Development of a macroseismic model for the seismic risk classification of existing buildings

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ABSTRACT
The assessment and reduction of the seismic risk associated to the existing constructions is a topic of great interest, especially when the life safety and the optimal use of available resources are pursued.
The paper presents and describes a new methodology for the classification of the seismic risk associated to the Italian existing constructions. Such methodology is based on the qualitative macroseismic classification proposed by the European Macroseismic Scale (EMS98) and proposes a "quantitative" version, analyzing the relationships among the seismic intensities, the vulnerability classes and the direct economic losses. The researched presented within this paper represents the base for the "Guidelines for the seismic risk classification of buildings" published by the Italian Ministry of Infrastructures and Transportations (Annex A of D.M. 65 del 07-03-2017).

1 INTRODUCTION

The evaluation and reduction of seismic risk of existing buildings, and the associated task of identifying the most useful means to such ends, is of great current importance when pursuing the aims of safeguarding human lives and making optimum use of the limited resources available. While modern, substantially homogeneous regulations (NTC08 2008; Eurocode 8 1998) exist for assessing the seismic vulnerability of individual constructions as well as for planning the necessary seismic strengthening and/or retrofitting operations, to date a unitary approach for the evaluation and reduction of seismic risk is still lacking.

Simply defining the rules for planning single interventions of seismic vulnerability reduction is not enough. It is necessary to formulate a seismic risk assessment methodology, able to be applied to various geographical levels (single site, town, province, region, nation, Europe). Such a vision, apart from enabling a more rational organization of the resources, would also allow a more effective management of emergencies (rescue operations) as well as a better post-seismic stage of securing and reconstructing buildings.

To such end, following the May-July 2012 earthquake in Emilia (Italy), a number of studies have been conducted (Braga et al., 2014; Braga et al. 2015) with the support of the Italian government, to enable quicker resumption of the production activities disrupted by the seismic event. Such studies, based on the application of the shake-maps furnished, practically in real time, by the Italian National Institute of Geophysics and Volcanology (INGV, Istituto Nazionale di Geofisica e Vulcanologia), have focused entirely on the distribution of the seismic demand following any given earthquake. However, they do not include any assessment of the buildings' vulnerability or exposure, which are determining factors for a correct seismic risk assessment.

In the past decades many researchers have been carried out in the framework of the seismic risk evaluation. (Giovinazzi 2005) and (Lagomarsino and Giovinazzi 2006) studied two methods for the vulnerability assessment of existing buildings to be employed with different hazard description. The first one is a macroseismic model, based on (EMS98 1998) and to be used with macroseismic intensity hazard maps. The second one is a mechanical based model to be applied when the hazard is provided in terms of peak ground acceleration and spectral values. The two models are both characterized by several advantages such as the possibility of taking into consideration the uncertainty affecting the vulnerability assessment, the soil amplification effects and they can be easily implemented within a GIS environment. They, however, focus the attention on the evaluation of the seismic vulnerability and do not allow a rapid estimation of the seismic risk in economical terms.

The literature contains also many proposed approaches for calculating the frequency with which the required performance associated with any given construction in any given place exceeds the performance capacity of the structure itself, e.g. the approach proposed by PEER.

Although correctly set up in analytical terms, the method requires accurate knowledge of the probabilistic distribution of all the variables. The needed information is however not easy to obtain, so that often the rather too sophisticated analytical approach loses its effectiveness due to the uncertainty inherent in the structural data available (epistemic uncertainty). In those rare cases in which it is possible to get reliable, precise information, the PEER method is nonetheless complex to use in practice for most technicians.

The losses can alternatively be fruitfully expressed in terms of the Expected Annual Loss, EAL (Porter, Beck and Shaikhutdinov 2004), which takes account of the frequency and severity of the different levels of loss considered (i.e. by associating them to different limit states). Different methods, more or less easy to apply, exist for evaluating EAL. In general, EAL can be calculated by integrating the product of the structure's seismic vulnerability function and the site's seismic hazard function, according to the following expression

$$EAL = V \int_{S=0}^{\infty} y(s)v(s)ds \qquad (1)$$

where V is the value subject to loss, s refers to a measure of seismic intensity, *y(s)* is the average seismic vulnerability function, and *v(s)* is the average annual frequency of occurrence of an earthquake of intensity greater than or equal to s.

