Damage risk and scenarios in the Veneto - Friuli area (NE Italy)

F. Meroni[1], V. Pessina[1] and A. Bernardini[2]

[1] *Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, Italy*
[2] *Dipartimento Costruzioni e Trasporti, Università di Padova, Italy*

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ABSTRACT The assessment of seismic damage to residential buildings and the estimation of human losses in the Veneto - Friuli area (NE Italy) have been considered at different scales of analysis and, in conformity with the hazard analysis trend, at different levels of investigation. Over a wide area, defined by nearly all the municipalities of three provinces in the area, a full probabilistic damage assessment has been performed, based on a regional probabilistic seismic hazard estimation. Then, deterministic seismic damage scenarios were generated on two sub-regional areas, centred on the Vittorio Veneto municipality; the ground motions derive from two different simulations of the 1936 Cansiglio event (*M* 5.8), and from a hypothetic *M* 6.7 seismic source located in the Montello area.

1. Introduction

Generally, both probabilistic and deterministic methods can be used in the assessment of seismic risk. The choice depends on the scale level of the investigation, on the available data given by the hazard analysis and, on the final application of the results.

In the selected area which is defined by the municipalities of the provinces of Treviso, Belluno and Pordenone (NE Italy), named AS1 in the following, a probabilistic analysis has been carried out. The expected cumulative damage in 50 years has been obtained by combining the probabilistic estimates of the macroseismic intensities and statistical information on the vulnerability of buildings.

The peak ground acceleration (*PGA*) values have been evaluated by a probabilistic seismic hazard assessment (PSHA) in the centroid of each census tract (Slejko *et al.*, 2008), and they have been converted into an equivalent continuous variable of macroseismic EMS98 (Grünthal, 1998) intensity by an appropriate correlation relationship calibrated on historical damage observations and acceleration records of the 1976 Friuli event (Slejko *et al.*, 2008). The full probabilistic risk analysis provides relatively low values of damage, conventionally expected in 50 years, slightly influenced by local site amplifications or by the source location, and useful to compare relative damage levels or to define a priority list of mitigation actions over large areas.

On the other hand, deterministic damage scenarios are based on the repetition of the 1936 Cansiglio event (*M* 5.8) and the *M* 6.7 Montello reference earthquake. They have been elaborated for two smaller areas, classified as medium-high seismic risk and located on the border of the provinces of Belluno, Treviso and Pordenone, using the hazard scenario analyses made by Laurenzano and Priolo (2008) and Pettenati and Sirovich (2004).

The elements considered at risk are the residential buildings and their inhabitants: data come from the ISTAT91 (1995) survey and they are gathered at the level of census tract. Moreover, nearly 5000 buildings in 46 census tracts have been inspected in the year 2003, by the AeDES (Bernardini, 2000a) survey form to evaluate the reliability of ISTAT91 data and, moreover, to update the statistics of the number of buidings and volumes.

The vulnerability classification of buildings is based on the EMS98 scale definitions (Bernardini, 2004); while the damage assessment is evaluated by the implicit fuzzy damage probability matrices (DPM) considered in the EMS98 scale. In the present work, we used the expected "white" DPM in the binomial version proposed by Bernardini *et al.* (2008).

The evaluation of collapsed or unusable buildings is based on some assumed correlations to the EMS98 damage levels (from D1 to D5), both in terms of expected number or volumes of buildings. Unusable buildings are structures presenting a high level of damage due to the seismic event: therefore they cannot be used in the emergency period and need to be reinforced.

The evaluation of the number of victims or homeless is carried out using a modified correlation based on Italian data (Lucantoni *et al.*, 2001). The computational method is based on properly developed Matlab codes, with the support of the Geographic Information System (GIS) technology.

2. Probabilistic damage scenario for AS1 area

Hazard maps are produced for the extended AS1 area on the basis of a probabilistic ground shaking scenario (Slejko *et al.*, 2008). *PGA* values, with a 90% probability of not exceeding, have been evaluated for 20 exposure times, on the centroids of each census section, following the Cornell (1968) approach. To compute robust seismic hazard estimations, a logic tree approach has been used (Slejko and Rebez, 2004) to quantify the epistemic uncertainties; the adopted options concern seismogenic zonation, maximum magnitude, and *PGA* attenuation relations. The assumed *PGA*s correspond to mean values plus a standard deviation of the random uncertainties plus the worst combination of the epistemic uncertainties.

The damage level for each census tract is computed through the following steps:

1. evaluation of the cumulative distribution function of the *PGA* values provided by PSHA for a given exposure time (50 years);
2. fitting of the latter cumulative distribution function into an appropriate statistical distribution;
3. evaluation of the probability distribution for *PGA* values corresponding to each intensity classes of EMS98 macroseismic scale;
4. damage evaluation following the DPM method, using the local corrected distribution of the vulnerability classes for buildings (both in building number and volume).

2.1. *Exceeding probability evaluation in terms of PGA*

In the adopted procedure for seismic hazard evaluation, the earthquake occurrence is assumed to follow the Poisson distribution; according to this assumption the probability of having k events in the t time interval is independent from the time of the last event and is completely defined by a constant occurrence rate μ (or the return period $T_r = 1/\mu$) through the distribution function:

$$P(k,t) = \frac{(\mu t)^k e^{-\mu t}}{k!}. \qquad (1)$$

A particular case, is the probability of no event in the t time interval:

$$P(0,t) = e^{-\mu t}. \qquad (2)$$

In the present application, the PSHA provides 20 *PGA* values a_i ($1 \le i \le 20$) not exceeded (at 90% of probability) in the corresponding 20 exposure times t_i (which have been opportunely chosen in the 2–5000-year range, with non constant interval). Thus one can get, for each exposiion time t_i, the occurrence rate for events having $a \ge a_i$:

$$\mu_i = -\frac{\ln(P = 0{,}9)}{t_i}. \qquad (3)$$

The risk maps for the regional area are developed in terms of damage indicators evaluated on a 50-year time interval: the probability to have at least one event with $a \ge a_i$, in 50 years, for each census tract, is

$$P_i = P(a \ge a_i)_{50} = 1 - F(a = a_i) = 1 - e^{-50\mu_i} \text{with } 1 \le i \le 20, \qquad (4)$$

where $F(a)$ is the cumulative distribution function of the *PGA*. Approximate values of probability density curve $f(a)$ of the *PGA* can be calculated, for each interval $[a_i; a_{i+1}]$, by

$$f(a_{mean}) = (a_i + a_{i+1})/2 = \frac{P(a \ge a_i) - P(a \ge a_{i+1})}{a_{i+1} - a_1}. \qquad (5)$$

In Fig. 1 the P_i and $f(a)$ curves are shown for one census tract of the town of Belluno.

