Empirical fragility curves for Italian residential buildings

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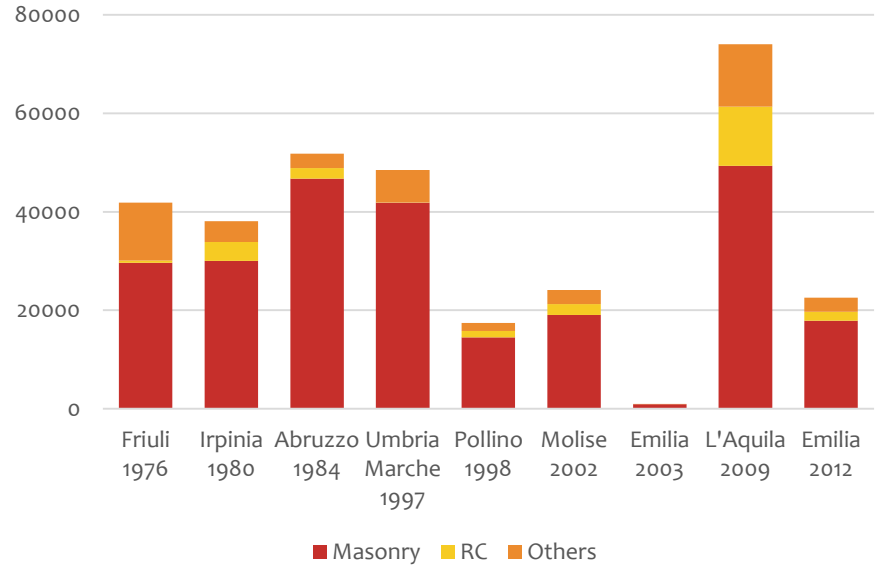
Damage database: Da.D.O. platform

	Masonry buildings	RC buildings	Others buildings	TOT
Friuli 1976	29641	469	11742	41852
Irpinia 1980	30033	3868	4178	38079
Abruzzo 1984	46763	2092	2962	51817
Umbria- Marche 1997	41852	50	6623	48525
Pollino 1998	14515	1285	1642	17442
Molise 2002	19086	2206	2849	24141
Emilia 2003	899	0	112	1011
L'Aquila 2009	49365	12019	12665	74049
Emilia 2012	17881	1795	2878	22554
TOT	250035	23784	45651	319470



The Da.D.O. platform collects post-earthquake damage databases of nine seismic events occurred in Italy, from Friuli 1976 to Emilia 2012. On the whole, data on slightly more than 300.000 are available, with approximately 80% of masonry buildings, 8% of RC buildings and the remaining part made of other typologies.

Among all of the abovementioned events, available data differ for type and detail of information on damage (e.g., assumed damage scale, presence or not of information on damage extent and/or on damage to nonstructural components).

Dolce, M., Speranza, E., Giordano, F., Borzi, B., Bocchi, F., Conte, C., ... & Pascale, V. (2017). Da. DO – A web-based tool for analyzing and comparing post-earthquake damage database relevant to national seismic events since 1976. In Atti del XVII Convegno ANIDIS L'ingegneria Sismica in Italia (pp. 347-357). Pisa University Press.

