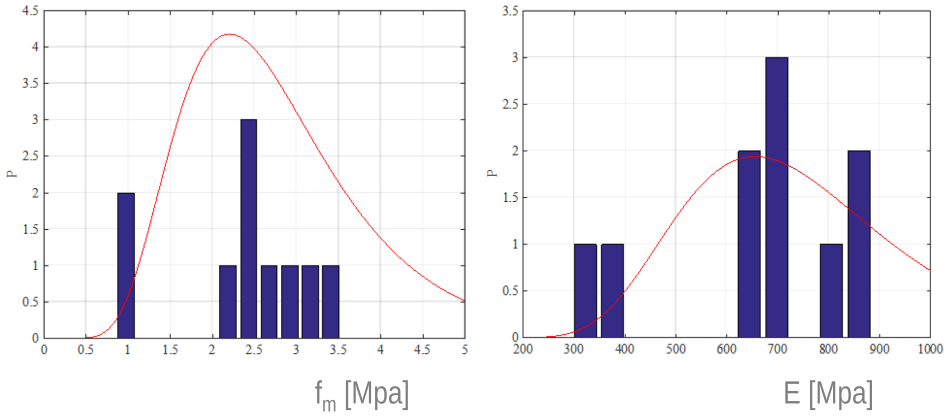


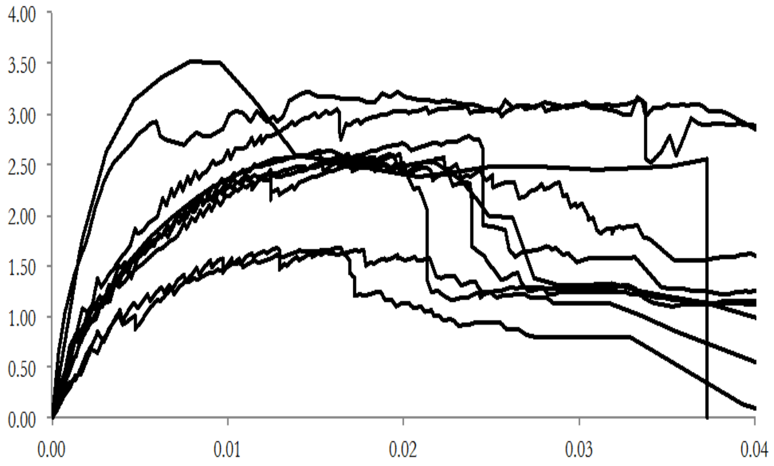
REGIONAL SCALE

Classes of buildings with a similar seismic behavior



Variability of parameters (mechanical, geometric, …) characteristic of the WHOLE CLASS OF BUILDINGS

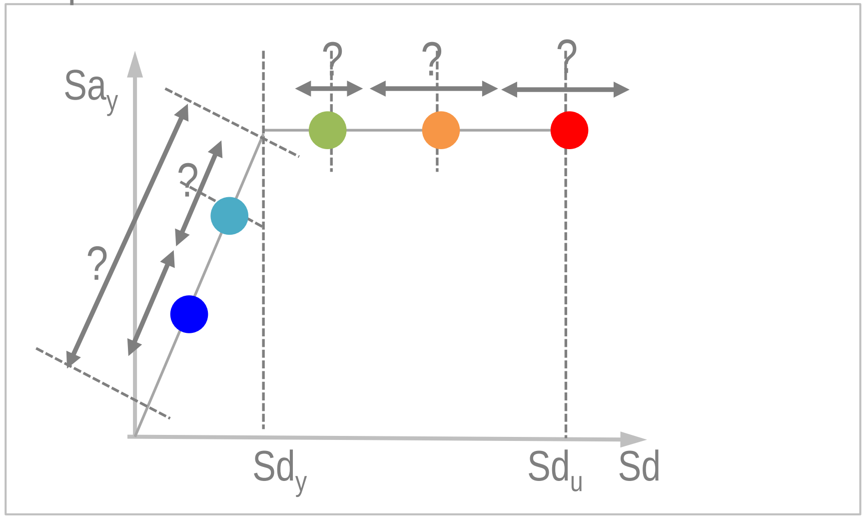


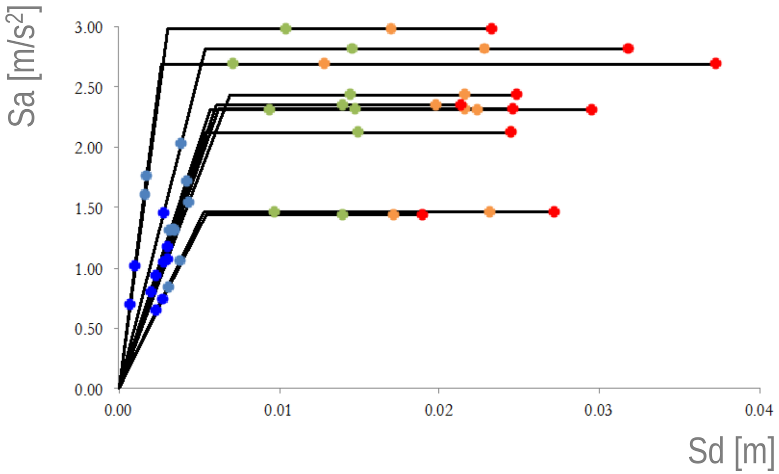


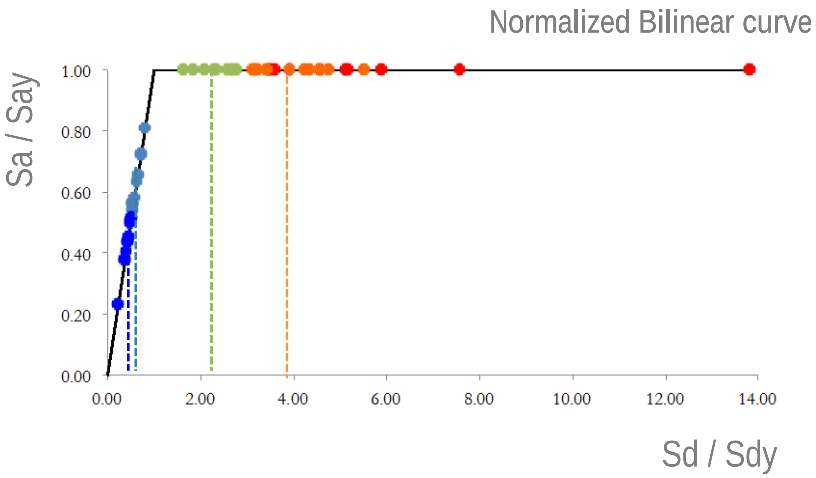
FRAGILITY FUNCTIONS – *involved uncertainties*

$$\beta_{DM} = \sqrt{\beta^2_{records} + \beta^2_{capacity} + \beta^2_{damage\ level}}$$

Simplified Bilinear Curve

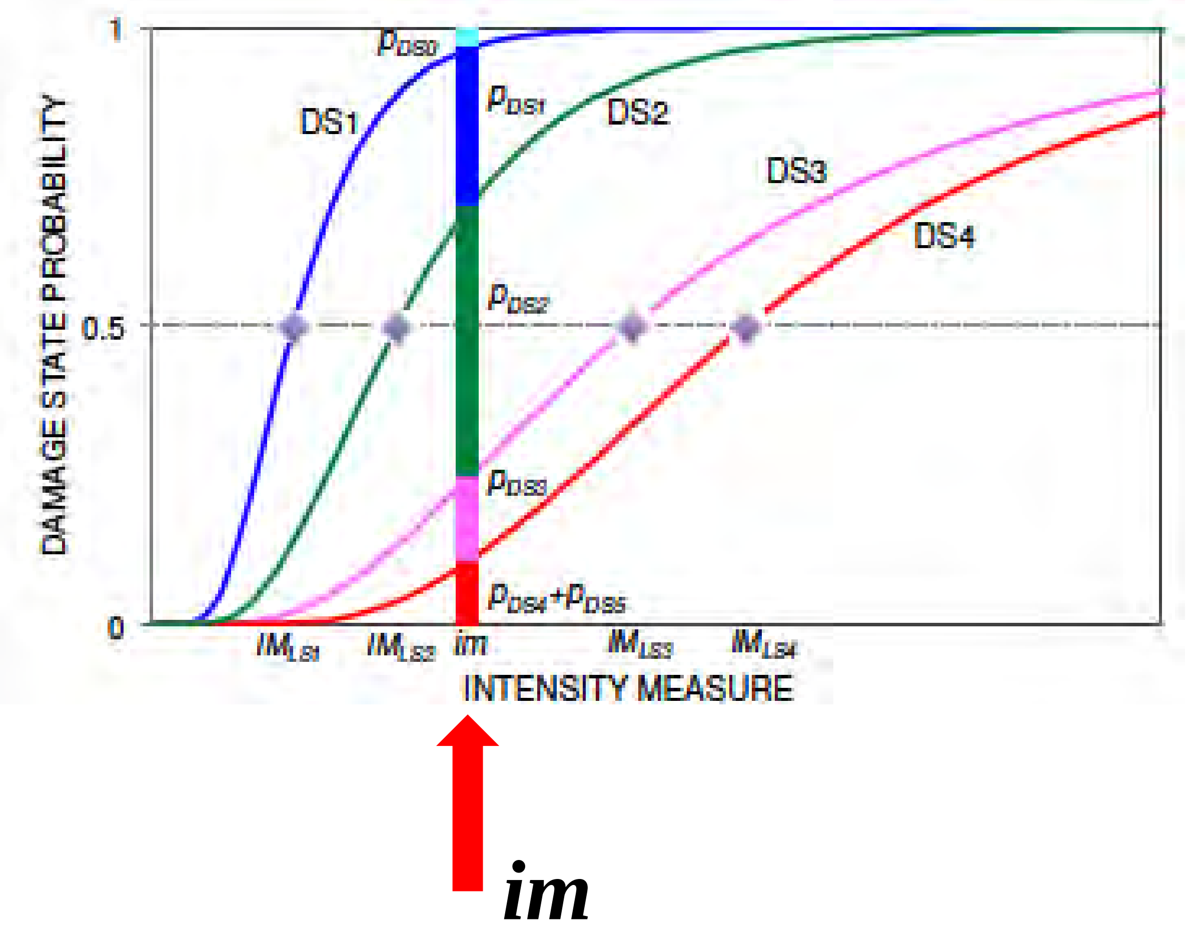




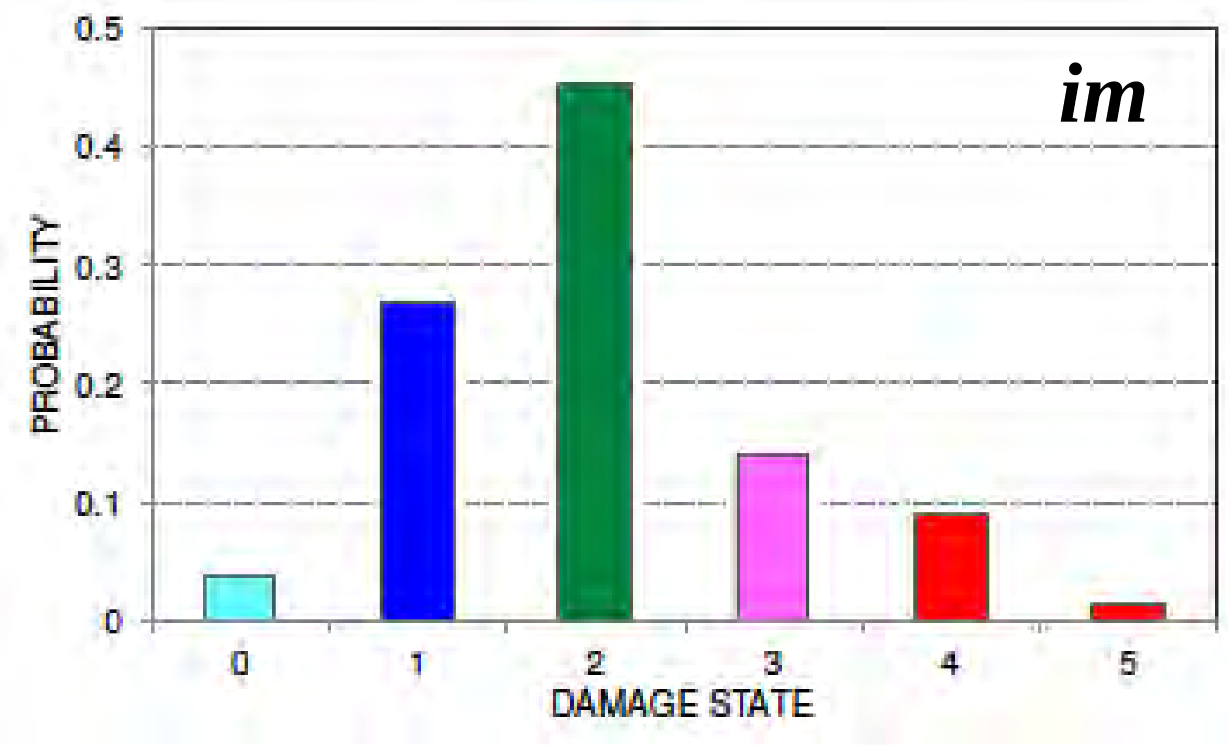


negligible DL1 DL2 DL3 DL4

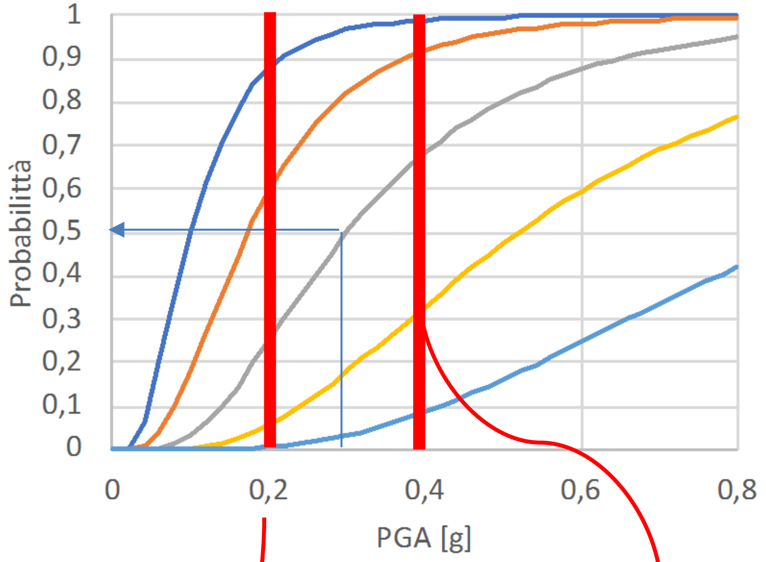
FRAGILITY OF A BUILDING STOCK
is represented by a set of curves that may be defined by the IM_{Dk}, the dispersion β and the distance between damage levels (ductility)



DAMAGE LEVEL HISTOGRAM
(when a discrete IM is used, like the macroseismic intensity, the vulnerability is defined by a DPM – Damage Probability Matrix