Figure 1 reports an example of graphical representation of the EAL evaluation, where: the hazard curve a) is an estimate of the maximum expected Peak Ground Acceleration (PGA) given the annual frequency of exceedance $\lambda=1/T_R$, where T_R is the earthquake return period; the seismic vulnerability curve b) is an estimate of the expected damage repair costs given the value of the seismic action (PGA); the crossing of a) and b) gives the direct economic losses curve (expressed in terms of percentage of the Reconstruction Cost %RC) shown in c). The area underlying the curve c) represents EAL value.

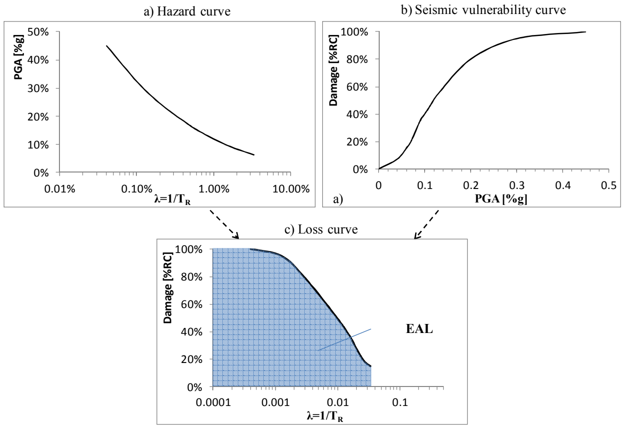

Figure 1. Examples of (a) hazard, (b) seismic vulnerability and (c) loss curves.

The operational limitations of any approach based on complex analyses can be effectively overcame, and without necessarily losing accuracy, by adopting a macro-seismic approach based on the European Macro-seismic Scale, EMS98, as already demonstrated by (Giovinazzi 2005) and (Lagomarsino and Giovinazzi 2006). But differently from (Giovinazzi 2005) and (Lagomarsino and Giovinazzi 2006), within this work, the scope is not to obtain vulnerability or capacity curves for existing buildings, but to associate to each vulnerability class defined by EMS98, a loss curve, relating the economical losses expressed in terms of EAL and the seismic intensity.

So an innovative methodology based on a classical qualitative macro-seismic approach for classifying buildings in Italy according to the seismic zones in which they are located and to their EAL values is proposed. A first description of the method, even if incomplete and with not updated results, is described in (Braga, Morelli, Salvatore 2015). The main outcome of the present study is a relation among earthquake-induced damages (considering structural and non-structural elements), seismic intensity (measured adopting a quantitative intensity measure) and the vulnerability of the building (adopting the vulnerability classes proposed by EMS98).

The proposed seismic risk classification forms the basis for the "Guidelines for the Seismic Risk Classification of Buildings" published by the Italian Ministry of Infrastructures and Transportations. It is particularized to Italy's current technical and regulatory situation. It therefore refers specifically to the 2008 Technical Regulations for Italian Constructions (NTC08 2008) and considering the subdivision of the Italian territory into 4 zones, where the seismic hazard, as assessed via the expected PGA associated to the Life-Safety Limit State, can reasonably be considered homogeneous (figure 2).

Nevertheless, the proposed approach is generalizable, and the present work provides all the necessary indications for extension of the method to other Countries characterized by different seismic hazard levels and/or different technical regulatory references, such as, for instance, Eurocode 8.

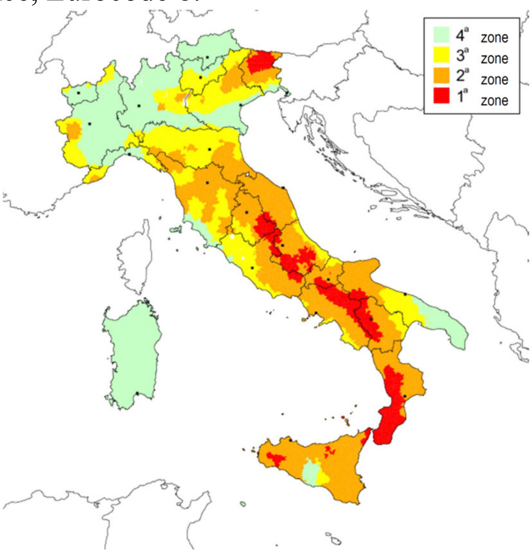

Figure 2. Italy's seismic zones according to the OPCM 3273/2003.