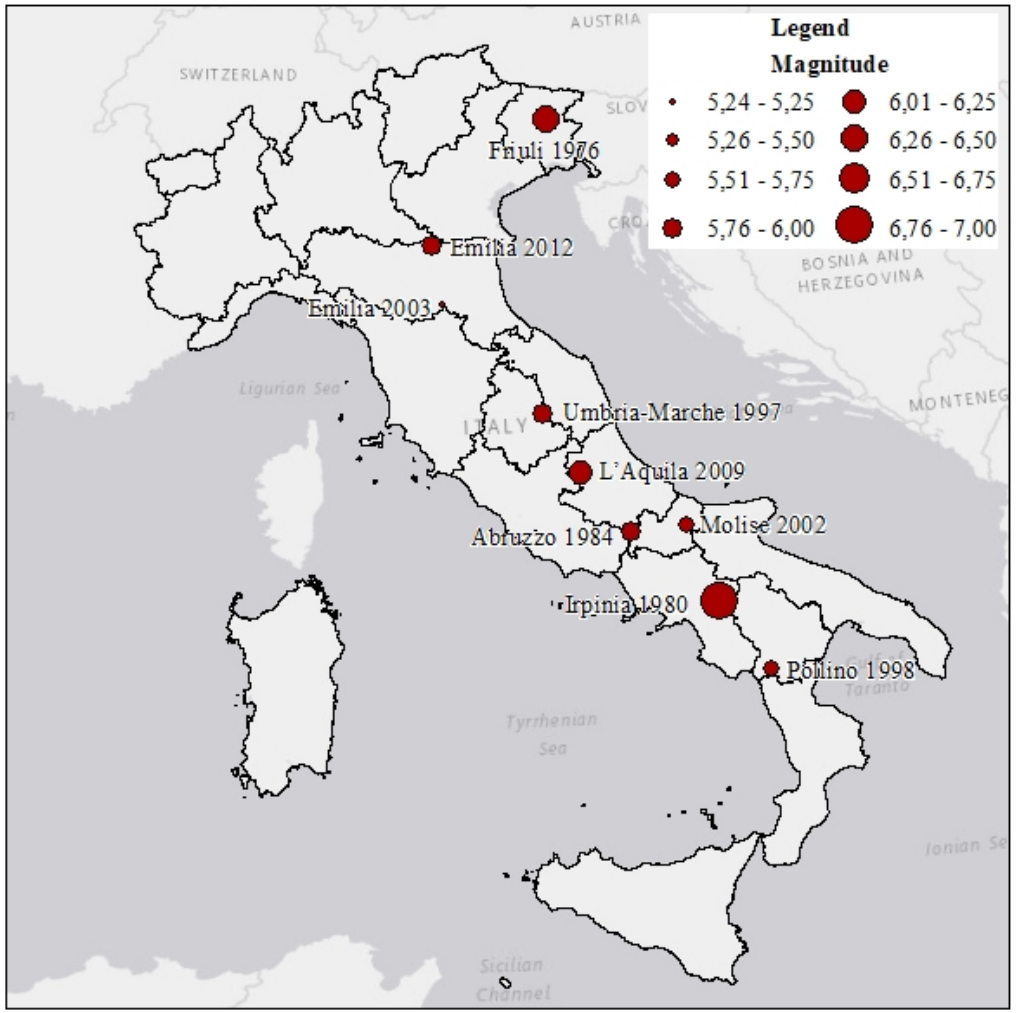
Damage database: Da.D.O. platform

Seismic Event	Survey form	Damage levels	Damage extension	Damage to different building components
Friuli 1976	Friuli	5+1	No	No
Irpinia 1980	Irpinia	7+1	No	5
Abruzzo 1984	Abruzzo	5+1	No	5
Umbria-Marche 1997	AeDES 09/97	3	Yes	3
Pollino 1998	AeDES 06/98	3+1	Yes	5
Molise 2002	AeDES 05/00	3+1	Yes	5
Emilia 2003	AeDES 05/00	3+1	Yes	5
L'Aquila 2009	AeDES 06/08	3+1	Yes	5
Emilia 2012	AeDES 06/08	3+1	Yes	5

The attribution of damage depends on the survey form that was used after the different seismic events.
Irpinia 1980 form considers (7+1) damage levels, whereas Abruzzo 1984 form (5+1) damage levels.
Starting from the Umbria-Marche 1997 event, the first level AeDES survey form for post-earthquake damage and usability assessment was adopted (Baggio et al., 2007). The latter considers (3+1) damage levels.
Moreover, starting from Irpinia 1980, the damage is reported for three or more structural components, while only from Umbria-Marche 1997 also the damage extension is considered.

Baggio C., Bernardini A., Colozza R., Coppari S., Corazza L., Della Bella M., Di Pasquale G., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F., Zuccaro G. (2007). Field manual for post-earthquake damage and safety assessment and short term countermeasures (Pinto A, Taucer F eds), Translation from Italian: Goretti A, Rota M, JRC Scientific and Technical Reports, EUR 22868 EN-2007.

Characteristics of considered seismic events

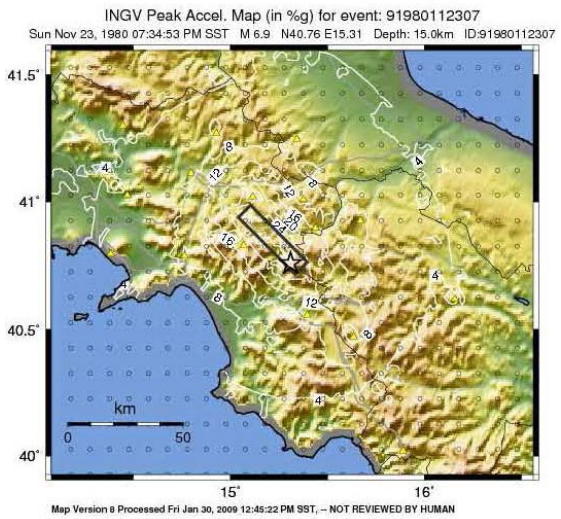


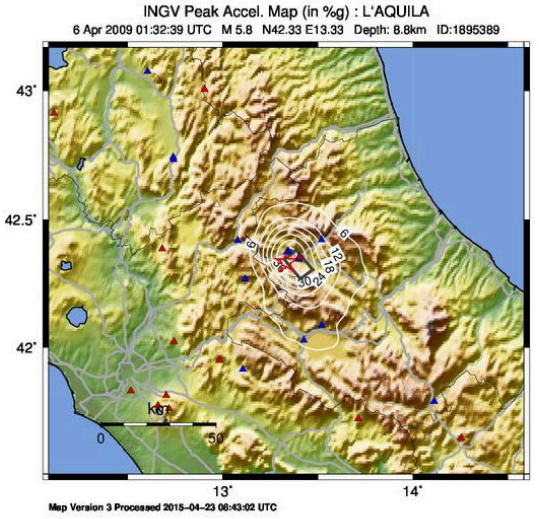
Events	Date	Time	M_w	M_l	Depth	Lat	Lon	$I_{MCS,max}$
Friuli 1976	06-mag-76	19.00.12	6.45			46.241	13.119	IX
Irpinia 1980	23-nov-80	18.34.52	6.81			40.842	15.283	IX
Abruzzo 1984	07-mag-84	17.50.00	5.86			41.667	14.057	VIII
Umbria-Marche 1997	26-set-97	09.40.26	5.97		9.8	43.014	12.853	IX
Pollino 1998	09-set-98	11.28.00	5.53		29.2	40.060	15.949	VII
Molise 2002	31-ott-02	10.32.59	5.74		25.1	41.716	14.893	VIII
Emilia 2003	14-set-03	21.42.53	5.24		8.3	44.255	11.380	VII
L'Aquila 2009	06-apr-09	01.32.40	6.10	5.90	8.0	42.340	13.380	IX
Emilia 2012	20-mag-12	02.03.50	5.80	5.90	10.0	44.900	11.260	VII

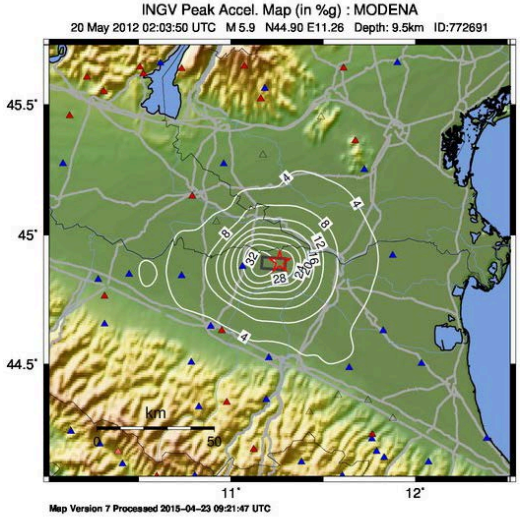
The seismic events included in the Da.D.O. platform are characterized by mainshock having moment magnitude $M \geq 5$. Main information on such earthquakes are derived from the National Centre for Earthquakes of INGV (http://cnt.rm.ingv.it/) and are coherent with parametric catalogues for Italian earthquakes CPT11 and CPT15. The information include date and time of the event, Magnitude (M_L and M_W), geographic coordinates of the epicenter and depth of the hypocenter