FRAGILITY FUNCTIONS – influence of β

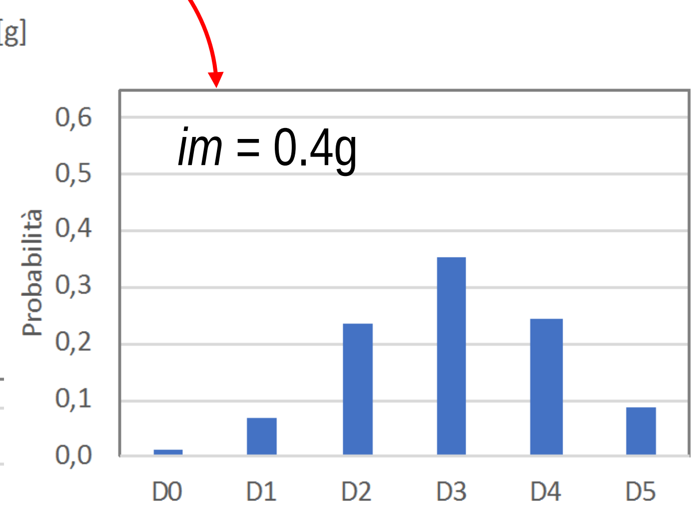


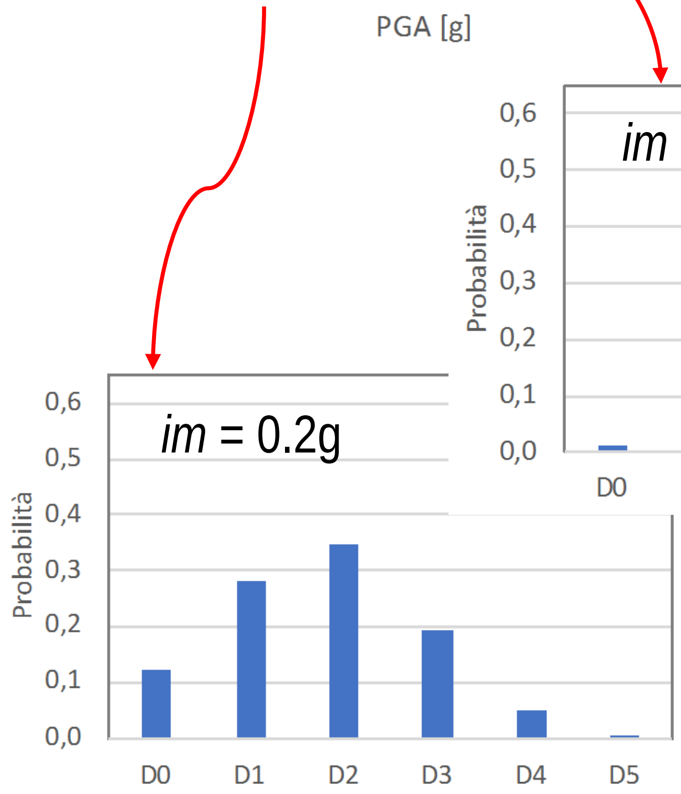
$IM_{D3} = 0.3g$

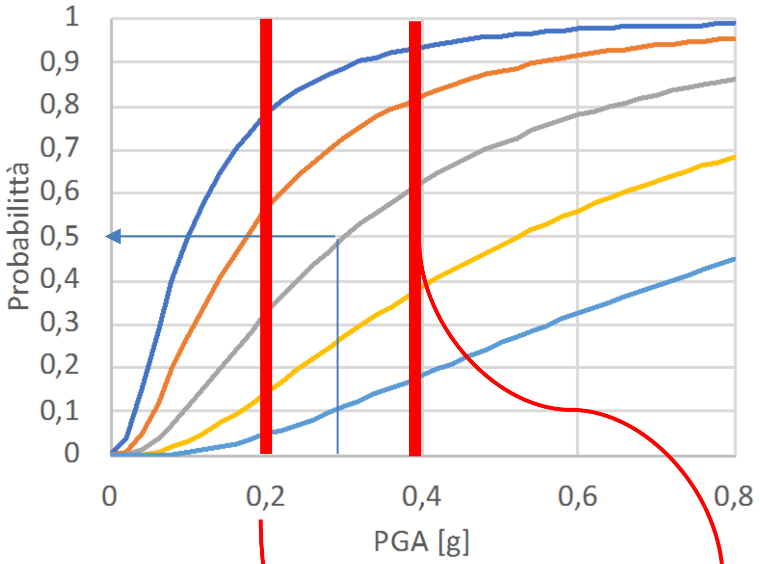
$\beta_{D3} = 0.6$

$IM_{D1} = 0.1g$

$IM_{D5} = 0.9g$





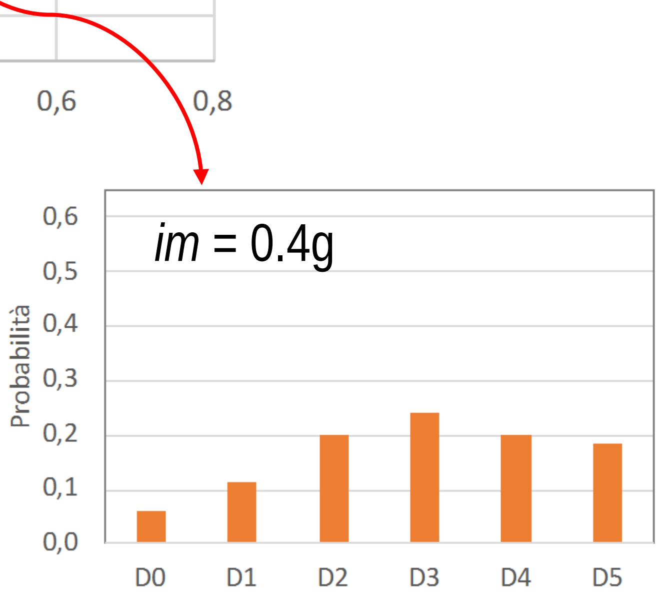


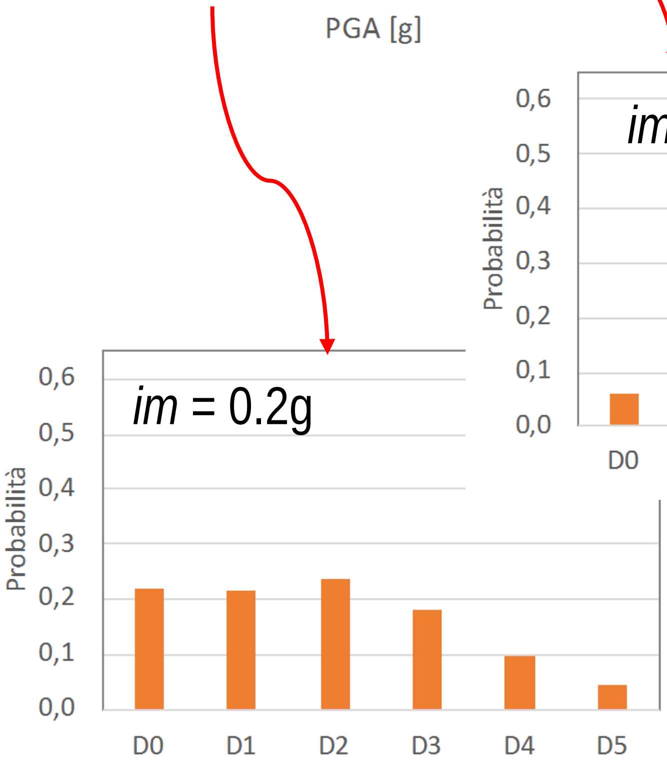
$IM_{D3} = 0.3g$

$\beta_{D3} = 0.9$

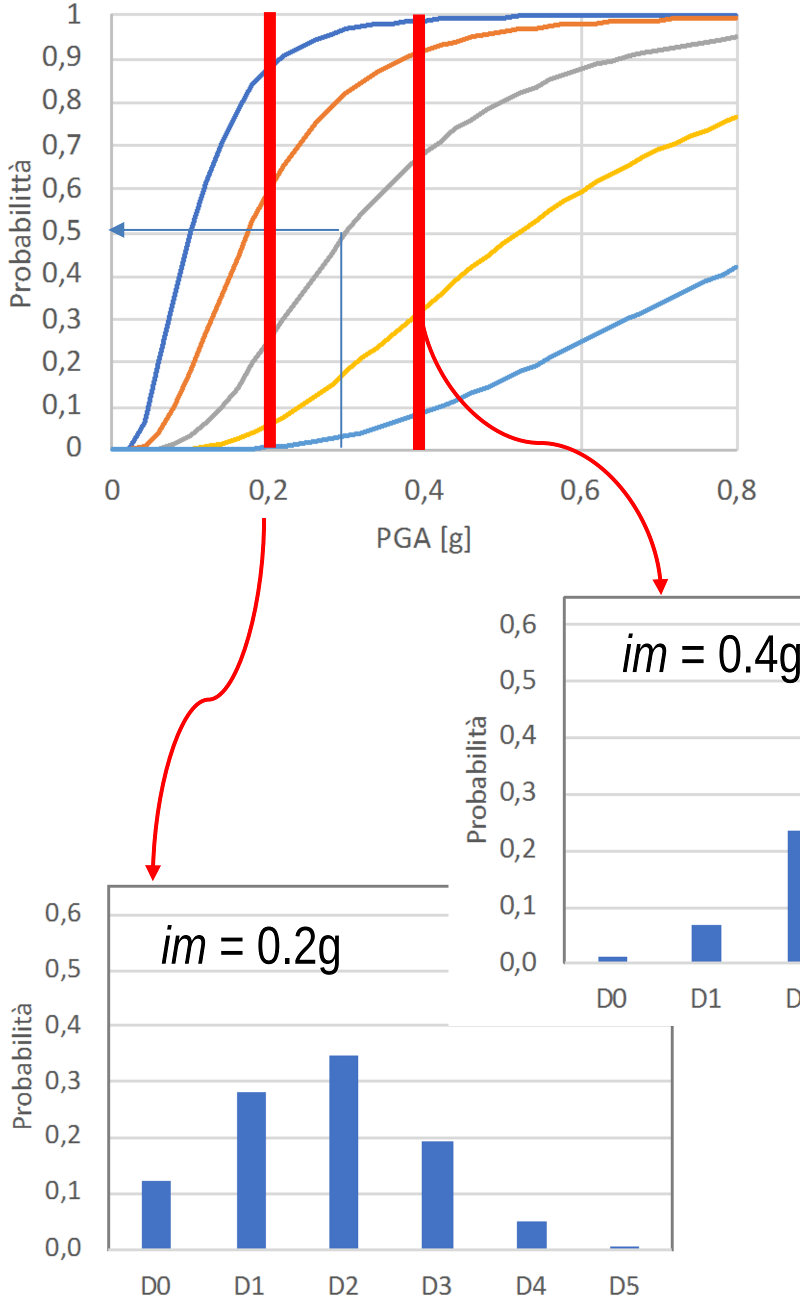
$IM_{D1} = 0.1g$

$IM_{D5} = 0.9g$





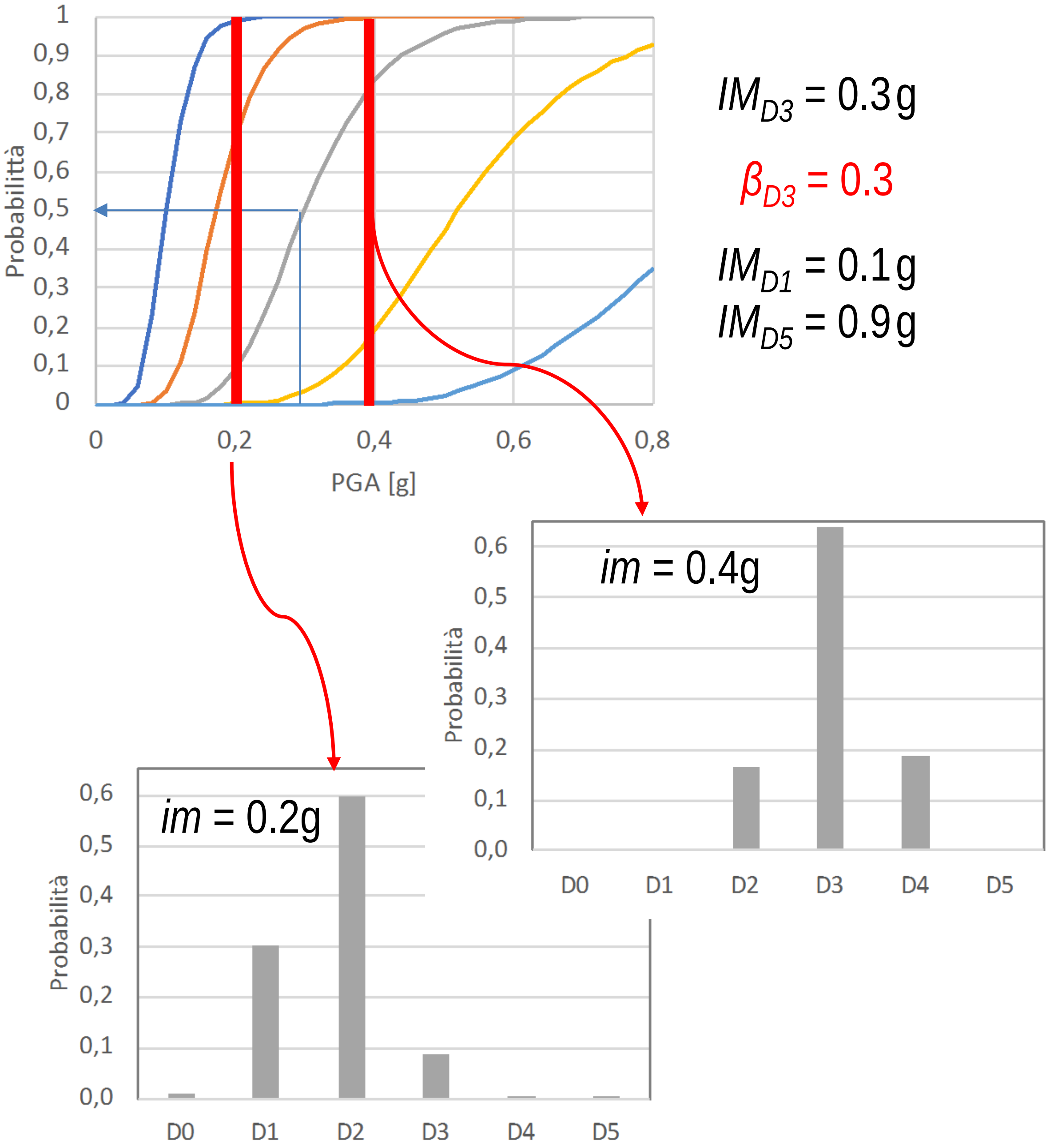
FRAGILITY FUNCTIONS – influence of β



IM_{D3} = 0.3g

β_{D3} = 0.6

IM_{D1} = 0.1g
IM_{D5} = 0.9g

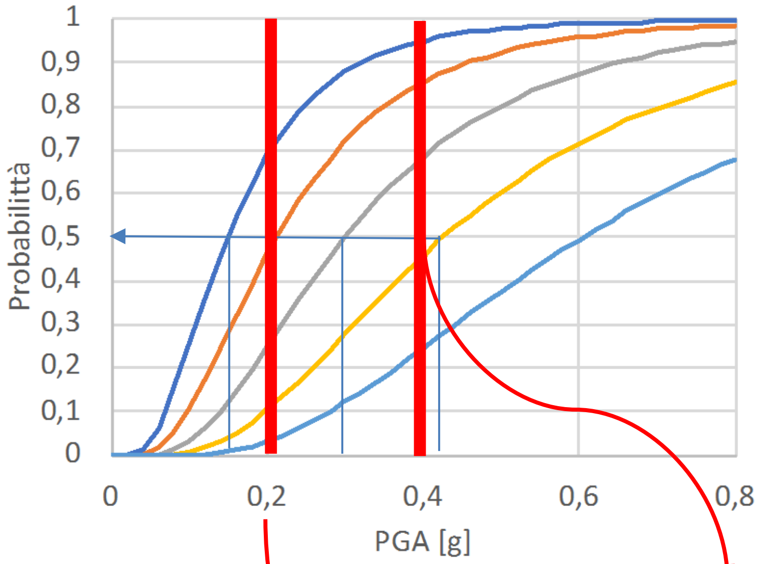


IM_{D3} = 0.3g

β_{D3} = 0.3

IM_{D1} = 0.1g
IM_{D5} = 0.9g

FRAGILITY FUNCTIONS – influence of the ductility

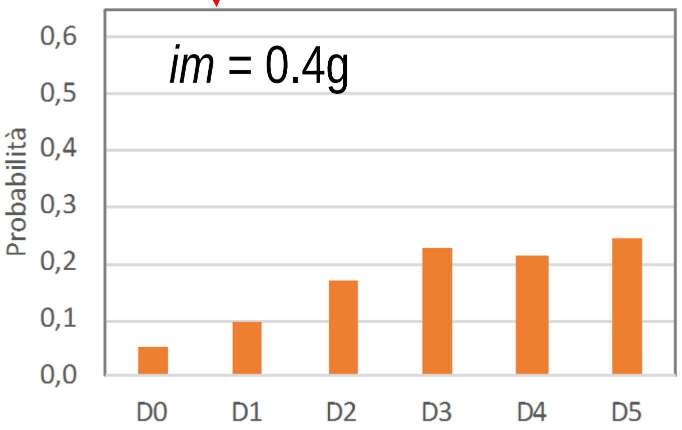


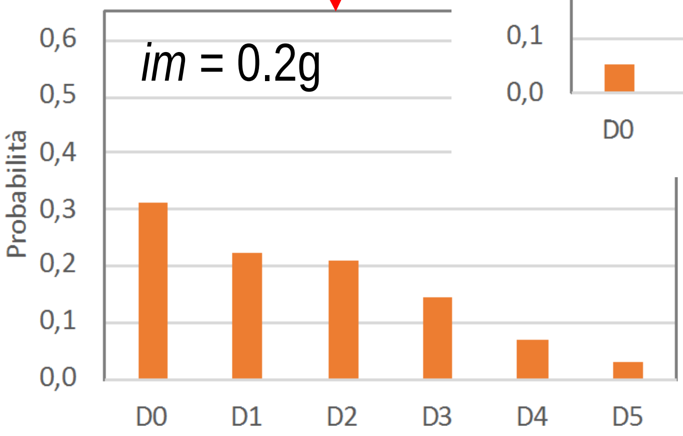
$IM_{D3} = 0.3g$

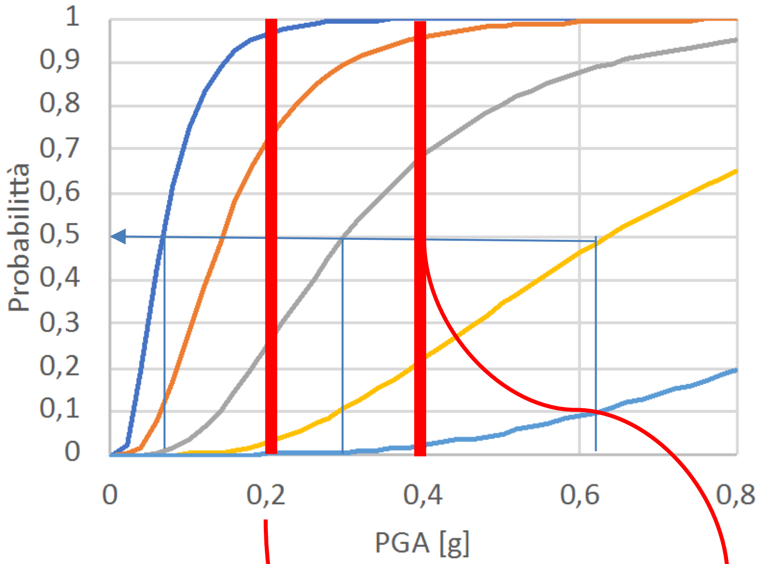
$IM_{D1} = 0.15g$

$IM_{D4} = 0.43g$

$\beta_{D3} = 0.6$





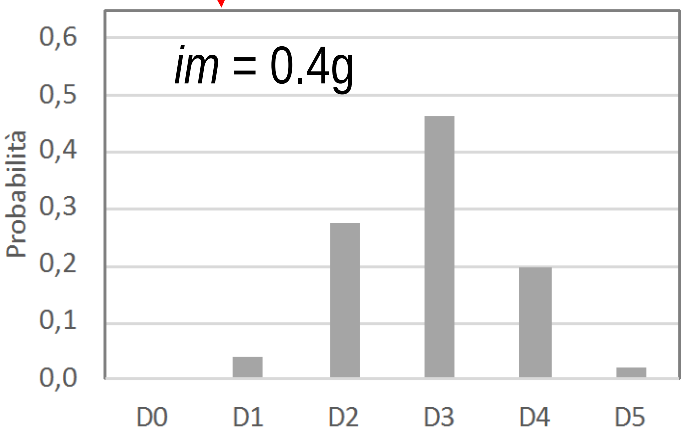


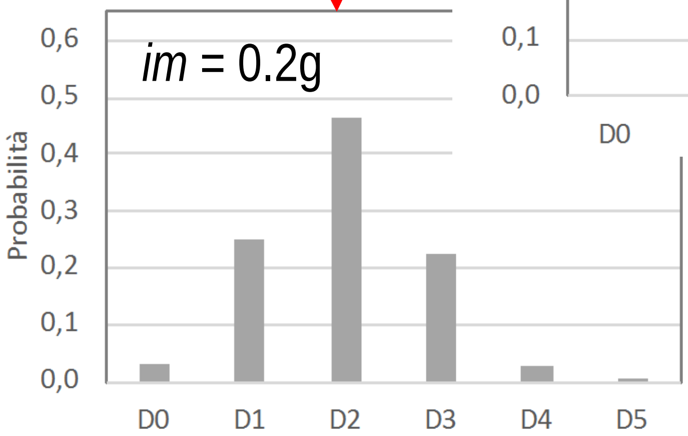
$IM_{D3} = 0.3g$

$IM_{D1} = 0.07g$

$IM_{D4} = 0.64g$

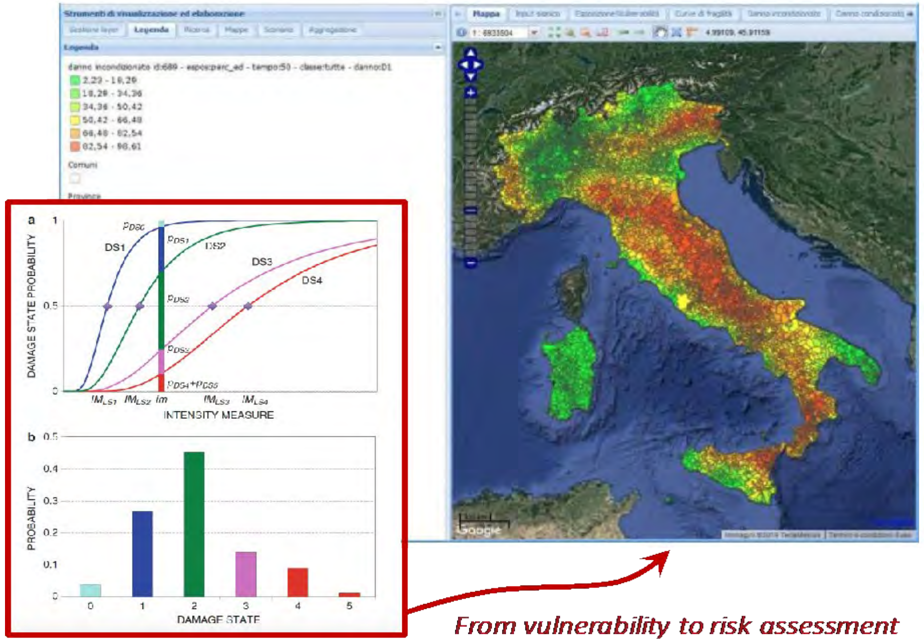
$\beta_{D3} = 0.6$





FRAGILITY CURVES

What do they represent?	Vulnerability as a component of seismic risk and loss assessment
What do they depend on?	Involved dispersions & influence on results of seismic risk analysis
How are they obtained?	**Overview of methods & focus on macroseismic and empirical ones**
How can they be used?	Practical issues & application to the Italian seismic risk assessment



FRAGILITY CURVES: *how are they obtained?*

- ❑ **Empirical / Observational**
- ❑ **Expertise-based / Heuristic**
- ❑ **Mechanical-based**
- ❑ **Hybrid methods**

Critical issues on:

- the incompleteness/reliability of empirical data and the definition of a robust damage metrics (Empirical/Observational)
- the representativeness of archetype buildings and the need of calibration & validation (Mechanical-based)
- ……

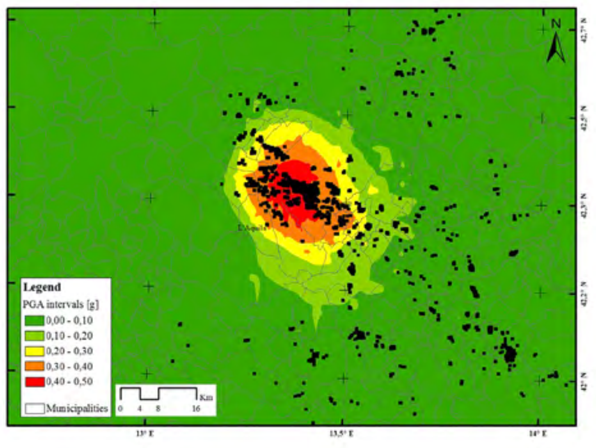
References for the classification of methods:
- Rossetto T., D’Ayala D., Ioannou I., Meslem A. (2014) Evaluation of existing fragility curves ,
- Chapter 3 In SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk: Elements at Seismic Risk, Geotechnical, Geological and Earthquake Engineering 27 pp. 420

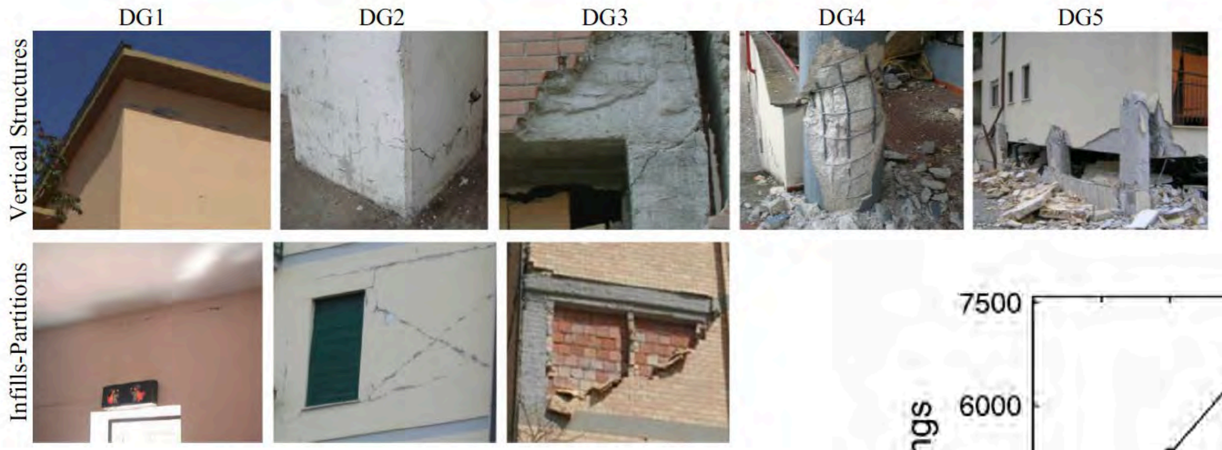
❑ Empirical / Observational

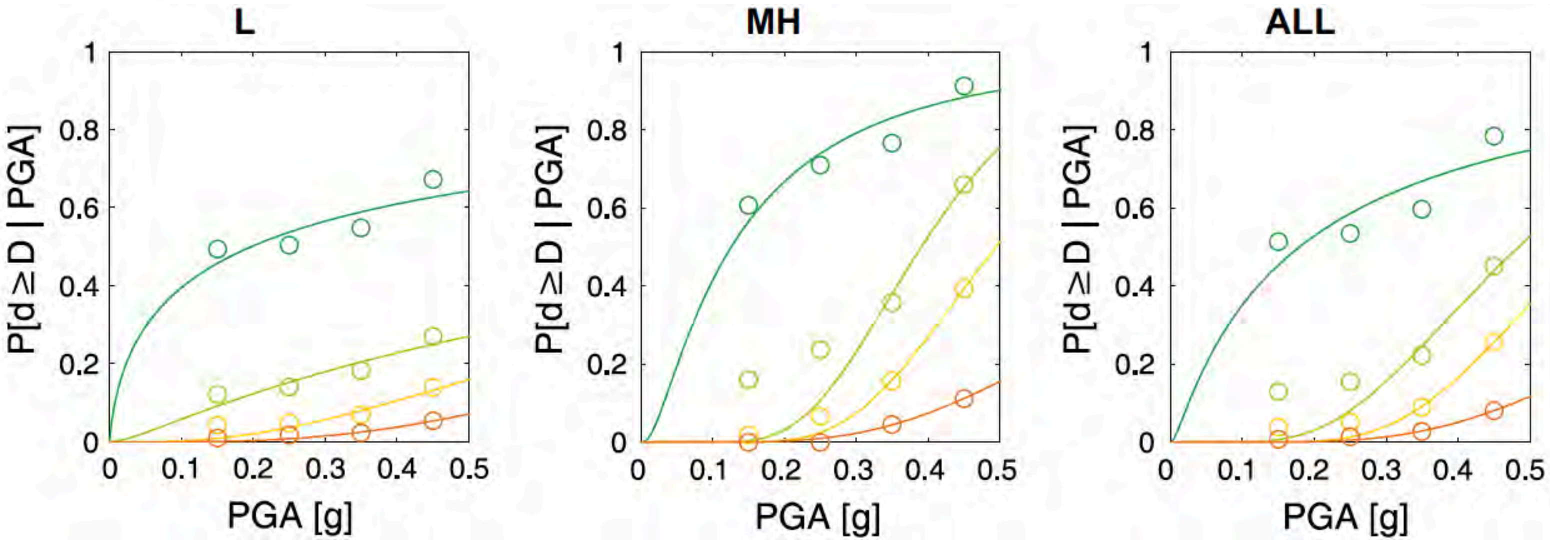
- ✓ Derived from observed damage, by a direct correlation with the intensity measure
- ✓ Empirical data are usually referred to macroseismic intensity, which is not an instrumental measure, but recently fragility curves are also derived directly in terms of PGA, thanks to the use of shake-maps
- ✓ Empirical data should represent the actual seismic behavior of buildings and can be very useful also for the validation of the others models
- ✓ Vulnerability is dependent on the local structural features of buildings, so the extrapolation of empirical fragility functions to other areas is questionable, in particular for traditional masonry buildings

