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HOW CAN INSURERS GET PREPARED TO CATASTROPHES? ASSESSING EARTHQUAKE EXPECTED LOSSES FROM HISTORICAL CATALOGUE.

Anna Bozza[1], Domenico Asprone[1], Fatemeh Jalayer[1], Gaetano Manfredi[1]

[1] Department of Structures for Engineering and Architecture,
University of Naples "Federico II",
Via Claudio 21 – 80125 Naples, Italy.
{anna.bozza, domenico.asprone, fatemeh.jalayer, gaetano.manfredi}@unina.it

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Abstract. *Countries around the world have had to face huge economic losses due to natural disasters over the past decade. This, of course represents a source of great concern for National Governments and even more so for the insurance industry. In the aftermath of a natural disaster, insurance and reinsurance markets are prone to severe insolvencies and destabilization. Therefore, the finance industry is looking for more reliable loss estimation procedures and insurance models, as effective means for resilience improvement.*

The present paper proposes an engineering-based methodology as a support for innovative insurance models. The study aims at defining a scientific instrument supporting insurers and reinsurers in forecasting expected losses and in mitigating the potential lack of financial capacity. This allows for catastrophe-linked modeling to be performed according to a risk-based framework. The proposed methodology is applied to the Italian residential building stock subjected to seismic risk. Expected losses are evaluated following the procedure outlined in Asprone et al. (2013)[1] for earthquake scenarios from the catalogue of historical earthquakes, of the National Institute of Volcanology and Geology (INGV) [2] and assuming present-day exposure characteristics. Hence the procedure can be implemented anywhere else a detailed catalogue collecting information about earthquakes from the past is available, as for Italy.

Statistical simulations of ground motion intensity (peak ground acceleration, PGA) using multivariate normal distributions are performed for each earthquake. The simulated PGA values are calculated based on the ground motion prediction equation of Sabetta and Pugliese (1996)[3], whose coefficient are re-estimated by Bindi et al. (2009)[4], for each Italian Municipality.

A set of different fragility curves from the literature has been selected and averaged for each building type, also accounting for seismic and non-seismic design. In the next step, the annual expected losses for insurers are evaluated and the results are aggregated in order to calculate total losses for the entire National building stock. Linear regression analysis is performed for predicting the expected loss as a function of earthquake magnitude. The resulting loss model can be used for efficient and rapid loss estimation for a given earthquake scenario.

1 INTRODUCTION

In last decades the rate of occurrence and the severity of natural catastrophes around the world have seriously increased. Hence the probability of severe losses is getting ever higher for homeowner, Governments and insurance industry, affecting simultaneously local and urban communities. This is also due to the growing urbanization in hazard-prone areas and to the existence of many old, non-seismic buildings, especially in European countries.

An effective and widely accepted means to mitigate seismic risk is the private insurance. Unfortunately, efforts for the roll-out of the insurance systems for residential buildings against natural disasters and, particularly, against seismic risk, are related to several different issues.

On the householder side, there is a widespread low risk perception, hence low willingness of people to voluntarily adopt cost-effective protective measures and to purchase insurance.

At the same time, insurance and reinsurance industry are not willing to promote and to sell coverage against such events, due to the high risk of exceeding their financial capacity.

According to Kunreuther [5], the challenges associated with reducing losses from natural hazards is attributed to “the natural disaster syndrome”, which consists of two strictly interrelated components: the limited interest in adopting pre-event protections and the high costs to the Governments and insurers following a catastrophe.

The optimization of engineering-based procedures to assess expected losses from disasters, has got the potential to meet the needs of householder and insurers, and is also an effective means for supporting mitigation actions. Reinsurers and Governments can then be represented just as bounds on the insurer-insured interactions, without being directly involved with catastrophic losses [6].

Different scientific studies focus on probability-based means aiming at estimating expected losses from earthquakes [26][27][28].

The integration of catastrophe modelling with insurance management is very popular in the modern insurance systems. Such methodology is usually highly conservative and prevent insurers to get an adequate gain mark up, in order to fix a high leeway to avoid insurers to get financial problems due to catastrophic losses.

Actually, a more precise assessment of expected losses allow insurers to know better the magnitude of losses they will have to face whenever a disaster occurs. Moreover, being losses not overestimated due to the conservatism of catastrophe modelling, insurers can sell insurance products at much lower premiums.

The present work proposes an engineering-based methodology to be used as a support for insurance systems modelling, based on the Italian territory hazard, on the vulnerability of its built environment and on its actual exposure. Such a methodology can potentially be implemented also for the insurance premium evaluation in other countries threatened by seismic risk. Two fundamental requirements are needed in order to effectively implement the procedure, that is, a detailed inventory of past earthquakes and a dataset containing information about the location of buildings in each municipality and their structural typology.

Peak ground acceleration (PGA) values are simulated based on the attenuation law of Bindi et al. (2009) [4]. Selected seismic events are the Italian historical earthquakes from the Catalogue of the National Institute of Geophysics and Volcanology (INGV). Intra-event and inter-event residuals are simulated in consistency with the log-normal attenuation law, using a multivariate normal distribution for the statistical simulation of PGA fields.

Fragility curves are selected from literature and averaged on each building type to evaluate the structural performance in terms of structural limit state exceedance probability given ground motion intensity.

Annual expected losses are estimated through the scenario analysis referring to the actual Italian building stock, according to data supplied by the National Institute of Statistics (ISTAT) [8]. Results are then aggregated to compute the total expected National loss.