2.2. Fit of the occurrence probability of PGA

The *PGA* exceeding probability $P(a \ge a_i)_{50}$ is fitted with an analytical distribution in order to evaluate the probability for every acceleration values, not only for those a_i related to the 20 available exposure times t_i.

Following this method the acceleration probabilities, which correspond to upper and lower bounds of the macroseismic intensities, can be evaluated and therefore the occurrence probability for each intensity degree can be computed in every census tract.

Different analytical distributions have been tested (exponential, double exponential, Pareto, Weibull) and the Weibull one was chosen for flexibility and dependence from only two

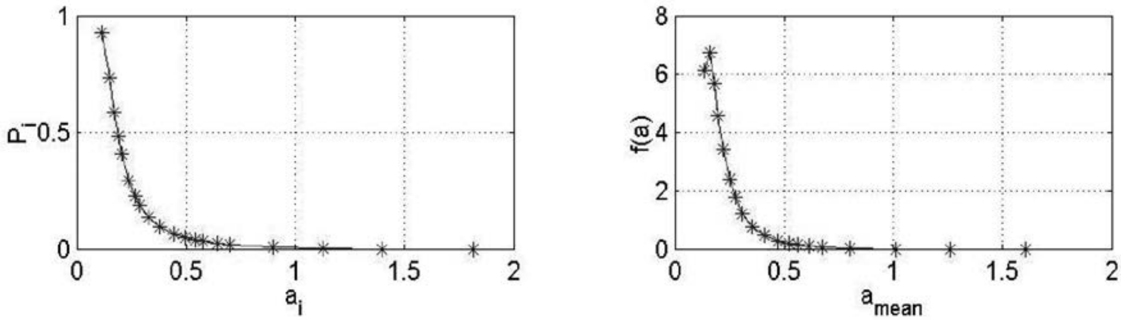

Fig. 1 - P_i=$P(a\geq a_i)$(left) and f=$(a$=$a_{mean})$ (right) evaluated for a census tract of Belluno town.

parameters, and because it provides the minimum square error in fitting the *PGA* probability distribution, in all the census tracts.

The Weibull cumulative distribution function (cdf) is:

$$F\,(x{=}a) = e^{-x^{\alpha}/\beta} \qquad (6)$$

where α and β are the distribution parameters, to be estimated minimizing the square error.

The comparison between the calculated exceeding probabilities P_i and the Weibull fitting distribution has been calculated for some representative sites: in Fig. 2 this comparison is displayed for a site of the Belluno province; similar behavior is shown in other sites of Treviso and Pordenone provinces, representative of different level of expected hazard.

The goodness of the fitting decreases for highest exposure times, but the influence on damage assessment is very poor: the *PGA* values have a very small occurrence probability ($\cong 10^{-5}$) for highest exposure times (over 700 years of return period).

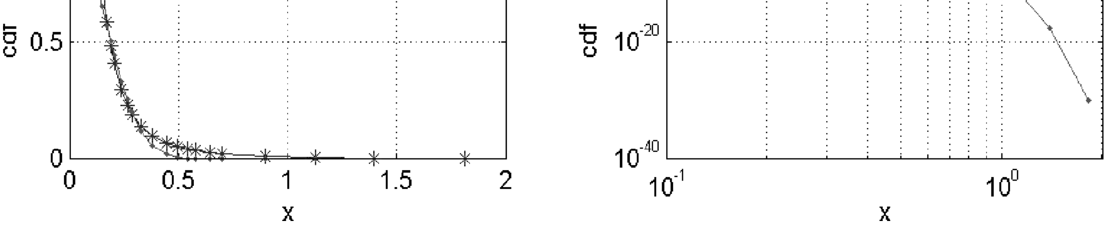

Fig. 2 - Comparison between calculated exceeding probability P_i (stars) and Weibull fitting distribution (dots), in linear (left) and logarithmical (right) scale.

Table 1 - Limits of intensity and acceleration classes used in the evaluation of occurrence probability P_{I_i}, calculated by the intensity - *PGA* correlation (Slejko *et al.,* 2008).

Intensity class **I_i**	Superior intensity limit I_i	Superior acceleration limit x_i
IV	4.499	0.03560
V	5.499	0.06045
VI	6.499	0.10263
VII	7.499	0.17424
VIII	8.499	0.29582
IX	9.499	0.50225
X	10.499	0.85272
XI	11.499	1.44774
XII	12	1.88739

2.3. Intensity class probability evaluation

To proceed with the damage calculation it is necessary to correlate the level of damage with the intensity of the ground shaking. For buildings of every EMS98 vulnerability class, the frequency of five damage grades [from D1 (= light) to D5 (= collapse)] are given, for eight intensity classes, from V to XII by the DPM.

As the *PGA* values provided by the PSHA analysis are a continuous variable, while the intensity parameter is a discrete one, it was necessary to define intensity classes I_i by means of intervals [I_{i-1}, I_i], and fractional intensity values as shown in Table 1: together with the superior limit I_i of each class *i* it is shown the relative acceleration value x_i evaluated by the intensity-*PGA* correlation proposed during the project (Slejko *et al.,* 2008):

$$I_{MSK} = 4.35 * \mathrm{Log}\,(x_i) + 2.10. \quad (7)$$

The cumulative densities related to the acceleration threshold x_i (corresponding to the limit of the intensity class) can be calculated using the optimal Weibull cdf [Eq. (6)]; and finally the occurrence probability P_i of an intensity class I_i is:

$$P_{I_i}\,\{x_{i-1}<X<x_i\} = F(x_i) - F(x_{i-1}). \quad (8)$$

Following this approach, the probabilities of the DPM intensity classes are evaluated in order to estimate probabilistic levels of damage, weighing each intensity class with its probability.

2.4. Damage assessment

Damage scenarios are estimated by the DPM method that is based on a statistical correlation among the macroseismic intensity, the vulnerability class, and the apparent damage, described in terms of damage grades. In this approach, damage of every grade (D0-D5) is evaluated by a convolution integral on ground shaking maps (expressed in terms of intensity) and frequency of

Table 2 - Values of average damage *d* of the binomial function, for each vulnerability and EMS98 intensity classes (Bernardini *et al.*, 2008).

EMS98 Intensity	A	B	C	D	E	F
V	0.015	0.015	0	0	0	0
VI	0.100	0.100	0.015	0	0	0
VII	0.440	0.255	0.100	0.015	0	0
VIII	0.640	0.440	0.255	0.100	0.015	0
IX	0.765	0.640	0.440	0.255	0.100	0.015
X	0.940	0.765	0.640	0.440	0.255	0.100
XI	1	0.940	0.850	0.655	0.455	0.255
XII	1	1	0.995	0.970	0.940	0.895

buildings in the vulnerability classes. The integral gets summations in discrete terms, one on the intensity degree (I-XII) and the other on the number of buildings (or volumes) in each vulnerability class (A - F). In both summaries, the variables are weighted by the probability of the intensity classes (P_{I_i}) and by the probability (p_k) of the damage grade *k* given by the adopted DPM, respectively.