2 METHODOLOGY

At the current state of the art, rigorous probabilistic approaches or macro-seismic approaches can be used to define the seismic vulnerability of constructions. In the former case, a suitable EAL curve and, hence, suitable relations between the damage suffered and the intensity of the seismic event that caused such damage enable a quantitative classification of the seismic risk of a construction. Probabilistic approaches, however, suffer from difficulties in collecting reliable input data. They require very complex processing, and are therefore quite difficult to be applied in common practice.

The macro-seismic approaches currently available do not enable, differently, quantitative evaluations, even if they do allow for defining vulnerability classes correlated to the damage caused by a seismic event of given intensity level.

The procedure proposed and described in the following combines the probabilistic aspects of the quantitative approaches to risk evaluation with the simplicity of a macro-seismic approach, specifically the EMS98, for classification of building vulnerability. The result is a rigorous approach to risk classification that can be applied in real current practice.

The methodology adopted to derive the aforementioned approach is divided in the following steps:

Step 1. Development of a qualitative Damage Probability Matrix (DPM) base on EMS98 data. The qualitative DPM relates the vulnerability classes, a qualitative description of the damage degree (in terms of damaged buildings and damage level) and the seismic intensity in terms of Modified Mercalli Intensity.

Step 2. Calibration of a quantitative Damage Probability Matrix. Each qualitative term of the DPM obtained in Step 1 (number of damaged buildings, damage level, earthquake intensity) is expressed to a quantitative function suitably calibrated.

Step 3. Determination of the loss curves for each vulnerability class. These curves relate an engineering intensity measure of the earthquake and the economical loss associated to the damaging of structural and non-structural elements.

3 DEVELOPMENT OF THE MACROSEISMIC CLASSIFICATION

3.1 *Step 1 - Qualitative Damage Probability Matrix based on EMS98*

The EMS98 classifies the vulnerability of masonry and reinforced concrete (r.c.) constructions by dividing them into 13 categories according to their structural type and materials. Existing steel and wood constructions, representing a very low percentage of the Italian buildings, are not taken into account within this work.

The EMS98 defines then five damage levels, distinguishing, for each of them, the damage to structural and to non-structural elements:

- Level 1: negligible to slight damage (no structural damage, slight non-structural damage)
    - Level 2: moderate damage (slight structural damage, moderate non-structural damage)
    - Level 3: substantial to heavy damage (moderate structural damage, heavy non-structural damage)
    - Level 4: very heavy damage (heavy structural damage, very heavy non-structural damage)
    - Level 5: destruction (very heavy structural damage)

The five levels are separately detailed for buildings with r.c. structures and for masonry buildings, and, for both of them, the EMS98 highlights that non-structural damage of a certain level occurs in correspondence of a one level lower structural damage. The EMS98 finally relates the earthquake intensity to the degree of damage and to the vulnerability class. For each vulnerability class it is possible to obtain so a relationship between the macro-seismic intensity and the degree of damage, differentiating for the latter the damage suffered by structural and non-structural elements. Tables 1 and 2 show the qualitative Damage Probability Matrix (DPM) obtained for the C class buildings that relates the seismic intensities (evaluated through the Modified Mercalli Intensity, MMI, scale) and the number of buildings (quantified by the terms "few", "many", "most") damaged up to a certain degree (damage levels numbered from 1 to 5). Similar DPMs can be easily obtained for each vulnerability class.

Table 1. Qualitative Damage Probability Matrix obtained by the EMS98 data for the C class buildings considering only non-structural damage.

Earthquake intensity (MMI)	**NON-STRUCTURAL DAMAGE GRADE**				
	1	**2**	**3**	**4**	**5**
V	--	--	--	--	--
VI	few	--	--	--	--
VII	--	few	--	--	--
VIII	--	many	few	--	--
IX	--	--	many	few	--
X	--	--	--	many	few
XI	--	--	--	most	many
XII	--	--	--	--	practically all

Table 2. Qualitative Damage Probability Matrix obtained by the EMS98 data for the C class buildings considering only structural damage.