Linear regression analysis are then performed on 50°, 16° and 84° percentile values, for each simulated PGA field (100 values for each simulation) in order to obtain predictive expected loss versus event magnitude relationships.

2 EARTHQUAKES SCENARIO ANALYSIS AND SIMULATIONS

All historical earthquakes are selected, whose epicentre was located within the Italian frontier. Hence, 970 earthquakes on 1172 events are investigated from the updated catalogue of INGV [2], from 217 b.C. until 2002 and with magnitude larger than 4.

The catalogue provides some parameters which are fundamental for the implementation of the scenario analysis: geographical coordinates of epicentre and magnitude.

The ground motion equation used in this work for PGA estimate is outlined in Bindi et al. (2009) [4]. It adopts the same functional form of Sabetta and Pugliese (1996) [3], and updates its coefficients, as follows:

$$\log_{10}(PGA) = -1.344 + 0.328 \cdot M - \log_{10}\sqrt{(R^2 + h^2)} + 0{,}262 S_i \pm \sigma \qquad (1)$$

Some assumptions are made in the context of the present study: M is assumed to be equal to Msp, according to the INGV's historical catalogue, R is the epicentral distance from the centre of each municipality [km]. Other parameters are assumed to be the same as suggested by Bindi et al.. In this first step, S_i is assumed to be equal to zero, which means that PGA is evaluated assuming rock soil conditions. σ is the standard deviation of the log of PGA and is given by the following:

$$\sigma^2 = \sigma^2_{inter} + \sigma^2_{intra} = (0.174)^2 + (0.222)^2 \qquad (2)$$

where σ_{inter} is the inter-event standard deviation and σ_{intra} is the intra-event standard deviation. According to such distinction, to evaluate the differences attained in the evaluation of expected losses, in this study two limit cases are investigated when performing scenario simulations: PGA fully uncorrelated, assuming σ=σ, and PGA partially correlated, considering only the inter-event correlation in the residuals of the ground motion prediction equation. 100 values are simulated for each earthquake, drawn from the attenuation law.

The attenuation law is calculated for each seismic event with different magnitude, as shown in Figure 1, for each Italian municipality.

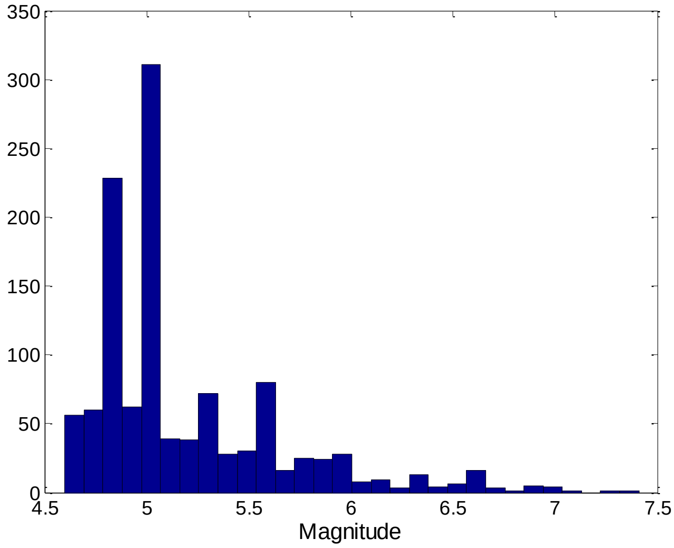


Figure 1 – Histogram of magnitude values of the simulated seismic events

For municipalities at distances lower than 5 km from the epicentre, PGA is assumed to be equal to the epicentral one. For municipalities at distances larger than 100 km from the epicentre PGA is assumed to be equal to zero.

In the case of both fully correlated PGA and partially correlated PGA, error simulations according to a multivariate normal distribution are performed, whose median is equal to the PGA calculated according to the attenuation law from Bindi et al. (2009), given in equation (2).

Regarding the standard deviation, Σ, of the multivariate normal distribution, it is differently calculated for the two limit cases.

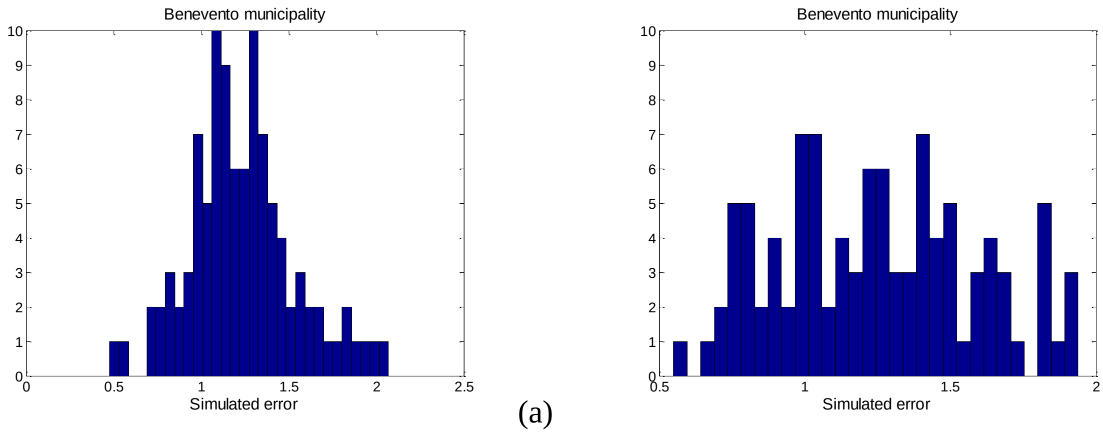
In the case of PGA fully uncorrelated it is given by a covariance matrix, which accounts for the total standard deviation as it is given by Bindi et al., and is defined as follows:

$$\Sigma = \sigma^2 \begin{bmatrix} 1 & 0 & \cdots & \cdots & 0 \\ 0 & \ddots & & & 0 \\ \vdots & & 1 & & \vdots \\ \vdots & & & \ddots & \vdots \\ 0 & \cdots & \cdots & 0 & 1 \end{bmatrix}_{8101 X 8101} \tag{3}$$