The binomial distribution appropriately represents the DPM assumed in the present work:

$$p_k = \frac{5!}{k!(5-k)!} d^k (1-d)^{5-k} \tag{9}$$

where p_k is the damage probability of level k ($k = 0, 1, ...5$).

The binomial distribution is completely defined by the binomial coefficient (or "average damage") *d*, ranging between 0 and 1, or by the correlated mean value of the variable *k* (5*d*), here simply derived by the mean value of the numerical cumulative distribution of the expected "white" probabilities implicitly given by the EMS98 scale (Bernardini *et al.,* 2008). Technically, using only the average damage *d*, it is possible to describe the whole damage distribution for each class of vulnerability and each intensity level.

In Table 2 the assumed values of average damage *d* are summarized.

The evaluation of the damage level of buildings (number of buildings or volume) is calculated in each census tract according to the following relation:

$$D_k = \sum_{i=1}^{12} P_{I_i} \sum_{j=1}^{6} n_j p_{k_{ij}} \tag{10}$$

where D_k is the estimation of the number of buildings with damage *k*, with $k = 0, 1, ...5$; P_{I_i} is the occurrence probability of the EMS98 intensity level I_i, with $i = 1, ... 12$; n_j is the corrected number of buildings in the vulnerability class *j*, with $j = 1, ...6$ according to the six EMS98 vulnerability classes (A, B, C, … F); $p_{k_{ij}}$ is the conditional probability of the k level of damage (k = 1, ... 5), given the intensity degree i (i = 1, ... 12) and the vulnerability class j (j = 1, ... 6) from DPM.

3. Deterministic damage scenarios

In the case of the deterministic damage assessment, Eq. (10) is reduced to a simple sum:

$$D_{I_k} = \sum_{j=1}^{6} n_j p_{k_{ij}} \quad (11)$$

where D_{I_k} is the estimation of the number of buildings with damage k (k = 0, 1, ...5), given the intensity I_k; n_j is the corrected number of buildings in the vulnerability class j, with j = 1, ...6; $p_{k_{ij}}$ is the conditional probability of a k level damage (k = 1, ...5), given the intensity degree i (i = 1, ...12) and the vulnerability class j (j = 1, ...6).

4. Computational analysis

The computational method is based on the combination of a proper developed Matlab code, to perform vulnerability and damage assessment, and GIS technology, dealing with the geographic elaboration of residential buildings and the population data. The ISTAT91 data have been modified and updated through corrective coefficients regionally calibrated on the AeDES survey performed in 2003, and the damage has been evaluated according to the EMS98 scale classification into grades D1-D5. The evaluation of victims or homeless was carried out using a correlation based on Italian data [modified from Lucantoni *et al.* (2001)].

The analysis was carried out for each census tract, both at sub-regional scale and at local scale. However, there are some census tracts that are not considered by the ISTAT91 survey because they have no residential buildings, because they are industrial or commercial zones, public services, natural reserves, fields with crops, etc. All the non-classified tracts were characterized, one by one, into 3 groups of mountain/forest, lake/river or countryside class, using orthophotomaps at 1:10,000, available at http://www.atlanteitaliano.it (see for instance Fig. 7 and the following figures).

A synthetic vulnerability index I_V is introduced to display and compare the vulnerability of the different census tracts; it is defined by the weighted sum of volumes, for each vulnerability class:

$$I_V = \sum_{i=1}^{6} k_i V_i / V_{tot} * 100 \quad (12)$$

where V_i is the volume of buildings in the vulnerability class i; V_{tot} is the sum of the volume of all buildings in the census tract; k_i is equal to (-40, -20, 0, 20, 40, 60) with i (i = 1, ...6) corresponding to the score of each vulnerability class (A, B, C, …F).

More meaningful damage parameters are calculated as:

- **collapsed buildings** = all buildings with D5 level damage;
- **unusable buildings** = 40% buildings with damage D3 + 100% buildings with damage D4 or D5.

The expected number of victims (deaths and injured) and homeless have been calculated from the population of the ISTAT91 census as follows:

- **victims** = 30% of inhabitants in buildings with damage D5;
- **homeless** = 70% of inhabitants in buildings with damage D5 + 100% of those hit by damage D4 + 30% of those in D3;

considering inhabitants distributed in the damage class proportionally to the building classification.

We should consider the following caveats in the evaluation of the previous indicators:

(i) damage and victim assessment is based only on residential buildings;

(ii) time factors as seasonal or day/night conditions have not been considered, even if we could assume that the distribution of residents reflects the night condition more;

(iii) induced risk factors (such as fires, landslides, ground braking, etc.) have not been considered in the number evaluation of the victimis.

The GIS support (Arc/Info and Arcview ESRI), besides pointing out the presence of areas without residential data or with an inhomogeneous distribution of urbanization, allows us also a deep level of analysis: indeed damage indicators have been calculated at a level of census tract both for local analysis and for a regional one (AS1 area). Thanks to the GIS, it is easy to move from one scale to another, with the same level of resolution.

The only restriction to this level of approach regards the presentation of results: if, on one side, the census tract resolution avoids impressive extrapolation of results over areas differently populated, on the other side some indicators (as number of victims, for instance) should be better presented, at least at municipal level.

5. Results and maps

5.1. Risk maps for the regional scale area (AS1)

The *PGA* values have been calculated by PSHA analysis in each of the 6537 census tracts of the AS1 area, including the effects of ground conditions (rock, stiff or soft soil), as shown in Fig. 3a: the geological characterization of each tract has been evaluated according to the soil features of its centroid. The estimated and amplified values of *PGA* have also been increased by the value of the standard deviation of the adopted attenuation law, and by the value of the epistemic uncertainties of the different branches of logic tree method.

The vulnerability index I_v of the residential buildings has been calculated, in each census tract, as average value of the overall building stock in the tract (Fig. 3b). Average values are slightly lower than those of a similar index evaluated at national scale in previous works (Bernardini, 2000b). The vulnerability index distribution seems to reflect the morphological setting of the area: in the south plain the values are lower than those of the hills, while, in the northern mountainous zone, the vulnerability range is irregular.