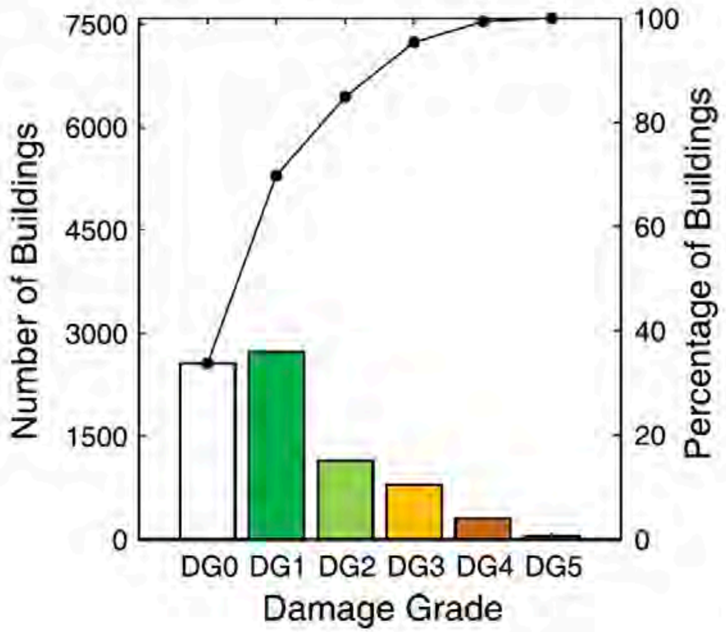
❑ Empirical / Observational – *Examples for RC structures*

L'AQUILA 2009 earthquake: derivation of fragility curves for sub-typologies





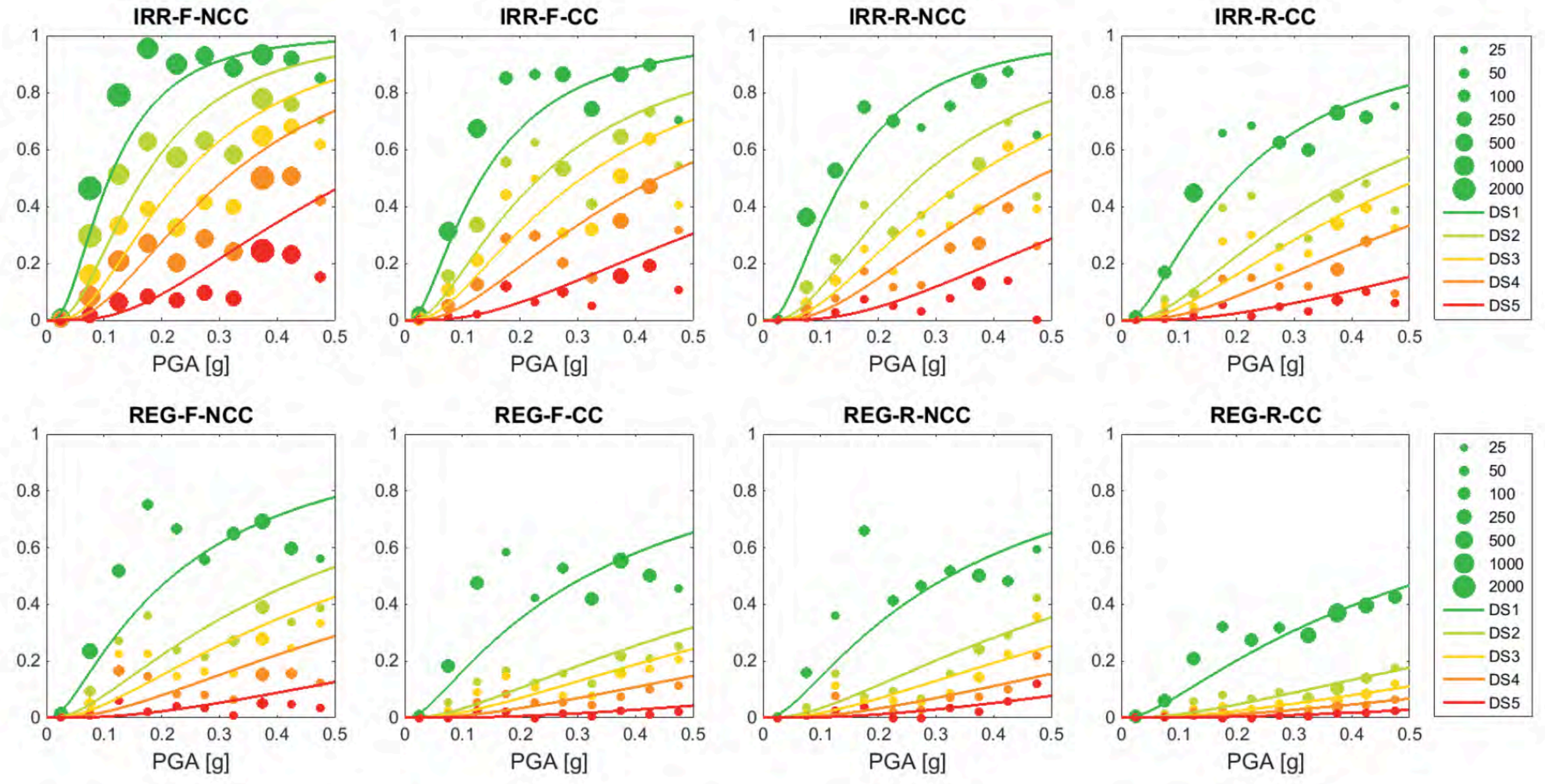




REF: Del Gaudio et al. (2017) Empirical fragility curves from damage data on RC buildings after the 2009 L'Aquila earthquake, Bull Earthqyake Eng 15: 1425-1450

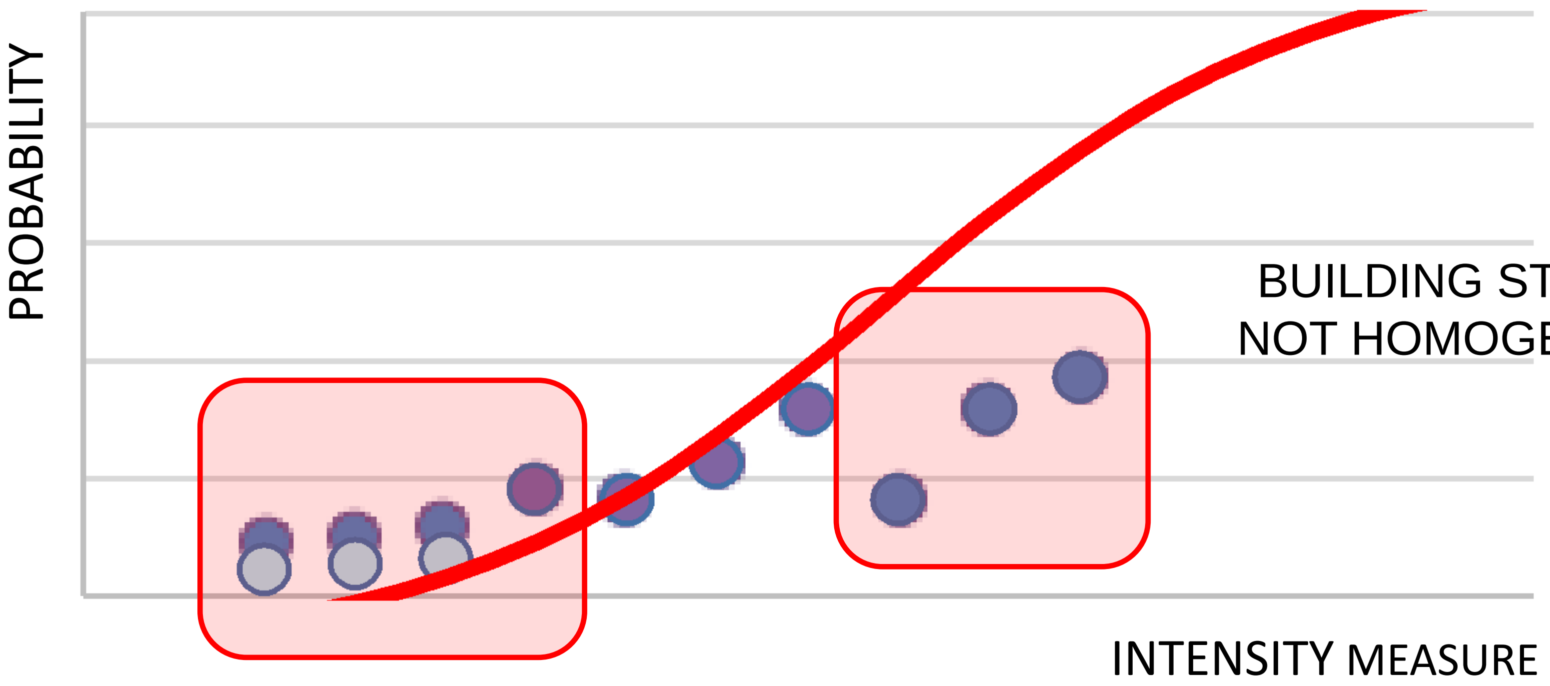
❑ Empirical / Observational – *Examples for URM structures*

L'AQUILA 2009 earthquake: derivation of fragility curves for sub-typologies



REF: Rosti et al. (2019) Derivazione di curve di fragilità empiriche per edifici residenziali in muratura, ANIDIS Conference, Ascoli Piceno 2019.

❑ Empirical / Observational – *some critical issues*



BUILDING STOCK IS
NOT HOMOGENEOUS

completeness of data for low intensity level

NOT ALL BUILDINGS ARE SURVEYED IN
THE AREA FAR TO THE EPICENTER

❑ Mechanical-based

Incresing computational effort

- Analytical simplified
- Numerical by nonlinear static analyses
- Numerical by nonlinear dynamic analyses

key features of the building class (structural system, geometry, material properties) are quantified (median values, dispersion)

archetype buildings are identified and modelled in detail; dispersion of parameters are related to the whole building stock and not to the uncertainties of the single building

❑ Expertise-based / Heuristic – Expert elicitation

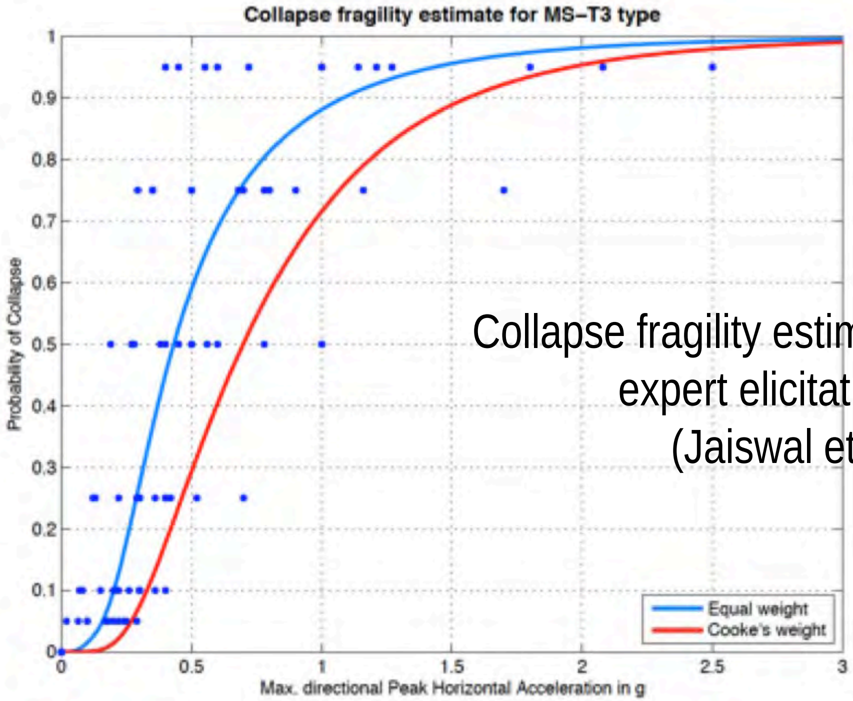
- ✓ Expert elicitation is used to assess vulnerability of building types, if no data is available and structural analysis is not feasible; one or more experts can offer an opinion on the level of demand at which damage is likely to occur.
- ✓ To process expert judgments the Delphi method (Dalkey, 1969) or the Cooke's method (Cooke, 1991) can be used.

Lisbon workshop, September 23, 2012 (Jaiswal et al 2013)

Organized by U.S. Geological Survey's Prompt Assessment for Global Earthquakes Response (PAGER) and Global Earthquake Model (GEM) -

Expert solicitation to develop DPM for 20 building classes, after checking the reliability of experts by seed questions

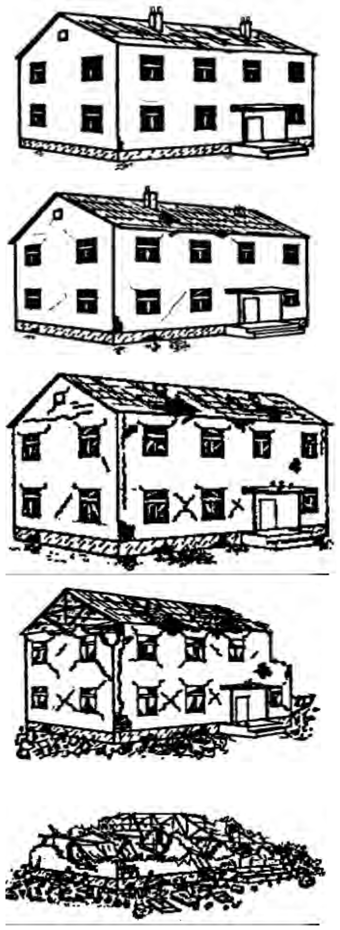
Experts responding to target questions at the workshop



Collapse fragility estimates obtained using expert elicitation process.
(Jaiswal et al 2013)

- Classifiable as **Expertise-based / Heuristic**
- Derived from the **European Macroseismic Scale** (Grunthal 1998), which defines six vulnerability classes (from A to F) and various building types (seven of them related to masonry buildings).

EMS 98



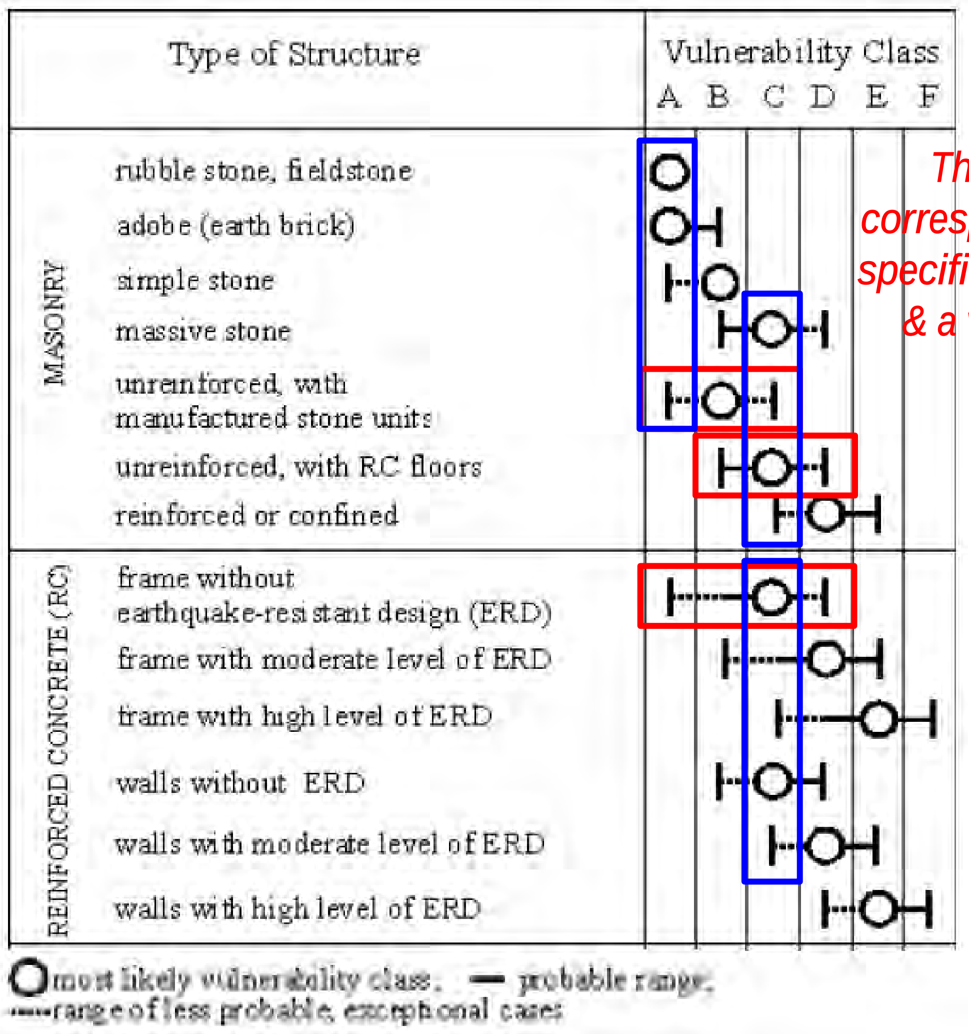
GRADE 1: Negligible to slight damage

GRADE 2: Moderate damage

GRADE 3: Substantial to heavy damage

GRADE 4: Very heavy damage

GRADE 5: Destruction



There isn't a direct correspondance between a specific structural typology & a vulnerability class

MACROSEISMIC MODEL – Lagomarsino & Giovinazzi 2006

- ❑ For each building class, the linguistic definitions of EMS98 may be translated in quantitative terms, by the fuzzy set theory, and an incomplete **Damage Probability Matrix** (DPM) is obtained.
- ❑ The completion is made by using the **binomial probability distribution**.

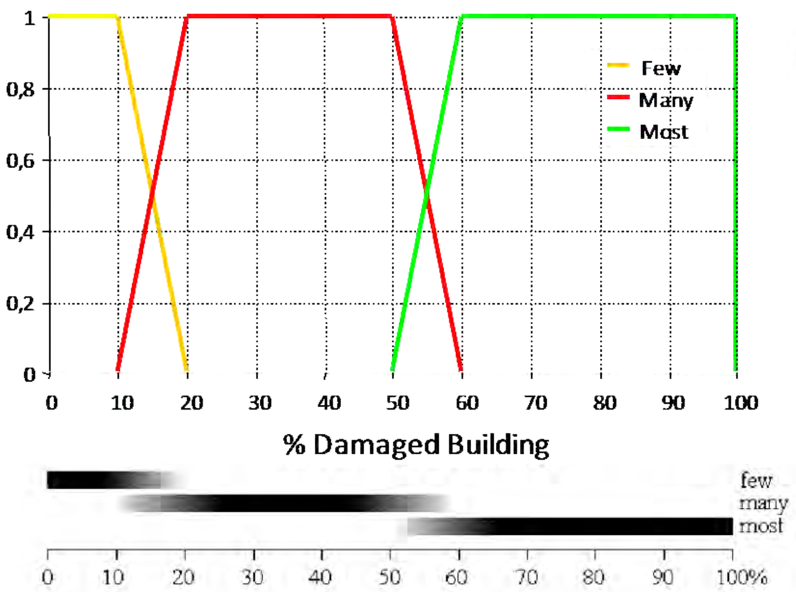
quantified → *completed* →

EMS 98

D_k/I	$k=0$	$k=1$ (negligible to slight)	$k=2$ (moderate)	$k=3$ (substantial to heavy)	$k=4$ (very heavy)	$k=5$ (destruction)
5		Few A or B				
6		Many A or B, Few C	Few A or B			
7			Many B, Few C	Many A, Few B	Few A	
8			Many C, Few D	Many B, Few C	Many A, Few B	Few A
9			Many D, Few E	Many C, Few D	Many B, Few C	Many A, Few B
10			Many E, Few F	Many D, Few E	Many C, Few D	Most A, Many B, Few C
11			Many F	Many E, Few F	Most C, Many D, Few E	Most B, Many C, Few D
12						All A or B, Nearly All C, Most D or E or F

CLASS B						
I	D_0	D_1	D_2	D_3	D_4	D_5
V	All-Few	**Few**	None	None	None	None
VI	Many + 7/3Few	**Many**	**Few**	None	None	None
VII	7/3Few	Many	**Many**	**Few**	None	None
VIII	1/3Few	2Few	Many	**Many**	**Few**	None
IX	None	1/3Few	2Few	Many	**Many**	**Few**
X	None	None	1/3Few	2Few	Many+ Few	**Many**
XI	None	None	None	Nearly Few	8/3Few	**Most**
XII	None	None	None	None	None	**All**

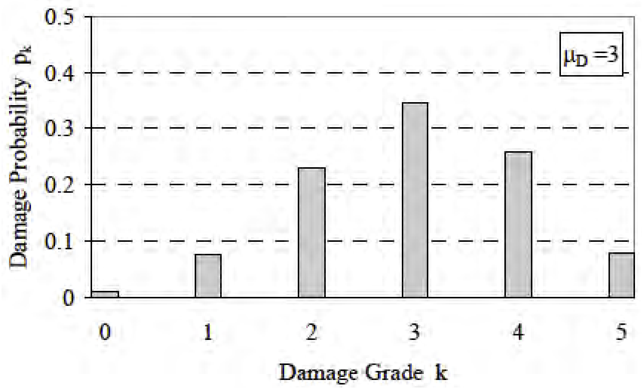
FUZZY SET THEORY



BINOMIAL PROBABILITY DISTRIBUTION

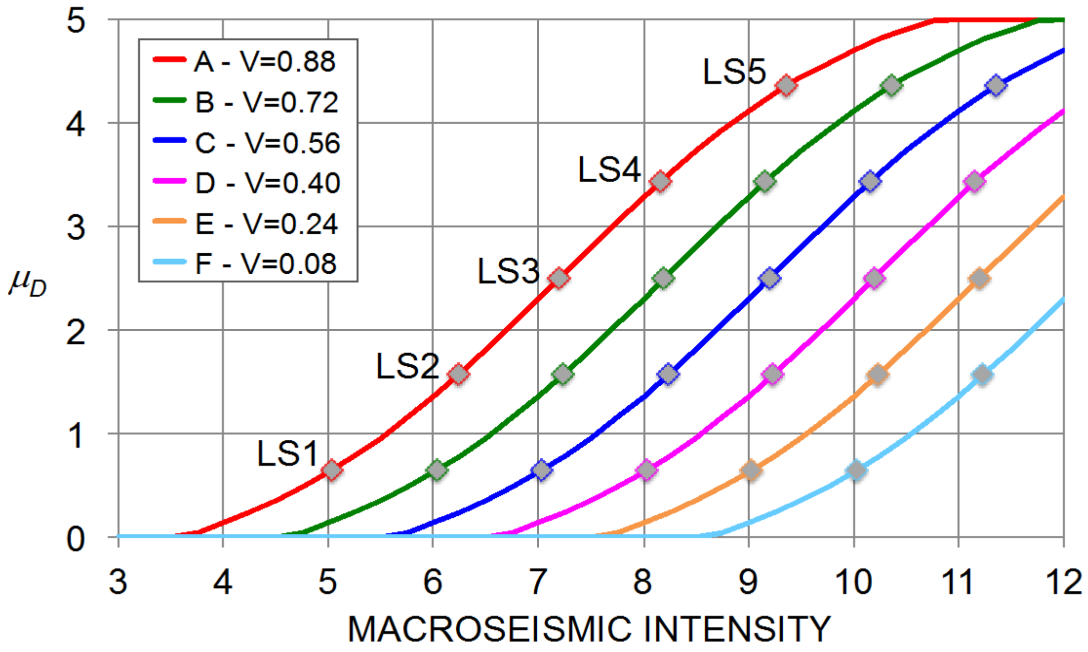
$$\text{PMF: } p_k = \frac{5!}{k!\,(5-k)!}\left(\frac{\mu_D}{5}\right)^k\left(1-\frac{\mu_D}{5}\right)^{5-k}$$