Earthquake intensity (MMI)	**STRUCTURAL DAMAGE GRADE**				
	1	**2**	**3**	**4**	**5**
V	--	--	--	--	--
VI	--	--	--	--	--
VII	few	--	--		--
VIII	many	few	--		--
IX	--	many	few		--
X	--	--	many	few	--
XI	--	--	most	many	--
XII	--	--	--	practically all	--

3.2 Step 2 - Definition of a quantitative Damage Probability Matrix

In order to obtain a quantitative DPM to be used for the estimation of economical damages related to earthquakes, it is necessary to supply a more refined quantitative value or definition to each terms composing the DPM of table 1. More specifically, it is necessary to quantify with more engineering parameters:

- The number of buildings damaged.
- The building damage degree.
- The seismic intensity.

The number of buildings that fall into each damage class, relative to all those present, is defined by EMS98 by the terms “few”, “many” and “most”. Given the "fuzzy" representation supplied by EMS98, the conversion from a qualitative to a quantitative probabilistic approach is not univocally defined and can be achieved adopting different hypothesis, such as the representation through trapezoidal membership functions, as done by (Lagomarsino and Giovinazzi 2006), or probabilistic distributions. The former has the advantages of a simple representation, while the latter allows to take into account the uncertainties related to the fuzzy approach. Within this work, for each term “few”, “many”, “most” three different Poisson distribution are adopted and then the sixth degree interpolating line is used to represent the distribution. Figure 3 shows the Poisson distributions and interpolating lines for each term. A detailed explanation about the choice of the Poisson distribution adopted is reported in (Picchi 2017).

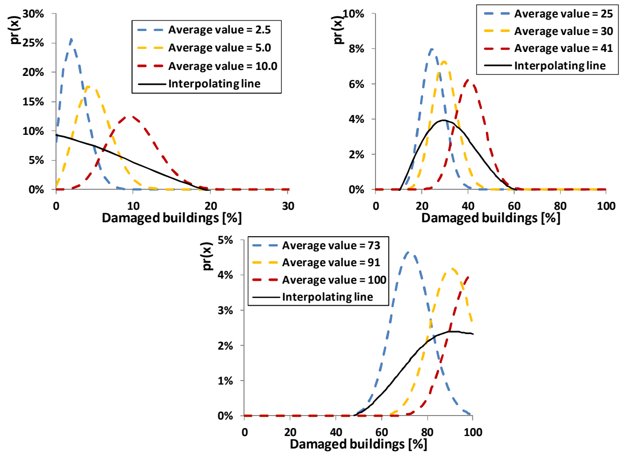

Figure 3. Poisson distributions adopted to evaluate the interpolating function to describe the "few"(top left), "many" (top right) and "most" terms (bottom)

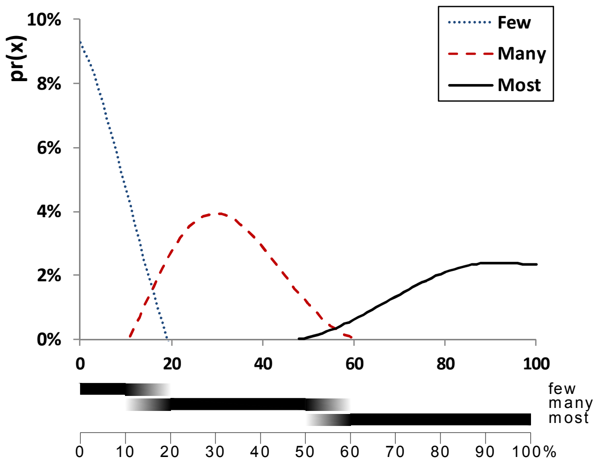

Figure 4. Comparison between the "few", "many" and "most" terms formalization using the interpolating lines of Poisson distributions (top) and fuzzy representation by EMS98 (bottom)

The interpolating lines obtained by the Poisson probability functions adopted are characterized by mean values equal to 7.5/100 for "few", 31/100 for "many and "82/100" for "most", in good agreement with the representation supplied by the EMS98, see figure 9, and in line with the trapezoidal model adopted by (Lagomarsino and Giovinazzi 2006), whose mean values are, respectively, 7.5/100, 35/100, 77.5/100.

In light of such consideration and substituting to terms "few", "many" and "most" the mean values obtained, the qualitative DPM of tables 1 and 2 can be quantified in the DPM of tables 3 and 4, where to the terms "practically all" was assigned a value of "95/100".

Table 3. Quantitative Damage Probability Matrix obtained by the EMS98 data for the C class buildings considering only non-structural damage.