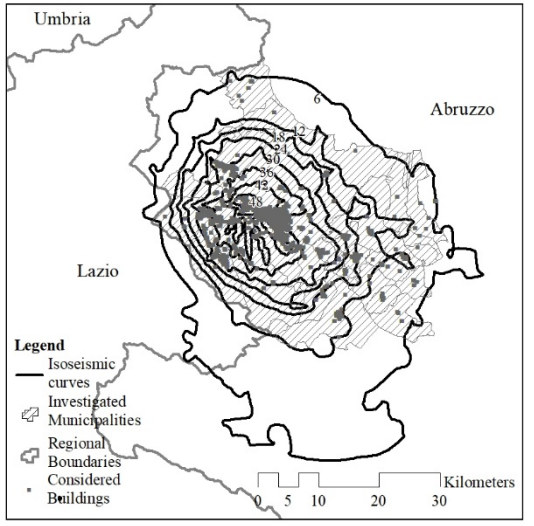
Characteristics of considered seismic events

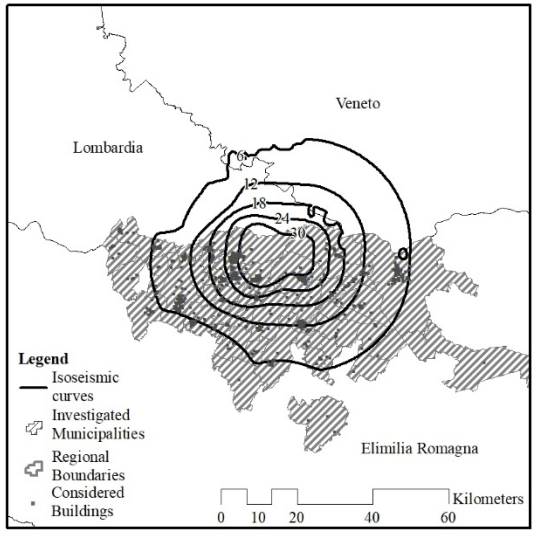
The methodology adopted by INGV to derive a ShakeMap of the event makes use of the software package ShakeMap® and adopts different Ground Motion Prediction Equations (Michelini et al., 2008) to determine peak ground motion parameters (e.g., PGA, PGV and PSA for different periods of vibration). As a matter of fact, the seismic events are registered by the digital strong-motion stations operated by Italian Strong Motion Network (*Rete Accelerometrica Nazionale*, RAN) managed by DPC and by the broad-band stations of the INGV itself.









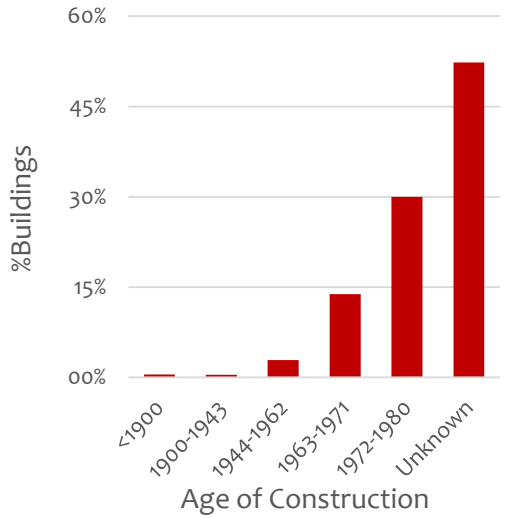


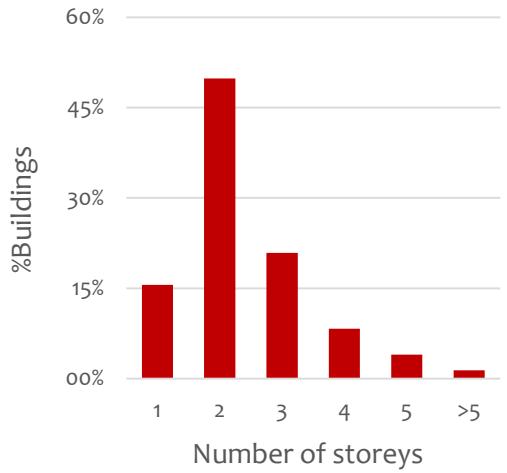
Michelini, A., Faenza, L., Lauciani, V., & Malagnini, L. (2008). ShakeMap implementation in Italy. Seismological Research Letters, 79(5), 688-697.