The histogram of sample simulations based on the fully uncorrelated assumption is shown for Benevento municipality for Molise 2002 (Msp=5.59) in Figure 2-(a). Conversely, in the case of partially correlated PGA, standard deviation for multivariate normal distribution for simulations is evaluated from a covariance matrix, Σ, accounting only for the inter-event correlation, as follows:

$$\Sigma = \sigma^2 \begin{bmatrix} 1 & \sigma^2_{\text{inter}}/\sigma^2 & \cdots & \sigma^2_{\text{inter}}/\sigma^2 & \sigma^2_{\text{inter}}/\sigma^2 \\ \sigma^2_{\text{inter}}/\sigma^2 & \ddots & & & \sigma^2_{\text{inter}}/\sigma^2 \\ \vdots & & 1 & & \vdots \\ \sigma^2_{\text{inter}}/\sigma^2 & & & \ddots & \sigma^2_{\text{inter}}/\sigma^2 \\ \sigma^2_{\text{inter}}/\sigma^2 & \sigma^2_{\text{inter}}/\sigma^2 & \cdots & \sigma^2_{\text{inter}}/\sigma^2 & 1 \end{bmatrix}_{8101 X 8101} \quad (4)$$

The histogram of sample simulations based on the partially correlated assumption is shown for Benevento municipality for Molise 2002 (Msp=5.59) in Figure 2-(b).



(a) (b)

Figure 2 - Error simulated (Nsim=100) for Molise 2002 (Msp=5.59) for Benevento municipality in the case of fully uncorrelated PGA (left side), and in the case of partially correlated PGA (right side)

Once the PGA field, derived from each earthquake, is evaluated for the entire Italian territory (assuming rock as soil type), PGA values are amplified according to the topographical and stratigraphic coefficient of each municipality, as defined by Colombi et al. (2010) [7].

3 FRAGILITY CURVE DATASET SELECTION

Seismic fragility curves define the probability of exceedance of a discrete set of limit states, as a function of an intensity measure of the earthquake (IM).

In this paper, the considered intensity measure is the PGA, hence the cumulative distribution function (CDF) representing each set of fragility curves is defined as:

$$F_{j,i} = \Phi\left(\frac{\log(PGA) - \log\mu(i,j)}{\sigma(i,j)}\right) \quad (5)$$

Being i the structural typology, j the number of limit states and Φ is the standard normal distribution function. Several studies have been investigated from the literature among which those referring to structural typologies which are more similar to the Italian ones, have been selected ([10]). Six structural typologies have been identified from ISTAT dataset: seismic and non-seismic reinforced concrete, seismic and non-seismic masonry and seismic and non-seismic mixed buildings.

The probability of the exceedance of limit state *sl* given PGA is evaluated as:

$$P\left[SL = sl / PGA\right] = F_{SL,i}(PGA) - F_{SL+1,i}(PGA) \qquad with \qquad 1 \le sl \le j \qquad (6)$$

Actually a vulnerability assessment considering spectral acceleration, Sa, rather than PGA is more precise from a structural point of view and respects the ground motion IM as meant by the Italian building code. Unfortunately, to evaluate spectral acceleration at least the number of storeys of each residential building should be known. Such an information, which allow to estimate the fundamental period, T, of the buildings, is not given by the ISTAT database.

4 LOSS ESTIMATION MODEL

In this paper, a discrete version of the Performance-based Earthquake Engineering (PBEE) framework equation (e.g., [9]) is used (see Asprone et al. (2013) for more details):

$$l_i = \sum_{LS=1}^{n} RC(LS) \cdot [F_{SL,i}(\overline{\mathrm{PGA}}) - F_{SL+1,i}(\overline{\mathrm{PGA}})] \qquad [€ / sqm] \qquad (7)$$

where l_i is the expected loss given PGA per square meters of residential units; $\overline{\mathrm{PGA}}$ is the earthquake IM evaluated for each municipality through the attenuation law and then amplified for the stratigraphic and topographical coefficients, S_S and S_T.

The specific loss expected values, l_i, are averaged on all considered curves (i=1:N) for each structural typology and the resulting mean value, $l_m = {}^1\!/_N \sum_{i=1}^{N} l_i$, is then integrated on the square meters amount. Hence, the total expected loss, L_m, is evaluated, which represents an indicator of mean losses on the overall municipal territory. By summing up L_m for all municipalities, the National expected loss, L, is computed.

Some assumptions are made regarding the unit cost of reconstruction/restoration. Being n the number of limit states for each vulnerability curve, the reconstruction cost, $RC_{collapse}$, is assumed to be equal to 1500 €/sqm. It corresponds to the collapse limit state and its amount comes from the estimates of CRESME (2011) [25] regarding mean costs for new constructions in Italy.

Furthermore, according to the scenario analysis by Asprone et al. (2013), the reconstruction/restoration costs for residential buildings are assumed to have a linear trend against the limit states, i, as in the following:

$$RC(LS) = \left(\frac{i}{n}\right) \cdot RC_{collapse} \qquad (8)$$

Such relationship allows to evaluate the unit loss also for intermediate limit states and to keep this invariant for the assumptions made.