μ_D mean damage of distribution



MACROSEISMIC MODEL – Lagomarsino & Giovinazzi 2006

- For each building class, the linguistic definitions of EMS98 may be translated in quantitative terms, by the fuzzy set theory, and an incomplete **Damage Probability Matrix** (DPM) is obtained.
- The completion is made by using the **binomial probability distribution**.
- The vulnerability is analitycally expressed by a **curve** (Bernardini et al. 2011), which gives the mean damage μ_D as a function of the macroseismic intensity I



$$\mu_D = 2.5 + 3\tanh\left(\frac{I + 6.25V - 12.7}{Q}\right) \quad (0 \le \mu_D \le 5)$$

The curve is defined by two parameters representative of the seismic behavior of a group of homogeneous buildings: the vulnerability index **V** and the ductility index **Q**

Class	A	B	C	D	E
V	0.9	0.74	0.58	0.42	0.26

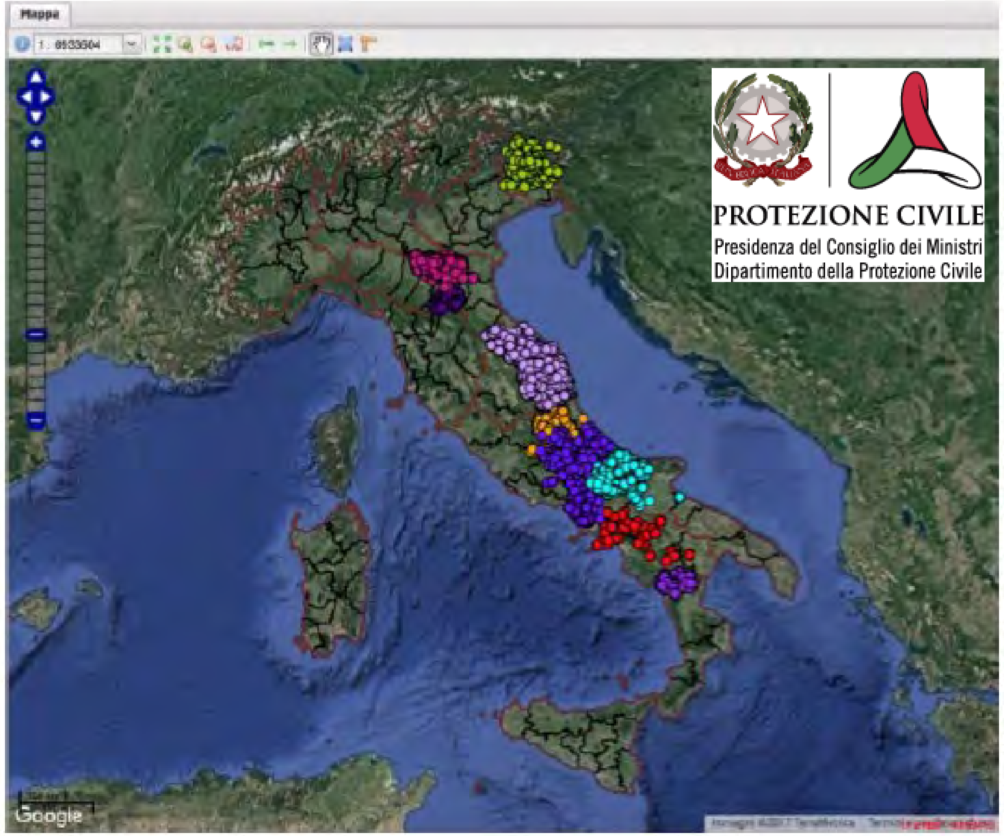
Q assumed costant and equal to 2.3 for residential buildings

Calibration of the macroseismic model by D.A.D.O. Database

The macroseismic model has been recently **calibrated by the observed damage**, collected after many earthquakes in Italy in the database Da.D.O. developed by the Italian Department of Civil Protection (DPC)

Evento	Anno	Record	Vers.scheda
Friuli '76	1976	41.852	Friuli '76
Irpinia '80	1980	38.079	Irpinia '80
Abruzzo '84	1984	51.817	Abruzzo '84
Umbria Marche '97	1997	48.525	AeDES 09/97
Pollino '98	1998	17.442	AeDES 06/98
Molise Puglia 2002	2002	24.141	AeDES 05/2000
Emilia 2003	2003	1011	AeDES 05/2000
L'aquila 2009	2009	74.049	AeDES 06/2008
Emilia 2012	2012	22.554	AeDES 06/2008
Totale		**319.470**	

DaDO database: more than 300000 buildings surveyed after 9 different earthquakes in Italy since Friuli 1976



REF: Dolce M., Speranza E., Giordano F., Borzi B., Bocchi F., Conte C., Di Meo A., Faravelli M., Pascale V. (2019)Observed damage database of past Italian earthqyakes: the Da.D.O. Webgis. Bollettino di Geofisica Teorica e Applicata 60 (2) 141-164.

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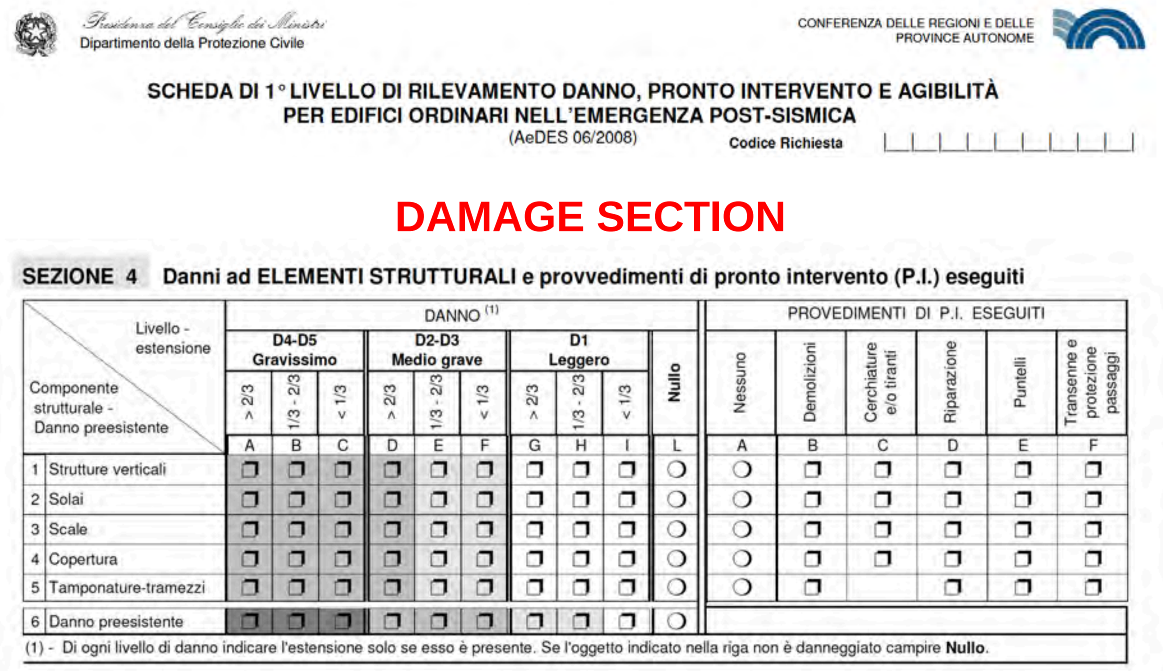
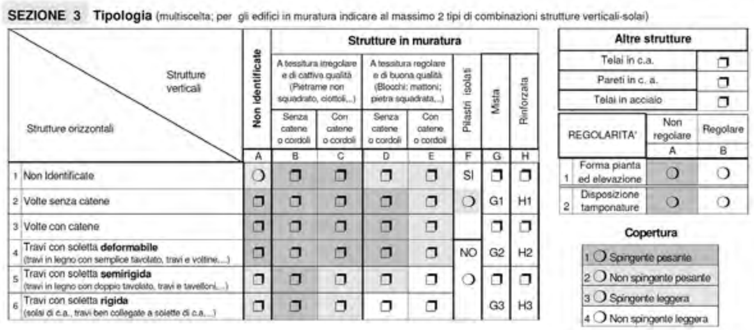


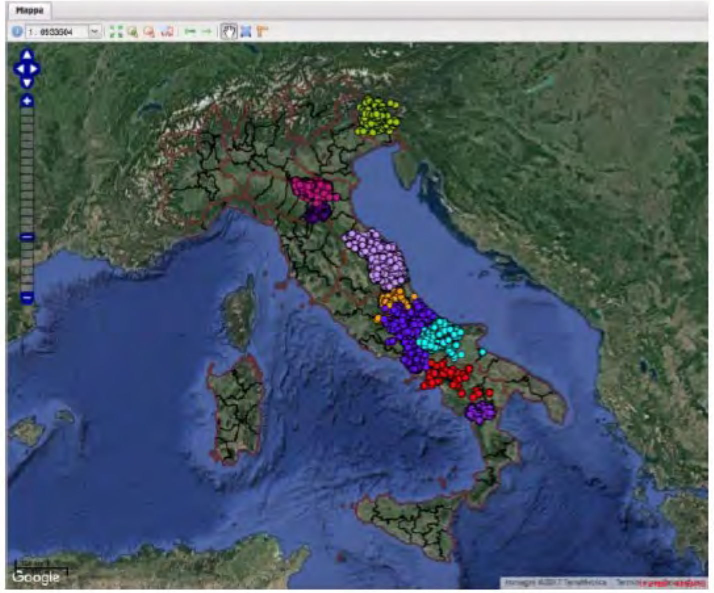
TYPOLOGICAL SECTION with valuable information also on vulnerability



MACROSEISMIC MODEL – Recent developments made by UNIGE

FIRST STEP: Conversion of damage data of AeDES forms into a DAMAGE LEVEL compatible with that defined at global scale according to the EMS98

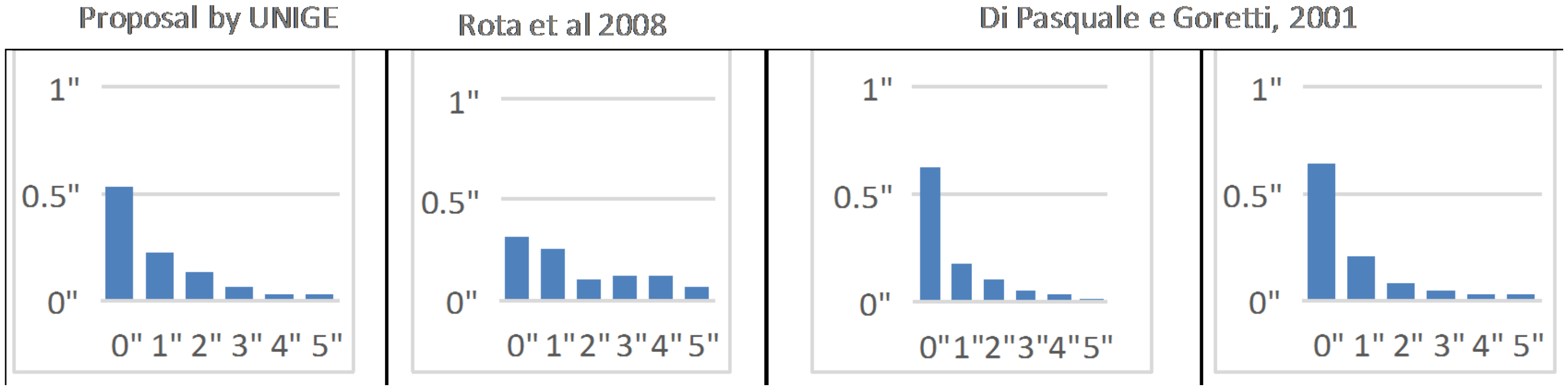
PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile



Different proposals:

- ❑ Rota et al. 2008
- ❑ Pasquale and Goretti 2001
- ❑ D.A.D.O proposal by DPC
- ❑ Proposal by UNIGE

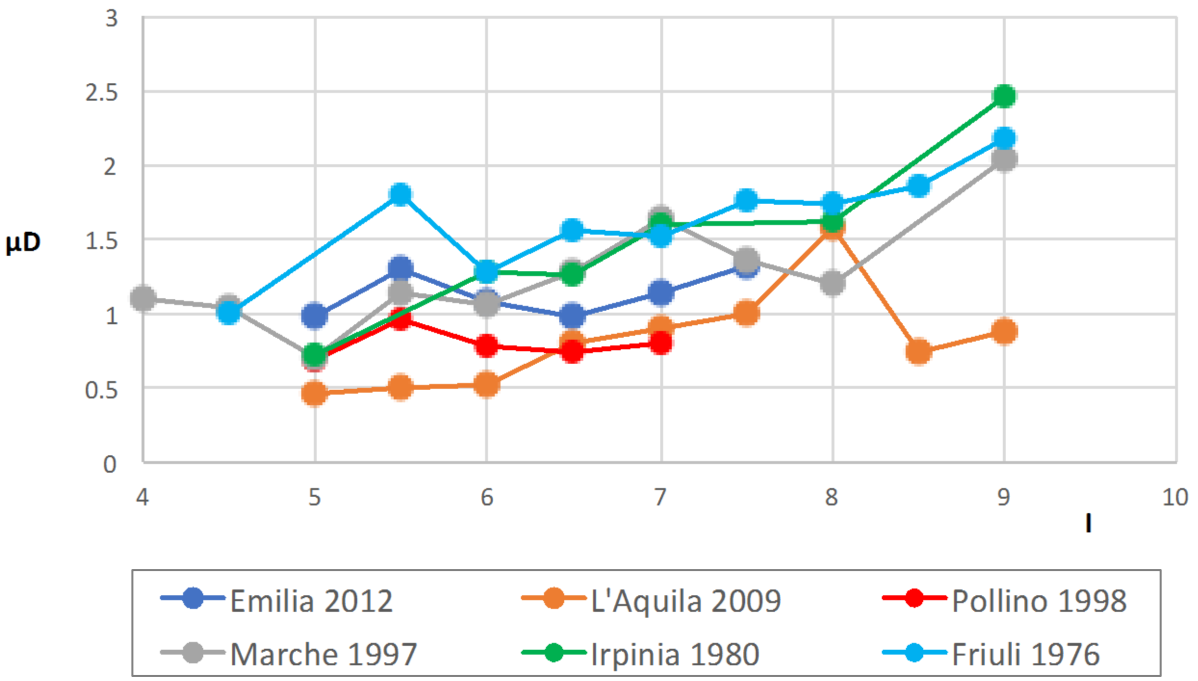
DPM for I=6.5

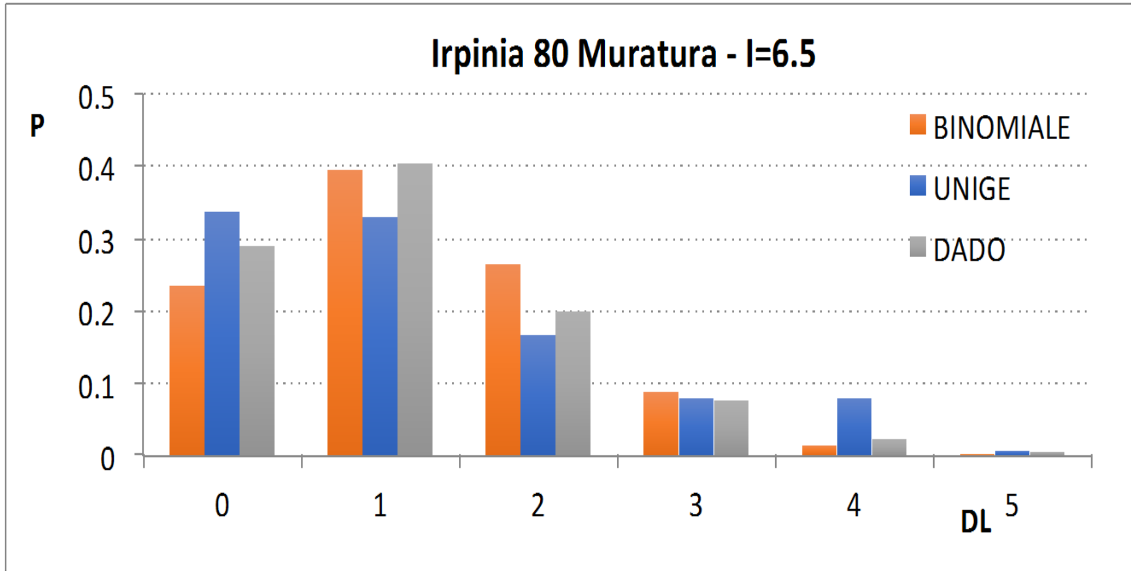


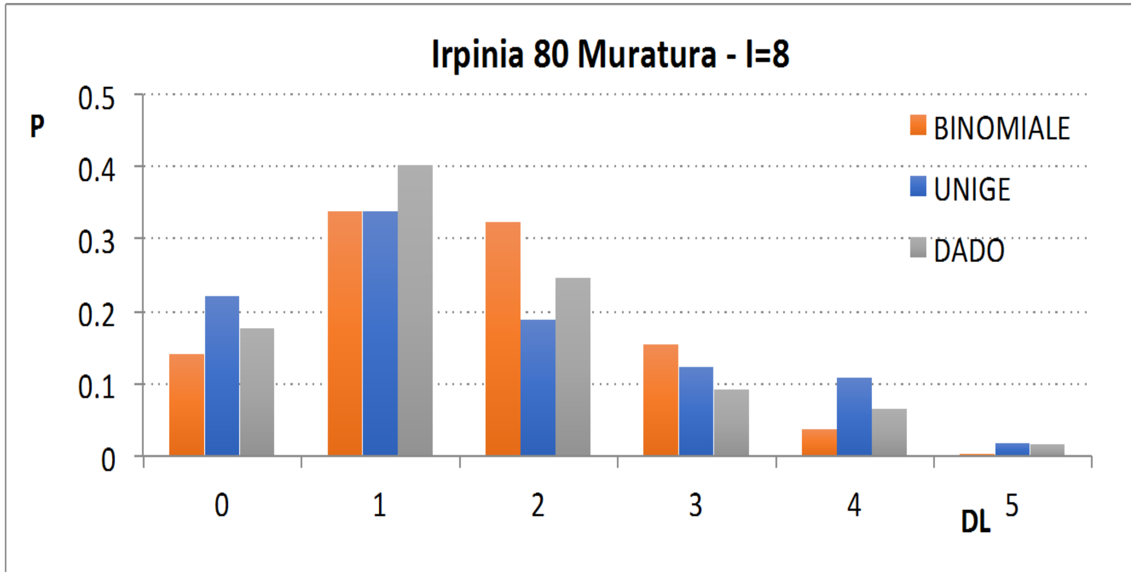
STATISTICAL REPROCESSING OF DATA AND DEFINITION OF DPM

REF: Lagomarsino S., Cattari S., Ottonelli D. (2020) Macroseismic fragility curves for Italian residential URM buildings calibrated by observed damage , Bulletin of Earthquake Engineering, to be submitted.

MACROSEISMIC MODEL – Recent developments made by UNIGE



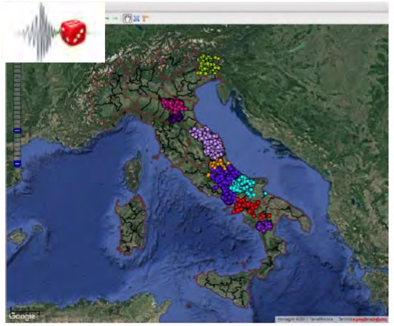




DATA from **Irpinia 1980** and **L'Aquila 2009** earthquakes are more robust and complete for the calibration

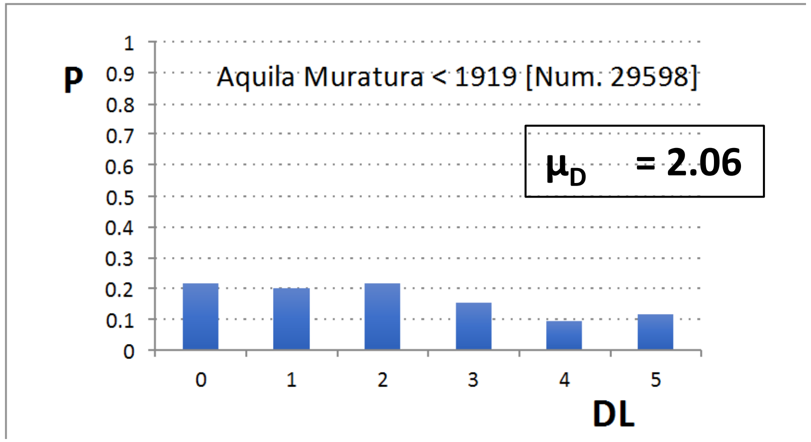
Evento Sismico	N° Edifici Iniziale	N° Edifici con Intensità	N° Edifici in Muratura
Friuli 1976	41852	41852	29641
Irpinia 1980	38079	33220	**26335**
Umbria-Marche 1997	48525	34873	29512
Pollino 1998	17442	16689	13887
L'Aquila 2009	74049	73793	**51438**
Emilia 2012	22554	22489	18194

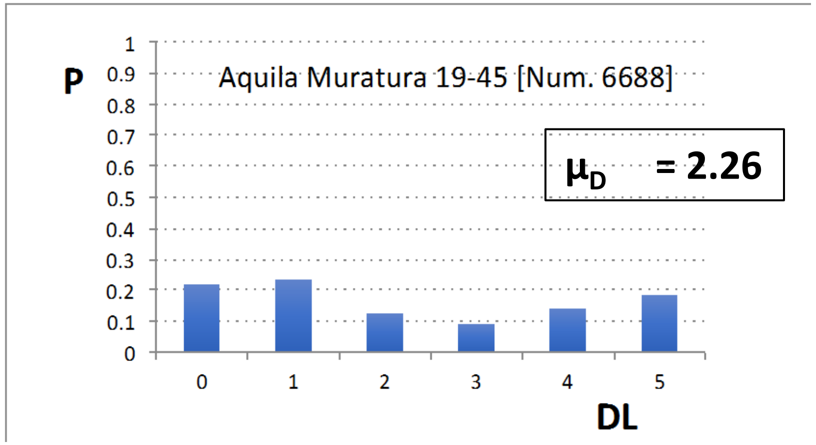
MACROSEISMIC MODEL – Recent developments made by UNIGE