The distribution of the number and volume of buildings provided by ISTAT91, in each

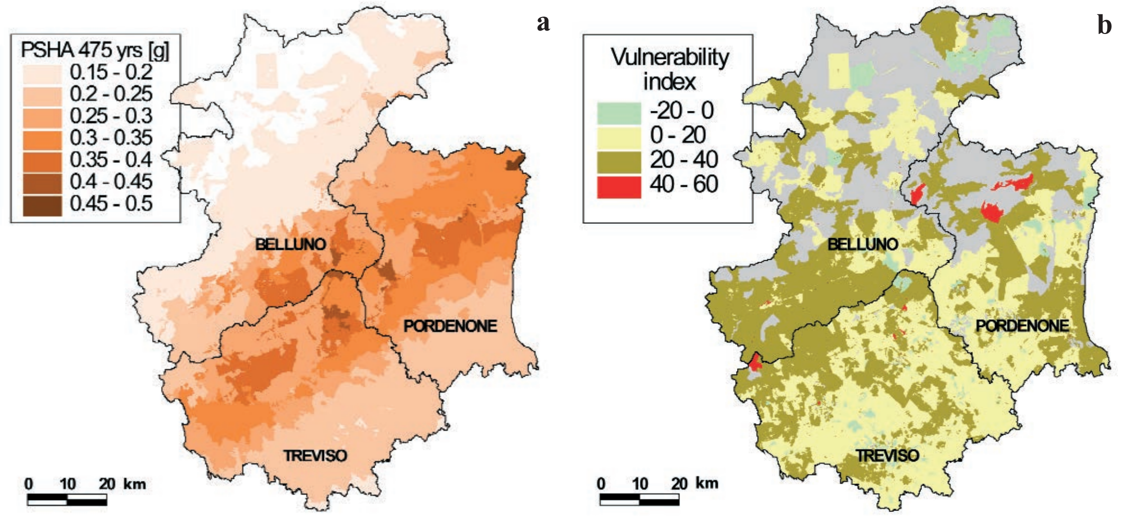

Fig. 3 - *PGA* map for AS1 area (a) obtained by the PSHA analysis (475-year return period) and vulnerability index map (b).

vulnerability, typological class, largely differs from the AeDES survey data, properly collected in 46 representative census tracts of the area. In order to correct the ISTAT91 buildings estimation, the distribution is adjusted by multiplicative coefficients (Bernardini *et al*., 2008). The more pessimistic hypothesis CR on the influence of the age of the buildings on the vulnerability has been assumed, and the coefficients are estimated using the better solutions given by both simple and robust regression methods.

The main results for the regional application are the maps of damage expected in 50 years: Fig. 4 illustrates the volume of collapsed and unusable buildings, while the number of victims and homeless is shown in Fig. 5. In the latter, census tracts with the maximum values are difficult to see at this scale because of their size: maximum losses are expected in small census tracts located in heavily built areas.

The risk map of the AS1 area refers to a region of 214 municipalities counting approximately 1,200,000 inhabitants; in terms of volume, the expected value of collapsed buildings is approximately 0.6% of the total built up volume (that is about 2,100 buildings).

The expected number of victims for the whole area is 0.1% (corresponding to about 1,800 people), while the expected number of homeless is 4.6% (corresponding to 55,900 people approximately).

The areas with higher damage levels correspond to the zone with maximum level of *PGA* in the hazard map (Fig. 3a) and, on the other hand, some strong values are referred to particular high vulnerability conditions shown on the map of Fig. 3b.

5.2. Damage scenarios for the sub-regional areas

Two reference events are used to elaborate the deterministic damage scenarios: the first is based on the repetition of the 1936 Cansiglio earthquake (October 18, $M = 5.8$), and the other is

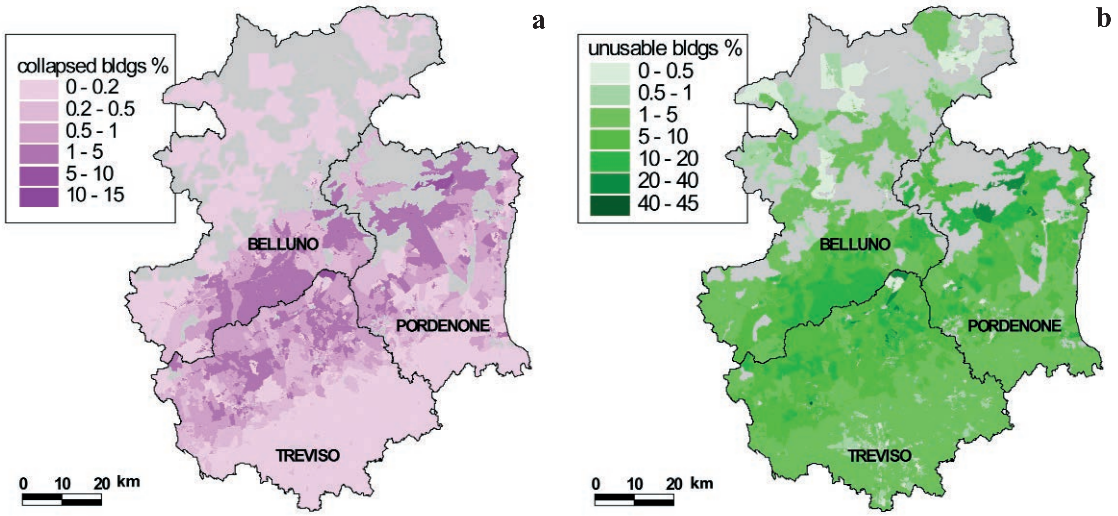

Fig. 4 - Risk maps for AS1 area: expected values, in 50 years, of volume of collapsed buildings (a) and unusable ones (b); values are expressed in percentage in each single tract.

generated by a hypothetic earthquake located on the inverse fault of Montello, with M = 6.7. Different research groups involved in the this project provided many hazard simulations, for each reference event: a first set of elaborations (Laurenzano and Priolo, 2008), named in the following as PL scenario, provides average *PGA* values on a regular grid of receivers; their conversion to intensity values is calculated by the intensity - *PGA* correlation (Slejko *et al.,* 2008). Other simulations (named SP) come from the method proposed by Pettenati and Sirovich (2004), and they provide intensity values calculated in the centroid of each census tract.

Damage scenarios have been elaborated for the Cansiglio area using both PL and SP hazard scenarios, while, in the case of Montello area, only the PL scenario has been considered, as summarized in Table 3.

5.2.1. Deterministic scenarios for the Cansiglio area

The extension of the area of interest for the Cansiglio scenario comes from the intersection between the grid points of the PL simulations with the municipality boundaries: in this case the selected area extends over 80 municipalities.

The hazard scenario over the same area was calculated also with the SP method. Fig. 6 shows both PL and SP scenarios, together with the distribution of the macroseismic observations (MCS)

Table 3 - Damage scenarios calculated.

