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The cost of insuring Italy's residential buildings for earthquake under alternative models of seismic hazard

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The cost of insuring Italy's residential buildings for earthquake under alternative models of seismic hazard

Riccardo Cesari[(a)] and Leandro D'Aurizio[(b)*]

Abstract

Almost two decades have passed since the publication of Italy's official model of seismic risk (MPS04) by the National Institute of Geophysics and Volcanology (INGV). A proposed revision of the model (MPS19) is still waiting the official approval. Meanwhile, an alternative approach was recently proposed in the geo-physical literature (REASSESS) taking fully into account the soil characteristics. Moreover, in 2023 the INGV has officially updated its method of converting the earthquake's physical measures into an evaluation of macro-seismic intensity.

Using only publicly available data, we exploit these major advancements by applying this INGV's new method to the three models of seismic risk. We then use the hazard probabilities to derive the complete insurance indicators that assess the cost of protecting all Italy's housing units under different scenarios. The inclusion by REASSESS of soil effects produces a riskier picture of the vulnerability of Italy's houses with respect to the MPS04 baseline model, whereas the results obtained with MPS19 are much less worrying. Overall, the price for insuring all the Italian houses against seismic risk under a certain level of mutuality appears to be sustainable for Italian household.

JEL codes: G22
Keywords: earthquake, seismic risk, hazard, exceedance loss, insurance pricing.

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1. Introduction*

A commonly accepted approach to measure the damages of natural risks (Poljanšek et al., 2017, cap. 2) defines their values as the product of three factors: 1) the probability distribution of events (hazard), 2) the exposure value of constructions, 3) the vulnerability measure of buildings.

Following this method, we aim to evaluate the probabilistic hazard of Italy' seismic risk, the most relevant physical peril for the country (EIOPA, 2023), and to assess the cost of insuring against it all the Italian residential buildings.

We assess this hazard on the extensive grids of spatial points used by the Italian National Institute of Geophysics and Vulcanology (INGV) to evaluate seismic risk.[1]

Our starting point is the evaluation of Peak Ground Acceleration (PGA), a physical measure of ground shaking in different micro-areas, expressed as a percent of g (the acceleration due to Earth's gravity, amounting to 9.81 meters per second squared, m/s2). We use:

1) the PGA publicly available on the INGV web site since 2004, obtained by the MPS04 model,
2) the one obtained from a recently developed technique (REASSESS) that relies on the superficial soil's features,
3) the one from the MPS19 model of seismic risk, which should have replaced MPS04 but it is still waiting to be officially adopted.

In order to transform these PGAs into exceedance probabilities for the hazard according to a methodology already developed and tested on the PGA from MPS04 (Cesari and D'Aurizio, 2021), we preliminarily need to convert this physical measure of earthquake's intensity into MCS, a commonly used evaluation of macro-seismic intensity that used an ordinal scale ranging from I to XI.

We operate this conversion by using a recently developed method (Oliveti *et al.*, 2022), officially adopted since March 2023 by the INGV for the production of its *ShakeMaps*[2] after each recorded seismic event in Italy or in the surrounding areas. It has replaced the method developed by Faenza and Michelini (2010). The distribution of the new *MCS* turns out to be more skewed towards the right tail.

We use the hazard probabilities to derive the complete insurance indicators to assess the protection of all Italy's housing units in a variety of scenarios. Results are different from those obtained under the MPS04 baseline model, since the inclusion by REASSESS of soil effects produces a riskier picture of Italy's houses, whereas that obtained with MPS19 is much less worrying.

The paper is organised as follows. The second paragraph describes the three models compared in the study. The third paragraph briefly explains how to transform physical measures of earthquake intensity into a widely used indicator of the damages caused by seismic events and the relative generalized exceedance probability. The fourth paragraph presents some evidence on the consistence of the measures obtained. The fifth paragraph illustrates a map of Italy's seismic hazard also under the

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[1] Only 54% of these points are on the ground, while almost all the other are in the sea and a very limited number on the ice of glaciers.

[2] The *ShakeMaps* are downloadable from the web page: http://shakemap.rm.ingv.it/shake/archive/. They collect a measure of the earthquake's local momentum, a map of the geographical diffusion of the MCS/MMI and a complete list of PGA and PGV for all the points of the INGV grid covering all the Italian territory, with an estimate for MCS/MMI. The *ShakeMap* is available within a few hours after the seismic event.

point of view of the population at risk. The sixth compares the results of the three models with those of a historical catalogue of Italy's seismic events. The seventh examines the cost of a hypothetical insurance cover against seismic risk protecting all Italy's residential buildings. The last paragraph concludes.

2. The models for Italy's seismic hazard

2.1 The MPS04 model

The INGV divides Italy's surface into areas with uniform seismic hazard by using 16,852 points forming an evenly spaced grid, with each square having 0.02 degrees of longitude and latitude.

For every point of the grid, the official INGV methodology called *Modello di Pericolosità Sismica* 2004 (INGV, 2004), known under the acronym MPS04, derives sixteen values for the PGA, each obtained by combining all the levels of three factors: a) different degree of completeness of the historical catalogues of earthquakes used (2 levels), b) different methods of determining seismic intensity (2 levels), c) different measurements of earth-shaking attenuation (4 levels). Each geographical distribution is assigned a weight, representing the degree of trust in the specific method. From the sixteen possible values obtained for each point of the map, the weighted 16th, 50th and 84th percentiles are finally determined. The median is the central evaluation, with the 16th and 84th percentiles, respectively representing an optimistic and a pessimistic assessment of the local seismic risk. These sixteen measures are obtained for the nine exceedance probabilities {2%;5%;10%;22%;30%;39%;50%;63%;81%}, representing the probabilities of at least one event with PGA equal or higher than the assigned PGA over a 50-year observation period. We consider the median values of the PGA in our developments.

If we indicate the exceedance probability per grid point z over 50 years with $\alpha_{z,50,PGA}$ and if the events are distributed according to a Poisson law, the average yearly number of events with PGA higher or equal than the assigned PGA, denoted with $\lambda_{z,50,PGA}$, can be written as:

$$\lambda_{z,50,PGA} = -\frac{\ln(1-\alpha_{z,50,PGA})}{50} \qquad [eq.1]$$

The return period $n_{z,50,PGA} = \frac{1}{\lambda_{z,50,PGA}}$ is the average number of years between two consecutive events with PGA higher or equal than the assigned PGA.[3]

For any given exceedance probability α_m in *m* years, the MCS04 model provides a PGA for the point *z,* corresponding to this probability, formally expressed as:

$$PGA_{z,\alpha_m} = max\left\{PGA_z\text{:} \quad Prob\left(\left[\sum_{t=1}^{m} I_{PGA_{z,t}>PGA_z}\right] \geq 1\right) = \alpha_m\right\}, \qquad where\ m = 50 \qquad [eq.2]$$

In eq. 2, $I_{PGA_{z,t}>PGA_z}$ denotes a dummy variable equal to one in case of occurrence of the event $PGA_{z,t} > PGA_z$, zero otherwise (*z* and *t* indicate respectively a point of the grid and a year). PGA_{z,α_m} is hence the greatest value exceeded with probability α_m over *m* years by at least one ground shaking.

[3] By using the previous equation, the nine exceedance probabilities used by INGV become the following nine return periods (in years): {2;475; 975; 475; 201;140;101;72; 50; 30}.

The Italian building code NTC18 (NTC, 2018), which civil engineers use to compute buildings' resilience to seismic events, is based on this model, with $m = 50$ and $\alpha_m = 10\%$.

2.2 The REASSESS model

The first alternative model we use takes into account that during an earthquake the seismic wave amplification related to local site conditions can have a significant impact on the ground motion (Forte *et al.*, 2019) and that the average shear-wave velocity of the upper 30m ($V_{S,30}$), or the equivalent shear-wave velocity from the ground to the depth of the seismic bedrock when this is less than 30m ($V_{S,eq}$) must be also considered.[4] The paper's authors have made available to the practitioner a stand-alone software (SSC-Italy), which derives those parameters and is therefore a useful support for large-scale seismic risk studies such as this one.

Building on this software, we classify all the points of the INGV grid according to the characteristics of the shallow soil and hence derive the shear-wave velocity. This parameter is an input to get an estimate of the PGA according to the Reassess method (Chioccarelli *et al.*, 2019). The software also provides the standard deviation of the shear-wave velocity.

The method uses the Probabilistic Seismic Hazard Analysis (PSHA) in order to evaluate the rate of earthquakes causing an exceedance of any arbitrary ground-motion intensity measure at an arbitrary site of interest. The measurement is carried out by focusing on the main shock of a seismic event and considering the exceedance beyond a given threshold due to the earthquake of prominent magnitude within a cluster of events so that the homogeneous Poisson process can be used.[5]

According to the homogeneous Poisson process, earthquakes on a seismic source exceeding a given intensity *im* take place by the rate λ_{im} and the probability of observing $N_{im}(\Delta T)=n$ events of this kind in the time interval ΔT is given by:

$$Prob(N_{im}(\Delta T) = n) = e^{-\lambda_{im}\Delta T}\frac{(\lambda_{im}\Delta T)^n}{n!} \qquad n = 0,1,2,\ldots$$

The main feature of the Reassess method is the computation by numerical methods of the following hazard integral for the rate λ_{im}, when the given site is exposed to earthquake risk derived from n_s seismic sources.

$$\lambda_{im} = \sum_{i=1}^{n_s} \nu_i \cdot \iiint_{M\,X\,Y} P[IM > im|m,x,y]_i\, f_{M,x,y,i}(m,x,y)dm \cdot dx \cdot dy$$

In the equation the *i* subscript indicates the i[th] seismic source; ν_i is the rate of earthquakes within the range deemed possible for the source; $f_{M,x,y,i}(m,x,y)$ is the joint probability density function (PDF) of earthquake magnitude *M* and location {*X, Y*} ; $P[IM > im|m,x,y]_i$ is the exceedance probability conditional on the magnitude and location (via a source-to-site distance metric).