Description of complete damage datasets

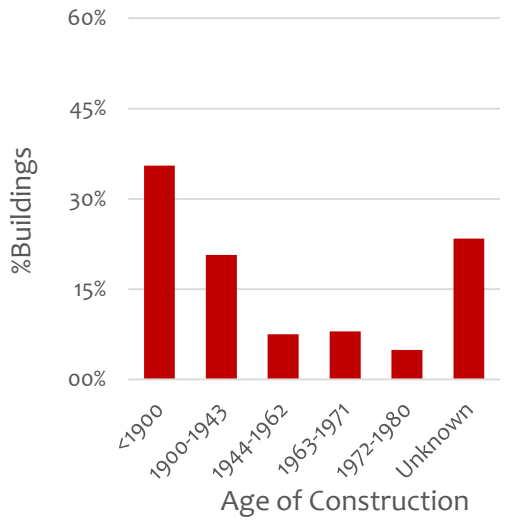
Irpinia 1980 Database

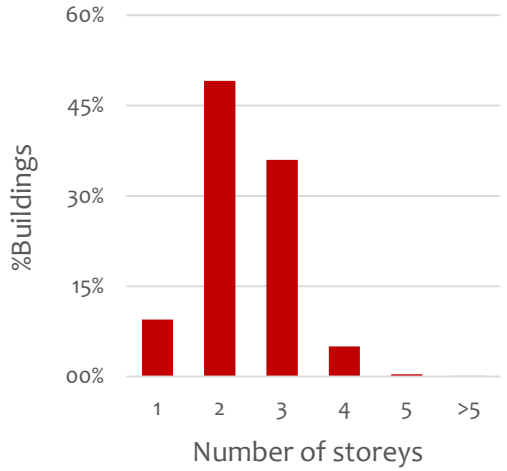
RC





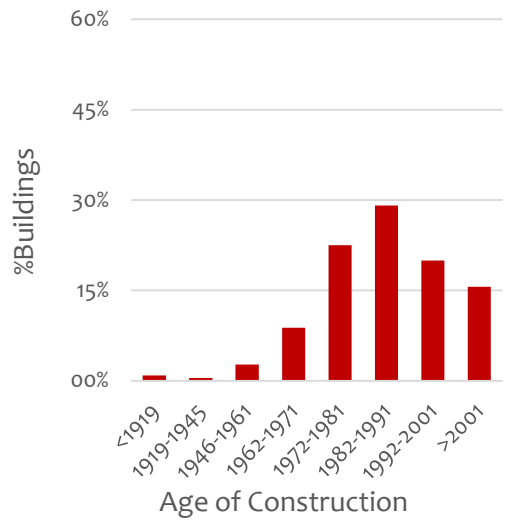
Masonry

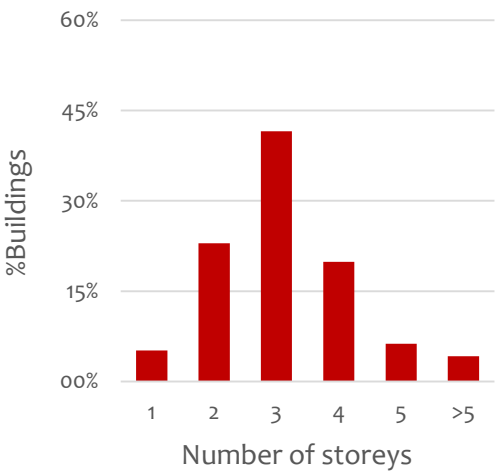




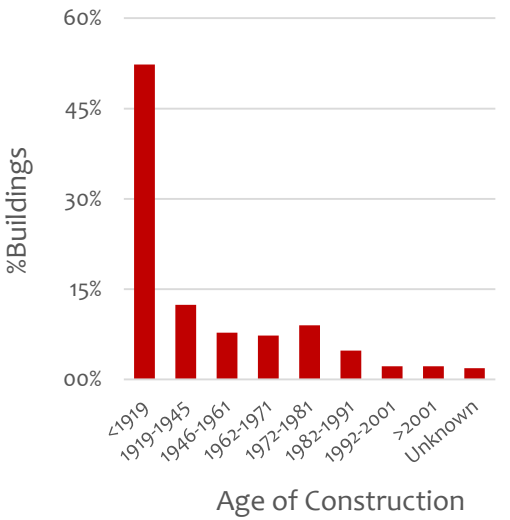
L'Aquila 2009 Database

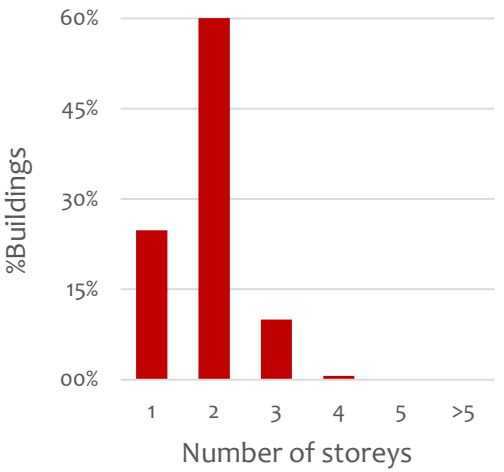
RC





Masonry





Damage scale definition according to EMS98

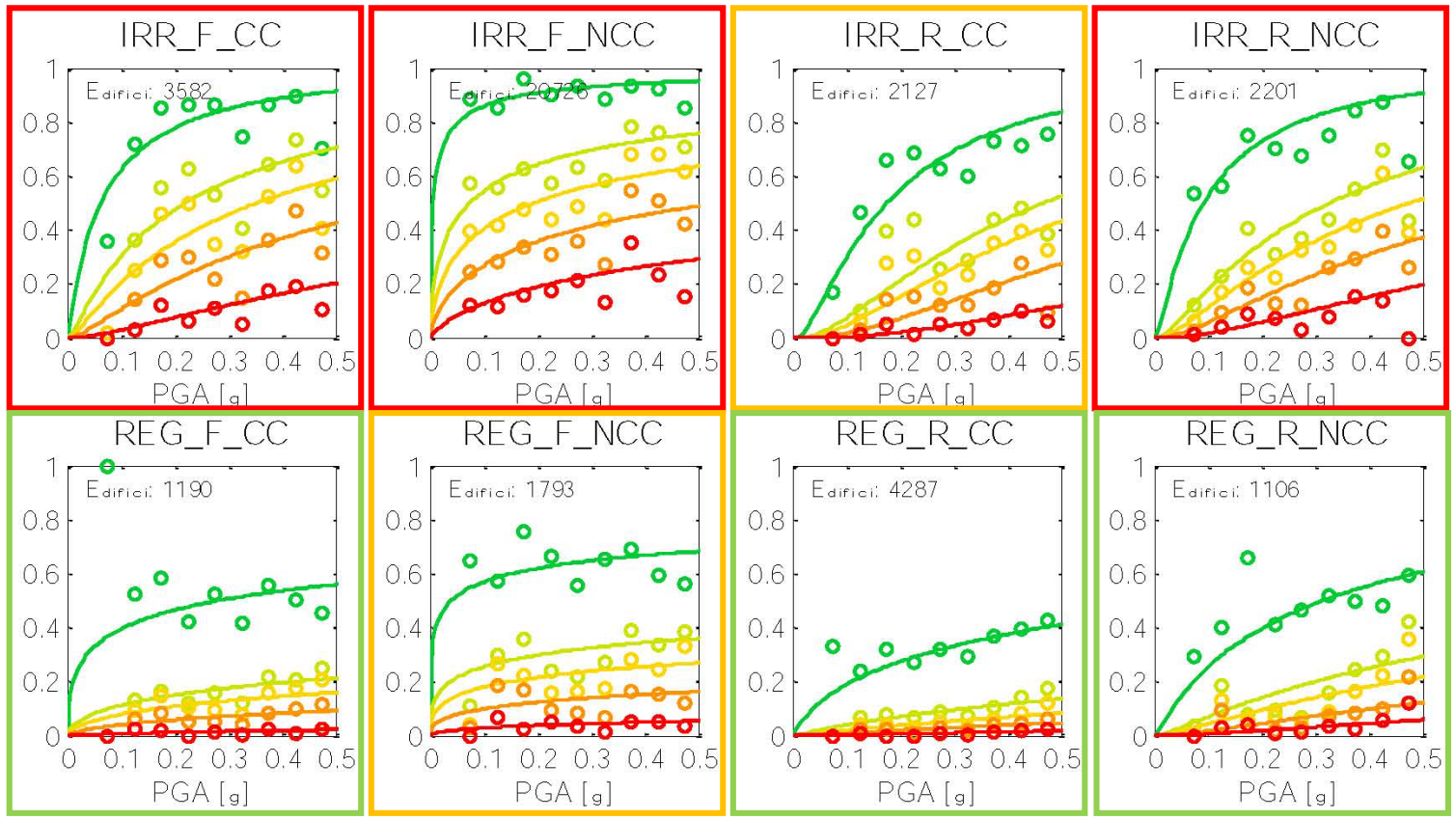
The homogenization is performed converting the damage levels relative to the survey form utilized for the specific seismic event to the damage metric introduced in EMS98 (Grunthal, 1998).
Damage states were defined consistently with the European Macroseismic Scale EMS-98. To this aim, a global damage level was assigned to each inspected building, in accordance with the damage conversion rules proposed by Rota et al. (2008) and Del Gaudio et al. (2017), considering the maximum level of damage observed on preselected building components.

DANNO		
SCHEDA IRPINIA	Struttura	Tamponat
L1 - Nessun Danno	DS0	DS0
L2 - Irrilevante - Riparazione non urgente	DS1	DS1
L3 - Lieve - Da Riparare	DS1	DS1
L4 - Notevole - Da sgombrare parz. - Riparabile	DS2	DS2
L5 - Grave - Da sgombrare - Riparabile	DS3	DS3
L6 - Gravissimo - Da sgombrare e demolire	DS4	DS3
L7 - Crollato parzialmente - Da demolire	DS5	DS3