	PL scenario *PGA*	SP scenario Intensity
Cansiglio	**PL_C**	**SP_C**
Montello	**PL_M**	—

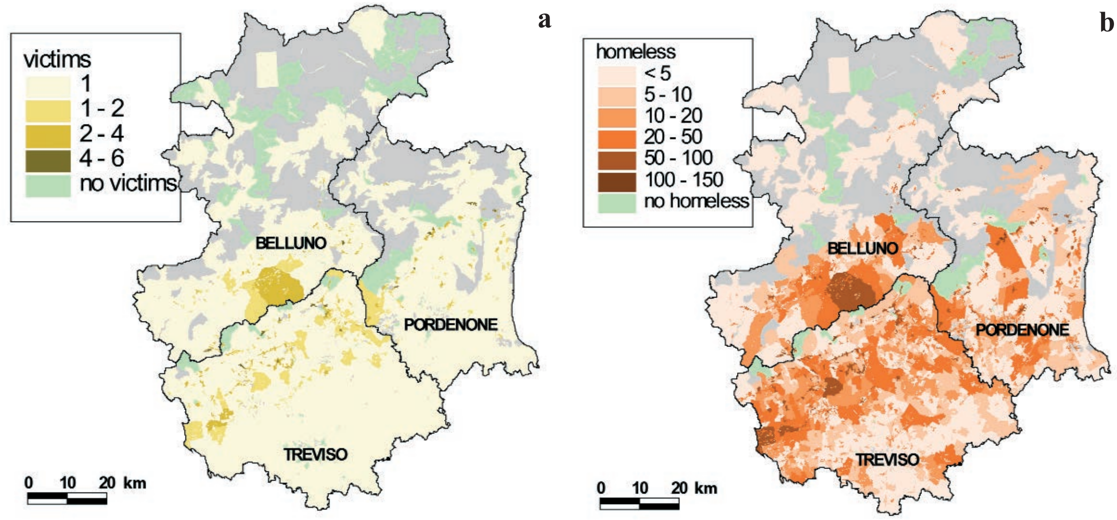

Fig. 5 - Risk maps for AS1 area: expected values, in 50 years, of number of victims (a) and homeless (b); values are expressed in percentage in each single tract.

of the 1936 Cansiglio event (Monachesi and Stucchi, 1997). Notable are the differences between the PL and SP scenarios, affecting the considered area with dissimilar ground shaking level.

In Table 4 the distribution of the population for each class of intensity is shown. The repetition of the Cansiglio event, according to the PL simulation, strikes an area of more than 450,000 inhabitants, 63% of which could experience an intensity bigger than V. The municipalities of

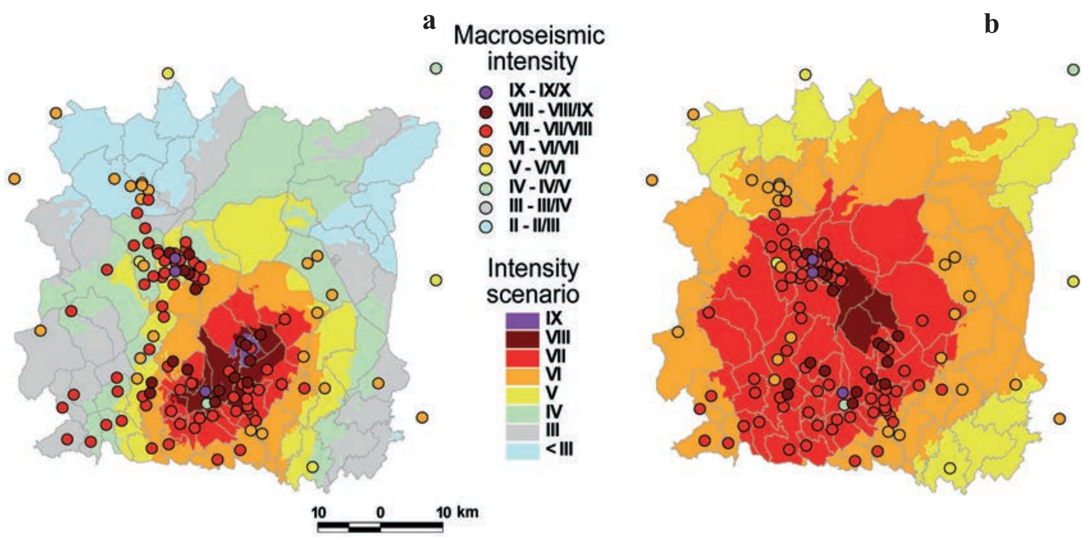

Fig. 6 - Maps of the EMS98 intensity scenarios for the Cansiglio area together with the macroseismic MCS intensities felt during the 1936 Cansiglio event (*M* 5.8): the PL simulation (a) provides higher values in a narrow zone and lower values in the peripheral ones, with respect to the SP simulation (b).

Table 4 - Population involved according to the PL Cansiglio scenario.

Intensity *average value*	**Population**
IX	5400
VIII	30442
VII	41011
VI	96631
V	110916
Total	**284400**

Polcenigo and Caneva, in the Pordenone province, suffer IX intensity grade, and they correspond to 1.2% of the population involved.

The PL simulation has been assumed as a reference scenario for the damage assessment evaluation, and a comparison is made with the SP scenario in terms of the expected losses.

Fig. 7 shows the percentage of the collapsed buildings (Fig. 7a) and of unusable ones (Fig. 7b), in each census tract. Collapsed structures are roughly 275, equal to 0.3% of the total building stock; the worst situation is in the Polcenigo municipality where the collapsed buildings represents 12% of the interested area, while the unusable ones are 43%.

Distribution of the number of damaged buildings and victims are shown according to the intensity level in Fig. 8. The results of the Cansiglio simulation provide an estimation of about 200 victims and about 5,400 homeless. In the IX intensity area 98 victims are expected, in the VIII area the number is 90, while at VII intensity the victims are 12. The percentage of homeless is 1.6% of the inhabitants of the whole considered area.

The results of the analysis are shown in Fig. 9: estimations of victims and homeless are displayed at municipal scale instead of census tract, because the latter kind of representation would have underestimated the effective size of the problem. Indeed, Fig. 10a shows the number of victims in each census tract, to be compared to the municipal cumulative value of the