Expected National Losses are evaluated for each earthquake simulation performed, and plotted against magnitude, in the case of PGA fully uncorrelated (Figure 3) and PGA partially correlated (Figure 4).

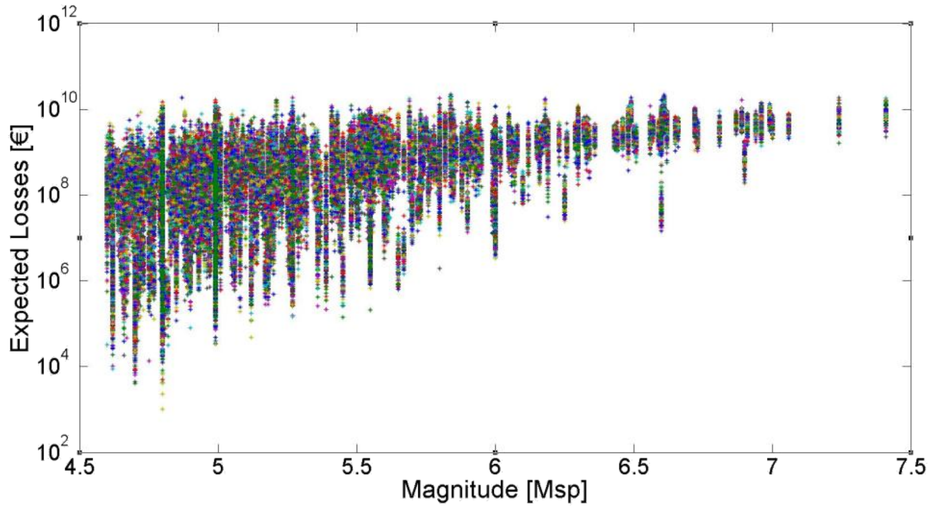


Figure 3 – Expected National Losses for each simulated earthquake, in the case of PGA fully uncorrelated

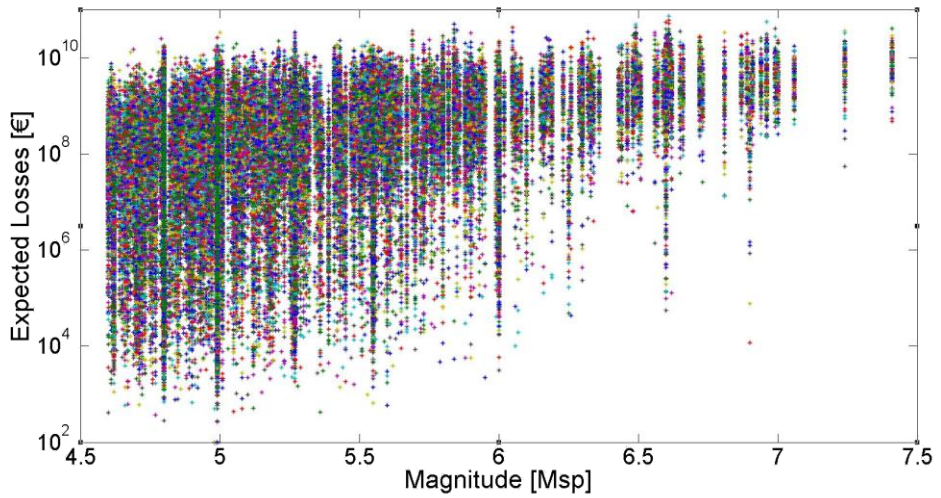


Figure 4 - Expected National Losses for each simulated earthquake, in the case of PGA partially correlated (considering only the inter-event correlation)

The results demonstrate more scatter in expected loss given magnitude for the case when PGA values are partially correlated (with respect to the uncorrelated case). Figure 5 below shows the histogram of expected loss for the Italian built environment (residential) for two historic events of Messina (1908, Msp=7.24) and Irpinia-Basilicata (1980, Msp=6.89).

