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Expected losses *vs* earthquake magnitude curves, for seismic risk mitigation and for insurance purposes

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Abstract

Nowadays, seismic risk is matter of concern for public authorities and private entities since numerous fatalities and significant economic losses can be caused by a seismic event. In this context, the present study aims to simulate all the possible seismic events that can potentially occur in North-eastern Italy in order to derive the potential economic losses as function of the earthquake's epicenter and magnitude. To this end, an analysis of the residential building stock aimed at developing a suitable taxonomy class for the definition of the structural vulnerability is herein developed and presented. Results are provided in term of loss maps, that show the loss associate di a given earthquake occurring in a specific location. These maps allow risk practitioners to derive for each location a curve showing the behaviors of seismic losses as function of the earthquake magnitude, and represent the first national attempt to represent the seismic susceptibility at local level.

Keywords: Seismic risk, insurance, losses, loss analysis, earthquake, engineering.

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1. Introduction

Seismic risk mitigation involves an accurate analysis of the potential losses to which a territory may be exposed. The major seismic events that have occurred in Italy in recent decades have shown how the Italian built heritage is still characterized by a high structural vulnerability and how medium-high events, relatively frequent throughout the national territory, are sufficient to cause non-negligible losses, both in terms of victims and monetary losses. This essentially derives from two factors: the first regards the increasing exposure deriving from an high urbanization and industrialization (Hofer et al. 2018a), while the second is related to the high vulnerability of a large part of the Italian built heritage (Hofer et al. 2018b), which in many cases is dated and does not comply with current safety standards required by current legislation. Nonetheless, seismic retrofitting is still a relatively uncommon practice, especially for private buildings, being a costly investment and not of immediate benefit. Furthermore, the penetration of insurance coverage for the transfer of risk is still limited throughout the country (Zanini et al. 2015 and Hofer et al. 2015).

In recent years, scientific research at a national level has pushed towards the development of seismic risk maps, capable of providing government bodies with a quantitative picture of the spatial distribution of the same for a nation (Zanini et al. 2019a, Zanini et al. 2019b and Dolce et to 2021). Starting from the calculation of the seismic risk for the national territory, strategies were proposed for the implementation on a territorial scale of a plan for the seismic retrofit of buildings (Zanini et al. 2019a) and also solutions based on the use of CAT bonds for the transfer of risk to the financial market (Hofer et al. 2019 and Hofer et al. 2020). In this context, this work aims to develop loss maps conditioned to a certain magnitude useful for a preventive estimate of the potential losses expected following a seismic event. These maps are therefore useful in terms of emergency management, but also risk mitigation, lending themselves to economic-insurance analysis. This work is part of the European Interreg Crossit Safer Project which involves the Veneto Region and the Friuli-Venezia Giulia Region, together with other Italian and foreign partners. For this reason, the areas of study coincide with the two regions mentioned.

2. Methodology

The exposure model considered in the analysis is the national residential building stock, modelled with a granularity at the municipality-level, based on census data from ISTAT2011 (National Institute of Statistics, 2011). The unitary reconstruction cost (*URC*) is assumed to be homogeneous in the study area and equal to 1200 €/m^2. Fig. 1 shows the exposure model used to calculate the losses, computed as the product of the total built area in each municipality for the URC.