L8 - Distrutto	DS5	DS3

DANNO			
SCHEDA		Struttura Verticale	Tamponature/ Tramezzi
AEDES L'AQUILA			
Nullo		DS0	DS0
D1 leggero	<1/3	DS1	DS1
	1/3 – 2/3	DS1	DS1
	>2/3	DS2	DS1
D2 Medio-grave	<1/3	DS2	DS2
	1/3 – 2/3	DS3	DS2
	>2/3	DS3	DS2
D4-D5 gravissimo crollo	<1/3	DS4	DS3
	1/3 – 2/3	DS4	DS3
	>2/3	DS5	DS3

Grünthal G. (1998). Cahiers du Centre Européen de Géodynamique et de Séismologie: Volume 15 – European Macroseismic Scale 1998. European Center for Geodynamics and Seismology, Luxembourg.
Del Gaudio C., De Martino G., Di Ludovico M., Ricci P., Verderame G.M. (2016) Empirical fragility curves from damage data on RC buildings after the 2009 L'Aquila earthquake. Bull Earthquake Eng (2017) 15: 1425. https://doi.org/10.1007/s10518-016-0026-1
Rota M., Penna A., and Strobbia C.L. (2008). Processing Italian damage data to derive typological fragility curves. Soil Dynamics and Earthquake Engineering, 28.10: 933-947.

Typological fragility curves for masonry buildings

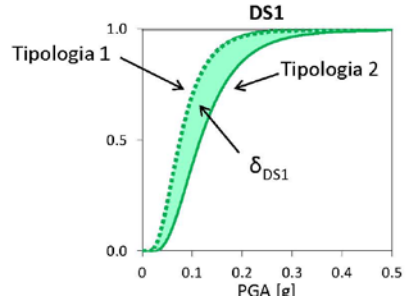


Starting from the eight masonry building typologies, identified based on the *(i)* layout and quality of the masonry fabric, *(ii)* in-plane flexibility of diaphragms and *(iii)* presence of connecting devices an agglomerative hierarchical clustering is performed aiming at the definition of three vulnerability classes (A, B and C1).