Earth. intensity (MMI)	**NON-STRUCTURAL DAMAGE GRADE**				
	1	**2**	**3**	**4**	**5**
V	--	--	--	--	--
VI	7.5%	--	--	--	--
VII	--	7.5%	--	--	--
VIII	--	31%	7.5%	--	--
IX	--	--	31%	7.5%	--
X	--	--	--	31%	7.5%
XI	--	--	--	82%	31%
XII	--	--	--	--	95%

Table 4. Quantitative Damage Probability Matrix obtained by the EMS98 data for the C class buildings considering only structural damage.

Earth. intensity (MMI)	**STRUCTURAL DAMAGE GRADE**				
	1	**2**	**3**	**4**	**5**
V	--	--	--	--	--
VI	--	--	--	--	--
VII	7.5%	--	--	--	--
VIII	31%	7.5%	--	--	--
IX	--	31%	7.5%	--	--
X	--	--	31%	7.5%	--
XI	--	--	82%	31%	--
XII	--	--	--	95%	--

An exact economical quantification of the damage degree, associated to each damage level defined by EMS98, would require a precise and detailed knowledge of buildings and theirs content value. In the following, the economical quantification of the damage degree, is carried out in two steps: i) calibrating a probabilistic distribution on the base of the DPM obtained for each vulnerability class, ii) calibrating the damage level on the base of real data collected during the reconstruction of the L'Aquila (Italy) 2009 earthquake.

It is assumed therefore that the distribution of the damage level to all elements, both structural and not, of a population of buildings can be represented by means of a binomial distribution such as:

$$P(k)=\binom{n}{k}\cdot p_r^k\cdot(1-p_r)^{n-k} \quad (2)$$

where p_r *is* the probability of damage to a single building, n is the number of damage levels considered (level *0* indicates no damage) equal to 5 for non-structural damage and to 4 for structural damage, k *is* the damage level effectively assumed for each degree of damage, It is so possible to formulate the binomial distribution that best approximates the mean number of damaged buildings and the corresponding mean damage level as represented in Table 3 for C class buildings. The comparison of tables 3 and 4 with tables 5 and 6 shows the good agreement between the damage distributions associated to "few", "many" and "most" buildings (encased in red in tables 5 and 6).

Table 5. Binomial distribution (expressed in %) of the non-structural damage among the different damage levels with varying probability of damage, pr, the associated vulnerability class and the corresponding seismic intensity (according to EMS98).

MMI	NON-STRUCTURAL DAMAGE GRADE [%]						
	p_r	0	1	2	3	4	5
V	0%	100	0	0	0	0	0
VI	2%	91	9	0	0	0	0
VII	10%	59	33	7	1	0	0
VIII	25%	24	40	26	9	1	0
IX	45%	5	21	34	28	11	2
X	65%	1	5	18	34	31	12
XI	80%	0	1	5	20	41	33
XII	99%	0	0	0	0	5	95

Table 6. Binomial distribution (expressed in %) of the structural damage among the different damage levels with varying probability of damage, pr, the associated vulnerability class and the corresponding seismic intensity (according to EMS98).

MMI	STRUCTURAL DAMAGE GRADE [%]						
	p_r	0	1	2	3	4	5
V	0%	100	0	0	0	0	--
VI	0%	100	0	0	0	0	--
VII	2%	92	8	0	0	0	--
VIII	12%	60	33	7	1	0	--
IX	35%	18	38	31	11	2	--
X	55%	4	20	37	30	9	--
XI	75%	0	5	21	42	32	--
XII	99%	0	0	0	4	96	--

In order to correlate the macro-seismic intensity, MMI, with the damage suffered by buildings expressed in economical terms the EMS98 damage grades are correlated to the percentage of the Reconstruction Cost (%RC), making useful reference to the damage suffered by a specific typology of buildings after the 2009 L'Aquila earthquake.