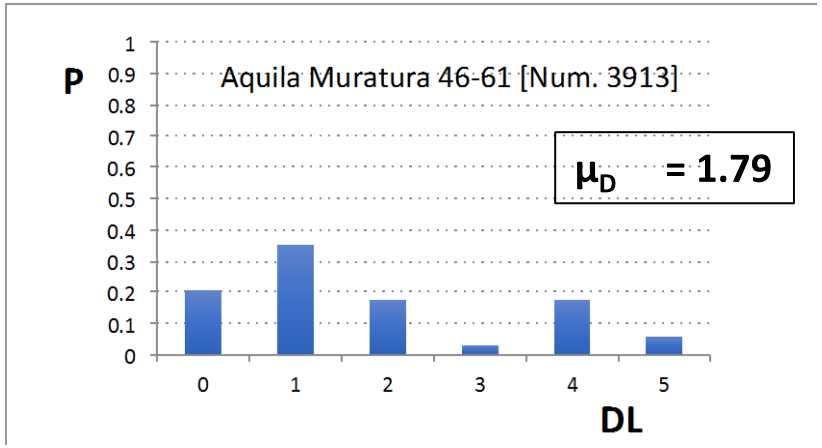


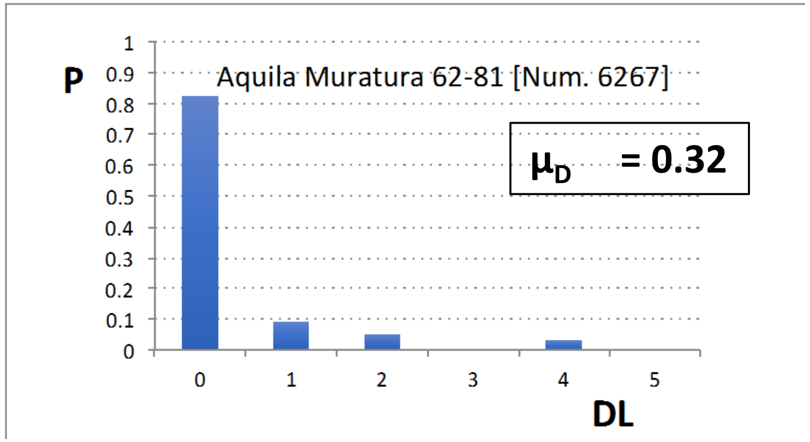
The vulnerability of masonry buildings decreases significantly with the age of construction

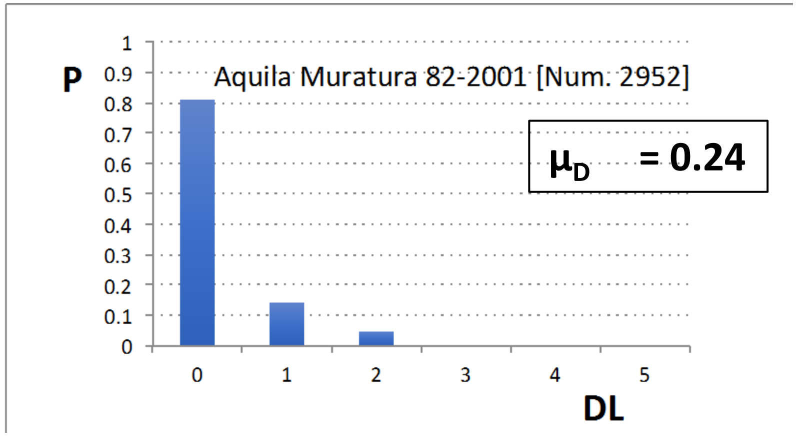
DAMAGE HISTOGRAM FOR L'AQUILA 2009 EARTHQUAKE VARYING THE AGE

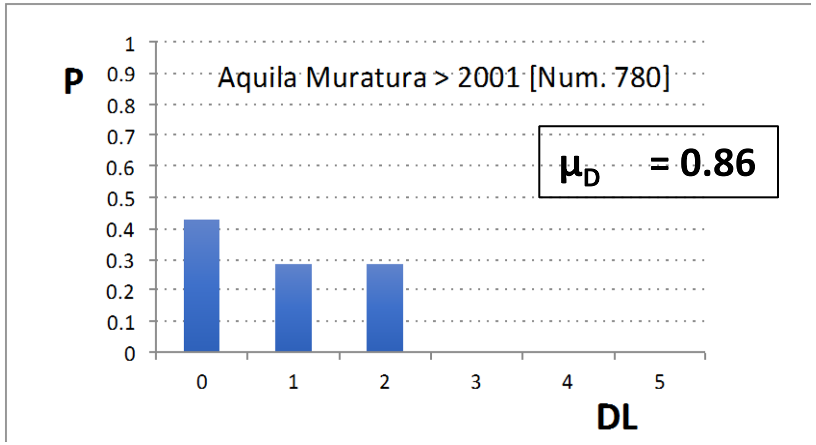








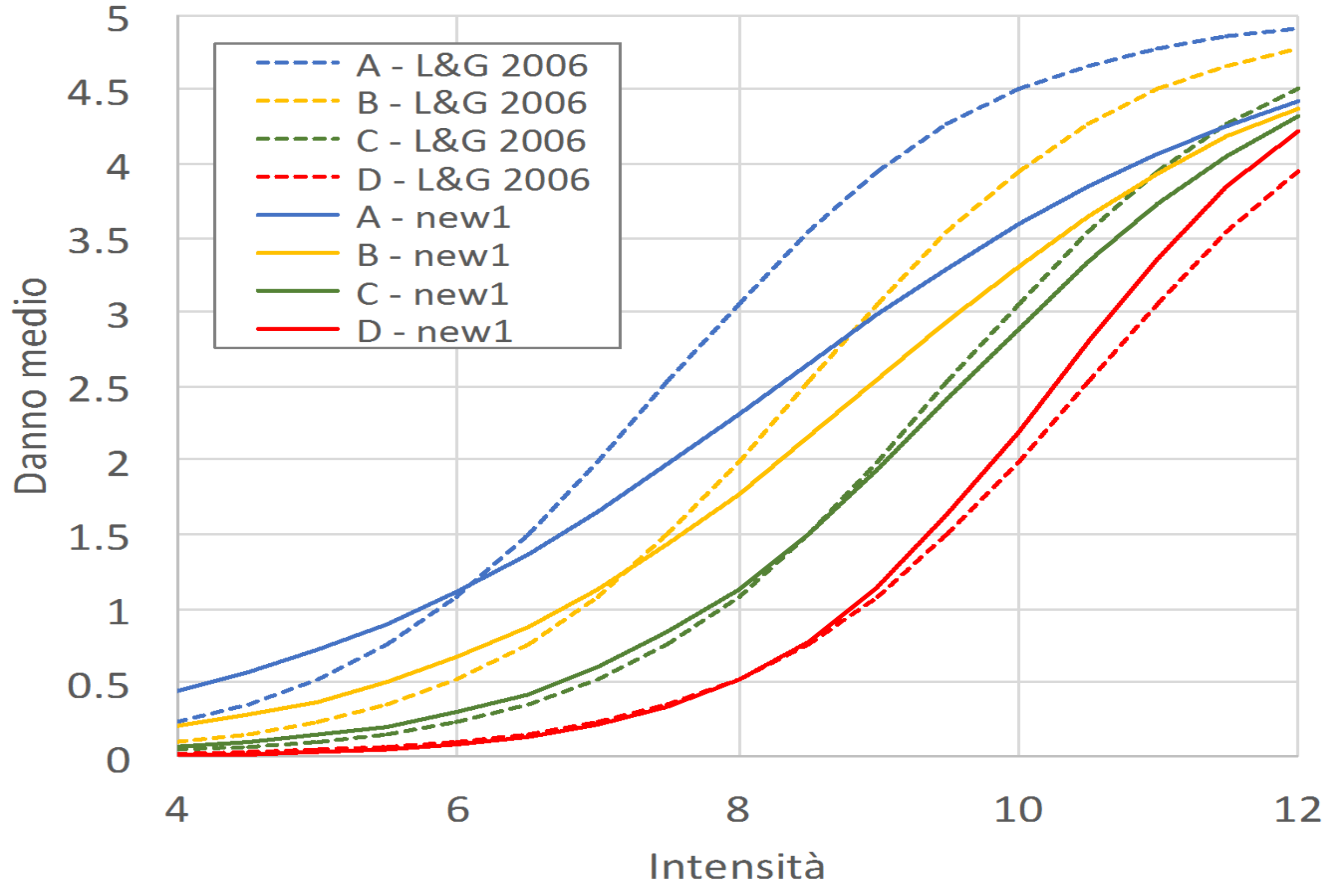


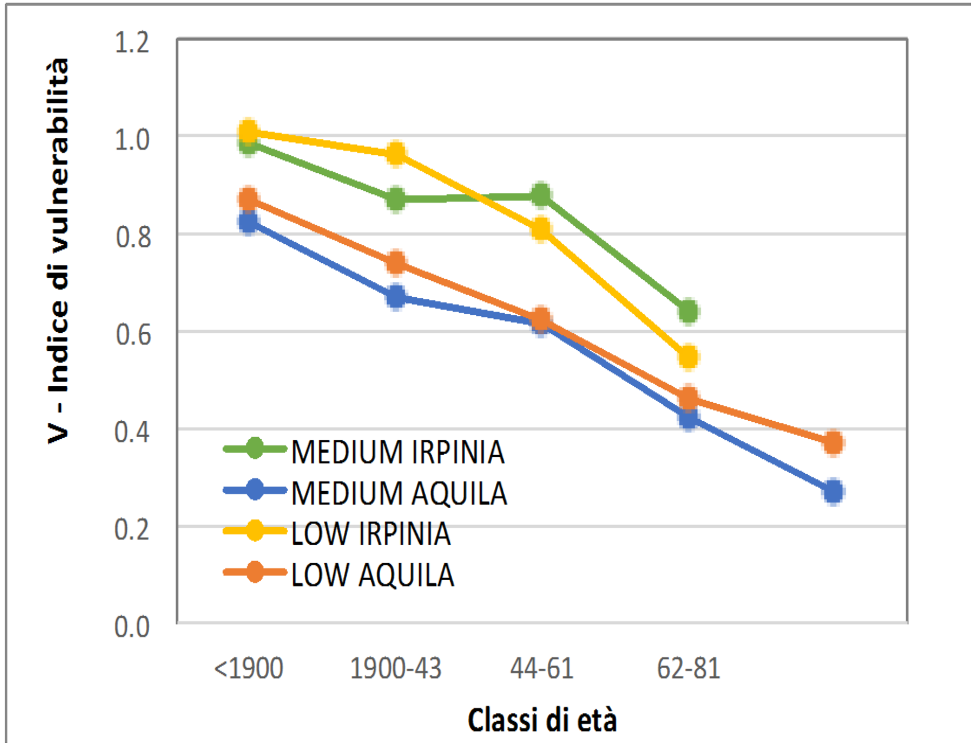


MACROSEISMIC MODEL – Recent developments made by UNIGE

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 3.45V - 11.7}{2.8V + 0.9}\right)\right]$$

Class	A	B	C	D
V	0.99	0.80	0.61	0.42



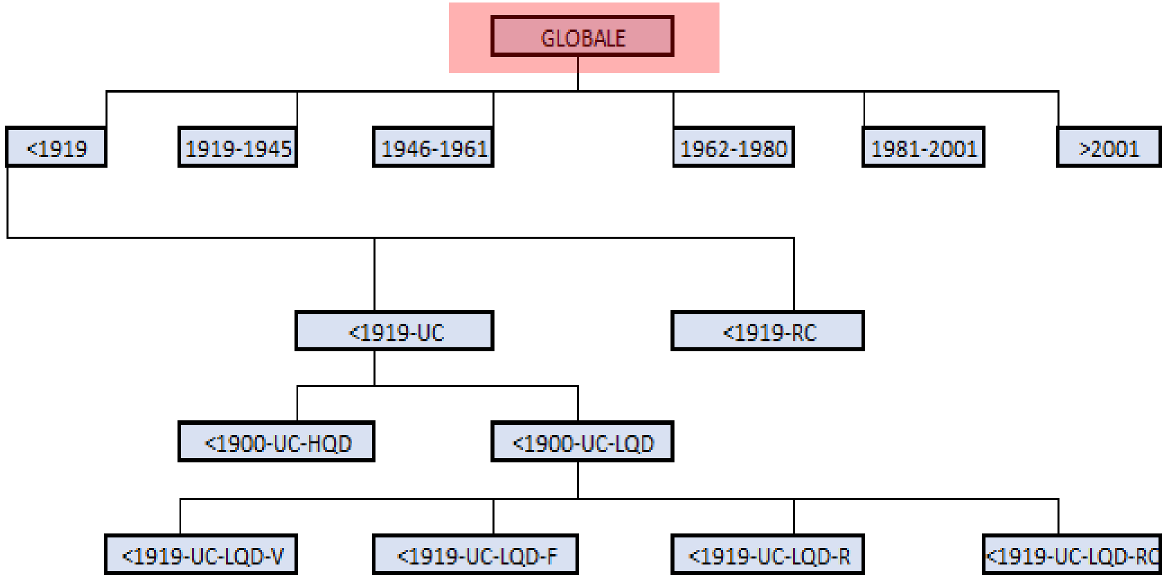


$$V = V_0 + \sum V_s$$

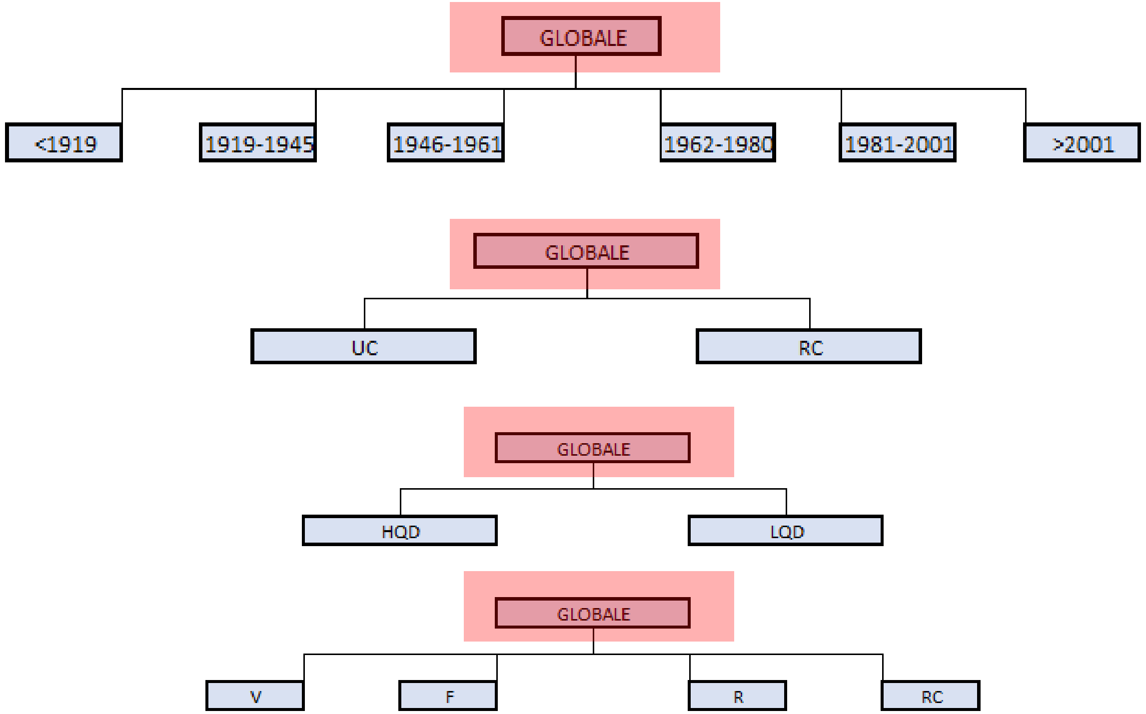
CALIBRATION AND COMBINATION OF BEHAVIOUR MODIFIERS

DERIVATION OF BEHAVIOUR MODIFIERS BY GROUPING THE DATA ON SPECIFIC SUB-CLASSES

Cascade process



Independent process



TAXONOMY of reference (Lagomarsino and Cattari 2013)

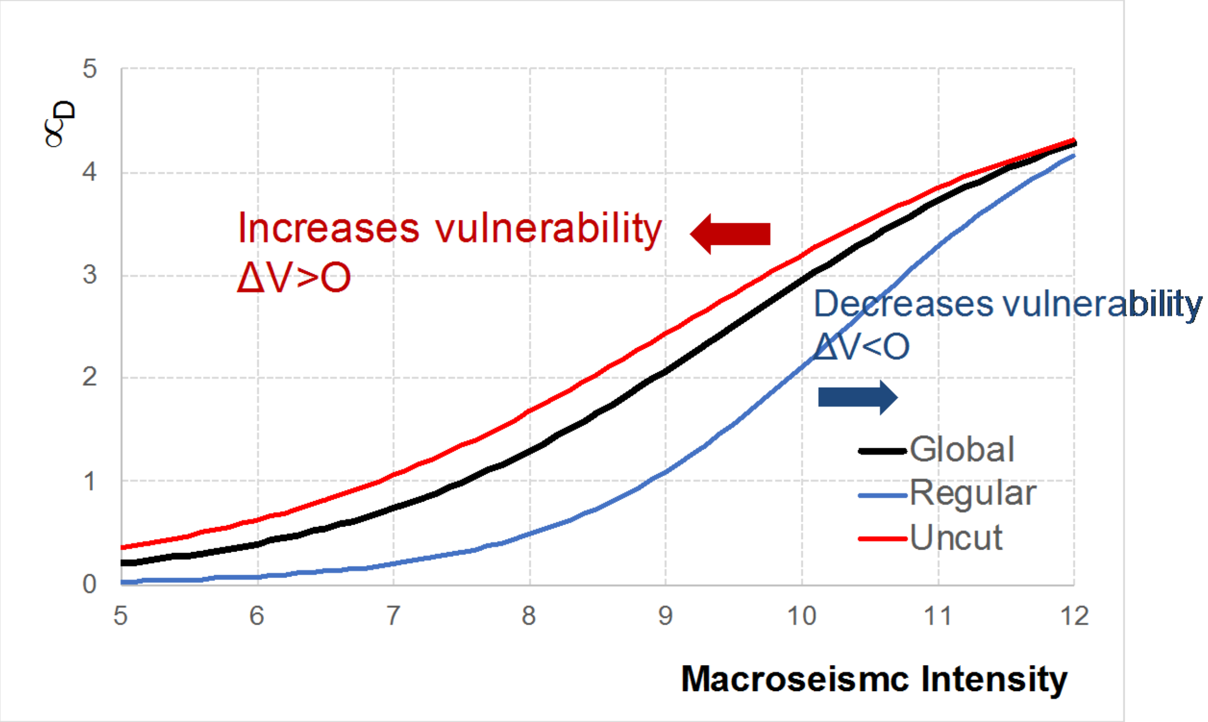
RC= Regular Cut masonry // UC=Uncut masonry

HQD=High Quality Details (tie rods & ring beams) // LQD=Low Quality Details (no tie rods / ring beams)

V=Vauls // F=Flexible Floor // R=Semi-rigid Floor // RC=Rigid Floor

CALIBRATION AND COMBINATION OF BEHAVIOUR MODIFIERS

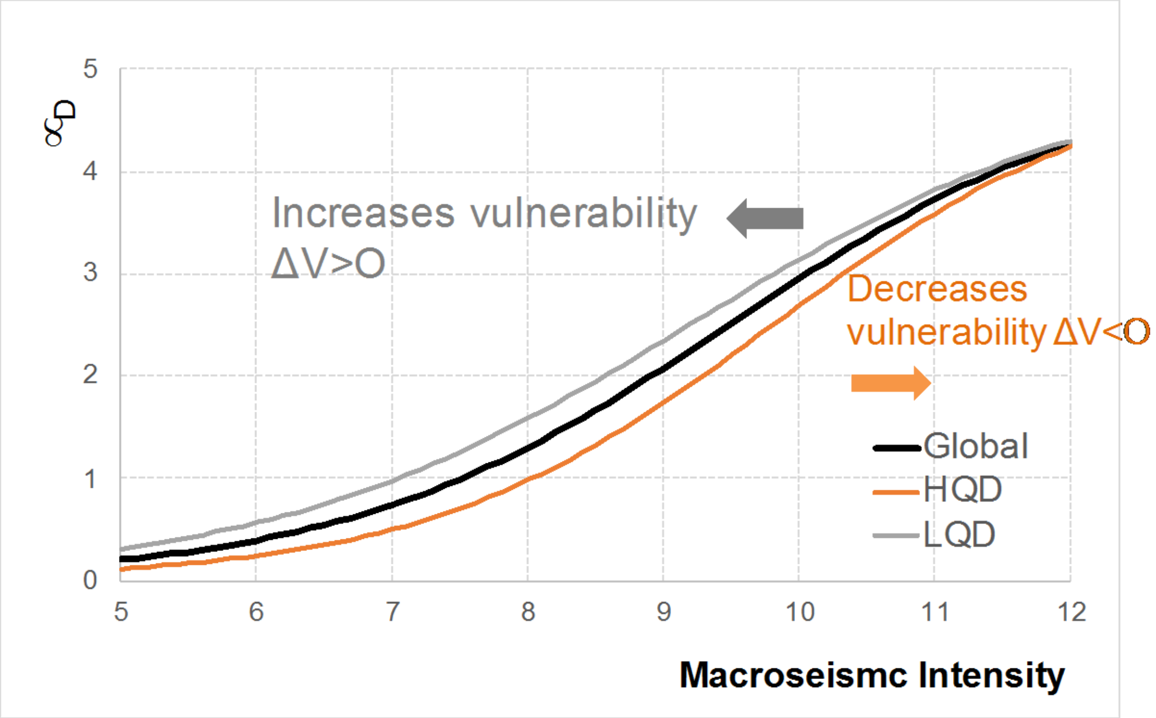
Indipendent Process



Vulnerability Index

V_Global Abruzzo= 0.692 [40781] Buildings]
V_Regular Cut Abruzzo = 0.426 [12369] Buildings]
V_Uncut Abruzzo = 0.814 [25763] Buildings]

ROLE OF MASONRY TYPE

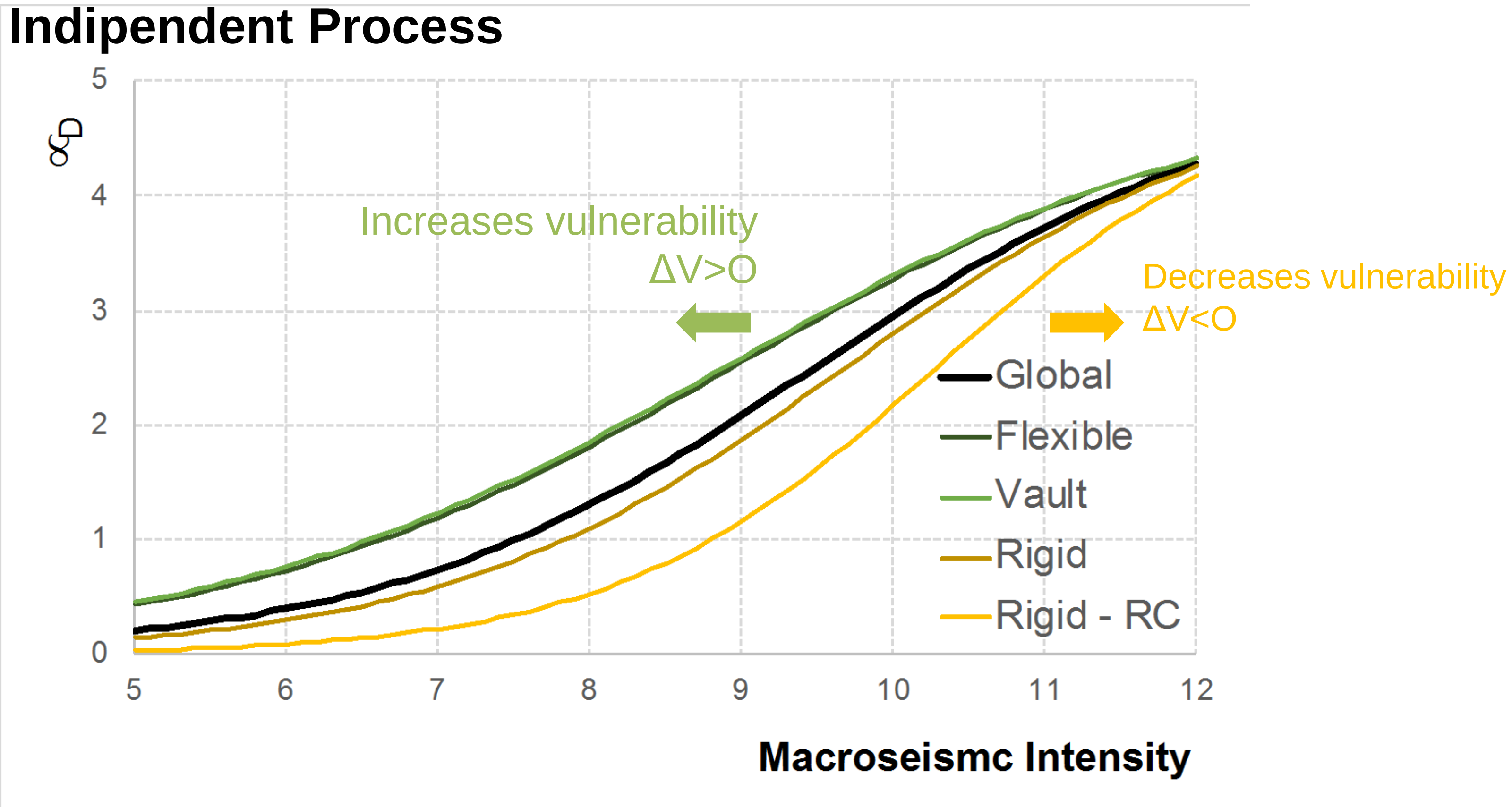


Vulnerability Index

V_Global Abruzzo= 0.692 [40781] Buildings]
V_HQD Abruzzo = 0.594 [13749] Buildings]
V_LQD Abruzzo = 0.786 [24200] Buildings]