Metrica:

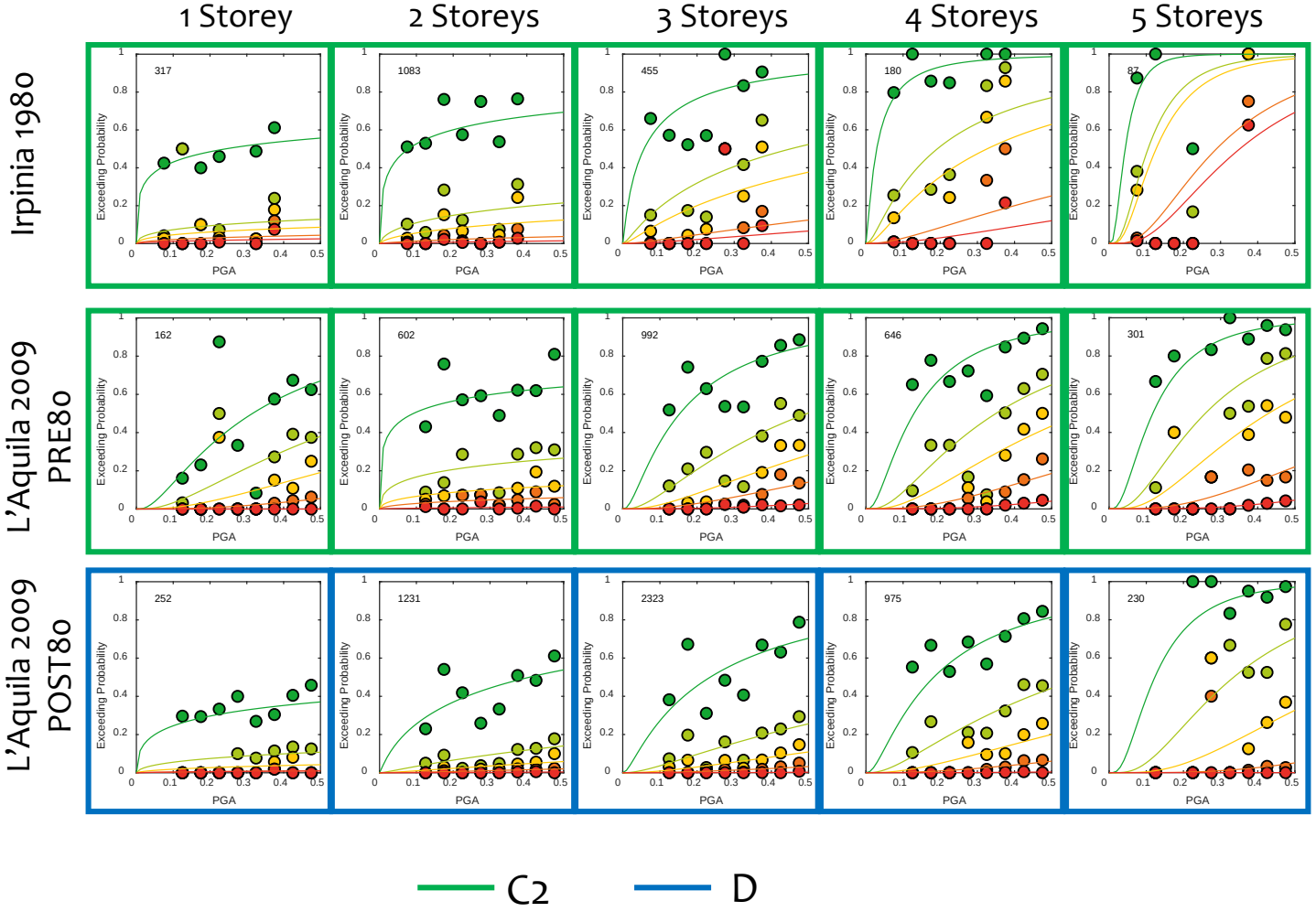
$$\delta_{DS_k}^{ij} = \int_{x=0}^{0.5} \left| F\left(x|\mu_{DS_k}^{i}, \sigma_{DS_k}^{i}\right) - F\left(x|\mu_{DS_k}^{j}, \sigma_{DS_k}^{j}\right) \right| dx$$

$$d^{ij} = \sqrt{\sum_{k=1}^{5} \left(\delta_{DS_k}^{ij}\right)^2}$$



The fragility curve was expressed as a linear combination of the 8 classes which coefficients, representing the fractions of each typology, were obtained by solving an optimization problem.