Such damage are documented, studied and classified in several works, such as (De Martino 2017; Di Ludovico 2017a; Di Ludovico 2017b), while a full comprehensive and detailed description is contained in the White Book ("Libro Bianco") (DPC, 2009), containing information collected during the survey and reconstruction phases of the private buildings after the 2009 L'Aquila earthquake. The surveys were carried out on buildings located in municipalities with macro seismic intensity greater than VI in MMI scale and the AeDES form (Baggio et al. 2007) was used as a rapid tool to assess the buildings structural and non-structural damage. The data contained within the White Book refers to private residential buildings damaged by the earthquake classified, following the AeDES forms, as B_{AeDES} (usable after short term countermeasures), C_{AeDES} (partially usable) and as E_{AeDES} (unusable) but treated as B_{AeDES} or C_{AeDES} (the "light reconstruction"). For all of the buildings, it was foreseen the repair of damage and the local strengthening. Among all the data collected within the White Book, within this work, only the data concerning the r.c. buildings built in the period 1972-1991 and the masonry buildings built after the 1972, were considered. Such buildings can be, indeed, classified with reasonable reliability following the EMS98 indications as C class buildings. Considering for such buildings only the repair cost, neglecting so the cost associated to the local strengthening, it is so possible to estimate the damage induced by the earthquake and correlate it the MMI scale, as shown in figure 5.

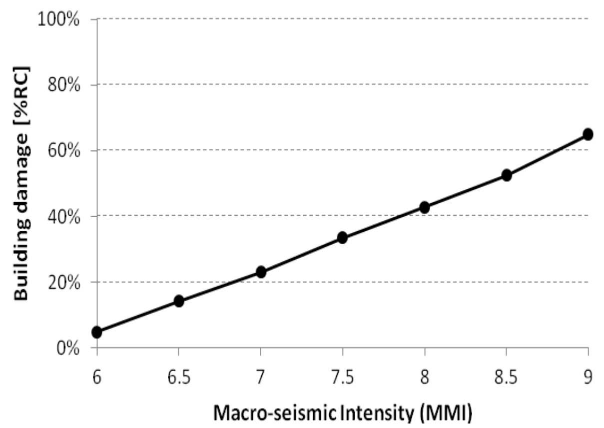

Figure 5. Relationship between the repair costs (in terms of percentage of Reconstruction Costs) and earthquake MMI for the EMS98 C class buildings, as obtained from the analysis of buildings damaged by the 2009 L'Aquila earthquake.

To correlate the damage levels defined by EMS98 and the real damage represented in figure 10, it is necessary to hypothesize an average division between structural and non-structural elements. Based on the report FEMA E-74 (FEMA 2004), it is possible to attribute 25% of the RC to the structures themselves, and the remaining 75% to non structural elements. This subdivision well represents framed r.c. residential buildings and will be used in the following to derive the numerical values of the economical losses. However the procedure maintains his general value and calibrated numerical results can be derived for other buildings categories adopting different structural-non-structural elements percentage subdivisions.

The values of economical loss, in terms of %RC, associated to each damage level defined by the EMS98 is obtained minimizing the differences between the results reported in figure 5 and the ones obtained adopting the damage distribution reported in tables 5 and 6. The differences are minimized adopting the procedure of ordinary least square. The resulting economical loss associated to each damage level and the comparison between the actual economical losses estimated for the 2009 L'Aquila earthquake and the ones evaluated adopting the described procedure are shown in figure 6.

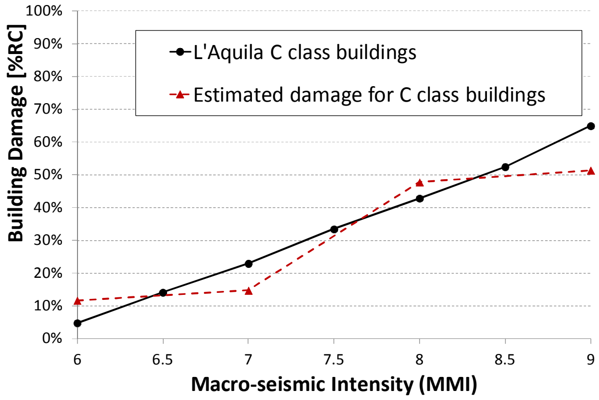

Figure 6. Repair costs for the C class buildings, as obtained from the analysis of buildings damaged by the 2009 L'Aquila earthquake, and economical loss estimated for the same class through the proposed procedure.

Adopting the values of economical loss associated to each damage grade shown in figure 6 and extending the procedure exposed for the C building class also to the other classes, it is possible to relate the economical losses of each building class defined to the earthquake macro-seismic intensities (MMI), see table 7.

Table 7. Values of %RC for each vulnerability class and MMI intensity level.