[4] $V_{S,eq}$ overcomes some limitations of $V_{S,30}$ and for this reason it is referred by the recent Italian building code ItBC2018.

[5] The method also enables to take into account of the aftershock effects by keeping the properties of the homogeneous Poisson process. This version of the method is called Sequence-based probabilistic seismic hazard analysis (SPSHA). We prefer not to use this version of the method in our paper in order to get PGA estimates more comparable with those obtained from the MPS04 method, which does not explicitly model aftershock effects. We have used the version of the method called *multi-site probabilistic seismic hazard analysis* (MSPSHA), to account for the stochastic dependence existing among the processes counting exceedances at each of the considered sites. This feature is suitable for the risk assessment of building portfolios or spatially-distributed infrastructure for which hazard must account for exceedances at multiple sites jointly.

This integral relies on a joint probability distribution of the exceedance where earthquake magnitude and location are considered stochastically independent, with the first factor modelled according to an exponential distribution and the second by a suitable form of the uniform distribution (see Forte *et al.*, 2019).

The model uses soil condition as input and enables to derive for the single points the PGA, together with an array of other physical parameters under two hypotheses of soil conditions: 1) rock, which is the standard condition; 2) user-defined soil condition identified by the shear-wave velocity obtained by the SSC-Italy software. We apply the model to the 8,859 points of the INGV grid that are neither at sea nor on ice, covering the whole surface of Italy's landmass, and obtain the PGA for the 9 INGV return periods.[6]

2.3 The MPS19 model

A new model known with the acronym MPS19 was introduced with the aim of replacing MPS04 (Meletti *et al.*, 2021). The new model should update the Italian building code actually based on MPS04. For this reason, the model considers only declustered seismicity (obtained by eliminating both after- and fore-shocks) and covers the whole national territory using rock as the reference soil; the hazard is expressed in terms of PGA, peak ground velocity (PGV), peak ground displacement (PGD) and other physical parameters.

Similarly to REASSESS, the model is based on Probabilistic Seismic Hazard Analysis and uses a probabilistic assessment for the forecast of a variety of ground motion intensity measures on the Italian territory partitioned by a grid made of 23,660 points, more extensive than the one used for MPS04. The openness and transparency of the used procedures guarantee completely reproducible outcomes. The model is still being evaluated by the competent official technical bodies.

The PGAs are provided for ten exceedance probabilities over a 50-year observation period {1%;2%;5%;10%;22%;30%;39%;50%;63%;81%} for the percentiles {2.5;16;84;97.5} and the mean.[7] Compared with MPS19, there is the additional exceedance of 1% (equivalent to a 4,975-year return period). We will consider the mean values for our developments without using the additional 1% exceedance, since it would provide results not comparable with those obtained from MPS04 and REASSESS.

3. Converting physical measures of seismic intensity into macro-seismic intensities

We have developed (Cesari and D'Aurizio, 2021) a method to derive from the PGA an expression for the exceedance probability for any point *z*:

$$\alpha_{z,m}(\overline{MCS}) = Prob\left(\left[\sum_{t=1}^{m} I_{MCS_{z,t}>\overline{MCS}}\right] \geq 1\right) \qquad [eq. 3]$$

[6] A preliminary analysis of the REASSESS model was carried out in Cesari and D'Aurizio (2023).

[7] In order to maximize the comparability with the results obtained from the median PGA of model MPS04, the results from model MPS19 are derived by using an estimate of the median PGA of model MPS19, obtained by a log-linear regression on the four available percentiles {2.5;16;84;97.5}. The modelled median removes a possible small positive bias of the mean PGA.

which requires an estimate of $MCS_{z,t}$, a measure of macro-seismic intensity developed by Mercalli, Cancani and Sieberg based on an ordinal scale ranging from I to XII that assesses the total damages caused by an earthquake to population and buildings.[8] Macro-seismic intensity is a relevant parameter in the domains of engineering, seismological and loss modelling and it also facilitates the information exchange between geo-scientists and practitioners interested in assessing and insuring natural risks .

We obtain the macro-seismic values by relying on a method routinely used since March 2023 by the INGV to produce an estimate of MCS within a few hours after a seismic event (Oliveti *et al.,* 2022). The method uses the regression technique based on orthogonal distance to fit a quadratic function linking MCS with both PGA and PGV.[9] The method is a continuation and an improvement of the work by Faenza and Michelini (2010), which developed a couple of similar functions previously used by the INGV. The new equations produce better results in terms of data fit by using a more robust and statistically sound approach also based on machine-learning techniques.

The equations of the two approaches are reported below (table 1).

Table 1

Equations of MCS as a function of PGA and PGV estimated by orthogonal regression

Michelini and Faenza (2010)	
MCS as a function of PGA	$MCS = (1.68 \pm 0.22) + (2.58 \pm 0.14)log_{10}(PGA)$
MCS as a function of PGV	$MCS = (5.11 \pm 0.07) + (2.35 \pm 0.09)log_{10}(PGV)$
Oliveti *et al.* (2022)	
MCS as a function of PGA	$MCS = (3.01 \pm 0.12) + (0.86 \pm 0.04)log_{10}^2(PGA)$
MCS as a function of PGV	$MCS = (4.31 \pm 0.15) + (1.99 \pm 0.18)log_{10}(PGV) + (0.58 \pm 0.18)log_{10}^2(PGV)$

We use the more recent equations to derive the MCS by applying the same method that we developed in Cesari and D'Aurizio (2021) for the previous equations. The new approach by Oliveti *et al.* (2022) produces a distribution of MCS more skewed towards the right tail for all the three models considered (fig. 1), especially for REASSESS.

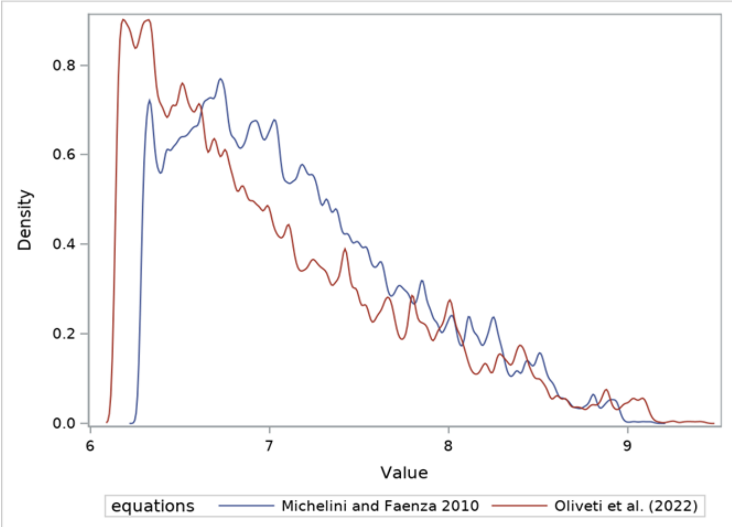
[8] MCS is a slight modification of the original scale proposed by Luigi Mercalli in 1908. When it is used (with small variations) in the English-speaking countries it is indicated as MMI (*Modified Mercalli Intensity*).

[9] The method also estimates the MCS by using the SA (spectral acceleration) as regressor. We do not use these equations since this parameter is not provided in the publicly available databases of MPS04 and MPS19.

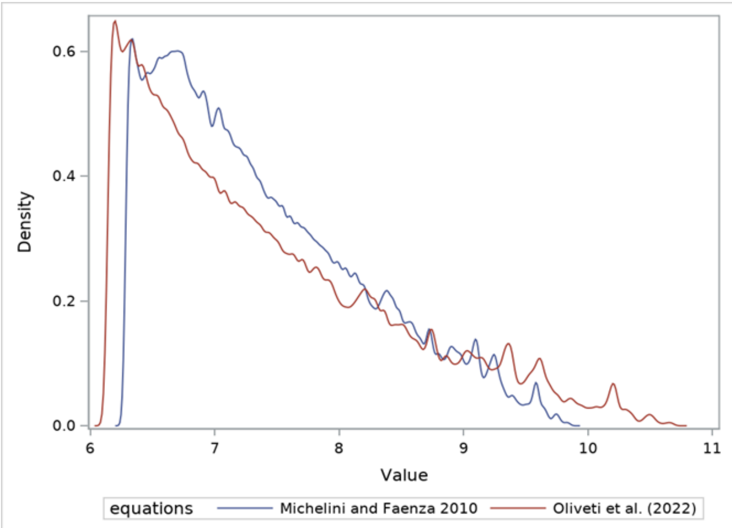
Figure 1

Kernel distribution of MCS from the two couples of equations in table 1 for the three models

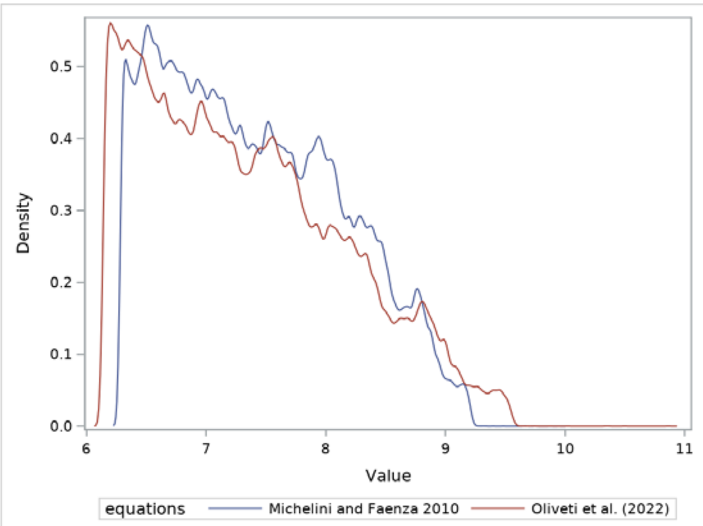
a. MPS04



b. REASSESS



c. MPS19



Once the MCS is available for a geographical point z, it can be transformed into an exceedance probability $\alpha_{z,m}(\overline{MCS})$ for any $MCS = \overline{MCS}$ and for any time horizon m measured in years. This method was originally applied to the model MPS04 (Cesari and D'Aurizio, 2021), but it is also applicable to other earthquake models such as REASSESS and MPS19. A feature of this method is that it does not explicitly require the knowledge of the exceedance probabilities for the PGA (not provided by the REASSESS model).