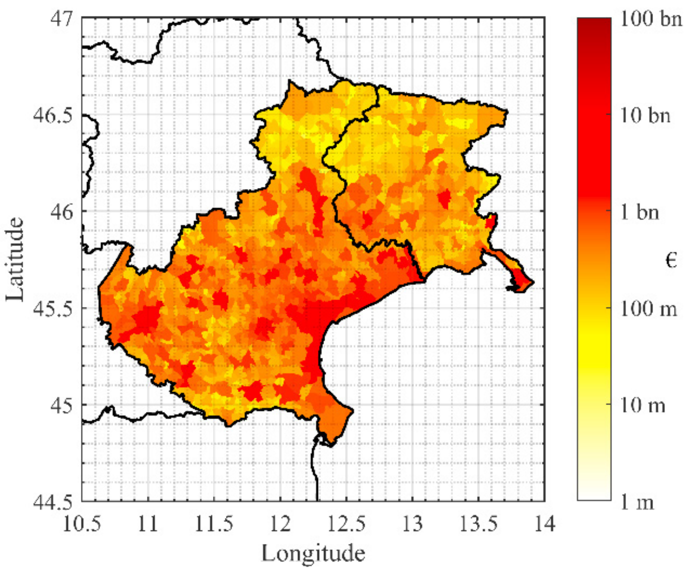

Fig. 1. Exposure map of Veneto and Friuli Venezia-Giulia region.

According to Zanini et al. 2019, a specific taxonomy was defined for characterizing the seismic vulnerability of the residential built stock, consisting in eight taxonomy classes (TCs). According to Kostov et al. 2004, two TCs have been considered for masonry buildings: masonry buildings built before and after 1919. Regarding reinforced concrete (RC) and combined RC-masonry structures, the distinction between gravity-load and seismic-load designed structures has been done comparing the age of construction with the temporal evolution of Italian seismic codes, to know whether or not each municipality was classified as a seismic risk-prone area. Hence, for each municipality, structures built before that year, have been considered gravity-load designed, whereas those built after that year as seismic-load designed. A further subdivision has been also performed both for RC-gravity and RC-seismic buildings, considering the number of stories and thus defining two additional subclasses (1-2 story, more than 3 stories). In addition, two TCs have been considered representative of other mixed structural types, i.e. combined RC-masonry structures. For each TC a suitable set of fragility functions with PGA as reference intensity measure has been assumed between those proposed in literature (Ahmad et al. 2011). Table 1 lists main parameters of the adopted sets of lognormal fragility curves for each of the 8 TCs considered. Fig. 2 shows the distribution of the eight structural categories in each municipality of the study area. In most of cases, residential buildings are made of masonry, in many cases built before 1919.

Table 1. Main parameters of fragility curves for each TC.

#	Taxonomy class	Authors	DS_1		DS_2		DS_3		DS_4	
			ϑ [g]	β	ϑ [g]	β	ϑ [g]	β	ϑ [g]	β
1	Masonry pre 1919	Kostov et al. 2004	0.10	0.79	0.14	0.80	0.17	0.81	0.24	0.80
2	Masonry pre 1919	Kostov et al. 2004	0.12	0.79	0.17	0.81	0.19	0.79	0.33	0.79
3	RC gravity d. (1-2)	Ahmad et al. 2011	0.09	0.33	0.12	0.44	0.25	0.37	0.33	0.36
4	RC gravity d. (3+)	Ahmad et al. 2011	0.08	0.32	0.11	0.43	0.17	0.40	0.22	0.38
5	RC seismic d. (1-2)	Ahmad et al. 2011	0.09	0.33	0.12	0.44	0.24	0.37	0.48	0.36
6	RC seismic d. (3+)	Ahmad et al. 2011	0.08	0.32	0.11	0.41	0.17	0.39	0.31	0.36
7	Other gravity d.	Kostov et al. 2004	0.11	0.79	0.16	0.78	0.27	0.78	0.35	0.79
8	Other seismic d.	Kostov et al. 2004	0.12	0.79	0.19	0.79	0.30	0.79	0.41	0.79