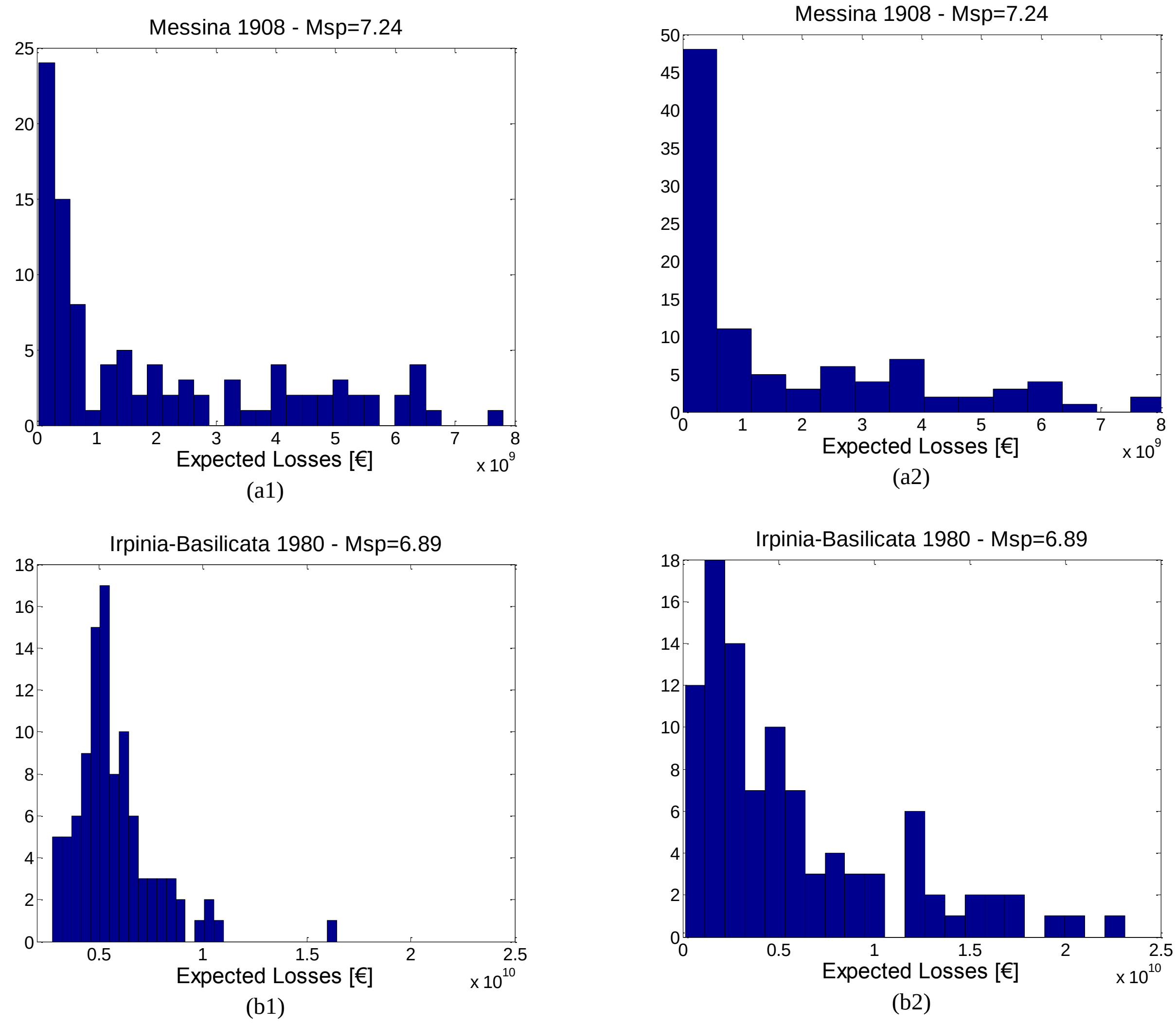


Figure 5 – Examples of total losses evaluated for the Italian built environment in the case of PGA fully uncorrelated (left side) and PGA partially correlated (right side). Analysis results refers to the following seismic events: 6.a1- 6.a2 Messina 1908, 6.b1 – 6.b2 Irpinia-Basilicata 1980.

5 PBEE SUPPORTING INSURANCE INDUSTRY: RESULTS AND DISCUSSION

Seismic insurance is a potential tool for seismic risk mitigation, whose modeling is currently of great concern.

Dealing with the Italian building stock, one has to consider that the set of residential buildings is a spatially distributed system. Hence, the joint distribution of ground motion parameters at different sites is needed when performing a scenario simulation. Since, the entire Italian built environment is investigated, and the spatial modeling of ground motion at the level of each municipality rather than the single building is performed. This is done based on the working assumption that PGA values are constant within the single municipality's area.

Once scenario simulations are executed, linear regression analysis are implemented according to the least square method. These leads to a predictive model for expected loss given magnitude .

First a linear regression on logarithms of 50th percentile of estimated losses for both the case of PGA fully uncorrelated and PGA inter-event correlated is performed:

$$\log_{10} L^{50th} = \log_{10} a + b \cdot \log_{10} M_{sp} \tag{9}$$

where L^{50th} is the median value of evaluated expected losses for each earthquake simulation, M_{sp}, is the magnitude according to the INGV catalogue, and $\log_{10}a$ and b are the coefficients of the regression curve (the intercept and the slope, respectively). The regression can be seen also as a probabilistic model for the residuals (errors), where the assumption of having constant dispersion, i.e. the homoskedasticity assumption, subsists. The sample variance can be then estimated as:

$$\sigma^2 \approx s^2 = \frac{\sum_{i=1}^{n} e_i^2}{n-2} \tag{10}$$

where the numerator represents the residual sum of squares and the denominator is the degree of freedom remaining, since the predicted values are calculated using two statistics, namely, the slope and the intercept of regression. Hence, the 16th and 84th percentiles for loss given magnitude according to the regression predictive model are calculated as:

$$STD(L \mid \mathrm{M}) = \mathrm{s} = \sqrt{\frac{\sum_{\mathrm{i=1}}^{\mathrm{n}} [\log_{10} L^{50th}{}_i - (\log_{10} a + b \cdot \log_{10} M_{sp,i})]^2}{\mathrm{n - 2}}} \tag{11}$$

$$\log_{10} L^{16th} = \log_{10} a + b \cdot \log_{10} M_{sp} - s$$

$$\log_{10} L^{84th} = \log_{10} a + b \cdot \log_{10} M_{sp} + s$$

Where L^{16th} and L^{84th} are the 16th and 84th percentiles of the loss. Alternatively, logarithmic linear regression is also performed taking the 16th and 84th percentile expected loss values as the dependent variables (in exactly the same manner described above for the case of the 50th percentile), for the cases of PGA fully uncorrelated and PGA inter-event correlated. The resulting predictive equations are plotted in Figure 6 and Figure 7. The black curves demonstrate the regression curve and its 84th and 16th percentiles; the blue curves demonstrate the regression curves fitted to the 16th and 84th percentiles of the expected loss values. It can be observed that the blue curves capture the fact that there are less data (less number of very big earthquakes) for very large magnitudes. On the other hand, the black lines are based on a homoskedastic regression model (constant dispersion) and cannot capture this trend.