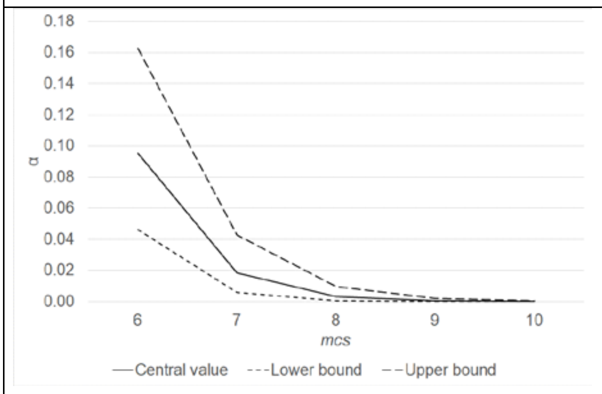
4. Evaluating the consistency of the exceedance probabilities

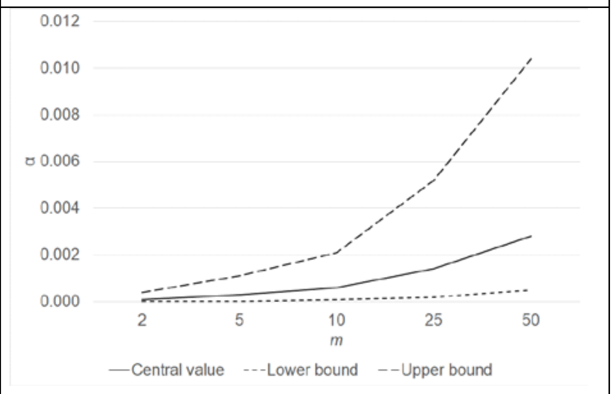
It is possible to derive $\alpha_{z,m}(\overline{MCS})$ for the lower, central and upper values of $\overline{MCS}$ by using the standard error of the coefficients of the orthogonal regression (tab. 1). The following plots (fig. 2) display the uncertainty of the estimated exceedance for model MPS04.[10] For a given time horizon the uncertainty diminishes with the increase of the macro-seismic intensity (fig. 2.a), whereas longer time horizons imply higher levels of uncertainty (fig. 2.b).

Figure 2

Confidence interval of the exceedance probability for MCS04

a.Bivariate plot of $\{\overline{\alpha}_m(\overline{MCS}), \overline{MCS}\}$ for m=10 *(mean values over all the points of the INGV grids)*	**b.Bivariate plot of $\{\overline{\alpha}_m(\overline{MCS}), m\}$ for $\overline{MCS}$ =9** *(mean values over all the points of the INGV grids)*





Due to this margin of error, we will derive the results that follows by using the upper bound of the equations.

A synthetic view of the three models can be obtained by representing over a 50-year horizon, for the 9 exceedances considered, four bivariate plots for: a) average MCS and average PGA, b) average MCS and average yearly frequency λ, c) average exceedance α and average yearly frequency λ, d) average exceedance α and average PGA (fig. 3). The trends of the plots are those expected, since PGA and MCS are positively correlated (fig x3.a) as well as λ and α (fig. 3.c), whereas it also emerges a negative correlation for the two couple of measures $\{\lambda, MCS\}$ and $\{PGA, \alpha\}$ (fig. 3.b and 3.d).

The highest hazard implied by REASSESS is shown in fig. 3.a, where the maximum values of PGA for an assigned MCS are reached under this model, and in fig. 3.d, which displays that with the same levels of PGA the highest values of α are reached by applying REASSESS.

The boxplots of MCS for the three models show that the distribution derived from REASSESS is the most dispersed and skewed towards the right tail (fig. 4) for all the levels of seismic macro-intensity considered.

A rank can therefore be established for the hazard severity derived from the three models, with that from REASSESS being the most severe, followed respectively by those of MPS04 and MPS19. This is also highlighted in a plot with the main percentiles of the exceedance probabilities, where those

[10] The corresponding plots for the two other models are similar and are not reported here for brevity.

obtained with REASSESS (fig. 5.a) and MPS19 (fig 5.b) are expressed as ratios relative to those from MPS04.

Figure 3

Average predictions of the three models MPS04, MPS19 and REASSESS over a 50-year horizon for the 9 exceedances {2%;5%;10%;22%;30%;39%;50%;63%;81%}

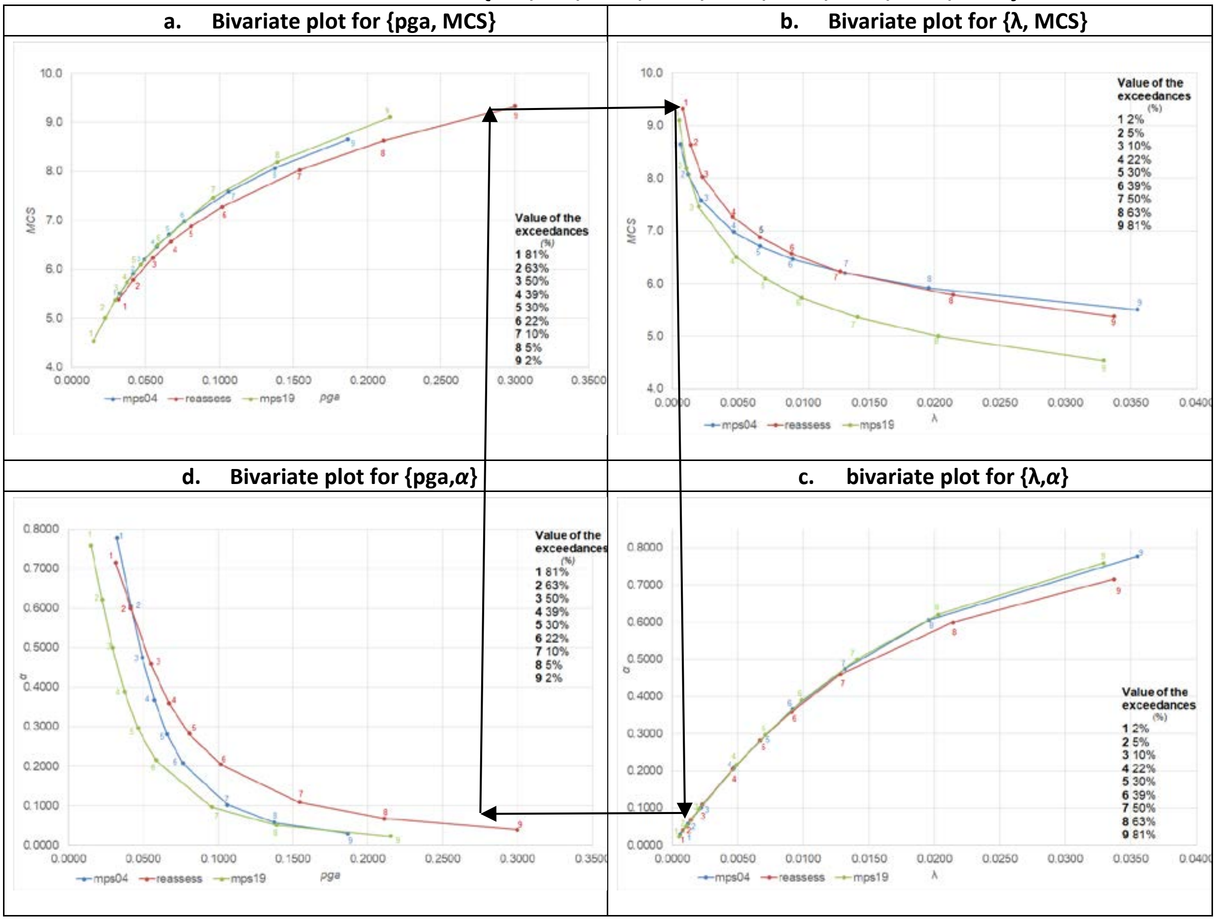
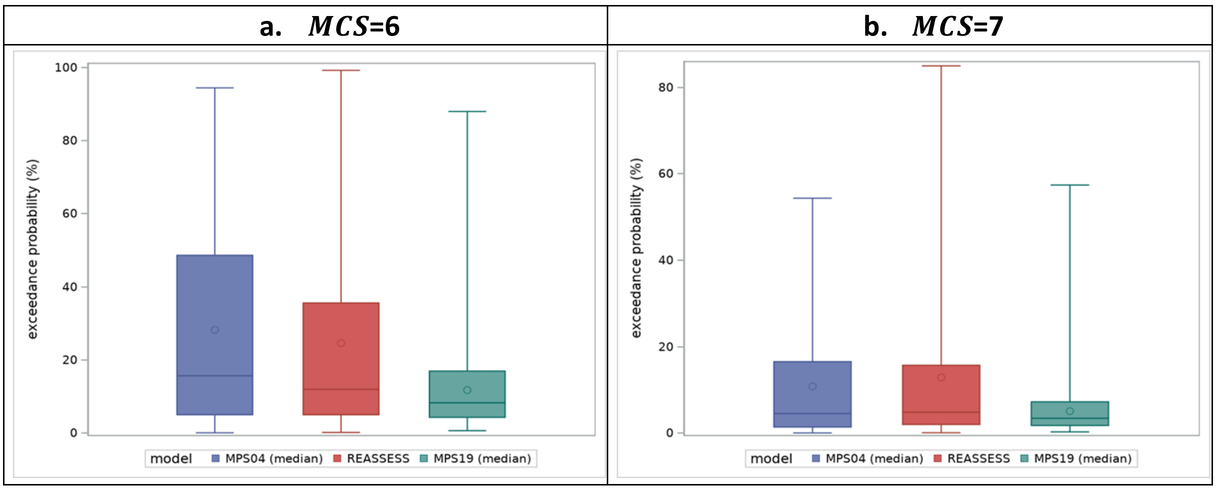