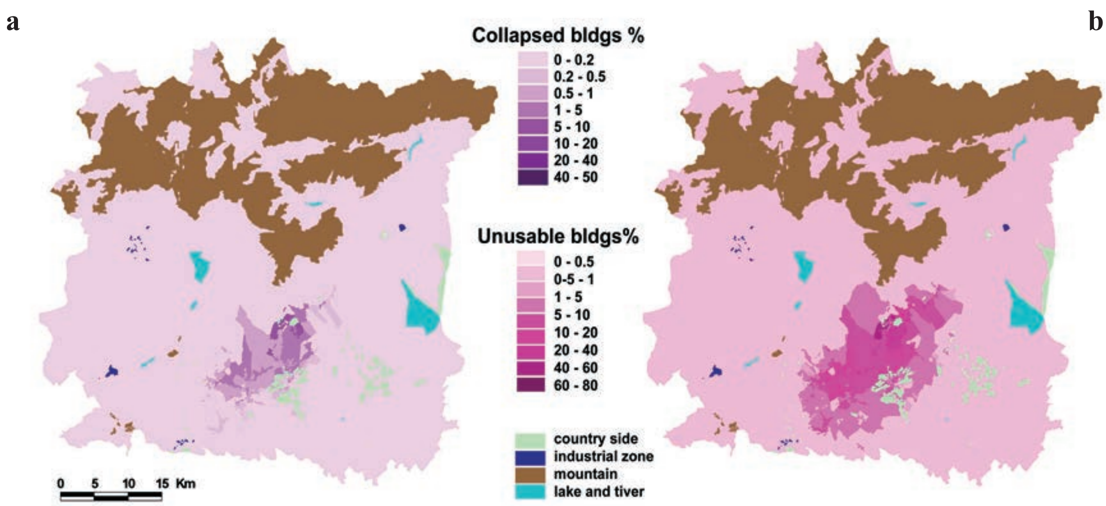

Fig. 7 - Collapsed buildings (a) and unusable buildings (b), in percentage for each census tract, for the Cansiglio PL scenario.

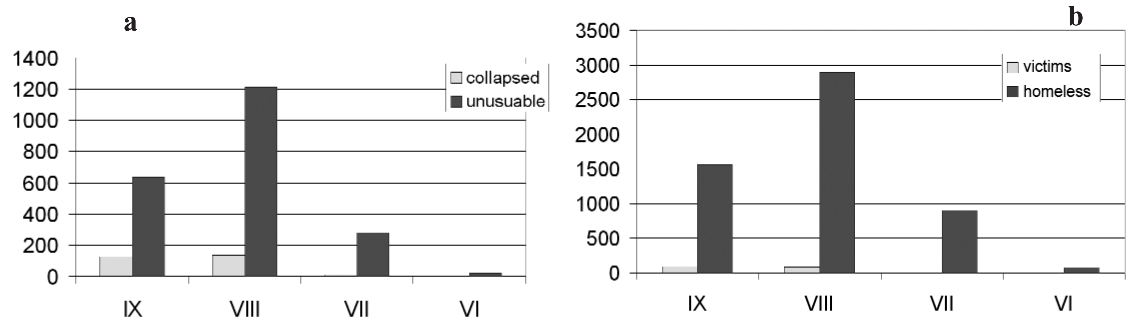

Fig. 8 - Distribution of collapsed and unusable buildings (a) and of victims and homeless (b), according to the intensity level for the Cansiglio PL scenario.

respective map in Fig. 9a: as can be easily noted, the impact of the two maps is quite different, even for a moderate magnitude event as the *M* 5.8 considered. So, bearing in mind that some preventive/operative actions are taken at municipal level at least, the knowledge of the expected number of total victims in the municipal area is more useful than the partial ones, in each census tract.

Referring to the comparison of both hazard scenarios illustrated in Fig. 6, the SP simulation provides lower values of intensity than the PL one, and they are dispersed over a larger area. This geographical hazard distribution obviously influences the risk distribution too. For instance, in Fig. 10b the number of victims, at the census tract level, for the Cansiglio SP scenario is illustrated: the differently struck area (shifted NW with respect to the PL simulation) seems to echo less serious effects. The same trend happens for all the other risk indicators (number of

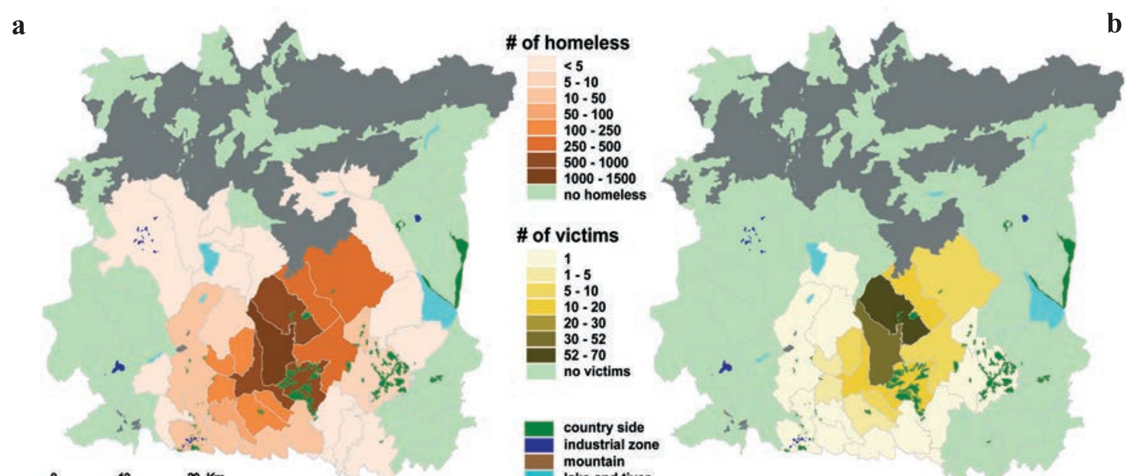

Fig. 9 - Number of homeless (a) and victims (b) in each municipality, for the Cansiglio PL scenario.

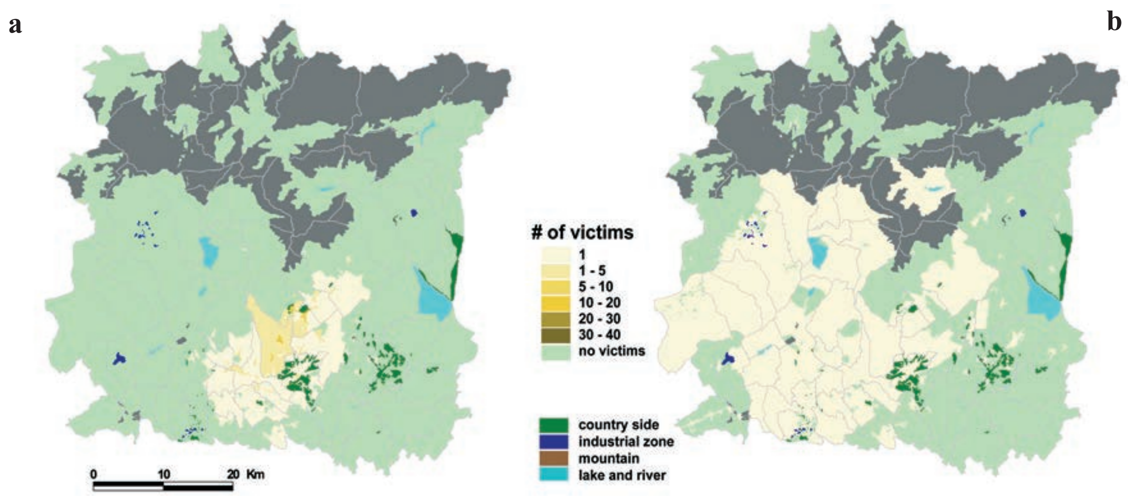

Fig. 10 - Number of victims in each census tract, for the Cansiglio PL scenario (a) and SP scenario (b).

homeless, collapsed buildings, etc.).