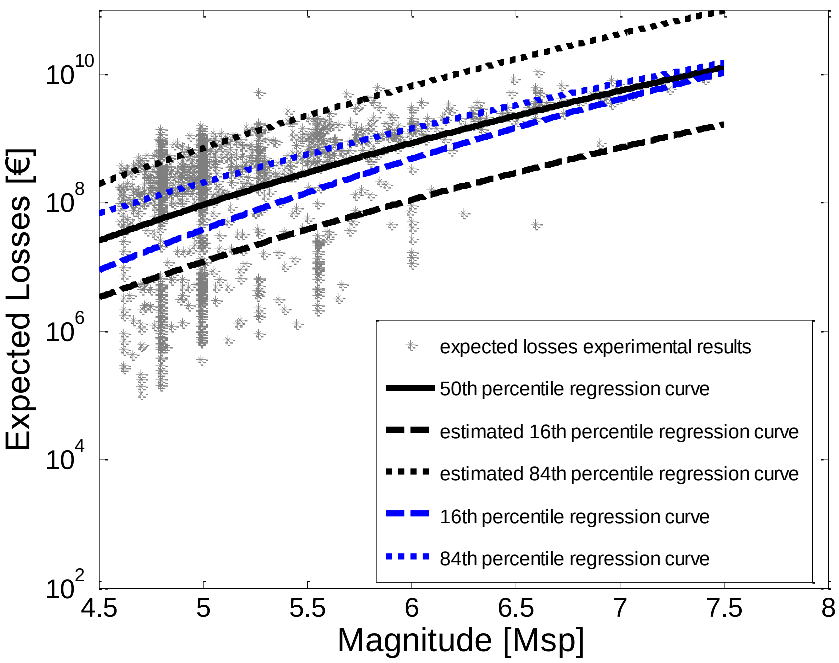


Figure 6 – Expected losses against magnitude and regression curves for the case of PGA fully uncorrelated

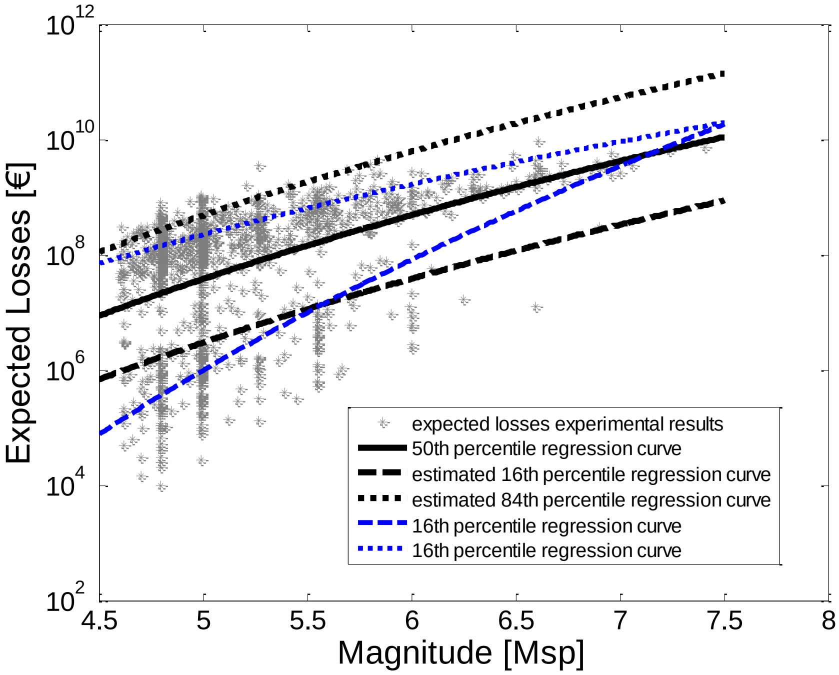


Figure 7 – Expected losses against magnitude and regression curves for the case of PGA partially correlated

In both Figure 6 and Figure 7, the expected losses are calculated for each historical event with a given magnitude for the built environment in the entire Italian territory. Table 1 below shows the statistics of the loss values simulated for a given historic event (Venafro 1873, Msp=4.99). It can be observed that the mean loss values are almost equal (something that is expected); whereas the partially correlated case shows a significantly higher dispersion.

ex. 500th earthquake [Venafro 1873 – Msp=4.99]	PGA FULLY UNCORRELATED	PGA INTER-EVENT CORRELATED
Mean	1.0646e+009	0.93656e+009
Standard deviation	5.7097e+008	1.2162e+009
Median	1.0205e+009	0.49394e+009

Table 1: statistics of expected loss distribution according to the two studied PGA limit case

Figues 8a,b below show the regression curves fitted to the median (Figure 8a) and the mean values (Figure 8b) for losses calculated for the two cases of uncorrelated (dashed dot) and partially correlated (dashed) PGA values. As it is expected the mean values curves are almost identical (the expected value for total losses over the entire territory does not depend on the correlation structure); whereas, the median values for the partially correlated case are lower (this is reasonable since the partially correlated case is associated with higher standard deviations, the median should be smaller so that the expected values are equal).