Figure 4

Average predictions of the three models MPS04, MPS19 and REASSESS over a 50-year horizon for different values of MCS



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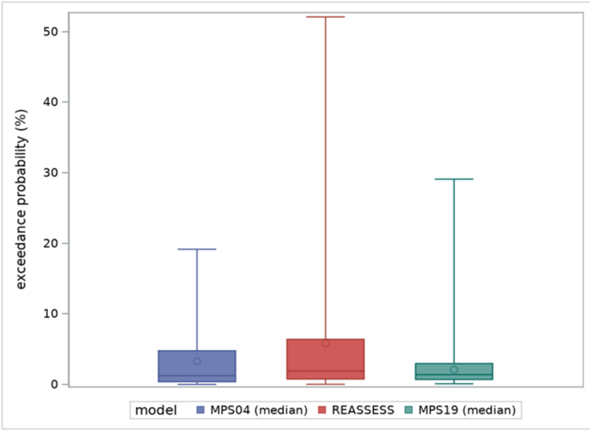
c. MCS=8



d. MCS =9

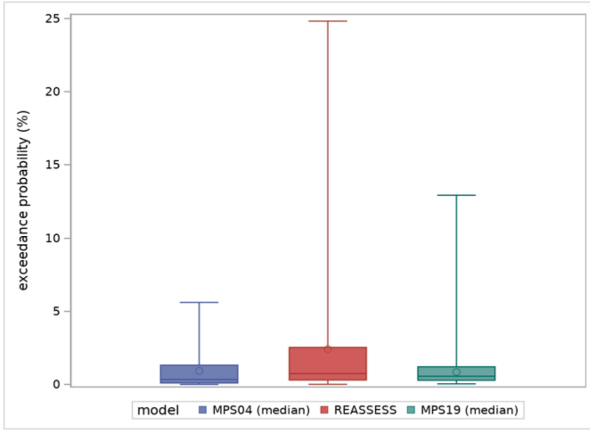
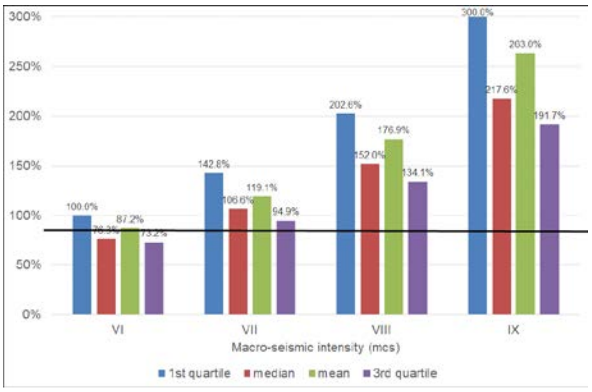


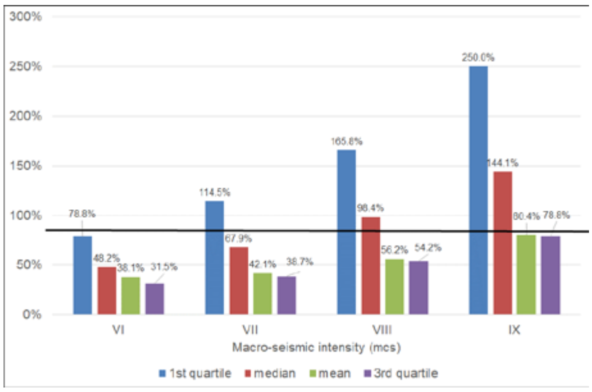
Figure 5

Magnitudes of the exceedances from REASSESS and MPS19 relative to those from MPS04 for different values of MCS

a. REASSESS



b. MPS19



5. Mapping Italy's seismic hazard

We select the 10-year time horizon and a suitable classification of the exceedance probabilities for each value of MCS to represent the seismic hazard for Italy on a geographical map. For brevity we confine ourselves to the values 6 and 9 for MCS, respectively corresponding to the lightest and most severe damages.[11]

Each map is also accompanied by a table with the discretization categories used for the exceedance and the distribution of the population at risk for each category (fig. 6). We derive these data by using for each Italian municipality (7.984 in total) the number of its inhabitants and the coordinates of its geographical centroid[12], which is matched to nearest point of each grid by using the Euclidean distance.

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[11] Apart from the intermediate values 7 and 8, we completely discard the intensities lower than 6, since they generally correspond to almost negligible damages.

12 The coordinates of Italian municipalities' centroids are available at the link: http://clisun.casaccia.enea.it/Comuni/Comuni.xls.

The maps clearly show that higher levels of risk affect smaller and smaller areas in the south-central Apennines with ramifications in the North-East. This diffusion pattern is consistent with the official representations of seismic risks.

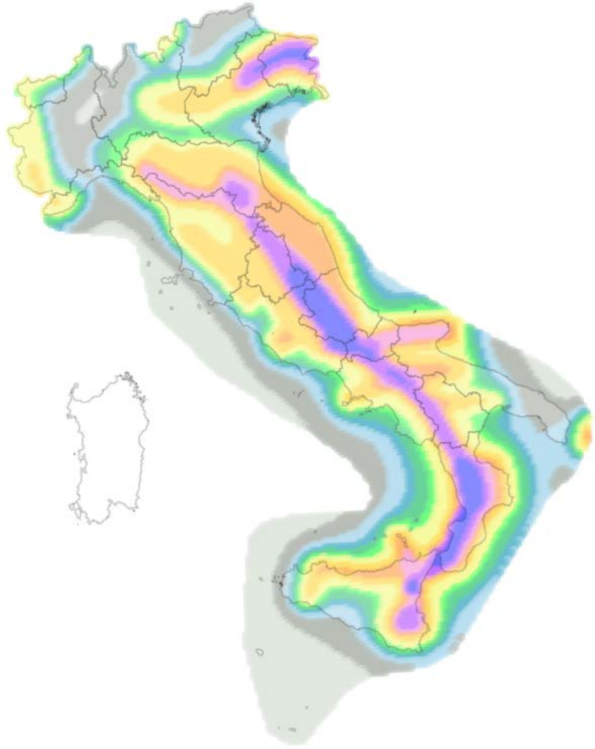
Concerning the population affected under model MPS04 1.5 million inhabitants (2.5% of the whole population) live in areas where an earthquake with intensity greater or equal than MCS=6 occurs with a probability at least of 90% (fig. 6.a). This number increases to 2.6 million (4.3% of the population) with model REASSESS (fix x6.c), whereas it drops to negligible values by using the risk view of model MPS19 (fig. 6.f).

The more dangerous macro-seismic level MCS=9 occurs with much lower exceedances, since an event with this macro-seismic intensity would affect 0.7 million people with probability greater than 5% with model MPS04 (fig. 6.b), but this number rises to 10.4 million by using REASSESS (fig. 6.d), as further evidence of the greater risk postulated by this latter model compared to the officially adopted view of MPS04. On the other hand, the risk outlook foreseen by MPS19 is the least dangerous of the three models considered.

Figure 6

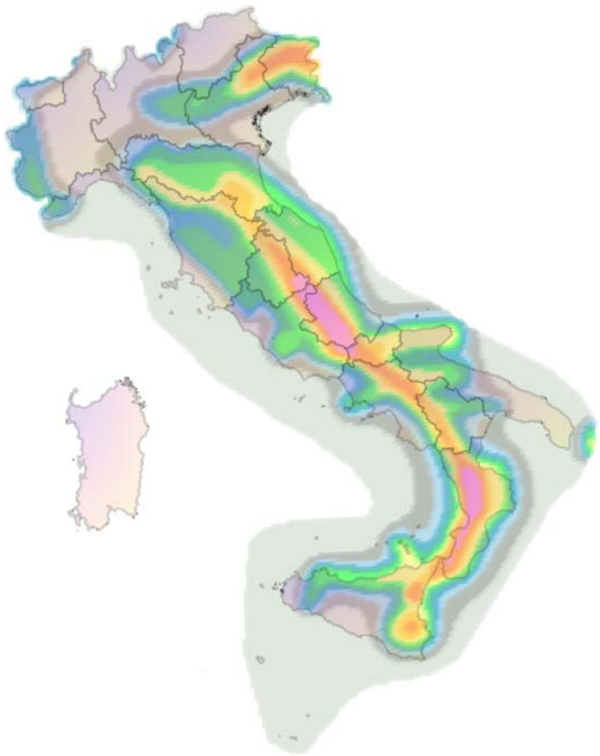
Risk maps of the exceedance probability over 10 years for MCS=6 and MCS=9 and tables of the Italian population at risk

a. MPS04 - $MCS = 6$



Probability	Population at risk millions of units	%
α_{10}<=2.5%	1.9	3.2%
2.5%<α_{10}<=5.0%	7.8	12.9%
5.0%<α_{10}<7.5%	4.9	8.0%
7.5%<α_{10}<=10.0%	2.1	3.5%
10.0%<α_{10}<=15.0%	3.1	5.1%
15.0%<α_{10}<=20.0%	2.7	4.5%
20.0%<α_{10}<=40.0%	12.9	21.2%
40.0%<α_{10}<=60.0%	14.2	23.4%
60.0%<α_{10}<=70.0%	4.1	6.7%
70.0%<α_{10}<=80.0%	2.8	4.5%
80.0%<α_{10}<=90.0%	2.8	4.6%
α_{10}>90.0%	1.5	2.5%