Nevertheless, the comparison of the total damage (displayed in Fig. 11), over the whole Cansiglio area, shows a comparable level of risk. This result is fairly unexpected. It is not sufficient to say that shaking ground scenarios generated with the same level of magnitude provide a comparable level of risk. In fact, on the one hand, the considered hazard scenarios are too dissimilar in geographical distribution and peak ground shaking values; on the other hand, the SP scenario, even if more diffused, interests a less populated area. The fortunate coincidence between hazard and exposition factors assures stable results in terms of loss prediction that can be profitably used by the civil protection administrators, at regional scale. The same situation is not usually guaranteed in case of earthquake scenarios with the same level of magnitude.

In any case, the expected number of victims and damage for the Cansiglio area, is relatively

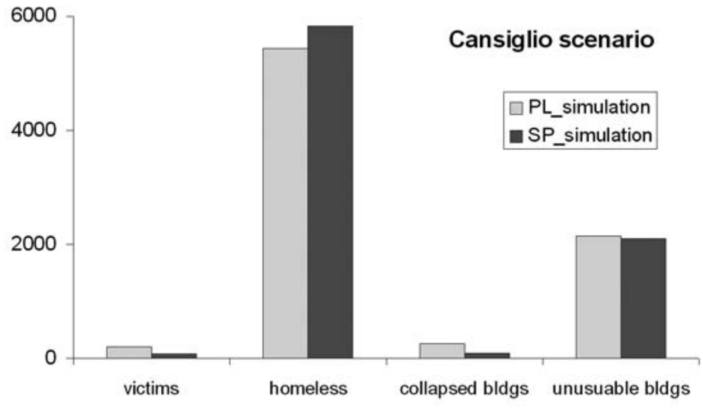

Fig. 11 - Distribution of total damage for the Cansiglio scenario, according to the PL and SP simulations.

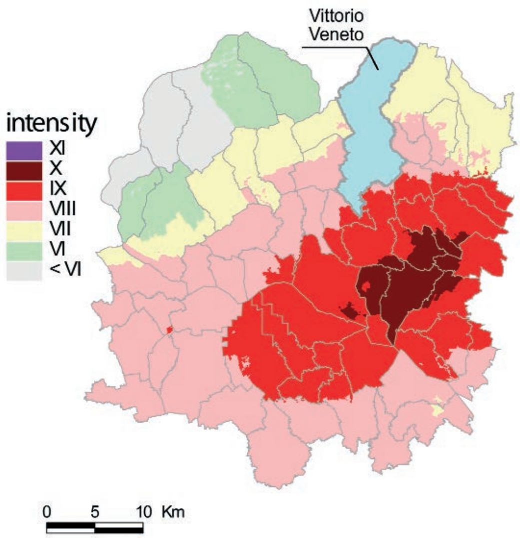

Fig. 12 - Intensity map for the Montello scenario, according to PL simulation.

low because of the medium level of vulnerability of the residential buildings, mostly built after 1945, at the end of the war, and conserved in a good state of maintenance (see vulnerability map for AS1 area, in Fig. 3b). More over, the most populated centres are not those strongly hit by this hypothetical event.

5.2.2. The Montello deterministic scenario

The same risk analysis is repeated also in the case of the Montello scenario elaborated on the basis of a hypothetical M 6.7 source. The intersection between the grid points of PL elaboration with the municipality boundaries provides a studied area of 59 municipalities.

Fig. 12 shows the distribution of a simulated intensity map of the PL approach: no macroseismic data can validate the scenario because of missing historical seismic evidence.

The Montello event is a reference scenario more severe than the previous one; in this case, more than 390,500 people could suffer a seismic intensity equal or bigger than VI (as illustrated in Table 5). For comparison, in the Cansiglio scenario, the number of population suffering intensity equal or bigger than VI is about 173,500 (44%), bigger is consequently the expected number of victims and damage buildings, too.

Table 5 - Involved population and municipalities according to the PL Montello scenario.

Intensity *average value*	**Population**
X	22,849
IX	120,414
VIII	208,798
VII	26,496
VI	12,135
V	11,622
Total	**402,314**

Fig. 13 shows the distribution of expected to collapse and unusable buildings, the values are in percentage on the number of buildings of each census tract. The total number of collapsed buildings is 2,087, and the unusable ones are 15,396. The maps show the maximum damage areas concentrated in the Treviso province, at Conegliano, Mareno di Piave e San Vendemiano

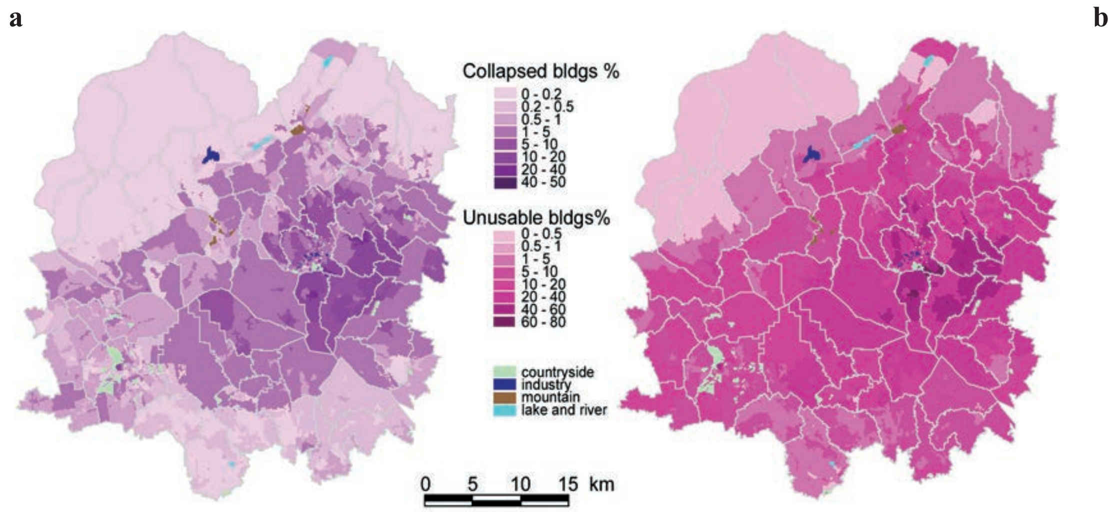

Fig. 13 - Percentage of collapsed buildings (a) and unusable buildings (b) for the Montello PL scenario.

municipalities.