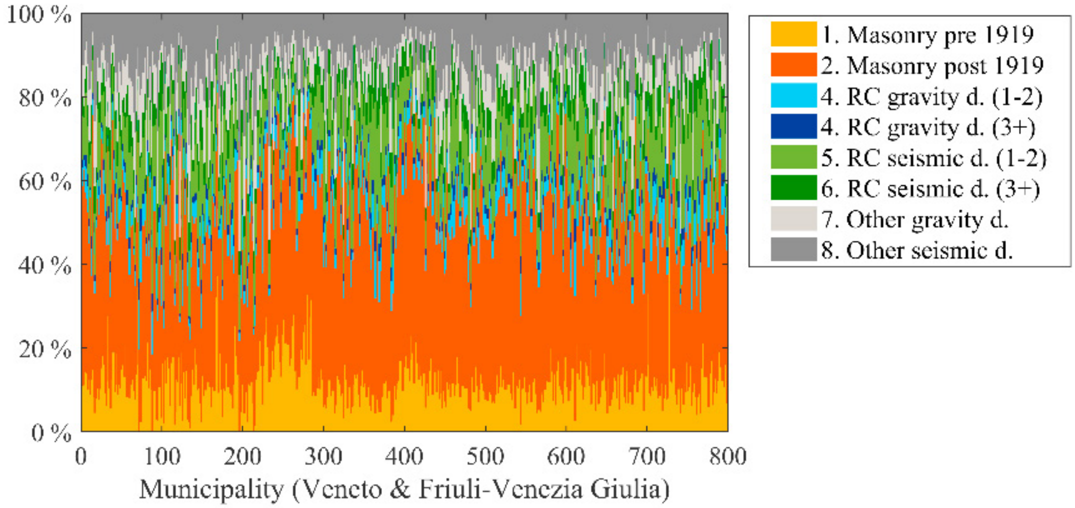

Fig. 2. Taxonomy disaggregation for all the considered municipalities.

For the generation of seismic scenarios, epicenters are arranged on a 5-km mesh grid, falling within the Seismogenic Zones provided by the seismogenic model of Meletti et al. 2008 and around 50 km from the borders of the two regions. The calculation points are represented in blue in Fig. 3. It is assumed that earthquakes cannot occur outside the seismogenic zones and that seismic events with epicenters more than 50 km away from the borders of Veneto and Friuli-Venezia Giulia have a negligible contribution to the calculation of total losses. For the losses computation, 5 levels of increasing damage are considered (DS_0 - no damage, DS_1 - mild damage, DS_2 - moderate damage, DS_3 - extended damage, DS_4 - collapse), and for each of them three sets of repair cost ratio (RCR) percentage values are considered for computing the average value and the lower and upper value of the expected losses (Vettore et al. 2020).

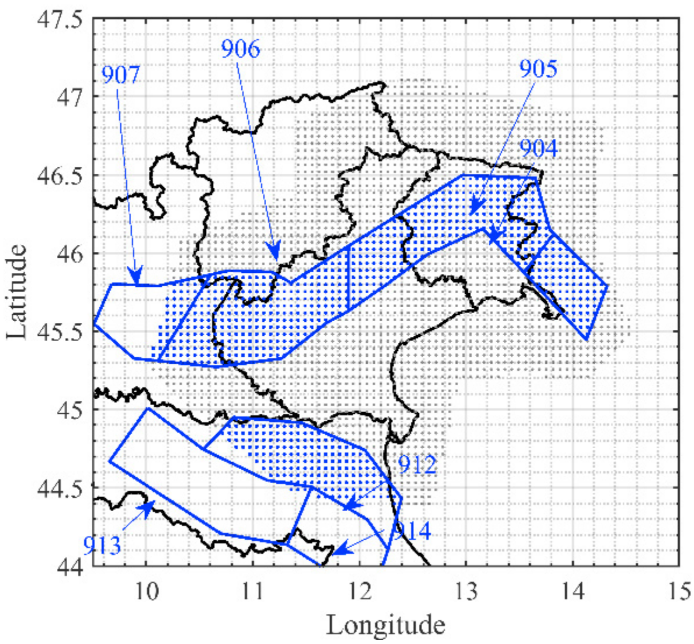

Fig. 3. Epicenters grid and considered Seismogenic Zones.