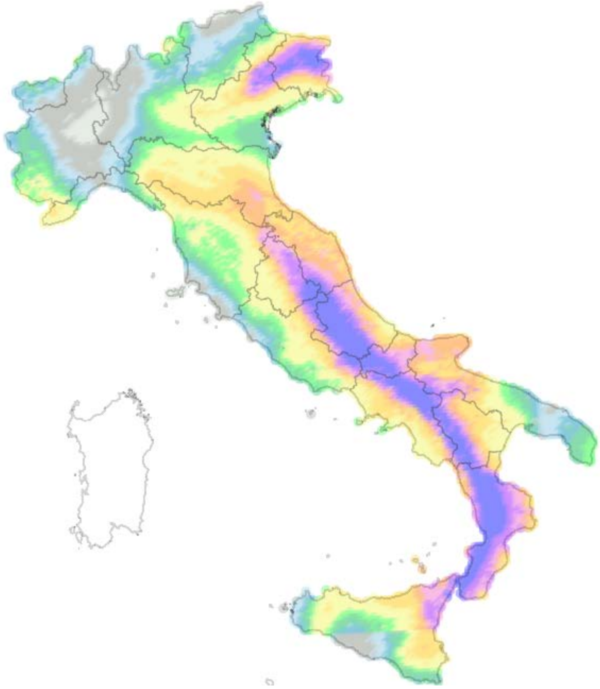
b. MPS04 - $MCS = 9$



Probability	Population at risk millions of units	%
α_{10}<=0.2%	15.8	26.1%
0.2%<α_{10}<=0.4%	6.1	10.0%
0.4%<α_{10}<0.6%	3.4	5.6%
0.6%<α_{10}<=1.0%	9.8	16.2%
1.0%<α_{10}<=1.5%	8.8	14.4%
1.5%<α_{10}<=2.0%	8.4	13.9%
2.0%<α_{10}<=3.0%	3.7	6.0%
3.0%<α_{10}<=4.0%	2.4	4.0%
4.0%<α_{10}<=5.0%	1.7	2.7%
α_{10}>5.0%	0.7	1.2%

[the other four panels on next two pages]

c. REASSESS - $MCS = 6$



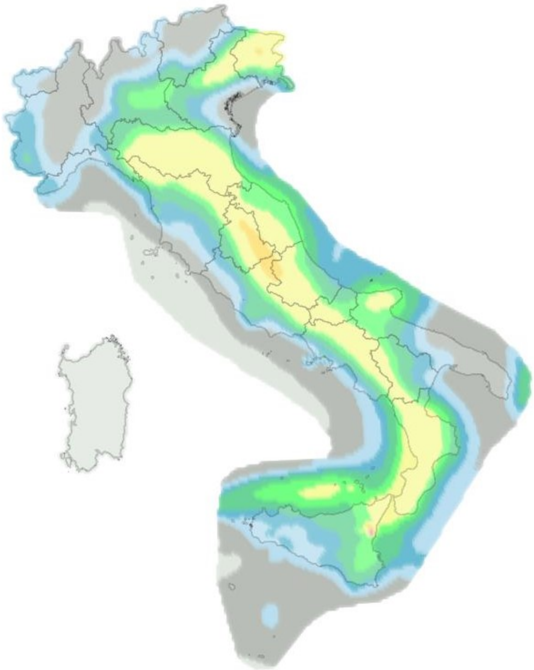
Probability	Population at risk	
	millions of units	*%*
α_{10}<=2.5%	2.2	3.5%
2.5%<α_{10}<=5.0%	9.3	15.3%
5.0%<α_{10}<7.5%	3.3	5.4%
7.5%<α_{10}<=10.0%	2.0	3.4%
10.0%<α_{10}<=15.0%	3.8	6.3%
15.0%<α_{10}<=20.0%	6.9	11.3%
20.0%<α_{10}<=40.0%	14.0	23.1%
40.0%<α_{10}<=60.0%	9.4	15.5%
60.0%<α_{10}<=70.0%	3.0	4.9%
70.0%<α_{10}<=80.0%	2.5	4.2%
80.0%<α_{10}<=90.0%	1.8	2.9%
α_{10}>90.0%	2.6	4.3%

d. REASSESS - $MCS = 9$

Probability	Population at risk	
	millions of units	*%*
α_{10}<=0.2%	4.6	7.6%
0.2%<α_{10}<=0.4%	9.3	15.3%
0.4%<α_{10}<0.6%	2.6	4.2%
0.6%<α_{10}<=1.0%	4.8	7.8%
1.0%<α_{10}<=1.5%	8.5	14.0%
1.5%<α_{10}<=2.0%	3.9	6.4%
2.0%<α_{10}<=3.0%	8.1	13.4%
3.0%<α_{10}<=4.0%	6.0	9.9%
4.0%<α_{10}<=5.0%	2.5	4.1%
α_{10}>5.0%	10.4	17.2%

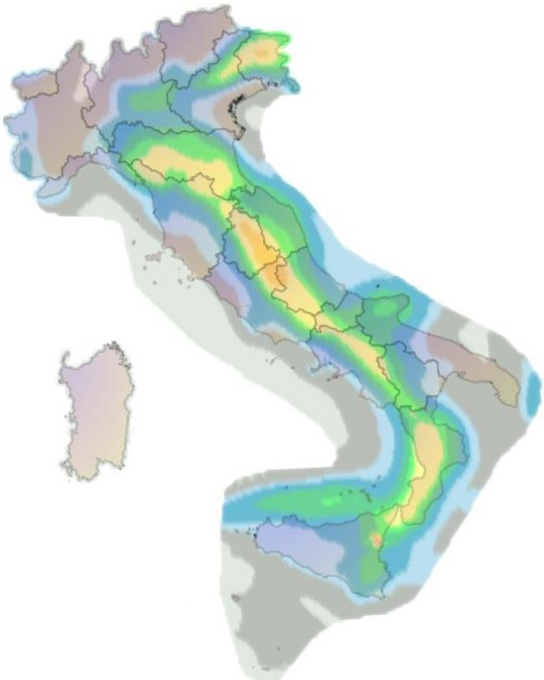
[the final two panels on next page]

e. MPS19 - $MCS = 6$



Probability	Population at risk	
	millions of units	*%*
α_{10}<=2.5%	1.7	2.8%
2.5%<α_{10}<=5.0%	9.4	15.4%
5.0%<α_{10}<7.5%	10.8	17.7%
7.5%<α_{10}<=10.0%	10.8	17.7%
10.0%<α_{10}<=15.0%	10.6	17.5%
15.0%<α_{10}<=20.0%	7.1	11.7%
20.0%<α_{10}<=40.0%	10.1	16.6%
40.0%<α_{10}<=60.0%	0.4	0.6%
60.0%<α_{10}<=70.0%	0.0	0.0%
70.0%<α_{10}<=80.0%	0.0	0.0%
80.0%<α_{10}<=90.0%	0.0	0.0%
α_{10}>90.0%	0.0	0.0%

f. MPS19 - $MCS = 9$



Probability	Population at risk	
	millions of units	*%*
α_{10}<=0.2%	2.5	4.1%
0.2%<α_{10}<=0.4%	15.3	25.3%
0.4%<α_{10}<0.6%	12.0	19.7%
0.6%<α_{10}<=1.0%	13.1	21.6%
1.0%<α_{10}<=1.5%	8.3	13.6%
1.5%<α_{10}<=2.0%	4.5	7.4%
2.0%<α_{10}<=3.0%	4.6	7.5%
3.0%<α_{10}<=4.0%	0.4	0.6%
4.0%<α_{10}<=5.0%	0.0	0.1%
α_{10}>5.0%	0.0	0.0%

6. Measuring the adaptation of the seismic models to event frequencies from an historical catalogue

The INGV produces a historical catalogue of the earthquakes occurred in Italy since the year 1000. The latest release covers all the seismic events until the year 2020.[13] For each of the 4.860 events recorded, homogeneous evaluations are provided for its physical and macroseismic characteristics. From the catalogue we can derive the yearly frequencies of seismic events with macroseismic intensity MCS greater than an assigned value. A measure of the validity of the three seismic models considered can therefore be obtained by comparing their yearly frequencies with those of the catalogue.

The catalogue reports earthquakes actually occurred with a destructive effect on inhabited areas, whereas the models use a regular grid of geographical points not necessarily corresponding to inhabited places. In order to compensate for this difference and to obtain frequencies comparable with the catalogue, for each model we map the grid points onto the centroids of the Italian municipalities (each centroid is assigned the frequency of the nearest grid point, selected by using the Euclidean distance). We finally compute a weighted average of these frequencies with the weight for each municipality represented by the share of the provincial population residing in it.

Under the assumption that also the seismic events recorded in the catalogue follow a Poisson distribution, for each model we can test the null hypothesis that its frequencies are the same as those of the catalogue by running a Wald chi-square test with one degree of freedom on the ratio between its weighted average yearly frequency and the average catalogue frequency. We carry out two versions of the test: the first one for all the catalogue, the second restricted to the events occurred since 1900, since the degree of accuracy of the parameters recorded for each seismic event might increase over the years. The table 2 below displays the value and the significance of the test for the difference between the empirical frequencies of the catalogue and those obtained from the models. The test is computed over five levels of macroseismic intensity from 6 to 10 for the average frequencies relative to all Italy. The model best fitting the complete catalogue is MPS19, whereas MPS04 and REASSESS (to a lesser degree) seem more suitable to reproduce the most recent seismic events.