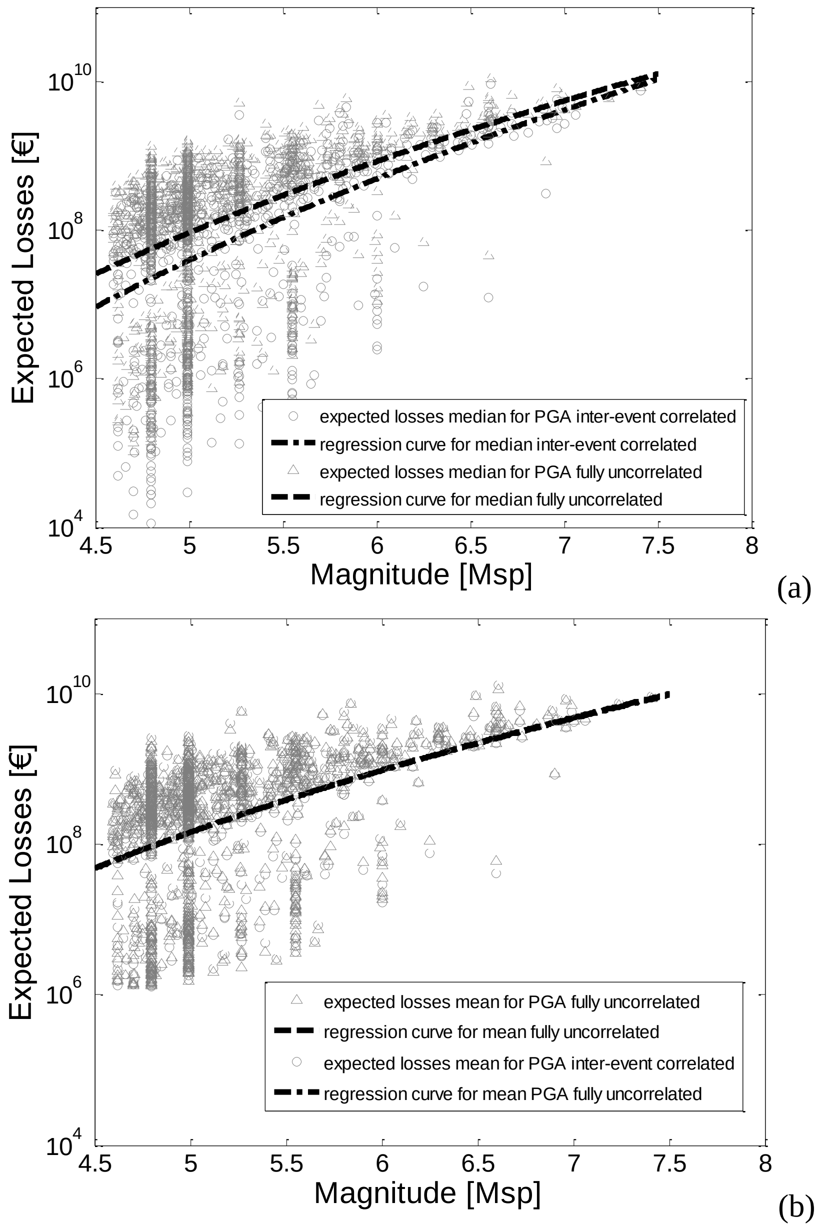


Figure 8 – Regression curve for expected losses against magnitude on median (a) and mean (b) values, showing almost complete correspondence between PGA fully uncorrelated and PGA partially correlated in the case of mean regression

6 CONCLUSIONS

The main criticality that insurers have to face when dealing with private seismic insurance is related to the knowledge of effective economic resources needed. It is fundamental to cope with the insurers' need to pay the insured, without incurring in insolvency, and also to cover expenses without getting into cash flow problems. Collecting information about past earthquakes and information about the population of residential buildings and their construction in the present, this study proposes predictive relationships for the expected economic losses given the magnitude. The procedure employed for deriving these predictive relationships takes into account (partially) the spatial correlation in the residuals of the ground motion prediction equation. The results are presented in terms of the 16th, median and 84th percentiles for expected loss curves given magnitude based on two distinct assumptions regarding the spatial correlation structure in PGA values (uncorrelated and partially correlated considering only the inter-event correlation). The above-mentioned percentile curves are calculated based on both homoskedastic (constant dispersion) linear regression and also by directly calculating the percentiles from the data. It can be observed that the $16^{th}/84^{th}$ percentiles' confidence interval around the median is larger in the case of partially correlated PGA values. This observation is in agreement with similar results in the literature (e.g., Goda and Hong 2008). Moreover, it is observed that the simple linear logarithmic regression based on the assumption of constant dispersion cannot capture the fact that there are less historical earthquakes available for the very large magnitudes (also reflecting the fact that there are fewer faults that are physically capable of producing very large events). The seismic events collected by the historical catalogue are, in fact, in higher number for lower magnitudes. In general, the predictive relationships derived for the expected loss given magnitude clearly show significant dependence on how the correlation in the peak ground acceleration is modeled (with the exception of the mean curve that demonstrates a certain insensitivity to spatial correlation). This confirms further (see e.g. see for example Yoshikawa and Goda 2014) that the choice of a suitable risk metric for insurers is of extreme importance for decision-making.

REFERENCES

[1] Asprone, D., Jalayer, F., Simonelli, S., Acconcia, A., Prota, A., Manfredi, G. Sesimic insurance model for the Italian residential building stock. *Structural Safety, 44, pp. 70-79,* 2013.

[2] A. Rovida, R. Camassi, P. Gasperini and M. Stucchi (eds.), "CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes.", Milano, Bologna, *http://emidius.mi.ingv.it/CPTI, DOI: 10.6092/INGV.IT-CPTI11,* 2011.