For each generated scenario, the shaking map is calculated at the municipal centroid through the attenuation law proposed by Bindi et al. 2011, while the subsoil category is obtained from Forte et al. 2019. Eight levels of magnitude are simulated for each epicenter of the grid (4.5, 4.75, 5, 5.25, 5.5, 5.75, 6, 6.5). According to Barani et al. 2009 only in zones 905 and 906 can the magnitude of 6.5 be reached; however, to obtain complete and comparable maps, M_W = 6.5 was also simulated in the other seismogenic zones. A total of 20’136 scenarios is thus generated, deriving from 8 simulated magnitudes in each of the 839 calculation points with 3 different sets of RCR.

3. Results and discussion

Fig. 4 shows the analysis results. In particular, each point of Fig. 4 represents the loss caused by an earthquake of a certain magnitude occurring in a specific epicenter.

Therefore, thanks to these maps, it is possible to derive the direct damage associated with each potential earthquake in the study area. Higher losses occur where the exposure is higher. Starting from a M_W = 5, in the areas of the seismogenic zones with the greatest exposure, losses in the order of one billion euros are reached. For greater magnitude, Fig. 5 provides the expected losses also in terms of percentage loss on the total exposed value, respectively of € 327 billion for the two regions, divided into € 261 billion for Veneto and 66 billion € for Friuli -Venice Giulia. These non-dimensional loss values are particularly useful for practitioners who want to adopt different reconstruction costs and property values. Finally, from the calculated maps it is possible to derive curves that express the expected potential losses as a function of a given seismic event magnitude occurring in a specific location of the regional territory.

Fig. 6 shows these curves for two possible epicenters; the first one near Vittorio Veneto (12.2669, 45.9341 - TV) and the second one near Tramonti (12.7841 - 46.2952 - PN). These curves represent the total losses that the two regions should face in case of seismic events located in those specific positions. It is worth noting the significant influence of exposure in the calculation of expected loss, that, for an earthquake of $M_W = 5$, can reach 2.9 billion € in the case of the first epicenter, while they stop at 500 million for the second one. Furthermore, Fig. 6 shows the effect of adopting different sets of RCRs.