MMI	A	B	C	D	E	F
V	1.1%	1.1%	0.0%	0.0%	0.0%	0.0%
VI	6.1%	6.1%	1.1%	0.0%	0.0%	0.0%
VII	37.3%	17.2%	6.1%	1.1%	0.0%	0.0%
VIII	61.2%	38.3%	17.6%	6.1%	0.0%	0.0%
IX	79.2%	61.2%	38.3%	17.6%	6.1%	0.0%
X	94.5%	79.2%	61.2%	38.3%	17.6%	6.1%
XI	96.9%	94.5%	79.2%	61.5%	38.3%	17.6%
XII	97.5%	96.9%	96.9%	94.8%	94.8%	94.5%

In order to obtain a quantitative engineering classification it is necessary to correlate the MMI with a quantitative measure, such as, for example, the return period of the seismic action.

With specific regard to the Italian territory, it is possible to use the following expression, proposed by project DPC-INGV S1 (Gomes et al. 2007):

$$\log(PGA) = A + B \cdot I \quad (3)$$

where I is the macro-seismic MCS intensity, PGA is the peak ground acceleration (in m/sec^2) and A and B are two constants whose values have been drawn from (Margottini et al. 1992) by applying a orthogonal regression to the DB1database (data from Margottini et al. 1992). Herein the values A=-1.71 and B=0.18 have been assumed.

The values of I are thus assigned to the 4 Italian seismic zones, defined for administrative purposes by the OPCM 3274/2003 and represented in figure 2. For each zone, the relation between I and the annual mean frequency of exceedance, λ, is obtained by regression according to the following expression:

$$\lambda = e^{-(I-b)/a} \quad (4)$$

Table 8 reports, for each of the 4 Italian seismic zones, the values obtained for the parameters a and b, together with the associated explained variance R^2.

Table 8. Values of a, b and R^2 for each of the 4 Italian seismic zones.

	ZONE 1	ZONE 2	ZONE 3	ZONE 4
a	1.085	1.010	0.890	0.747
b	5.0375	4.6926	3.7855	2.7841
R^2	0.9753	0.9240	0.7200	0.9217

Table 9 shows all values (lower than 10%) of the annual mean frequency of exceedance λ corresponding to the relevant values of intensities (between V and XII) obtained by adopting the values of a and b in Table 8 through equation (4) and assuming an acceptable correspondence between MCS and EMS98.

Table 9. Values of λ for each of the 4 seismic zones and the 8 EMS98 intensities of interest.

	$\lambda = 1/T_R$			
MMI	**ZONE 1**	**ZONE 2**	**ZONE 3**	**ZONE 4**
V	--	--	--	4.751%
VI	--	--	8.313%	1.246%
VII	--	10.183%	2.704%	0.327%
VIII	6.536%	3.783%	0.879%	0.086%
IX	2.602%	1.406%	0.286%	0.022%
X	1.036%	0.522%	0.093%	0.006%
XI	0.413%	0.194%	0.030%	0.002%
XII	0.164%	0.072%	0.010%	0.000%

3.3 *Determination of the loss curves for each vulnerability class*

By combining the direct losses, %RC, in Table 7 with the λ values in Table 9, the loss curves are obtained. Figure 7 shows the loss curves for Zones 1 and 2, while figure 8 refers to Zones 3 and 4. In both cases, such curves refer to plane, surface type "A" soil. The figures are flanked by tables containing the ranges of the mean values of the ratio EAL/RC (in %) for each seismic zone and vulnerability class, evaluated calculating the area under each curve.