[3] Sabetta, F., and Pugliese, A., "Estimation of response spectra and simulation of nonstationary earthquake ground motions.", *Bulletin of the Seismological Society of America* 86.2 , 1996.

[4] Bindi, D., Luzi, L., Pacor, F., Sabetta, F., Massa M., "Towards a new reference ground motion prediction equation for Italy: update of the Sabetta-Pugliese (1996)", *Bulletin of Earthquake Engineering* , 2009.

[5] Kunreuther H., "Mitigating Disaster Losses though Insurance", ..., 1996.

[6] Kesete , …, ..., 2014.

[7] Colombi M., Crowley H., Di Capua G., Peppoloni S., Borzi B., Pinho R., Calvi G.M., "Mappe di Rischio Sismico a Scala Nazionale con Dati Aggiornati sulla Pericolosità Sismica di base e locale". *Progettazione Sismica, 1, ISSN 1973-7432*, 2010.

[8] ISTAT - Istituto nazionale di statistica, 14° Censimento generale della popolazione e delle abitazioni, *http://dawinci.istat.it/MD/dawinciMD.jsp,* 2001.

[9] Goulet, Christine A., et al. "Evaluation of the seismic performance of a code-conforming reinforced-concrete frame building—from seismic hazard to collapse safety and economic losses.", *Earthquake Engineering and Structural Dynamics 36.13,* 2007.

[10] Ahmad N., H. Crowley, R. Pinho, "Analytical fragility functions for reinforced concrete and masonry buildings aggregates of euro-mediterranean regions – UPAV methodology" *Internal report, Syner-G Project, 2009/2012,* 2011.

[11] Borzi, B., Crowley, H., Pinho, R., "SP-BELA: Un metodo meccanico per la definizione della vulnerabilità basato su analisi pushover semplificate." *Proceedings of XII Convegno L'Ingegneria Sismica in Italia ANIDIS 2007, Pisa, paper no. 160 (in Italian),* 2007.

[12] Borzi B, Crowley H, Pinho R., "The influence of infill panels on vulnerability curves for RC buildings." *Proceeding. 14th World Conference on Earthquake Engineering, Beijing, China*, 2008.

[13] Crowley H., Borzi B., Pinho R., Colombi M., Onida M., "Comparison of two mechanics-based methods for simplified structural analysis in vulnerability assessment." *Adv Civil Eng 2008, Article ID 438379,* 2008.

[14] M.A. Erberik., "Generation of fragility curves for Turkish masonry buildings considering in-plane failure modes." *Earthquake Eng. and Str. Dyn., 37,* 2008.

[15] A. J. Kappos, C.Panagiotopoulos, G. Panagopoulos, El. Papadopoulos. "WP4 – Reinforce Concrete Buildings (Level 1 and Level 2 analysis)." *RISK-UE*, 2003.

[16] A. J. Kappos, G. Panagopoulos, C.Panagiotopoulos, G. Penelis, “A hybrid method for the vulnerability assessment of R/C and URM buildings” *Bulletin of Earthquake Engineering, 4, 391-413,* 2006.

[17] M. Kostov, E. Vaseva, A. Kaneva, N. Koleva, G. Varbanov, D.Stefanov, E. Darvarova, D. Solakov, S. Simeonova & L. Cristoskov,“Application to Sofia”, *RISK-UE WP13,* 2004.

[18] Kwon OS, Elnashai A. “The effect of material and ground motion uncertainty on the seismic vulnerability curves of RC structure.” *Engineering Structures, 28(2):289–303,* 2006.

[19] S. Lagomarsino & S. Giovinazzi. “Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings.” *Bulletin of Earthquake Engineering 4(4), 415-443,* 2006,

[20] H.B. Ozmen, M. Inel, E. Meral and M. Bucakli, “Vulnerability of Low and Mid-Rise Reinforced Concrete Buildings in Turkey”, *14ECEE, Ohrid, Turkey,* 2010.

[21] M. Rota, A. Penna, C.L. Strobbia, “Processing Italian damage data to derive typological fragility curves”, *Soil Dynamics and Earthquake Engineering 28(10-11), 933-947,* 2008.

[22] M. Rota, A, Penna, G. Magenes, “A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses”, *Engineering Structures 32, 1312-1323,* 2010.

[23] Spence, R., ed. 2007. “Earthquake disaster scenario predictions and loss modelling for urban areas”. *In LESSLOSS Report 7, Pavia, , Italy: IUSS Press.,* 2007.

[24] G. Tsionis A. Papailia M.N. Fardis, “Analytical fragility functions for reinforced concrete and masonry buildings aggregates of euro-mediterranean regions – UPAT methodology” *Internal report, Syner-G Project, 2009/2012,* 2011

[25] CRESME IL MERCATO DELLE COSTRUZIONI 2011-2015, “Rapporto congiunturale e previsionale Novembre 2011”, 2011.

[26] K. Goda, H. P. Hong, *“Estimation of Seismic Loss for Spatially Distributed Buildings”,* Earthquake Spectra, Volume 24, No. 4, pages 889–910, November 2008.

[27] H. Yoshikawa, K. Goda., *“Financial Seismic Risk Analysis of Building Portfolios.”* Natural Hazards Review, Volume 15, Issue 2, 1 May 2014, Pages 112-120.

[28] Jaiswal, Kishor, and David J. Wald. *"Estimating economic losses from earthquakes using an empirical approach."* Earthquake Spectra 29.1 (2013): 309-324.