ROLE OF STRUCTURAL DETAILS

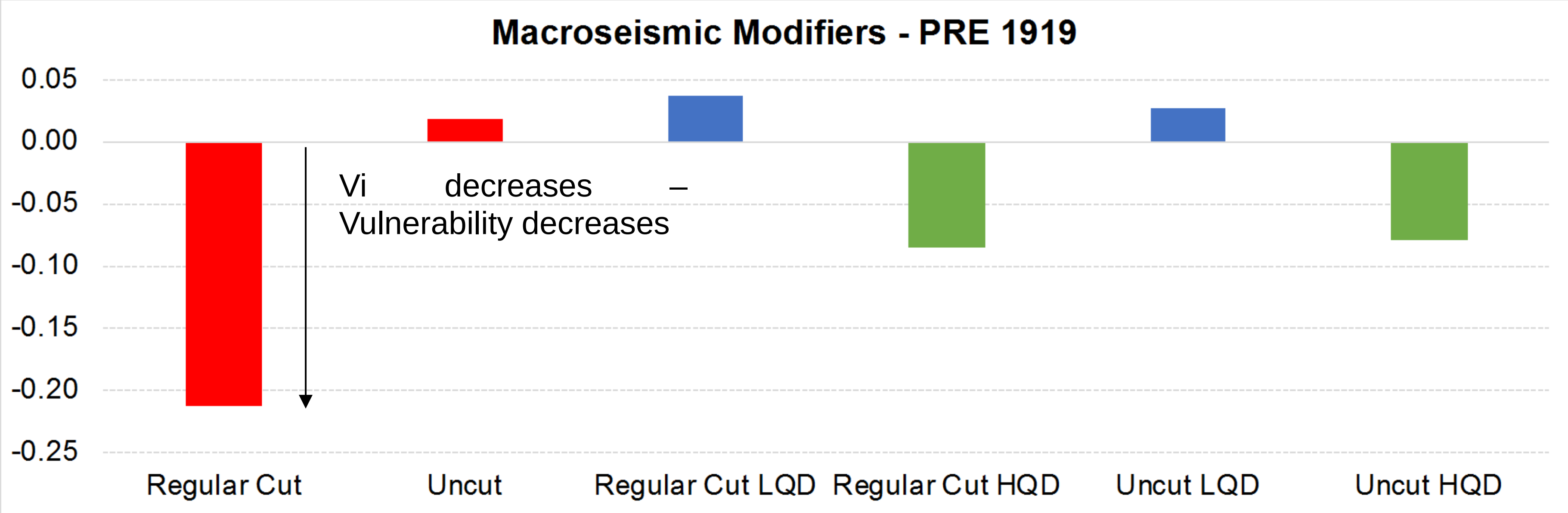
ROLE OF DIAPHRAGMS



Vulnerability Index

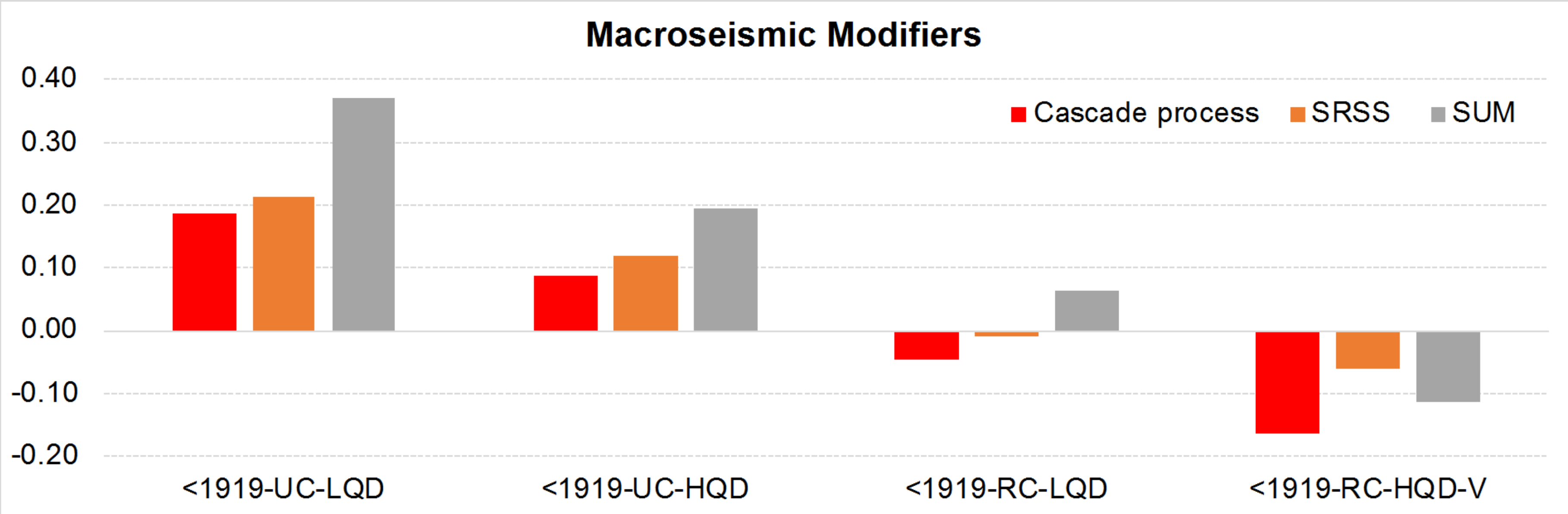
V_Global Abruzzo= 0.692 [40781] Buildings]
V_vault= 0.881 [3864] Buildings]
V_rigid = 0.865 [5660] Buildings]
V_rigid = 0.631 [9442] Buildings]
V_rigid = 0.444 [8300] Buildings]

SEISMIC BEHAVIOUR MODIFIERS



Modifiers in ΔV_m

- Type of masonry
- LQD: absence of aseismic devices
- HQD: presence of aseismic devices



Modifiers in ΔV_m

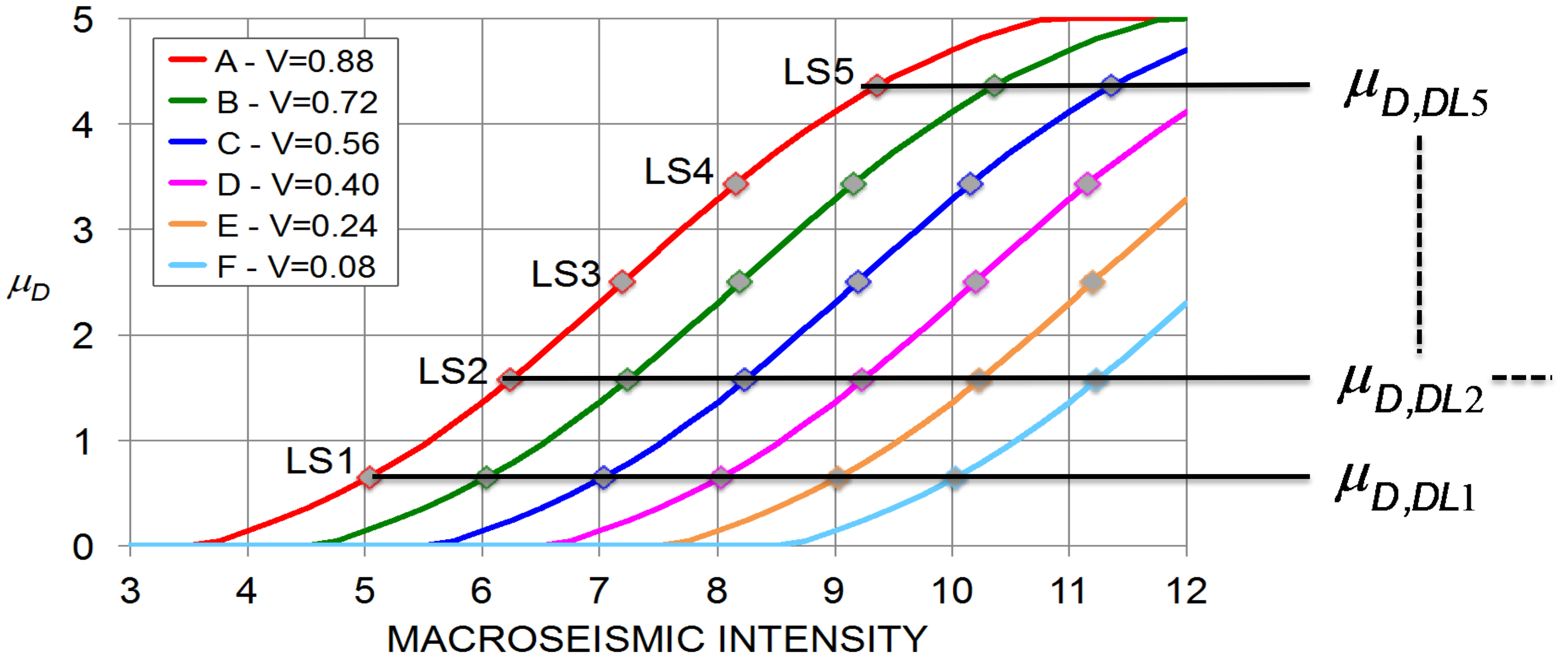
Costruction period < 1919	0.132
Masonry quality - RC	-0.180
Masonry quality - UC	0.127
Detail quality - LQD	0.112
Detail quality - HQD	-0.064

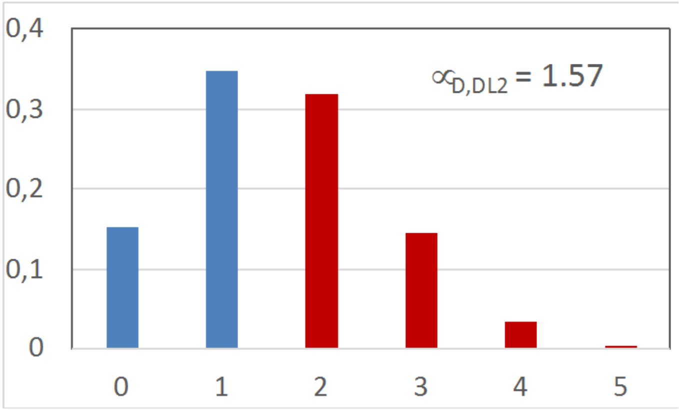
MACROSEISMIC MODEL – from vulnerability curves to fragility curves

- Firstly, it is necessary to define a reference **MEAN DAMAGE VALUE** to be associated to each **DAMAGE LEVEL**

$$\mu_{D,DLk} = 0.93k - 0.2$$

Linear regression from values obtained from the binomial distribution





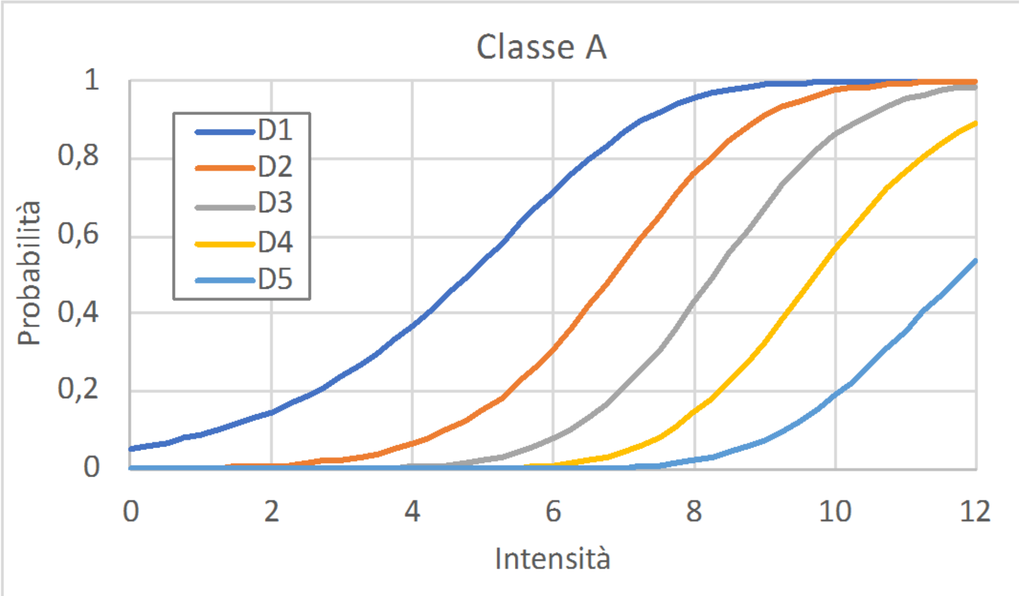
MACROSEISMIC MODEL – from vulnerability curves to fragility curves

- Firstly, it is necessary to define a reference **MEAND DAMAGE VALUE** to be associated to each **DAMAGE LEVEL**
- Then, it is possible computing the **fragility curve in terms of Intensity** by assessing the I value that produces the attainment of DLk

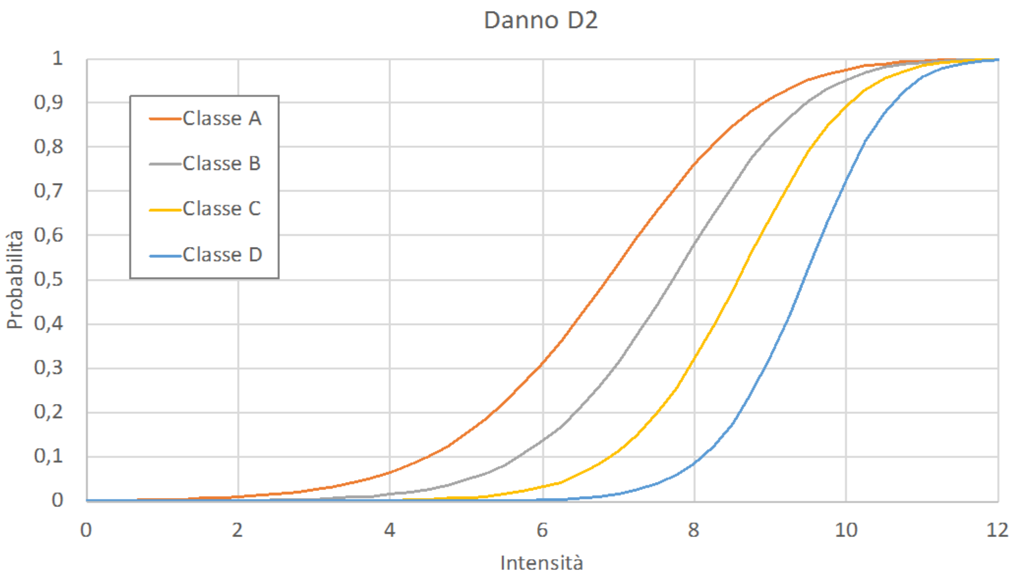
$$\mu_{D,DLk} = 0.93k - 0.2$$

$$I_{DLk} = 11.7 - 3.45V + (0.9 + 2.8V)\,atanh(0.4\mu_{DLk} - 1)$$

For a GIVEN vulnerability class varying the DL



For a GIVEN DL varying the vulnerability class

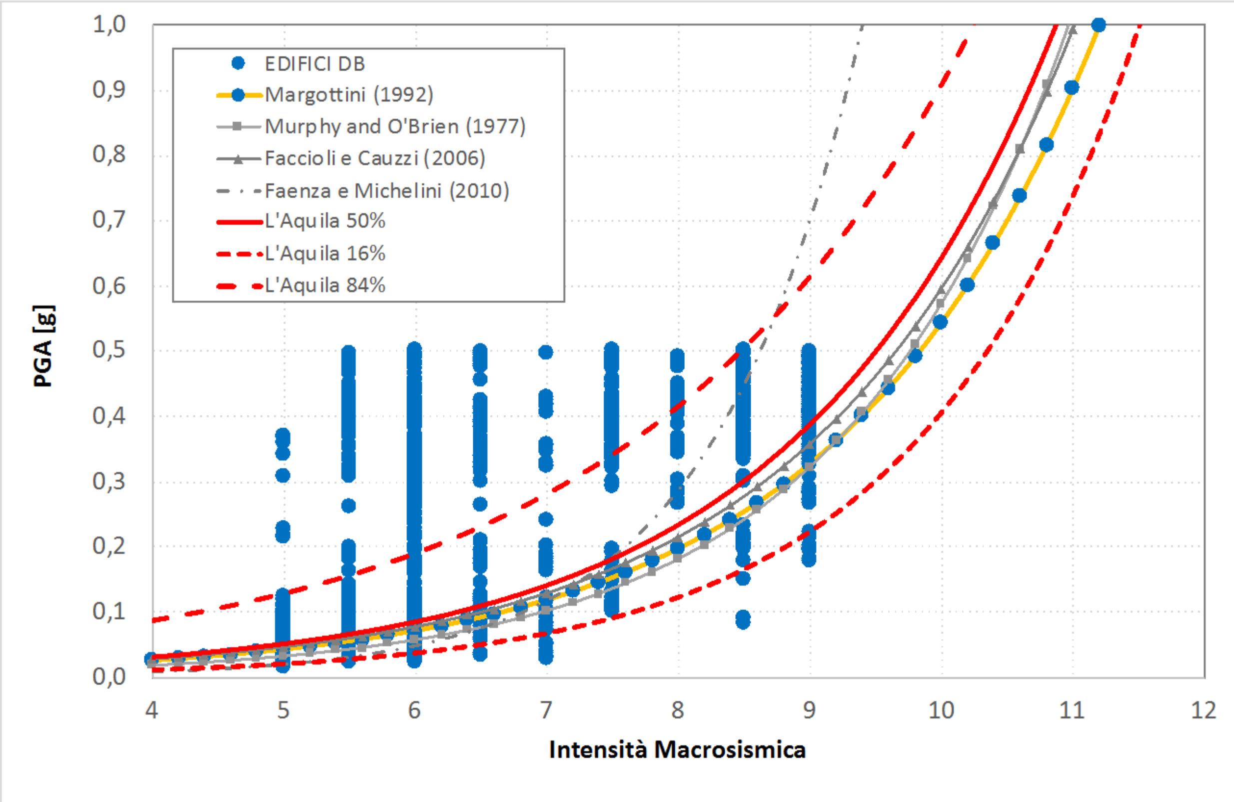


NOT WELL REPRESENTED BY THE CUMULATIVE LOGNORMAL FUNCTION…

MACROSEISMIC MODEL – from vulnerability curves to fragility curves

- Firstly, it is necessary to define a reference **MEAND DAMAGE VALUE** to be associated to each **DAMAGE LEVEL**
- Then, it is possible computing the **fragility curve in terms of Intensity** by assessing the generic I value that produces the attainment of DLk
- Finally, it is necessary to introduce a proper **Intensity – PGA correlation law** in order to define the fragility curve in terms of a instrumental intensity measure

Comparison between some I-PGA Correlation law available in literature and that calibrated by UNIGE on basis of shakemap data from L'Aquila 2009 earthquake



$$Log(PGA) = a\,I + b$$

$$I = A\,Log(PGA) + B$$

$$PGA = c_1\,c_2^{I-5}$$

Literature proposals

Correlazione I-PGA	c_1	c_2
Margottini et al. (1992)	0.0430	1.66
Murphy and O'Brien (1977)	0.0322	1.78
Faccioli e Cauzzi (2006)	0.0464	1.67
Faenza e Michelini (2010)	0.0197	2.44

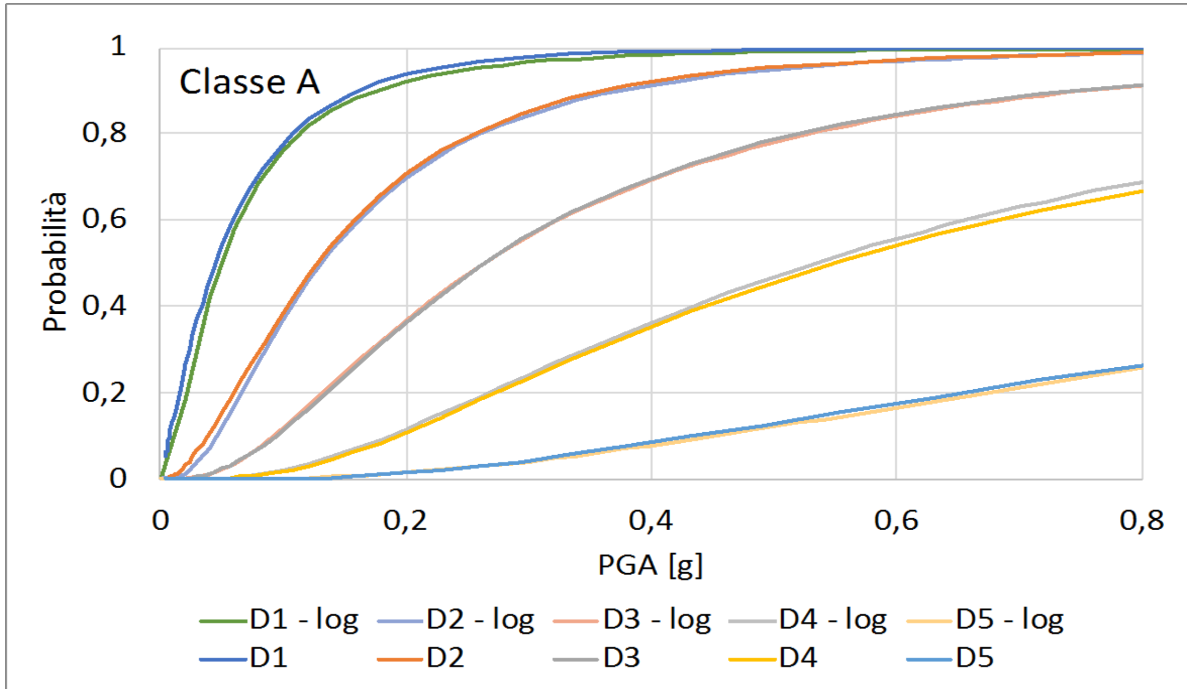
UNIGE proposal

Correlazione I-PGA	c_1	c_2
da ShakeMap L'Aquila (mediana)	0.05	1.66
da ShakeMap L'Aquila (16%)	0.02	1.82
da ShakeMap L'Aquila (84%)	0.13	1.48