Table 2[(a)]

Test of adaptation of models MPS04, REASSESS and MPS19 to the INGV historical catalogue of seismic events for all Italy

Macroseismic intensity	Time horizon	Earliest year considered in the seismic catalogue					
		1000			1900		
		Model			Model		
		MPS04	REASSESS	MPS19	MPS04	REASSESS	MPS19
6	10	0.0001 ***	0.0001 ***	0.8575	0.5960	0.5960	0.0001 ***
	50	0.0001 ***	0.0001 ***	0.6332	0.2068	0.2359	0.0001 ***
	100	0.0001 ***	0.0001 ***	0.4654	0.0697 *	0.0934 *	0.0001 ***
7	10	0.0563 *	0.0036 ***	0.5943	0.6313	0.4667	0.0068 ***
	50	0.0001 ***	0.0001 ***	0.2800	0.2560	0.1358	0.0001 ***
	100	0.0001 ***	0.0001 ***	0.1474	0.1201	0.0349 **	0.0001 ***
8	10	0.4843	0.0674 *	0.6569	0.7633	0.3226	0.1785
	50	0.0824 *	0.0001 ***	0.6952	0.5008	0.0270 **	0.0073 ***
	100	0.0140 **	0.0001 ***	0.5795	0.3892	0.0010 ***	0.0002 ***
9	10	1.0000	0.2150	1.0000	0.5714	0.4235	0.5714
	50	0.7817	0.0097 ***	0.7633	0.4692	0.0735 *	0.2057
	100	1.0000	0.0006 ***	0.5328	0.1742	0.0222 **	0.0535 *
10	10	0.0001 ***	0.5714	0.0001 ***	0.0001 ***	0.5714	0.0001 ***
	50	0.6569	0.1474	0.6569	0.4235	0.2577	0.4235
	100	0.5299	0.0578 *	0.5299	0.2577	0.1510	0.2577

(a) ***, ** and * indicate respectively significance levels below 1%, between 1% and 5% and between 5% and 10%.

[13] The catalogue is available at the web address: https://emidius.mi.ingv.it/CPTI15-DBMI15/.

In particular, REASSESS is the best model for the 10-year time horizon and all degree of macroseismic intensities.

7. The cost of insuring all the housing units of Italy for the earthquake risk

We carry out a simulation in order to evaluate a hypothetical insurance coverage protecting all the Italian residential buildings against seismic risk.[14] We use the same input dataset used in Cesari and D'Aurizio (2021), with a row of information for each municipality. We consider 34.8 million of housing units for a global value of 5,510 billion of euros (Bank of Italy, 2015).[15]

We have to define exposure and vulnerability, for which we introduce the following symbols:

$v_{c,l,p}$: value of the housing units for municipality *c*, building structure type *l* and state of preservation *p*, obtained as the product between the total value V_c of the municipality's residential units and the share of the buildings with type of structure equal to l and state of preservation equal to p;

$\bar{d}_{\overline{MCS},l,p} \in [0,1]$: average damage (expressed as a share of the value) for a housing unit with type of building structure *l* and preservation state *p* as a consequence of a seismic event with $\overline{MCS}$ intensity[16];

$\lambda^{\circ}{}_{c,1,\overline{MCS}}$: yearly frequency of seismic events with intensity equal to $\overline{MCS}$. It can be approximately derived from the yearly frequency of seismic events with an intensity equal to or greater than $\overline{MCS}$ ($\lambda_{c,1,\overline{MCS}}$) as follows:

$$\lambda^{\circ}{}_{c,1,\overline{MCS}} \cong \lambda_{c,1,\overline{MCS}} - \lambda_{c,1,\overline{MCS}+1} \qquad [eq. 4]$$

$n^{\circ}{}_{c,1,\overline{MCS}}$ and $d_{\overline{MCS},l,p}$ respectively stand for:

1) the stochastic number of seismic events with intensity equal to $\overline{MCS}$ in a given year in municipality *c* (conditional frequency), generated by a Poisson distribution with frequency parameter $\lambda^{\circ}{}_{c,1,\overline{MCS}}$;
2) the random damage (in terms of share of value) suffered by the buildings with type of structure l and state of preservation p (conditional severity), generated by a beta distribution with alpha=1 and mean=$\bar{d}_{\overline{MCS},l,p}$ (the beta parameter is $beta = alpha * (1 - \bar{d})/\bar{d}$).

These two random variables are by hypothesis independent. This structure is extensively used in natural catastrophe modelling oriented to insurance applications (Mitchell-Wallace K. et al., 2017).

We can therefore define a stochastic aggregate loss $\tilde{A}$ with the following expression:

$$\tilde{A} \equiv \sum_{c} \sum_{\overline{MCS}} \sum_{l} \sum_{p} v_{c,l,p} \, d_{\overline{MCS},l,p} n^{\circ}{}_{c,1,\overline{MCS}} \qquad [eq. 5]$$

with probability distribution F_A.

We estimate the two following parameters for their relevant meaning in insurance applications.

[14] In Italy the propensity to insure the housing units for this natural peril is very low: only 4.9% are covered, according to a figure provided by ANIA (the National Association of Italian Insurers) referred to 2024.

[15] We use figures provided by the Italian Revenue Agency at the level of single municipality.

[16] We use the same damage curves of our previous paper (Cesari and D'Aurizio, 2021), representative of those normally employed in the insurance market.

Aggregate Exceedance Loss (AEL)

$$AEL(n) \equiv min\left\{L: 1 - F_A(L) = \frac{1}{n}\right\} \qquad [eq. 6]$$

It represents, for a given return period *n*, the minimum value exceeded with $\frac{1}{n}$ probability by the total damages in a year. It measures the increase of the total damages as they become less probable.

Average Annual Loss (AAL)

$$AAL = \sum_{c} \sum_{\overline{MCS}} \sum_{l} \sum_{p} v_{c,l,p}\, \bar{d}_{\overline{MCS},l,p} \lambda°_{c,1,\overline{MCS}} \qquad [eq. 7]$$

It represents the average value of the losses in one year and it can be therefore regarded as a yearly pure premium for the risk.[17]

Our database considers three building structures (indicated with *l*) and four maintenance condition (indicated with *p*):

l ∈ {masonry, reinforced concrete, other}

p ∈ {very bad, bad, good, very good}.

For each of the three models, the simulation considers the benchmark scenario of actual building structures and maintenance conditions, which will be compared with two extreme hypothetical scenarios of building structures made entirely either by masonry or by reinforced concrete (with the actual maintenance conditions).

Each of these three main scenarios is divided into two sub-scenarios of: 1) total reimbursement of damages; 2) containment of companies' exposure with the introduction of deductibles and limits actually observed in the market.[18] We therefore consider 18 scenarios in all.

In order to obtain the $AEL(n)$ for a significant number of return periods, we generate 100,000 independent replications of $\tilde{A}$ for each scenario.[19]

The AAL (eq. 7), divided by the total value of the Italian housing stock and multiplied by 100,000 euros, is an estimate for the pure-risk premium of an insurance policy covering 100,000 euros of exposure if all the Italian residential buildings are protected against seismic risk. It is a standard measure for comparing the cost of different insurance contracts for the same risk.

This measure is obtained for all the municipalities and can be averaged according to the division of the Italian territory into CRESTA areas.[20]

[17] According to Poisson law, $\alpha°_{c,1}(\overline{MCS}) = 1 - e^{-\lambda°_{c,1,\overline{MCS}}} \cong \lambda°_{c,1,\overline{MCS}}$ is the yearly probability of at least a seismic event with intensity equal to $\overline{MCS}$.

[18] The simulation uses random drawings from the empirical distribution of deductibles and limits collected in an *ad-hoc* survey. The average limit is 6.2%, the average deductible is 65.3%.

[19] We refer to Cesari and D'Aurizio (2021) for the details of the procedure.

[20] The acronym CRESTA stands for Catastrophe Risk Evaluation and Standardizing Target Accumulations. It is a geographical classification of the world according to the different levels of the main natural risks (earthquakes, floods, storm), commonly used in the insurance industry.

The AEL are computed from *n*=2 up to the return period *n*=10,000, which evaluates the damages of a severe earthquake occurring on average every 10,000 years (tab. 3). The damages caused in the configuration of the REASSESS model are clearly the worst and those obtained with MPS19 are the least severe, with the scenario by the traditional MPS04 model being in the middle of these two extremes.[21] The return period *n=200* corresponds to the 0.5 percentile so that the corresponding AEL represents the Solvency Capital Requirement (SCR) needed by the current Solvency 2 regulation for the *natcat* module of a so-called internal model for earthquake risk. The insurance cost can be reduced both by improving the buildings structures and by applying limits and deductibles to the contracts (tab. 4).

The AAL reported at the bottom of the three panels inside each table can be regarded as a lower bound for the total amount of the premiums to pay for the insurance cover, before considering insurance indirect costs (general expenses and distribution commissions) and profit margins. The cost of the premium for the house-owner is better assessed in terms of an exposure amounting to 100,000 euros (fig. 7.a). Since the average value of an Italian housing unit is around 160,000 euros, by applying the limit and deductibles of the Italian market, the price of an average policy could be only slightly higher than 100 euros even under the worst scenario (fig 7.b).

The geographical variation of this standardized pure premium, obtained by dividing Italy into CRESTA areas, also highlights the different characteristics of the three models (tab. 5). It emerges that, compared with MPS04, REASSESS amplifies the peril in high-risk areas: for example, the pure premiums for L'Aquila under the two models are respectively 601.4 and 432.9 euros; similarly, for the other high-risk area of Udine-Pordenone the two values are 264.4 and 187.7.