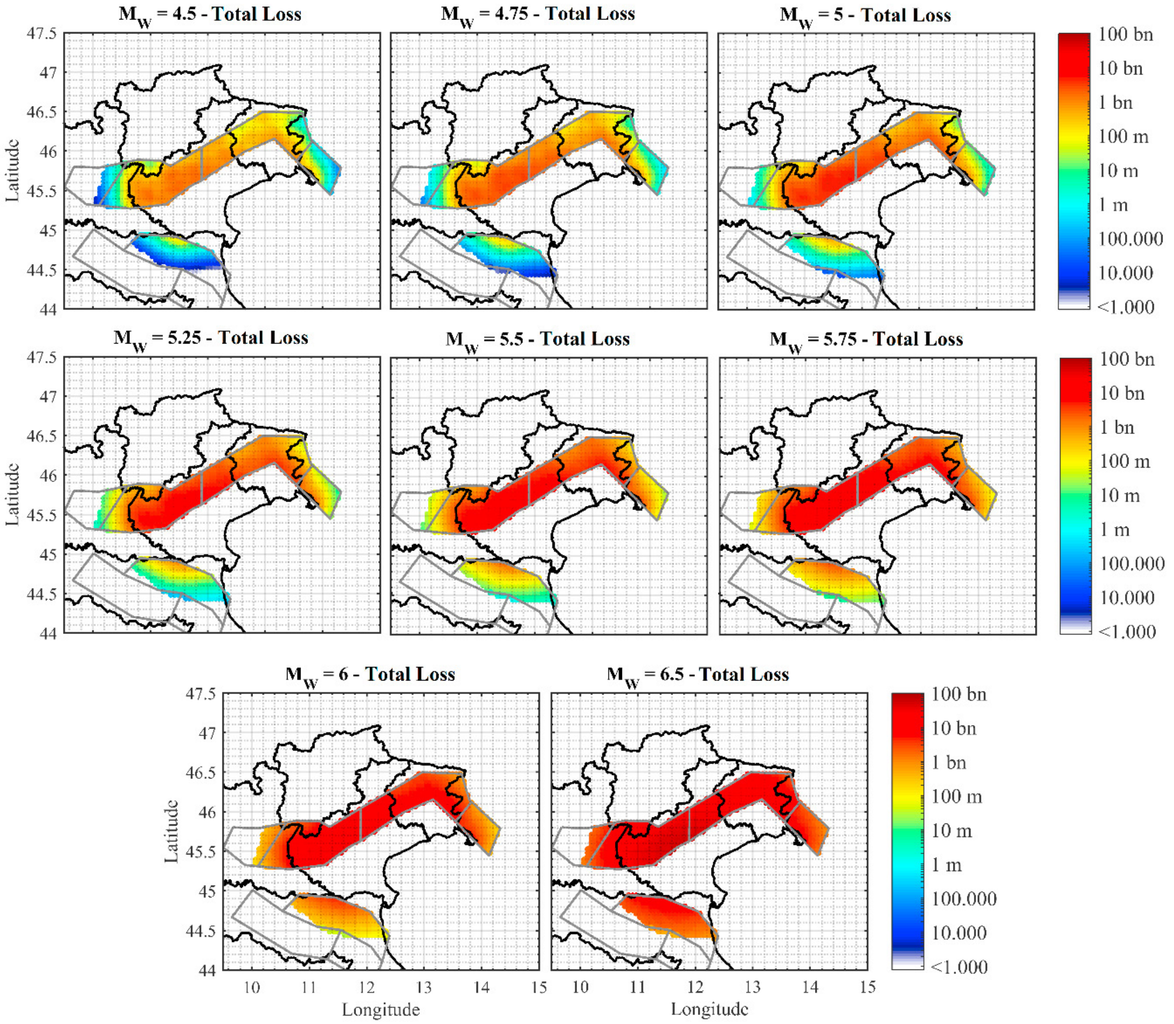

Fig. 4. Total losses for different magnitude values.