The distribution of damage for each intensity degree is shown in Fig. 14. The number of expected victims is roughly 2,200, that is about 0.6% of the people living in the considered area. About 700 victims are expected in the area struck by X degree and 1,100 those in the IX intensity area (as shown in Fig. 14), and they are concentrated at Conegliano, Santa Lucia di Piave and San Vendemiano. The homeless people represent 13.1% of the inhabitants of the considered Montello area.

Fig. 15 shows the geographical distribution of the number of victims and homeless (absolute values in each municipality) for the PL scenario in the Montello area. At Conegliano, 330 victims are expected; while in the municipalities of Santa Lucia di Piave and Marengo di Piave the expected number of victims are 207 and 174, respectively.

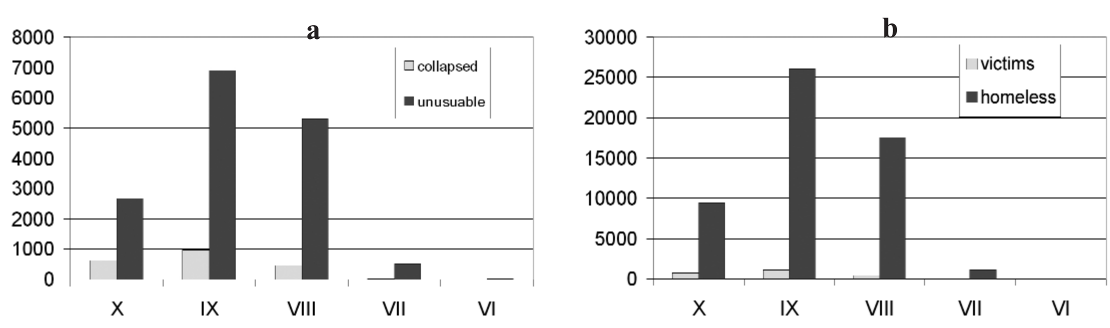

Fig. 14 - Number of collapsed and unusable buildings (a) and distribution of victims and homeless (b) for each intensity level, in the Montello area.

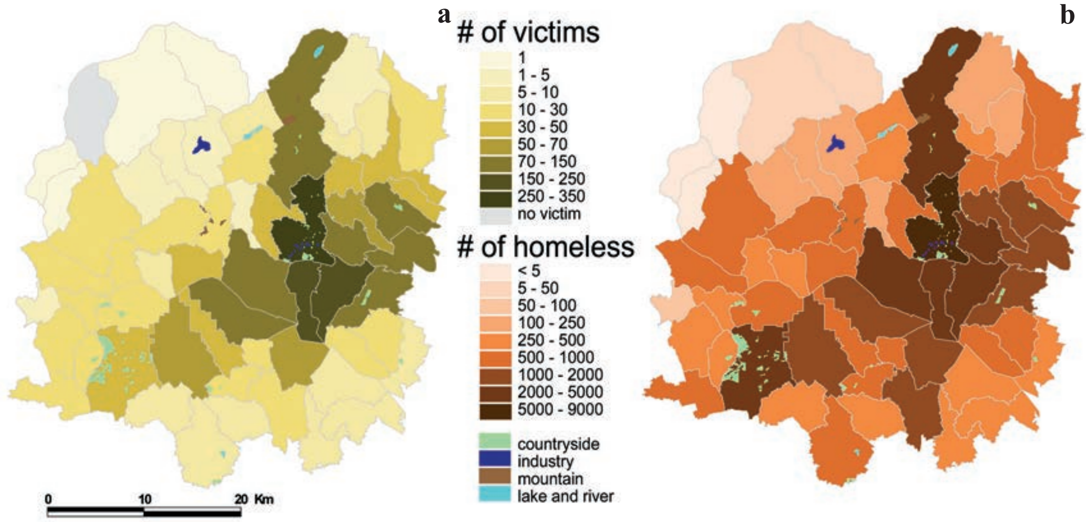

Fig. 15 - Maps of victims (a) and homeless (b) in each municipality of the Montello area, according to the PL scenario.

6. Conclusions

Different seismic risk scenarios at census tract scale in the Veneto-Friuli area have been generated using the same source of data on residential buildings (ISTAT91 data corrected and updated to 2003) and the same damage assessment model based on the definition of damage grade by EMS98 intensity and DPM vulnerability matrix (Bernardini *et al*., 2004). Using a PSHA provided for the total area (Slejko *et al.*, 2008), a complete probabilistic damage analysis is carried out; moreover, deterministic damage assessments are based on two different hazard scenarios provided for the *M* 5.8 Cansiglio earthquake (PL and SP) and one hazard scenario (PL) for an hypothetical *M* 6.7 earthquake triggered by a source in the Montello area.

The number (and volume) of collapsed buildings and unusable structures are defined by simple correlations from the damage classes of residential buildings, ranging from D1 to D5, according to the EMS98 definition. The number of victims and homeless, proportionally distributed in the census tracts according to the building allocation, are evaluated in the same way, adopting an empirical relationship based on Italian data.

The SP and PL simulations of the low/middle intensity Cansiglio earthquake suggest comparable values of the global damage but quite dissimilar in the geographical distribution: SP hazard scenario seems much more consistent with the damages recorded in the 1936 event (MCS macroseismic local intensities, generally higher than EMS98 intensities considered here). The difference underlines the strong uncertainties in forecasting the local intensities related to an active source with given magnitude and moreover, with reference to the Cansiglio earthquake, the PL scenario shows that higher intensities, and related damage, could be expected in a narrow area around the epicentre.

The Montello scenario shows that much severe damage could be expected in the area, particularly in the northern side of the Treviso province, although more research is needed to evaluate probabilities of occurrence of the considered event.

In any case, both the deterministic scenarios and the full probabilistic risk analysis of the total area of interest seems to suggest slowly higher values of seismic risk in many municipalities of the area than those related to the present classification (2003). Taking into account that a great part of the constructions in the area have been built without any specific measure of seismic protection, the importance of retrofitting programs in the most vulnerable and hazardous census tracts is clearly justified.

The main output of this analysis is a GIS collecting the corrected vulnerability level of the residential buildings in each census tracts and the damage indicators distribution. This GIS wants to be a useful support to decision makers both with probabilistic damage assessment in planning and preventive actions, as well as with deterministic damage scenarios, helpful in mitigation and intervention phases. Cumulative values of damage indicators could be easily calculated at municipal or provincial scale.

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Corresponding author: Fabrizio Meroni
Istituto Nazionale di Geofisica e Vulcanologia
Via Bassini 15, 20133 Milano, Italy
phone: +39 02 23699282; fax: +39 02 23699458; e-mail meroni@mi.ingv.it