Typological fragility curves for RC buildings

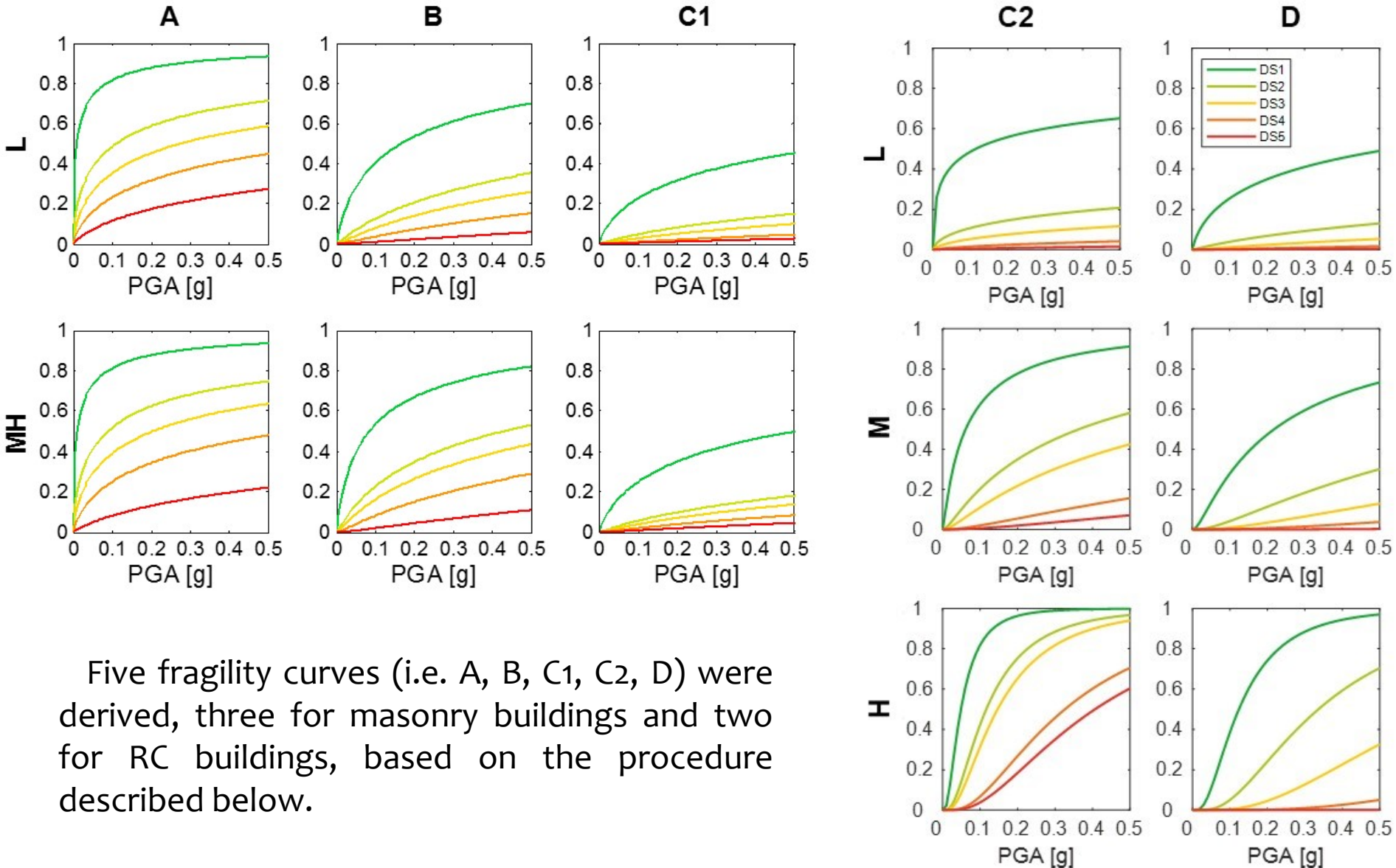


Fragility curves showed a clear hierarchy with *(i)* structural typology (gravity and seismic design), *(ii)* age of construction and *(iii)* number of storeys.

Fragility curves for RC buildings were defined for two vulnerability classes, C2 and D. More specifically, buildings designed for gravity loads only or for seismic loads pre-1981 were grouped in class C2, whereas buildings designed for seismic loads post-1981 were assigned to class D.

C2 and D fragility curves were derived as a weighted average of the abovementioned 15 sets of typological fragility curves, using as weights the probabilities of occurrence of each typology within the corresponding class, evaluated based on ISTAT census data at national scale.

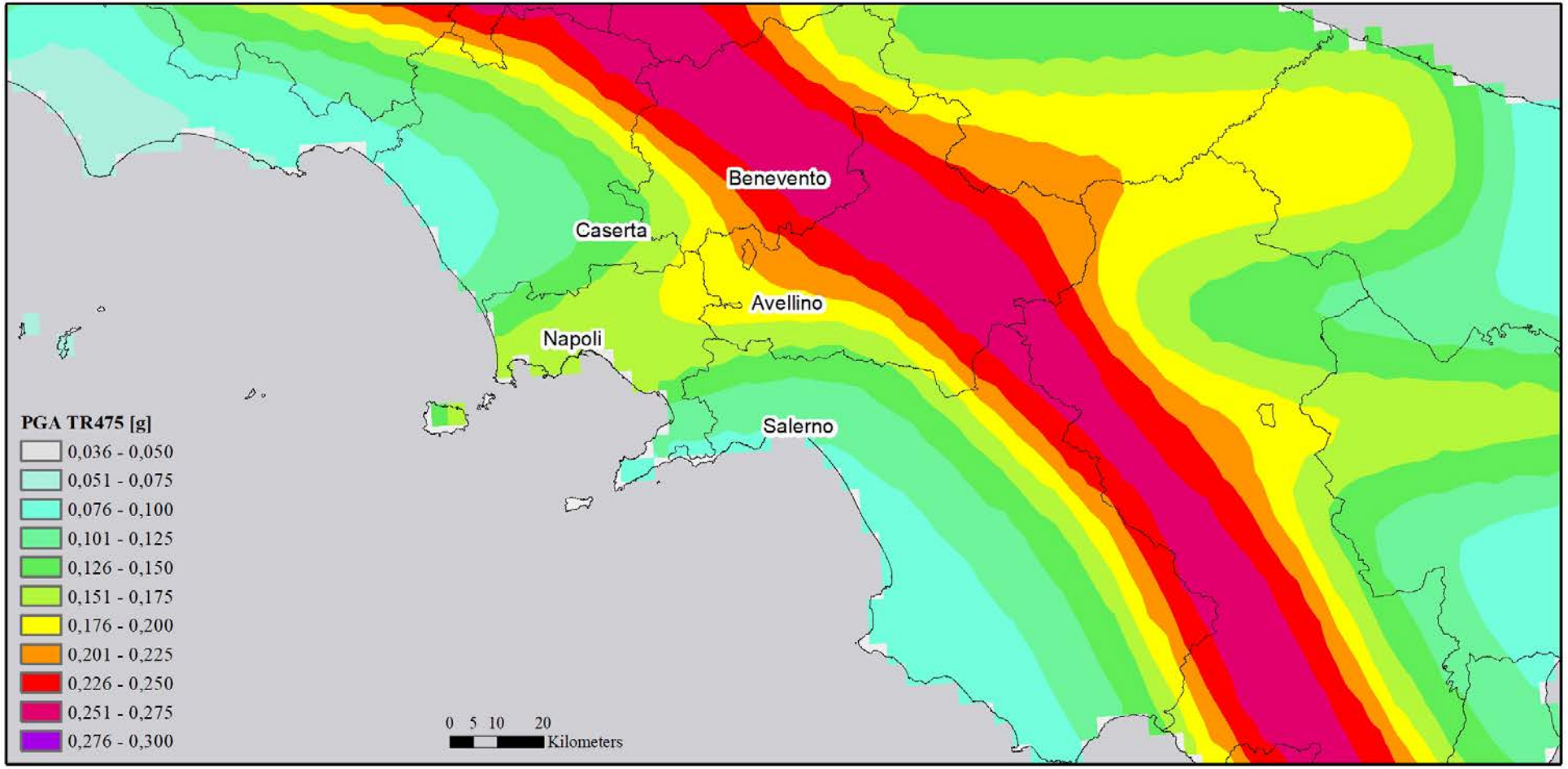
Class fragility curves for damage prediction based on census data



Five fragility curves (i.e. A, B, C1, C2, D) were derived, three for masonry buildings and two for RC buildings, based on the procedure described below.