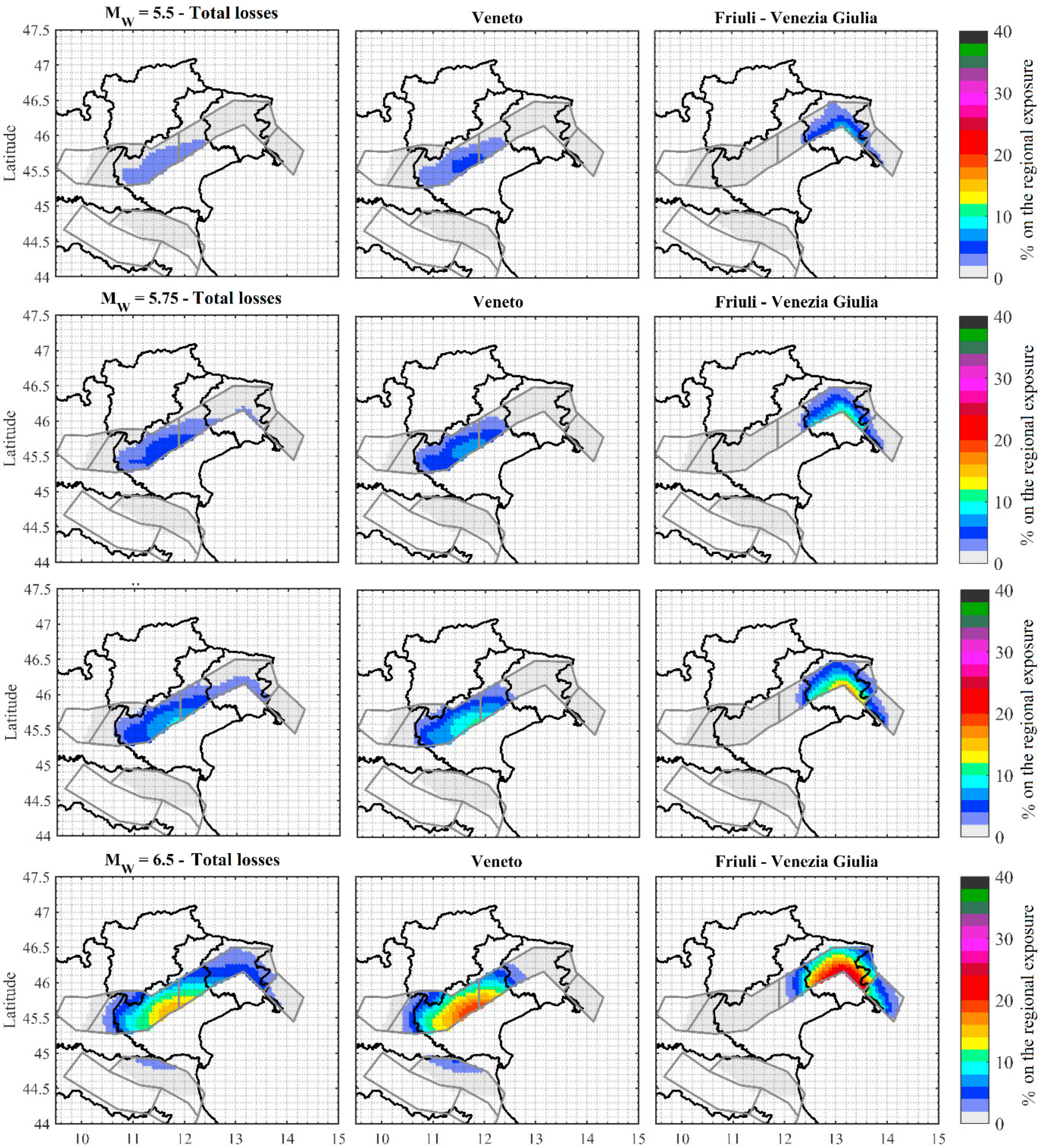

Fig. 5. Total losses in percentage term on the total exposed value (respectively 327, 261 and 66 billion €).

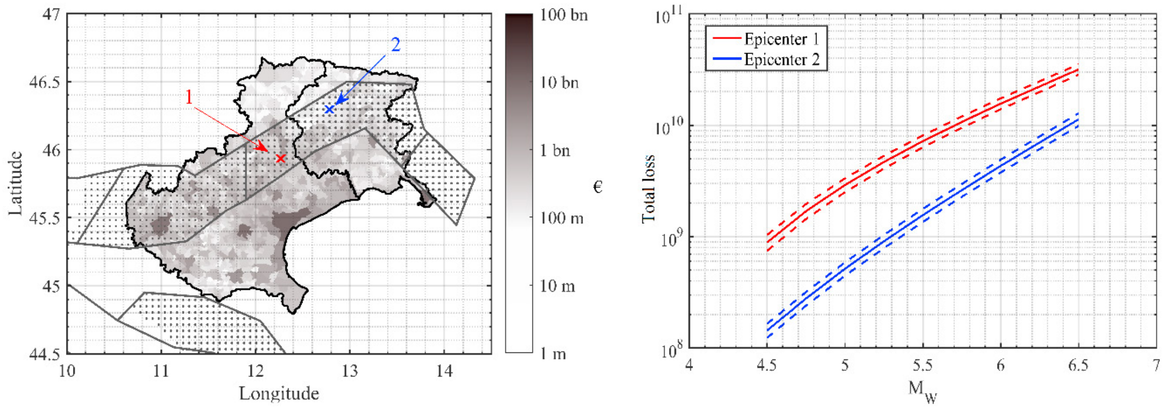

Fig. 6. Magnitude *vs* Loss curve for two epicenters locations.

4. Conclusions

The present work aimed at developing loss maps conditioned to a certain magnitude useful for a preventive estimate of the potential losses expected following a seismic event. These maps are therefore useful in terms of emergency management, but also risk mitigation, lending themselves to economic-insurance analysis. The results of this word are part of the European Interreg Crossit Safer Project which involves the Veneto Region and the Friuli-Venezia Giulia Region, together with other Italian and foreign partners.

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