MACROSEISMIC MODEL – from vulnerability curves to fragility curves

- Firstly, it is necessary to define a reference **MEAND DAMAGE VALUE** to be associated to each **DAMAGE LEVEL**
- Then, it is possible computing the **fragility curve in terms of Intensity** by assessing the generic I value that produces the attainment of DLk
- Finally, it is necessary to introduce a proper **Intensity – PGA correlation law** in order to define the **fragility curve in terms of a instrumental intensity measure**

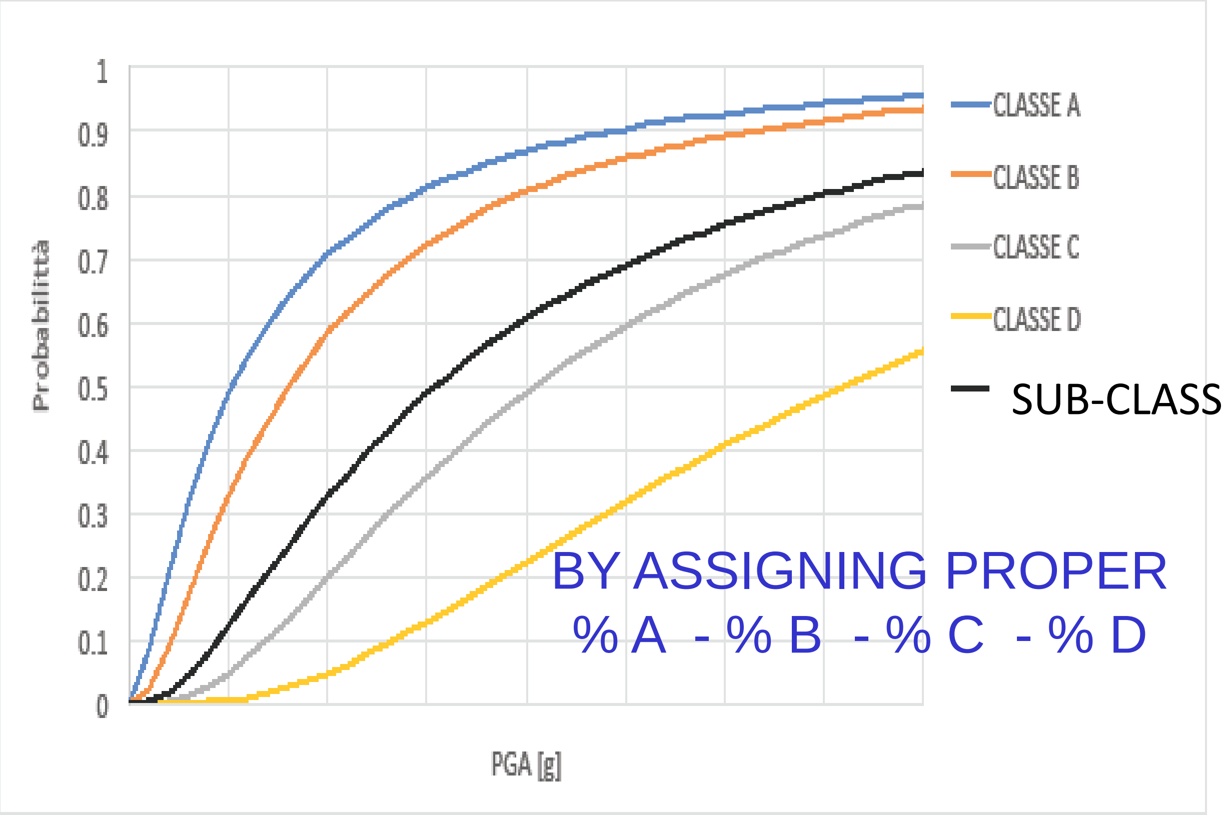
$$PGA_{Dk} = c_1 c_2^{(I_{Dk}-5)} = c_1 c_2^{[6.7-3.25V+(0.9+2.8V)atanh(0.36k-1.08)]}$$



The fragility curve in PGA is well fitted by the lognormal cumulative function

$$p_{LS}(im) = P(d > D_{LS}|im) = P(im_{LS} < im) = \Phi\left(\frac{log\left(\frac{im}{IM_{LS}}\right)}{\beta_{LS}}\right)$$

HOW WE CAN PASS FROM THE FRAGILITY CURVE OF THE EMS98 VULNERABILITY CLASSES TO OTHER SUB-CLASSES (→ TARGETED TO OUR INVENTORY & OUR AVAILABLE DATA)?



BY ASSIGNING PROPER
% A - % B - % C - % D

Class	A	B	C	D
V	0.99	0.80	0.61	0.42

LOW					
Classi età	$V_{EMPIRICI}$	A	B	C	D
< 1919	0.952	80	20		
1919 - 1945	0.847	25	75		
1946 - 1961	0.705		50	50	
1962 - 1981	0.550			70	30
> 1981	0.420				100

MEDIUM					
Classi età	$V_{EMPIRICI}$	A	B	C	D
< 1919	0.914	60	40		
1919 - 1945	0.781		90	10	
1946 - 1961	0.743		70	30	
1962 - 1981	0.648		20	80	
> 1981	0.496			40	60

NEW MACROSEISMIC MODEL – VALIDATION

For the aim of validation and within the context of ReLUIS-DPC project addressed to developing Italian seismic risk map the fragility curves have been implemented in the **IRMA Platform**

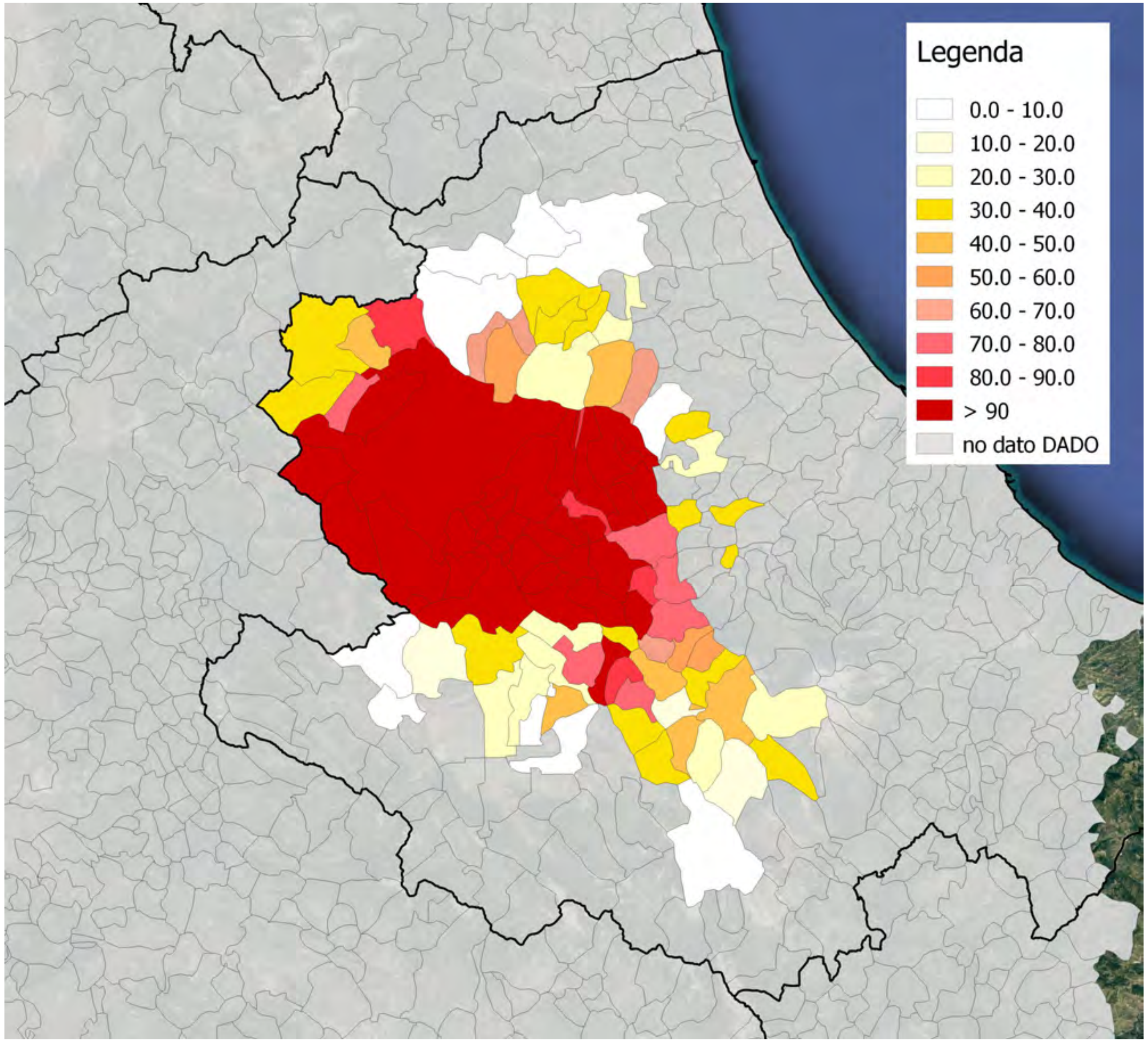
ReLUIS-DPC Project: Italian seismic risk map

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

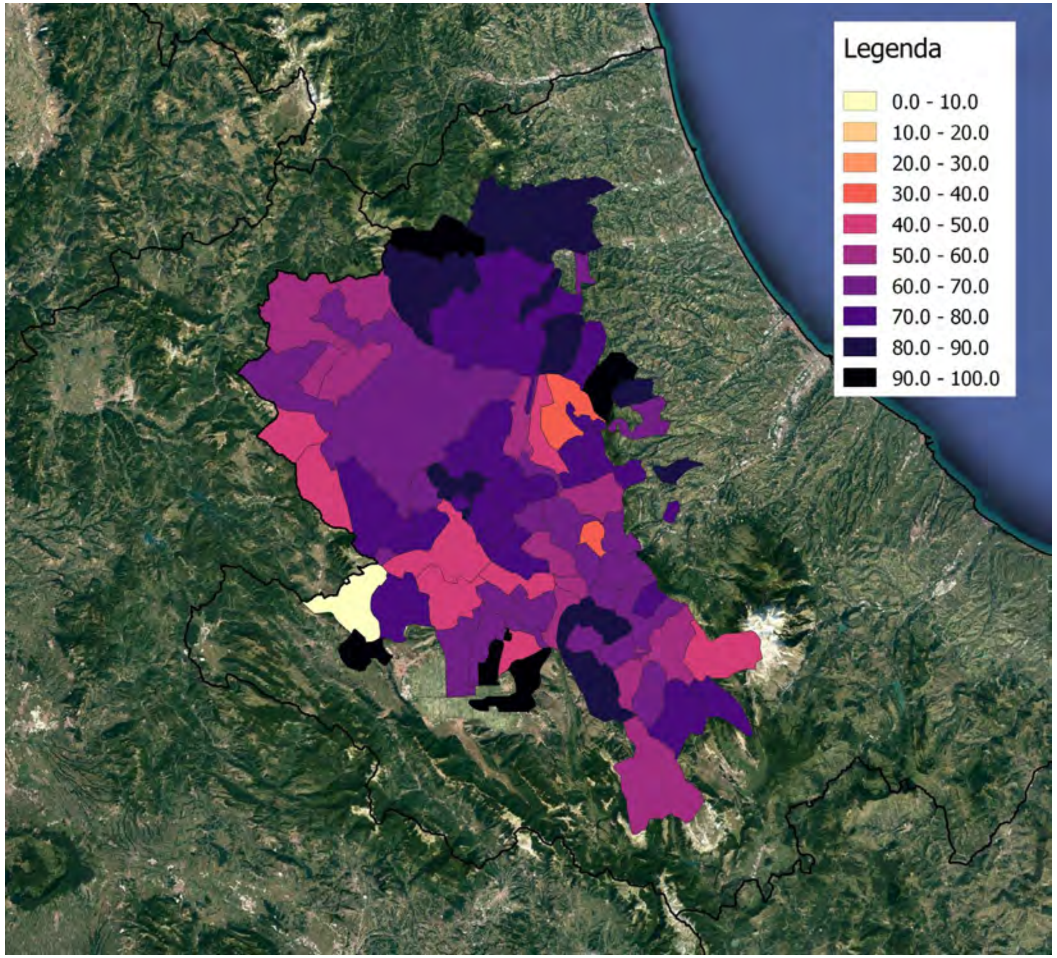
EUCENTRE
FOR YOUR SAFETY.

Borzi, B., Faravelli, M., Onida, M., Polli, D., Quaroni, D., Pagano, M., Di Meo, A., 2018. Piattaforma Irma (Italian Risk MAps). *37esimo Convegno Nazionale GNGTS.* 19-21 Novembre 2018, Bologna.