For all the three models, increasing the size of Italy's sub-areas decreases the variability of the average pure premium in terms of its range and variation coefficient. If premium rates are computed according to these geographical criteria, a part of the insurance cost that should be faced by the house-owners in high-risk areas is transferred to those residing in low-risk areas. This mutuality effect is all the more necessary under the risk profile of REASSESS, which tends to place a heavy financial burden for some sub-areas. This mechanism generates solidarity of resources among residents in areas affected by different levels of the risk and also decreases inequalities, given that peak premiums are more common in low-income areas: this is the case of Italy's *Mezzogiorno*, affected by both low per capita GDP and high seismic risk.

[21] By using the same inputs, two well-known proprietary models, respectively by *RMS* and *Swiss Re*, produce results comparable with those obtained from MPS04 and REASSESS, whereas those derived from MPS19 are rather more optimistic.

Table 3

Aggregate exceedance loss (AEL) and Average annual loss (AAL) with complete damage compensation for an insurance against seismic risk of all the Italian residential buildings

(€ millions)

	MPS04 Model		
return period (years)	all reinforced concrete	actual structure[(a)]	all unreinforced masonry
		AEL	
10,000	27,440	44,400	48,345
5,000	26,601	43,534	47,176
1,000	25,305	40,997	43,918
500	24,572	39,749	42,616
250	23,929	38,625	41,519
200	23,718	38,202	41,035
100	23,034	36,959	39,727
50	22,040	35,318	37,948
25	20,261	32,420	34,868
10	15,846	25,265	27,171
5	10,400	16,634	17,885
2	2,965	4,742	5,102
AAL	2,972	4,753	5,113

	REASSESS model		
return period (years)	all reinforced concrete	actual structure	all unreinforced masonry
		AEL	
10,000	55,450	100,218	107,021
5,000	55,009	98,645	105,509
1,000	53,327	94,091	101,463
500	52,325	92,302	99,721
250	51,296	90,322	97,794
200	50,907	89,508	97,120
100	49,301	86,680	93,991
50	46,483	81,583	88,531
25	41,264	72,654	78,910
10	29,064	51,141	55,373
5	16,173	28,397	30,844
2	2,784	4,903	5,312
AAL	2,787	4,900	5,320

	MPS19 model		
return period (years)	all reinforced concrete	actual structure	all unreinforced masonry
		AEL	
10,000	8,289	12,386	14,186
5,000	7,528	11,751	13,022
1,000	5,883	10,118	11,022
500	5,106	9,158	9,960
250	4,475	7,947	8,661
200	4,218	7,556	8,183
100	3,789	6,714	7,228
50	3,460	6,033	6,543
25	3,149	5,450	5,887
10	2,605	4,495	4,841
5	1,969	3,377	3,662
2	813	1,395	1,513
AAL	753	1,290	1,396

(a) Distribution of the residential buildings by type of structure and maintenance conditions available at municipality level (Istat, 2011 census).

Table 4

Aggregate exceedance loss (AEL) and Average annual loss (AAL) with partial damage compensation by the application of deductibles and limits for an insurance against seismic risk of all the Italian residential buildings

(€ millions)

	MPS04 Model		
return period (years)	all reinforced concrete	actual structure[a]	all unreinforced masonry
		AEL	
10,000	19,767	32,012	34,246
5,000	19,202	31,146	33,156
1,000	17,754	28,759	30,877
500	17,265	27,850	30,028
250	16,843	27,014	29,097
200	16,705	26,714	28,839
100	16,146	25,824	27,783
50	15,426	24,647	26,524
25	14,172	22,701	24,398
10	11,056	17,641	18,978
5	7,275	11,626	12,521
2	2,074	3,319	3,579
AAL	2,088	3,317	3,583

	REASSESS model		
return period (years)	all reinforced concrete	actual structure	all unreinforced masonry
		AEL	
10,000	39,490	69,350	76,112
5,000	38,789	68,445	74,651
1,000	37,323	65,779	71,391
500	36,636	64,495	69,943
250	35,811	63,149	68,543
200	35,554	62,656	67,933
100	34,453	60,598	65,747
50	32,517	57,147	62,032
25	28,933	50,849	55,125
10	20,312	35,709	38,707
5	11,301	19,932	21,572
2	1,946	3,426	3,726
AAL	1,955	3,425	3,705

	MPS19 model		
return period (years)	all reinforced concrete	actual structure	all unreinforced masonry
		AEL	
10,000	5,792	10,196	10,811
5,000	5,355	9,517	10,115
1,000	4,186	7,629	7,946
500	3,596	6,729	7,120
250	3,111	5,667	6,126
200	2,956	5,334	5,739
100	2,645	4,677	5,079
50	2,425	4,225	4,592
25	2,207	3,804	4,104
10	1,827	3,136	3,384
5	1,379	2,364	2,565
2	569	972	1,058
AAL	526	902	977

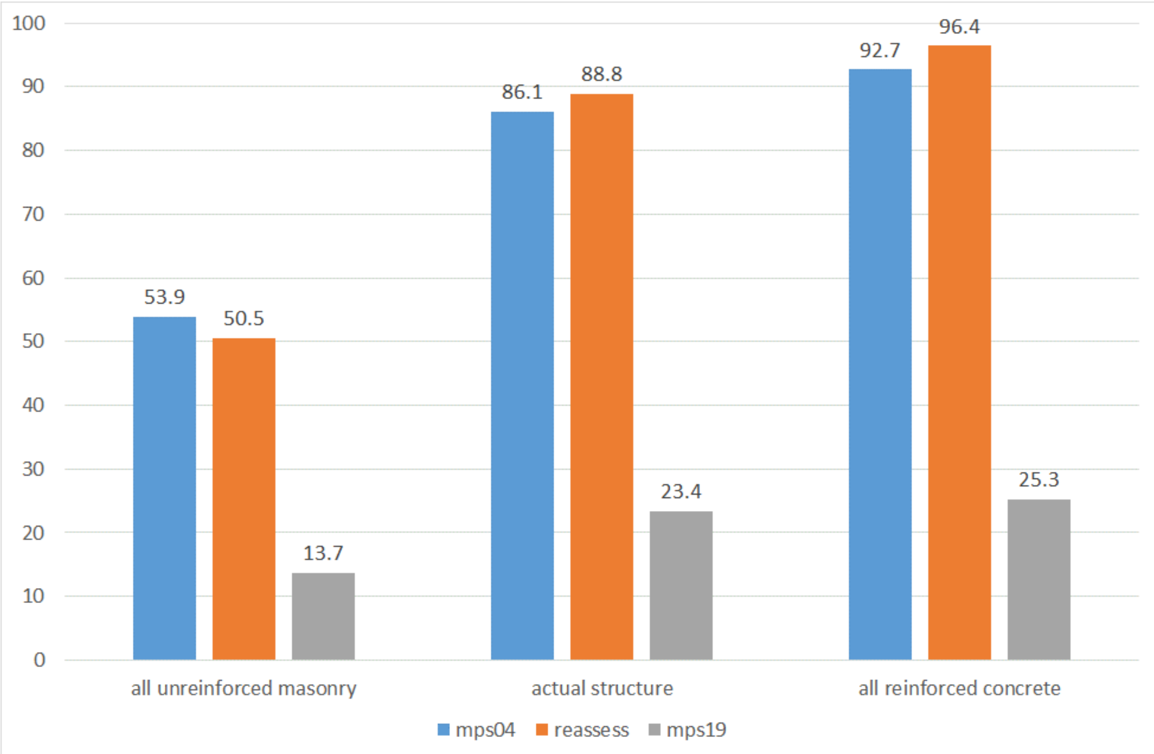
(a) Distribution of the residential buildings by type of structure and maintenance conditions available at municipality level (Istat, 2011 census).

Figure 7

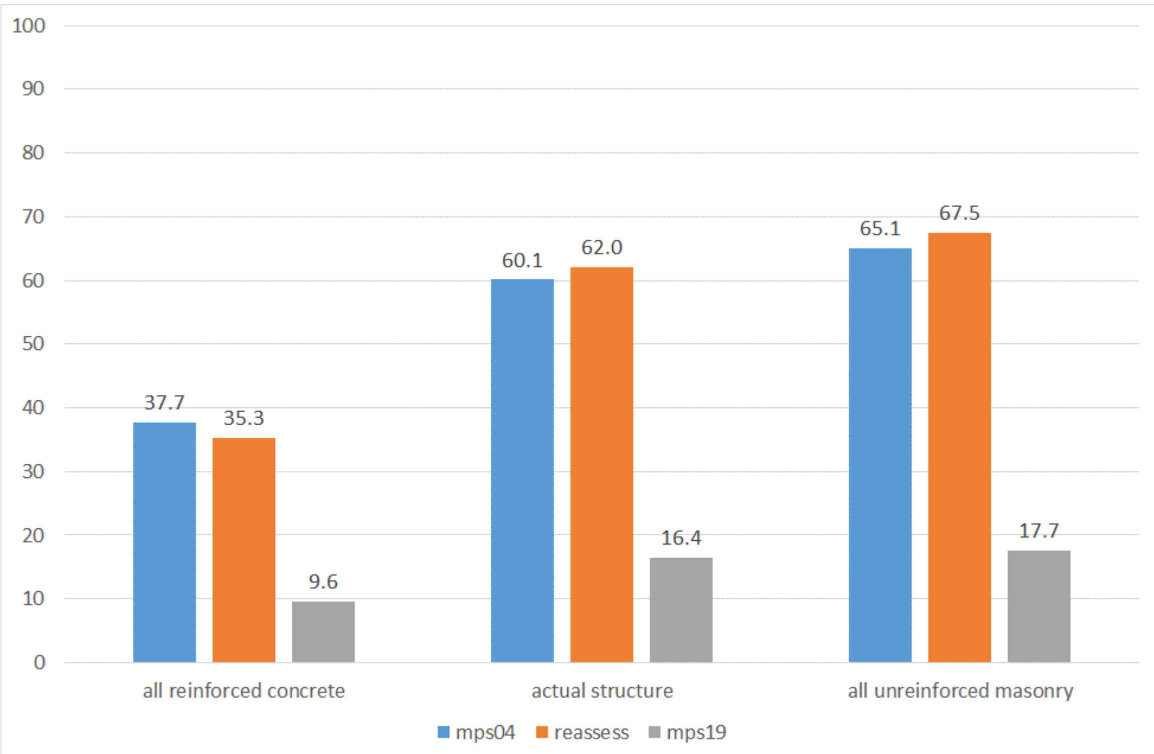
Average pure premium per 100,000 euros for an insurance against seismic risk of all the Italian residential buildings [(a)]

(€)

a. Complete damage compensation



b. Partial damage compensation by the application of deductibles and limits



(a) Distribution of the residential buildings by type of structure and maintenance conditions available at municipality level (Istat, 2011 census).