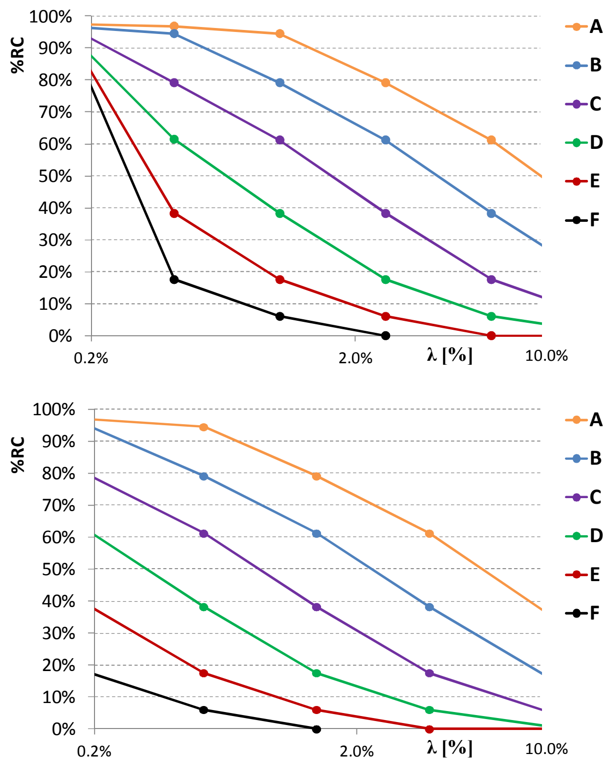

Figure 7. Losses associated with the different vulnerability classes for buildings in Zones 1 (top) and 2 (bottom)

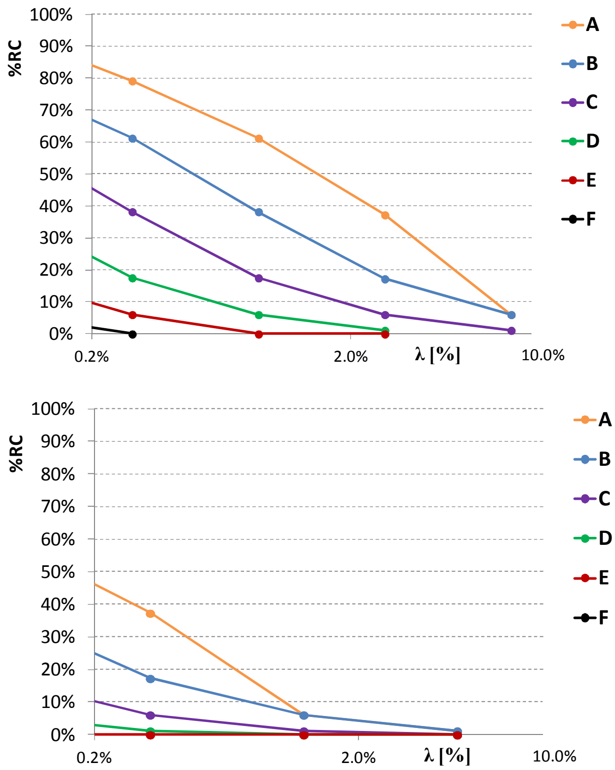

Figure 8. Losses associated with the different vulnerability classes for buildings in Zones 3 (top) and 4 (bottom)

From the analysis of figures 7 and 8 several observations, coherent with the post-earthquake evidences, can be made. In the high seismicity zones (zones 1 and 2 of the Italian territory) buildings belonging to F and E classes suffer very low damage for low values of λ, testifying the good quality of seismic design and in particular the high attention to non-structural elements. On the contrary, A and B buildings suffer severe damage even for high values of λ, leading to very high values of the expected annual losses (EAL). For the lower seismicity zone (zone 4) the seismic risk is so low that can be neglected when compared to other sources of loss, such as ageing and ordinary maintenance of the building. A similar conclusion can be done also for low vulnerability classes (F, E and D) in low-medium seismicity zone (zone 3). Finally, observing the loss curves of figure 7 associated to the high seismicity zone (zone 1), it can be noticed that the economical losses associated to all classes tend to uniform themselves for high low values of λ, meaning that for very severe earthquakes all the buildings reach a condition close the collapse. Such situation does not actually reflect very well the desired behavior of buildings designed following the most modern seismic standard, such as the buildings belonging to the E and F class. Such dissimilarity is caused by the unavoidable low accuracy of the λ-MMI relationship adopted for MMI grades higher than X.

4 CONCLUSIONS

Within the present research, an innovative methodology to classify seismic risk of buildings located in the Italian territory is presented and described in details. The classification proposed is organized on 6 vulnerability classes, reflecting those of the EMS98. To each class and for each Italian seismic zone, a specific loss curve, relating the mean building damage in terms of percentage of the Reconstruction Cost, %RC, with the annual frequency of exceedance, $\lambda=1/T_R$, is provided and the associated range of EAL evaluated. The loss curves obtained within this paper respects, as much as possible, the information provided by the EMS98. However, more reliable and specific calibration of such curves can be obtained once a wider range of actual post-earthquake damage recording are available.

The work described within this paper was used as a basis for the development of the "Guidelines for the Seismic Risk Classification of Buildings" published by the Italian Ministry of Infrastructures and Transportations.

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