Scenario of L'Aquila 2009 earthquake – *Validation made by the Platform IRMA*

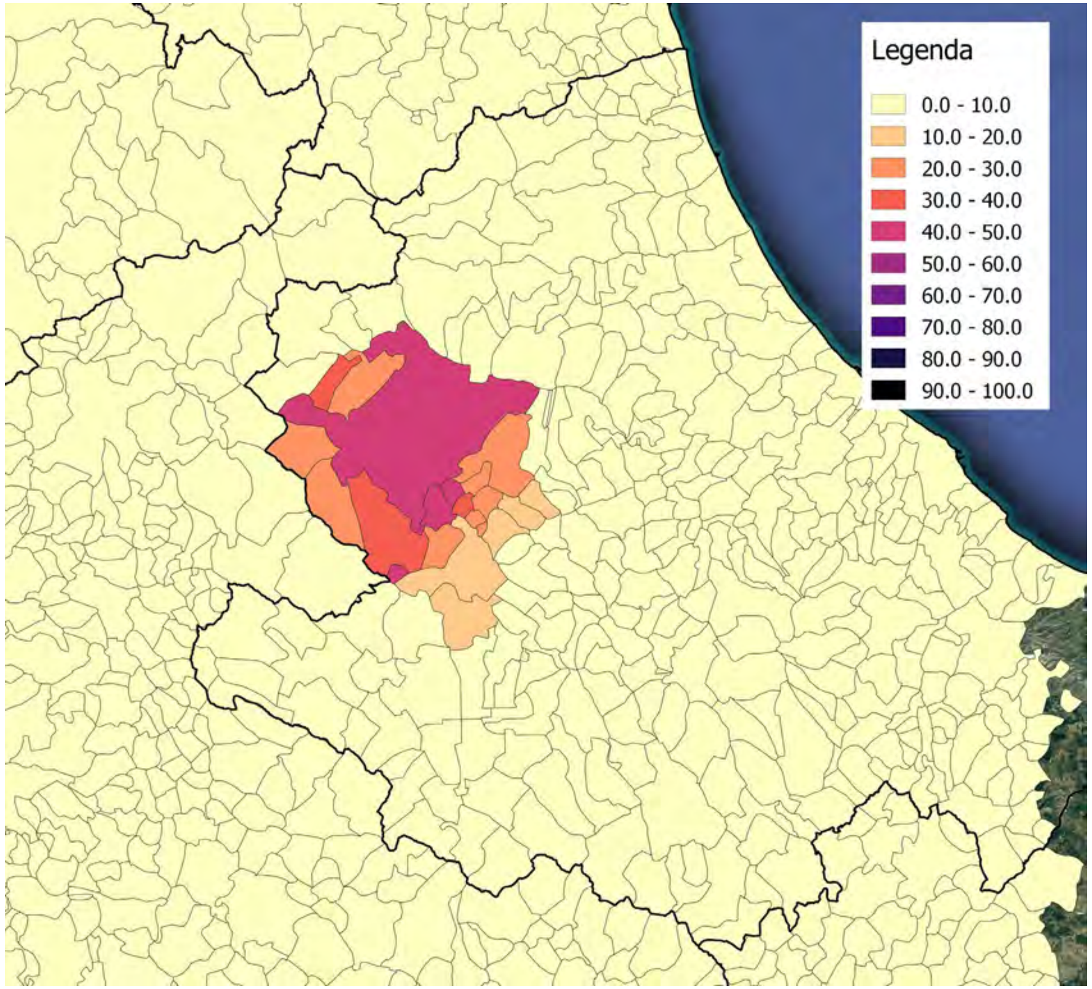


DL1 – real data from DaDO

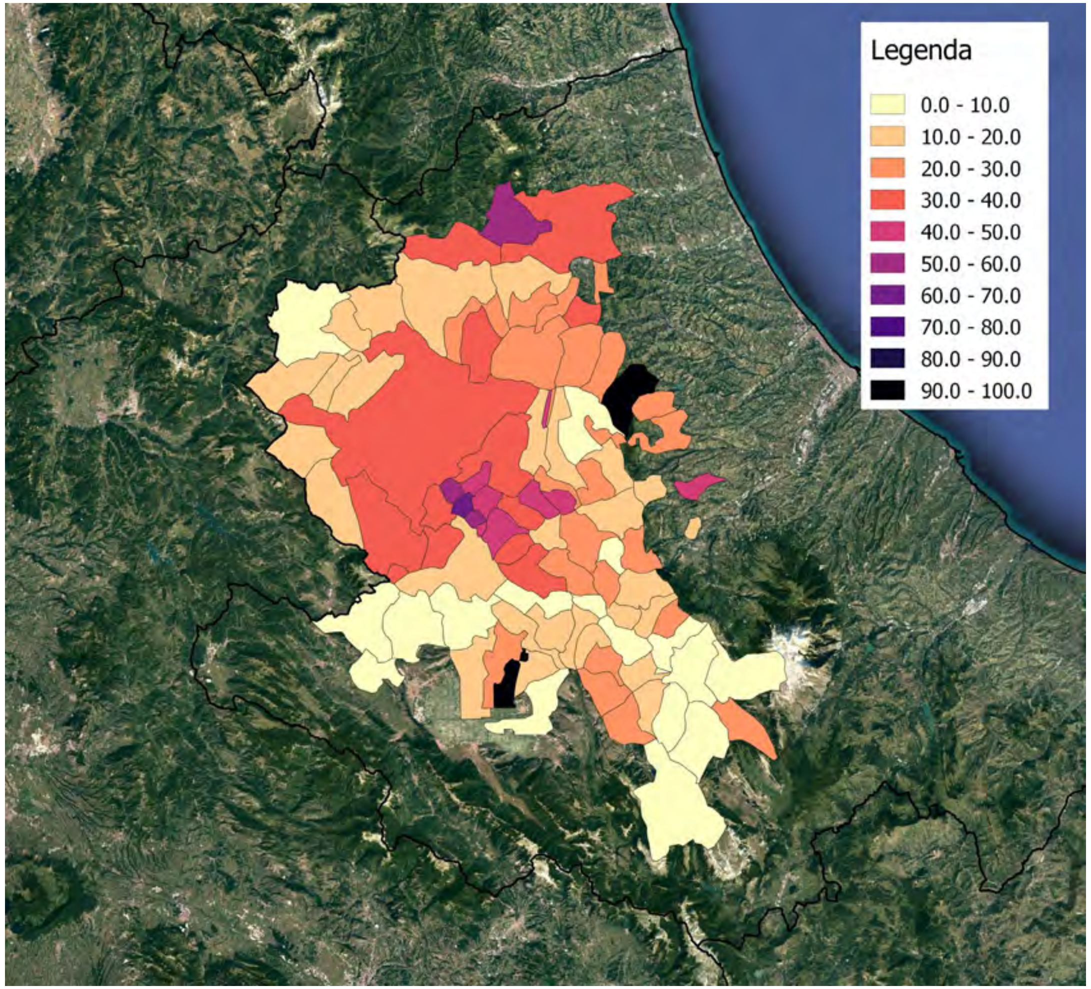


Scenario of L'Aquila 2009 earthquake- *Validation made by the Platform IRMA*

DL3 – Simulated by the macroseismic model

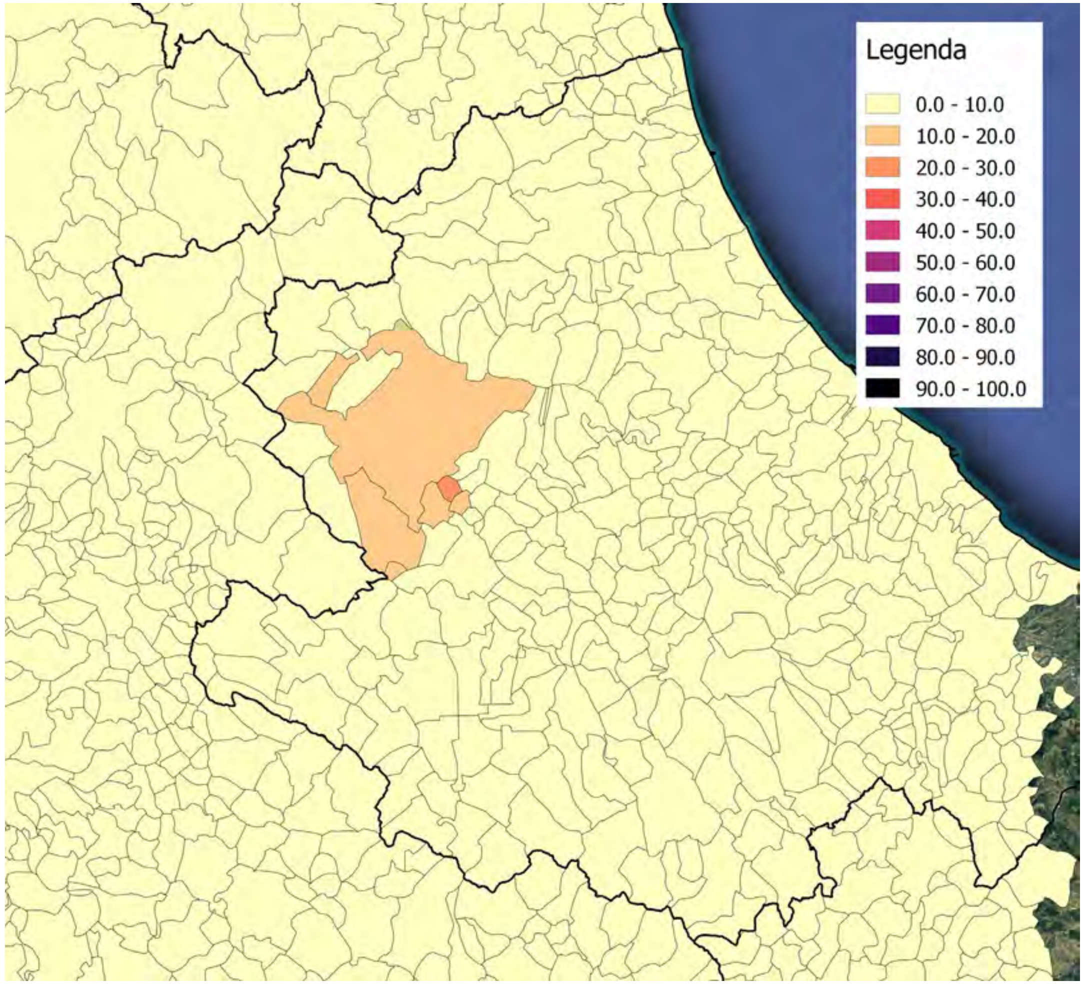


DL3 – real data from DaDO

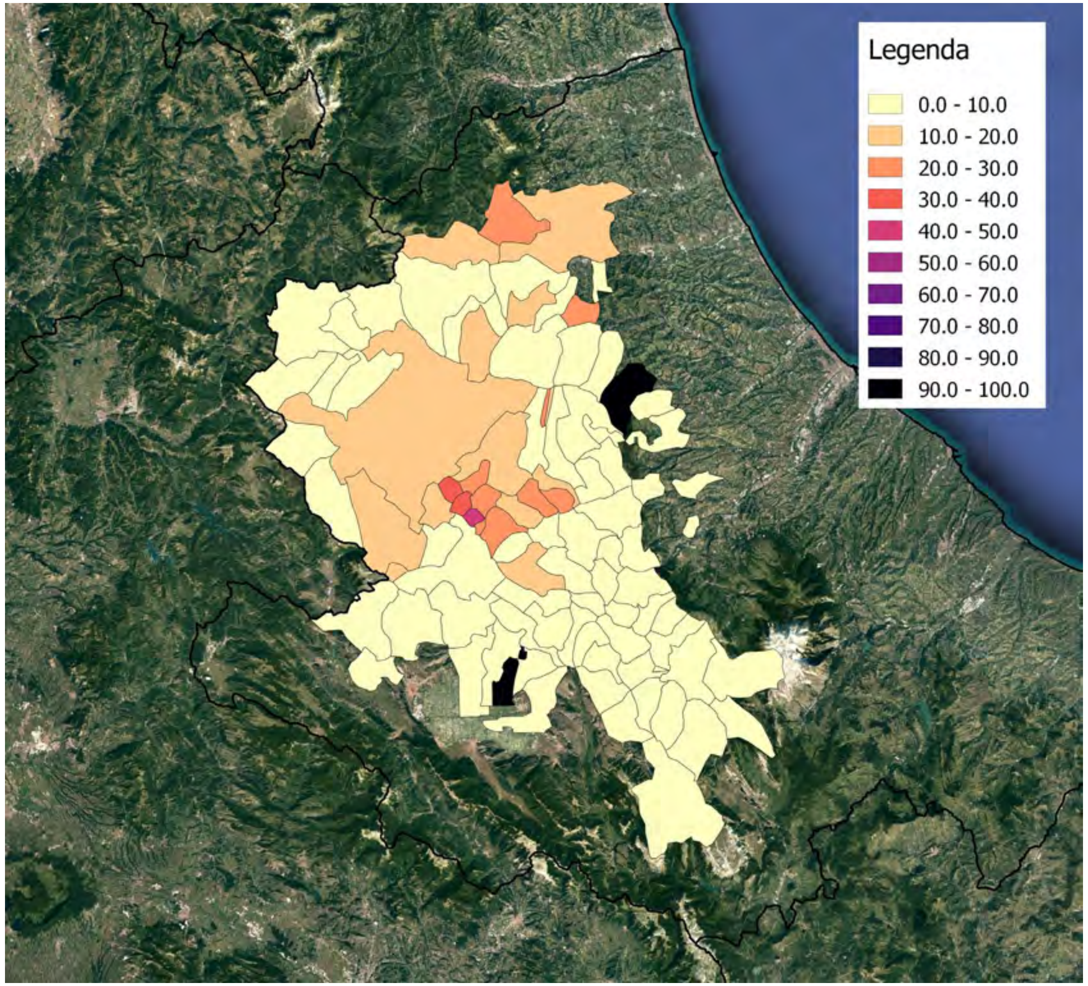


Scenario of L'Aquila 2009 earthquake - *Validation made by the Platform IRMA*

DL4 – Simulated by the macroseismic model

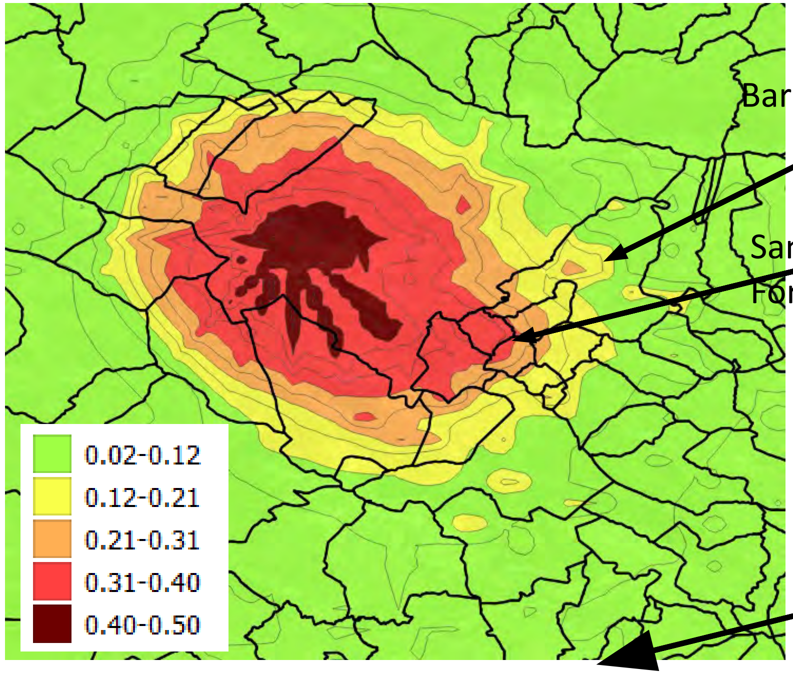


DL4– real data from DaDO

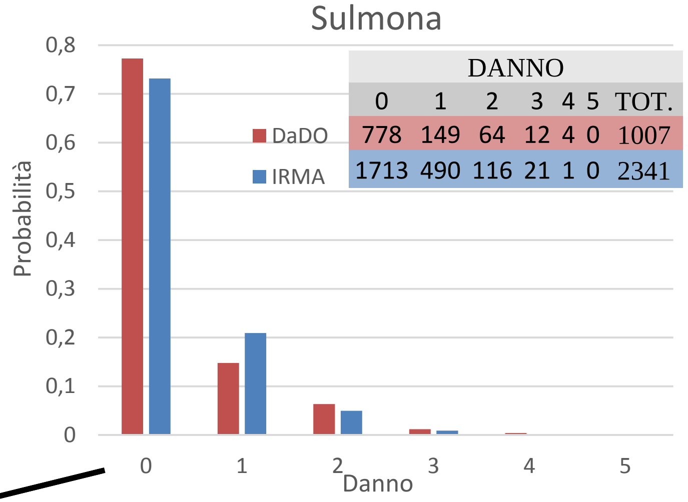


NEW MACROSEISMIC MODEL –VALIDATION

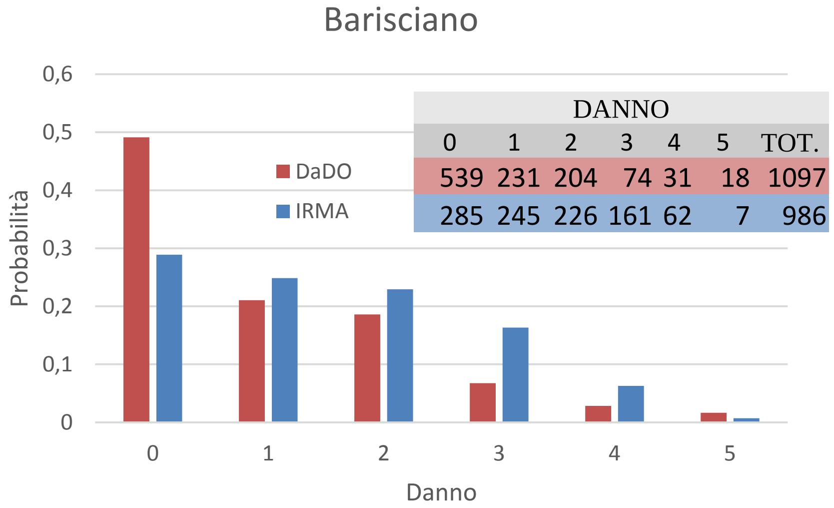
Shakemap of L'Aquila 2009



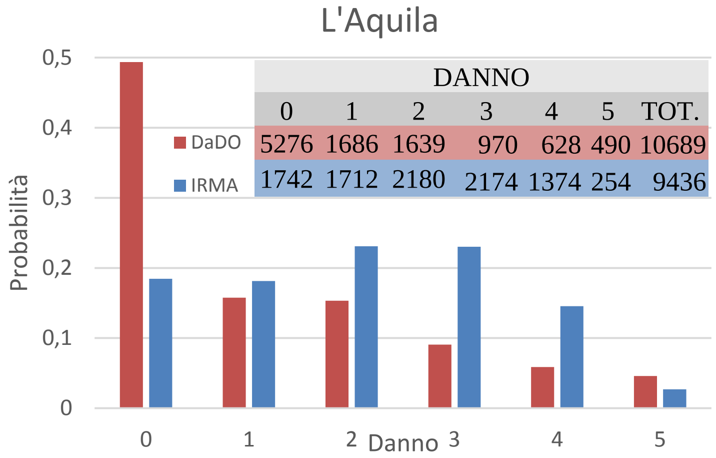
COMPARISON IN TERMS OF DPM FOR VARIOUS MUNICIPALITIES WITH DIFFERENT EPICENTRAL DISTANCE



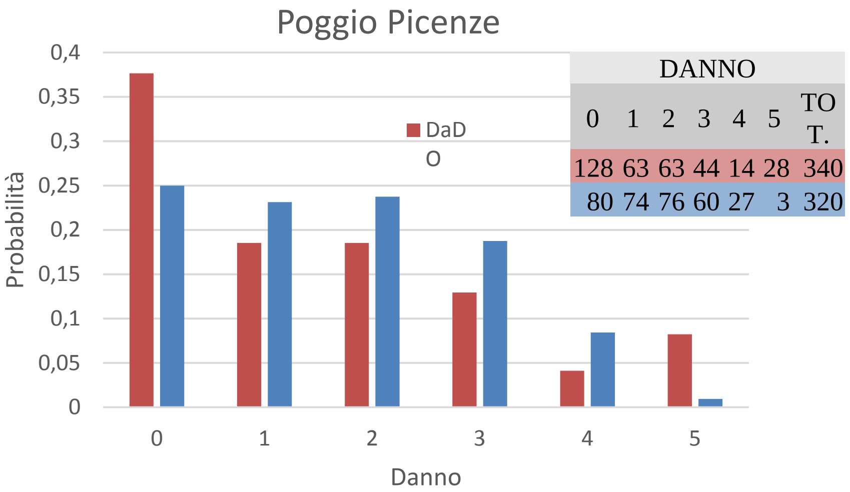
	DANNO						
	0	1	2	3	4	5	TOT.
DaDO	778	149	64	12	4	0	1007
IRMA	1713	490	116	21	1	0	2341



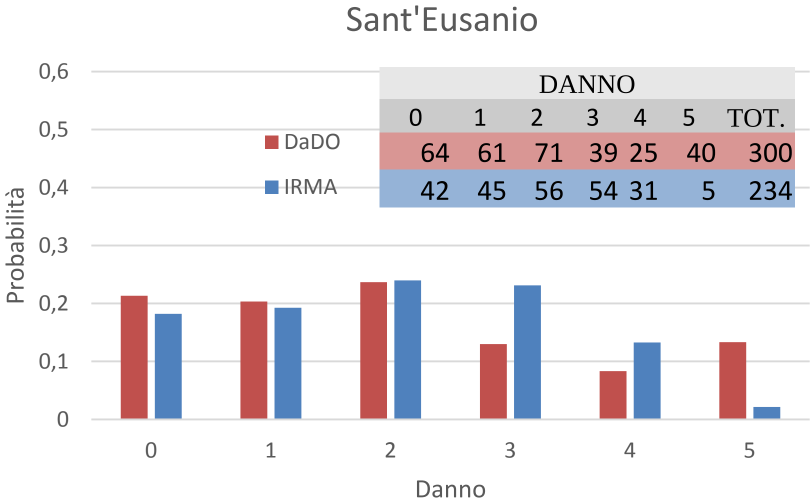
	DANNO						
	0	1	2	3	4	5	TOT.
DaDO	539	231	204	74	31	18	1097
IRMA	285	245	226	161	62	7	986



	DANNO						
	0	1	2	3	4	5	TOT.
DaDO	5276	1686	1639	970	628	490	10689
IRMA	1742	1712	2180	2174	1374	254	9436



	DANNO						
	0	1	2	3	4	5	TOT.
DaDO	128	63	63	44	14	28	340
IRMA	80	74	76	60	27	3	320

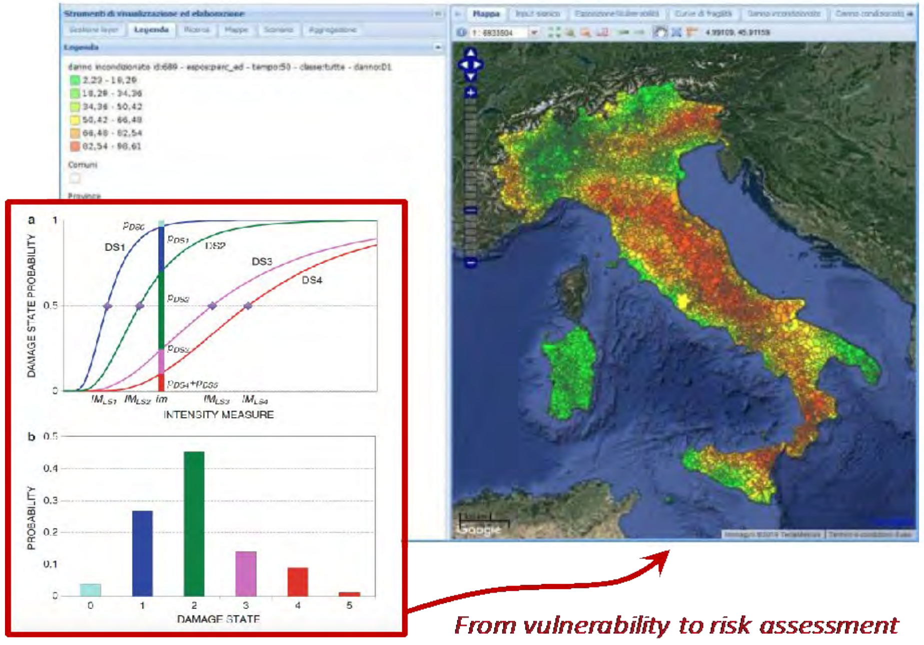


	DANNO						
	0	1	2	3	4	5	TOT.
DaDO	64	61	71	39	25	40	300
IRMA	42	45	56	54	31	5	234

OUTLINE OF THE PRESENTATION

FRAGILITY CURVES

What do they represent?	Vulnerability as a component of seismic risk and loss assessment
What do they depend on?	Involved dispersions & influence on results of seismic risk analysis
How are they obtained?	Overview of methods & focus on macroseismic and empirical ones
How can they be used?	Practical issues & application to the Italian seismic risk assessment



ReLUIS-DPC Project: Italian seismic risk map (2018 - ONGOING)

IRMA Platform has been used in 2018 for the National Risk Assessment (Italian seismic risk maps and losses) and is going to be improved in the MARS project (Coord. S. Lagomarsino & A. Masi)

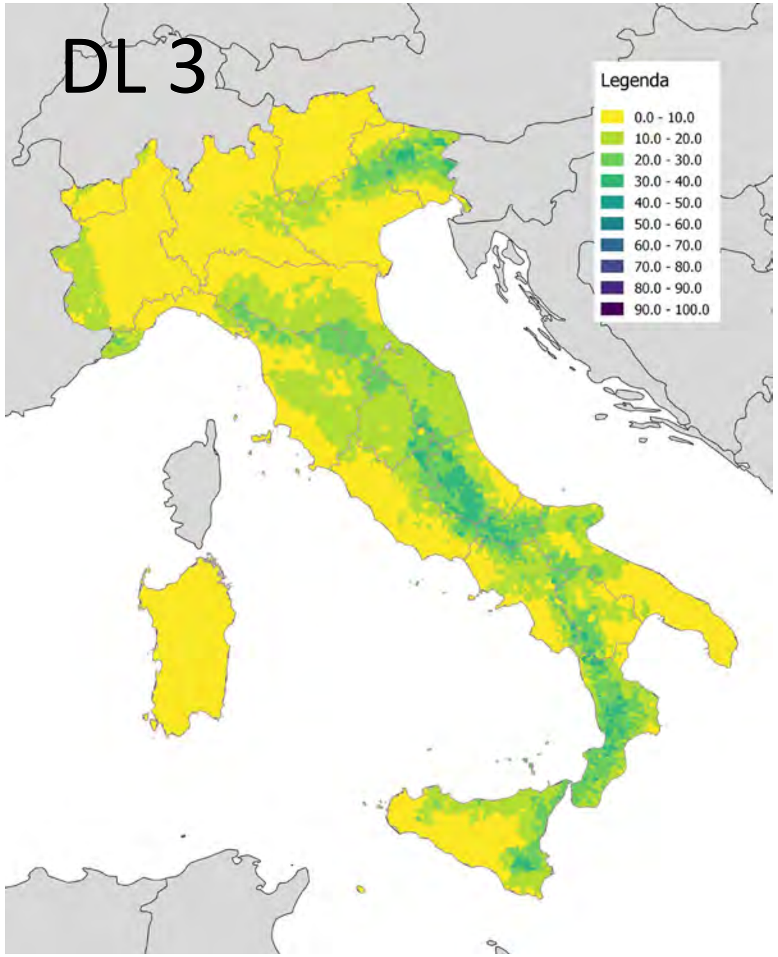
National Risk Assessment (2018) Overview of the potential major disasters in Italy: seismic, volcanic, tsunami, hydro-geological/hydraulic, extreme weather, droughts and forest fire risks, Presidency of the Council of Ministers Italian Civil Protection Department.

Dolce et al. (2019) Seismic risk maps for the Italian territory, XVIII ANIDIS Conference, Ascoli Piceno 2019

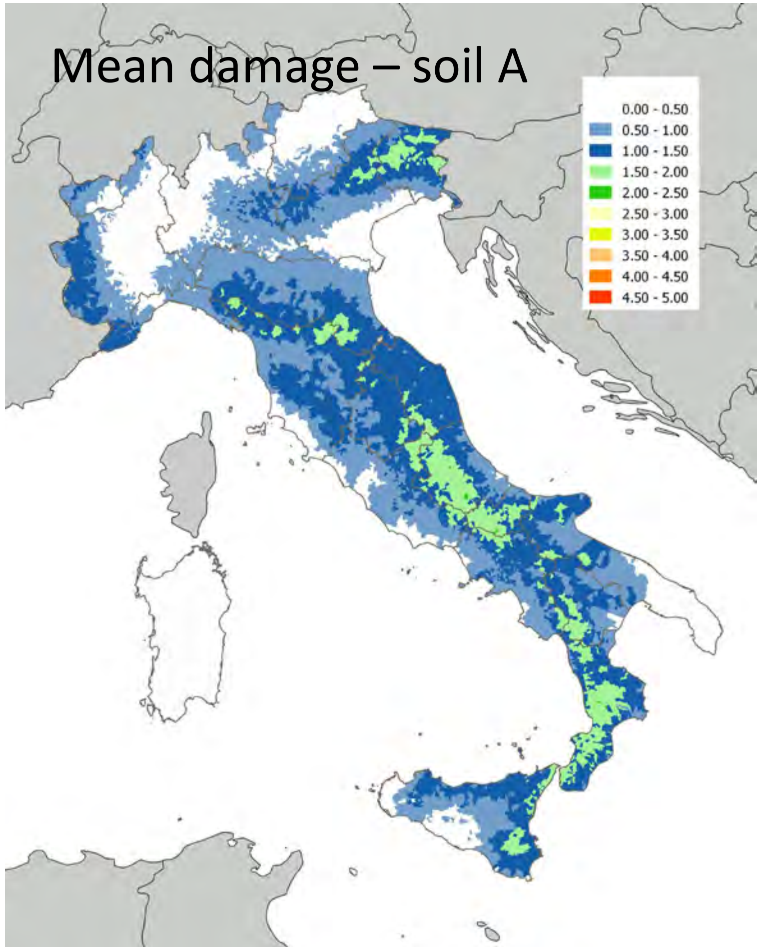
EXAMPLES OF MAPS THAT CAN BE PRODUCED
(through the implementation of the macroseismic model developed by UNIGE)

Classification: MATERIAL – AGE – HEIGHT

Scenario conditioned to 475 years – soil A



Scenario unconditioned to 1 year



ReLUIS-DPC Project: Italian seismic risk map (2018 - ONGOING)

Other research groups partecipated to ReLUIS project (from Padua, Naple, Pavia) by defininig fragility curves through different approaches (empirical, hybrid mechanical-based)

The result of maps in terms of **damage scenario** have been used to assess also the **expected LOSSES**

It requires the introduction of proper correlation laws

EXAMPLES of correlation laws between the DAMAGE LEVELS and:

CASUALTIES

Loss of life or serious injury

Perdite umane	D4	D5
Vittime	1 %	10 %
Feriti	5 %	30 %

MESSINA 1908

USABILITY

SAFE FOR USE/NOT SAFE FOR USE/COLLAPSE

Livello di danno	D1	D2	D3	D4	D5
Agibili	100	60	0	0	0
Inagibili b.t.	0	40	40	0	0
Inagibili l.t.	0	0	60	100	0
Crolli	0	0	0	0	100

IRPINIA 1980

DIRECT ECONOMIC LOSS

RECONSTRUCTION COSTS

CU (€/m^2)	D1	D2	D3	D4	D5
1350	2	10	30	60	100

REF. Dolce et al. (2019) Seismic risk maps for the Italian territory, XVIII ANIDIS Conference, Ascoli Piceno 2019

ReLUIS-DPC Project: Italian seismic risk map (2018 - ONGOING)

Other research groups partecipated to ReLUIS project (from Padua, Naple, Pavia) by defininig fragility curves through different approaches (empirical, hybrid mechanical-based)

RESULT FROM THE UNCONDITIONED EVALUATION AT 1 YEAR

CASUALTIES

	Vittime	Feriti	Senzatetto
Media	505	1.744	78.602
Massimo	763	2.588	131.952
Minimo	123	469	4.0381

DIRECT ECONOMIC LOSS
RECONSTRUCTION COSTS

COST in Billions

USABILITY

	Costi	Inagibili b.t.	Inagibili l.t.
Media	2,13	20.938	15.635
Massimo	3,27	31.847	22.024
Minimo	1,27	9.962	7.404

RESONABLE NUMBERS IF COMPARED WITH THE EARTHQUAKE HYSTORY OF LAST 50 YEARS IN ITALY BUT **SIGNIFICANT DISPERSION** DUE TO DIFFENCES IN VARIOUS MODELS ADOPTED

RESEARCH ONGOING IN 2019 WITHIN MARS – ReLUIS PROJECT

REF. Dolce et al. (2019) Seismic risk maps for the Italian territory, XVIII ANIDIS Conference, Ascoli Piceno 2019

THANK YOU FOR YOUR KIND ATTENTION

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