Example of application to Campania (Southern Italy) region

An application with reference to the Campania region in terms of damage scenario was derived with the PGA demand corresponding to a return period T_R=475 years (Progetto S1) making use of IRMA platform.

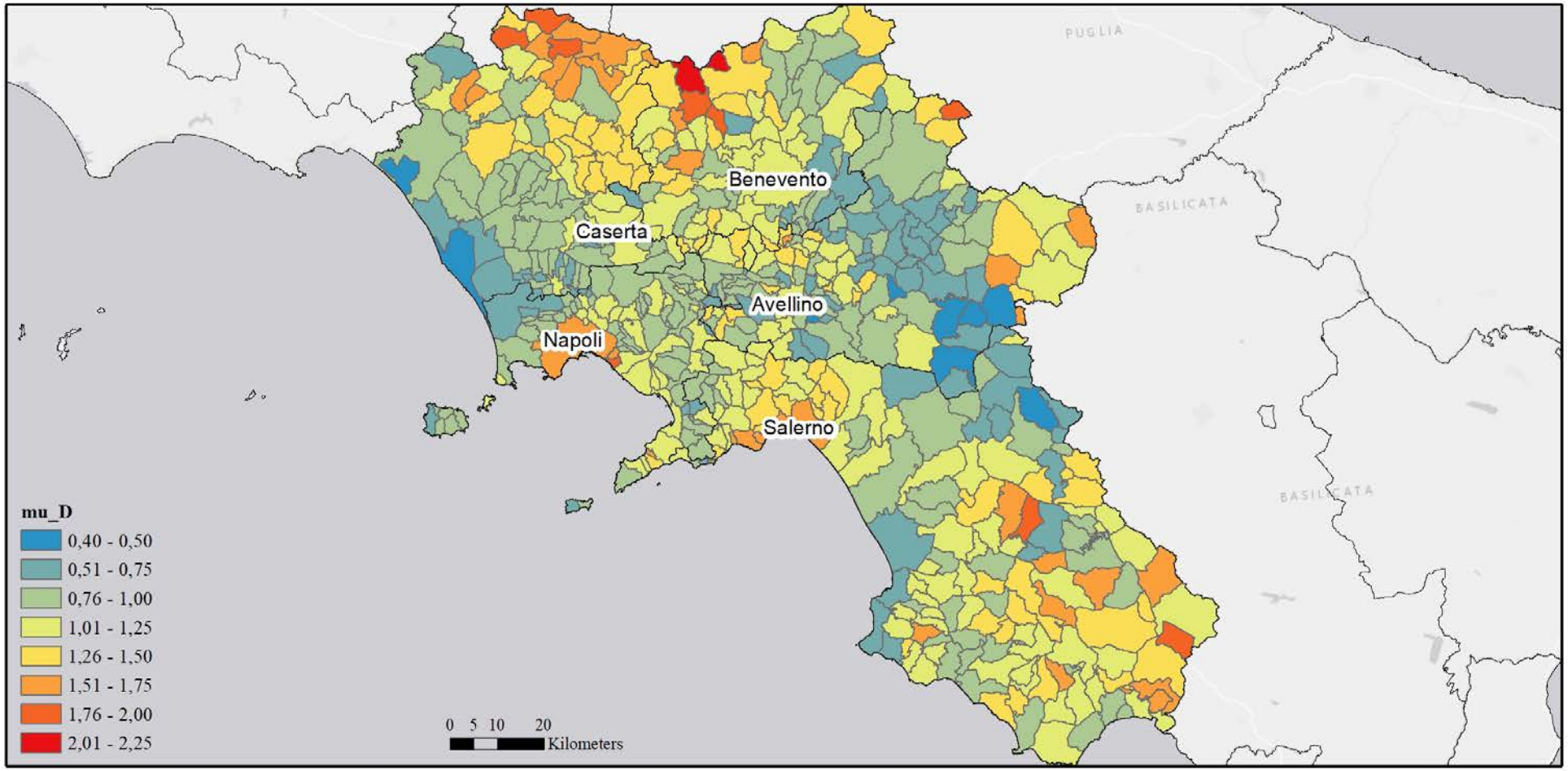


Meletti, C. (2007). Progetto S1. Proseguimento della assistenza al DPC per il completamento e la gestione della mappa di pericolosità sismica prevista dall'Ordinanza PCM 3274/2003 e progettazione di ulteriori sviluppi. Rapporto finale, del Progetto INGV-DPC S1.

Example of application to Campania (Southern Italy) region

For each Municipality the results are illustrated in terms of mean damage (μ_D), i.e. the weighted average of the DS index (from 0 to 5) within a given Municipality.

The territorial distribution of μ_D roughly reflects the distribution of PGA intensity, as expected, except for some cases in the provinces of Avellino and Salerno.



Conclusions and future developments

- Data on observed post-earthquake damage provided by the by the Italian Department of Civil Protection through the online platform Da.D.O. were used to derive empirical fragility curves for classes of masonry and RC residential buildings;

- Damage States were assumed consistent with EMS-98 and damage data were processed accordingly;

- Fragility curves were derived for different building typologies and then for building classes, in accordance with the aim of a national-scale application based on census data.

Future developments

- Considering uncertainty in PGA definition through the use of 16^{th} and 84^{th} percentile provided by (Progetto S1);

- Derive conditional scenario for different return periods or unconditional scenario.

- Derive damage scenario using the fragility curves with reference to whole National territory.

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Dipartimento della Protezione Civile

Dipartimento della Protezione Civile

reluis

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Thank you for attention

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