Table 5

Geographical variability of the pure premium for an insurance against seismic risk of all the Italian residential buildings[(a)]

(per 100,000 € of exposure, €)

Complete damage compensation										
First-level Cresta zone	**Second-level Cresta zone**	**MPS04**			**REASSESS**			**MPS19**		
Piemonte, Valle d'Aosta, Liguria			21.9			17.5			10.9	
	Torino	17.0			10.7			10.9		
	Other provinces in the first-level Cresta zone	24.9			21.7			10.9		
Lombardia, Emilia-Romagna			48.5			37.5			22.8	
	Milano	7.6			6.7			9.3		
	Bologna	133.8			104.7			52.9		
	Other provinces in the first-level Cresta zone	55.1			42.2			24.8		
Veneto, Trentino-Alto Adige, Friuli-V.G.			79.8			95.0			20.8	
	Udine, Pordenone	187.7			264.4			44.2		
	Other provinces in the first-level Cresta zone	68.3			76.9			18.2		
Northern Italy				48.9			46.5			18.9
Toscana, Lazio			90.4			62.2			23.1	
	Roma	73.4			38.0			15.9		
	Other provinces in the first-level Cresta zone	102.6			79.7			28.2		
Marche, Umbria, Abruzzo,Molise			199.1			234.2			47.9	
	L'Aquila	432.9			601.4			85.5		
	Other provinces in the first-level Cresta zone	172.8			192.9			43.6		
Central Italy				123.0			113.8			30.5
Puglia			51.1			74.4			15.1	
	Foggia	165.1			204.7			41.0		
	Other provinces in the first-level Cresta zone	25.9			45.7			9.3		
Campania,Basilicata,Calabria			189.4			247.5			35.8	
	Napoli	140.1			132.4			19.8		
	Benevento, Avellino	277.3			418.2			53.4		
	Potenza	216.0			349.3			44.7		
	Catanzaro, Reggio Calabria	343.2			447.2			62.9		
	Other provinces in the first-level Cresta zone	155.8			230.9			35.6		
Sicilia			148.6			125.4			29.5	
	Messina, Catania	277.5			282.5			51.9		
	Siracusa, Ragusa	148.6			63.1			24.6		
	Other provinces in the first-level Cresta zone	66.9			44.5			16.8		
Sardegna			0.6			3.8			0.9	
Southern Italy and major islands				134.6			157.9			27.0
Range		*425.3*	*150.6*	*74.1*	*594.7*	*210.0*	*67.3*	*76.2*	*32.8*	*11.6*
Variation coefficient		*76.9%*	*55.0%*	*61.0%*	*95.7%*	*66.8%*	*59.4%*	*61.3%*	*39.5%*	*33.2%*
Total for Italy				**86.1**			**88.8**			**23.4**

8. Conclusions

Since earthquake risk is the most dangerous natural peril in Italy, it is relevant to reliably assess its characteristics in terms of hazard, geographical diffusion and risk for the population and then to evaluate the costs of protecting the residential buildings for seismic risk by means of a universal insurance cover.

Even if we keep our analysis within the perspective of statistical analysis for insurance applications, we have taken into account the most recent scientific advancements in earthquake geophysics, represented by the generalized approach of Probabilistic Seismic Hazard Analysis (PSHA), also combined with the consideration of the soil characteristics (in the REASSESS model). We have compared the results obtained from these new methodologies with those derived from the traditional MPS04 model that is still the official standard for the construction code. For all the models considered, we have used the most recent method available in the literature for transforming the physical measures of seismic intensity into the macro-seismic intensities, required by our procedure to derive the exceedance probabilities.

The scenarios we have developed show the higher risk profile of the REASSESS model relative to that of MPS04, whereas the MPS19 model features a risk magnitude significantly below those of the other two.

From our results, an insurance policy covering all the Italian housing stock would require a pure-risk premium slightly higher than one hundred euros for an average housing unit. This cost could go down well below this threshold by considering the deductibles and limits normally used in the market and it could by further contained by applying, in the case of new buildings or in the refurbishing of old constructions, the building structures most robust to withstand the consequences of seismic events.

Finally, our work contributes to the debate of how to integrate insurance among the instruments to speed up the economic and social recovery of the areas stricken by natural disasters, with potential benefits to economic resilience and the state finances traditionally used in Italy for *ex post* interventions.

References

Cesari, R., & D'Aurizio, L. (2021). From Earthquake Geophysical Measures to Insurance Premium: A Generalised Method for the Evaluation of Seismic Risk, with Application to Italy's Housing Stock. *Asia-Pacific Journal of Risk and Insurance*, *16*(2), 155-185. DOI: https://doi.org/10.1515/apjri-2020-0034

Cesari, R., & D'Aurizio, L. (2023). Reassessing the Italian seismic hazard using soil classification. Quaderno n. 27 dell'IVASS.
https://www.ivass.it/pubblicazioni-e-statistiche/pubblicazioni/quaderni/2023/iv27/Quaderno_27.pdf

Chioccarelli, E., Cito, P., Iervolino, I., & Giorgio, M. (2019). REASSESS V2. 0: software for single-and multi-site probabilistic seismic hazard analysis. *Bulletin of Earthquake Engineering*, *17*, 1769-1793.
http://wpage.unina.it/iuniervo/papers/REASSESS_BEE.pdf

EIOPA (2023). Dashboard on insurance protection gap for natural catastrophes.
https://www.eiopa.europa.eu/tools-and-data/dashboard-insurance-protection-gap-natural-catastrophes_en

Faenza, L., & Michelini, A. (2010). Regression analysis of MCS intensity and ground motion parameters in Italy and its application in ShakeMap. *Geophysical Journal International*, *180*(3), 1138-1152.
DOI: https://doi.org/10.1111/j.1365-246X.2011.05125.x

Forte, G., Chioccarelli, E., De Falco, M., Cito, P., Santo, A., & Iervolino, I. (2019). Seismic soil classification of Italy based on surface geology and shear-wave velocity measurements. *Soil Dynamics and Earthquake Engineering*, *122*, 79-93.
https://d1wqtxts1xzle7.cloudfront.net/78188706/SDEE-VS30_Italy-libre.pdf?1641547873=&response-content-disposition=inline%3B+filename%3DSeismic_soil_classification_of_Italy_bas.pdf&Expires=1694168877&Signature=MjCtGj1LP6cKgUikaHo6oaSrBhDYV0oFuqVxObNoS5g2HOETAeBnVYu3-u3clzF0EWGA5Oz53TD8-JdqCVaaNohrcAI4kjyijTjbDmSVZq6U5wtmXqGy8vmPt1xTX~yniVu-elGW35Vf0sUrGY5GkqbCweS1JRI-bVTHyxm33MBUvHkJTFTsAU4WkTCUSk8aww~UmXpgiwHMPAo6QFYYjY61OZXlCzf9Fl-dDmkco6RG5pMlW0Os885-yBkxGkjQRgoc-ajhZdFXrSzvoEYcJjKXGIV36ZR13MphBig2VN2FUA6hhWG8V3qzAwlDRQTR4BhMB0vHdPnhKhZbhk5AqQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA

INGV (2004). Seismic Risk Maps for Italy - Final Report (*only in Italian*).
http://zonesismiche.mi.ingv.it/documenti/rapporto_conclusivo.pdf

Meletti, C., Marzocchi, W., D'amico, V., Lanzano, G., Luzi, L., Martinelli, F., ... & Seno, S. (2021). The new Italian seismic hazard model (MPS19). *Annals of Geophysics*, *64*(1).
https://gfzpublic.gfz-potsdam.de/rest/items/item_5009923_1/component/file_5009924/content

Mitchell-Wallace, K., Jones, M., Hillier, J. and Foote, M. (eds.) (2017). *Natural catastrophe risk management and modelling: A practitioner's guide*. John Wiley & Sons.

NTC (2018). Norme Tecniche per le Costruzioni NTC18, Ministerial Decree 17/01/2018. Italian Official Gazzette 42, 20 February 2018.

Oliveti, I., Faenza, L., & Michelini, A. (2022). New reversible relationships between ground motion parameters and macroseismic intensity for Italy and their application in ShakeMap. *Geophysical Journal International*, *231*(2). DOI: https://doi.org/10.1093/gji/ggac245

Poljanšek, K., Marín Ferrer, M., De Groeve, T., Clark, I. (eds.) (2017). *Science for disaster risk management 2017: knowing better and losing less.* Publications Office of the European Union, Luxembourg, ISBN 978-92-79-60679-3, JRC102482. DOI: https://doi.org/10.2788/842809

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