

## SEISMIC HAZARD MAP IN THE UMBRIA AND MARCHE REGIONS: FROM THE PRESENT UNDERESTIMATED ASSESSMENT TO A NEW MORE RELIABLE EVALUATION

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**Introduction.** Some zones of the Umbria and Marche Regions have been hit since 1000 A.D. by numerous strong earthquakes that have reached intensity XI (MCS), involving an high number of victims and very large damages (Tab.1).

Tab. 1 - List of major earthquakes ( $M \geq 5.5$  or  $I \geq VIII$ ) occurred in the Umbria and Marche Regions since 1000 A.D. (from Rovida *et al.*, 2011).

Year	Epicentral zone	M	I <sub>max</sub>
1276	Orvietano	5.6	VIII-IX
1279	Camerino	6.3	X
1298	Reatino	6.2	X
1328	Norcia	6.4	X
1352	Monterchi	6.4	IX
1353	Sansepolcro	6.0	IX
1389	Bocca Serriola	6.0	IX
1458	Val Tiberina	5.8	VIII-IX
1599	Valnerina	6.0	IX
1639	Amatrice	5.9	X
1672	Riminese	5.6	VIII
1690	Anconetano	5.6	VIII-IX
1695	Bagnoregio	5.7	IX
1703	Appennino Umbro-Reatino	6.7	XI
1703	Aquilano	6.7	X
1730	Valnerina	5.9	IX
1741	Fabrianese	6.2	IX
1747	Nocera Umbra	5.9	IX

Year	Epicentral zone	M	I <sub>max</sub>
1751	Appennino Umbro-Marchigiano	6.3	X
1781	Cagliese	6.4	X
1785	Umbria meridionale	5.7	VIII-IX
1789	Val Tiberina	5.8	IX
1799	Appennino Marchigiano	6.1	IX-X
1832	Valle Del Topino	6.3	X
1859	Norcia	5.5	VIII-IX
1916	Alto Adriatico	6.0	VIII
1916	Alto Adriatico	6.1	VIII
1917	Valtiberina	5.9	IX-X
1930	Senigallia	5.8	VIII-IX
1943	Marche meridionali Abruzzo	5.8	IX
1979	Valnerina	5.9	VIII-IX
1997	Appennino Umbro-Marchigiano	6.0	IX
1997	Appennino Umbro-Marchigiano	5.7	VIII-IX

This seismic history would suggest the opportunity of adopting an adequate strategy of defence from the eventual occurrence of shocks comparable to the past strongest ones. However, this reasonable intention is not encouraged by the hazard map (Fig.1) which has been obtained by the probabilistic procedure presently adopted in Italy (Gomez Capera *et al.*, 2010). When expressed in term of macroseismic intensity, such procedure predicts for the above Regions a low probability (<10%) for the occurrence of shocks with  $I > VIII$  in the next 50 years. Only for a small zone of southeastern Umbria an higher intensity value (IX) is predicted.

Since the damage associated to intensity VIII is not high and above all can hardly provide victims (unless very weak buildings are involved), the present hazard map could produce a dangerous drop of attention for seismic risk. This is mainly due to the fact that the approach presently adopted for hazard assessment (Cornell, 1968) arbitrarily assumes that the probability

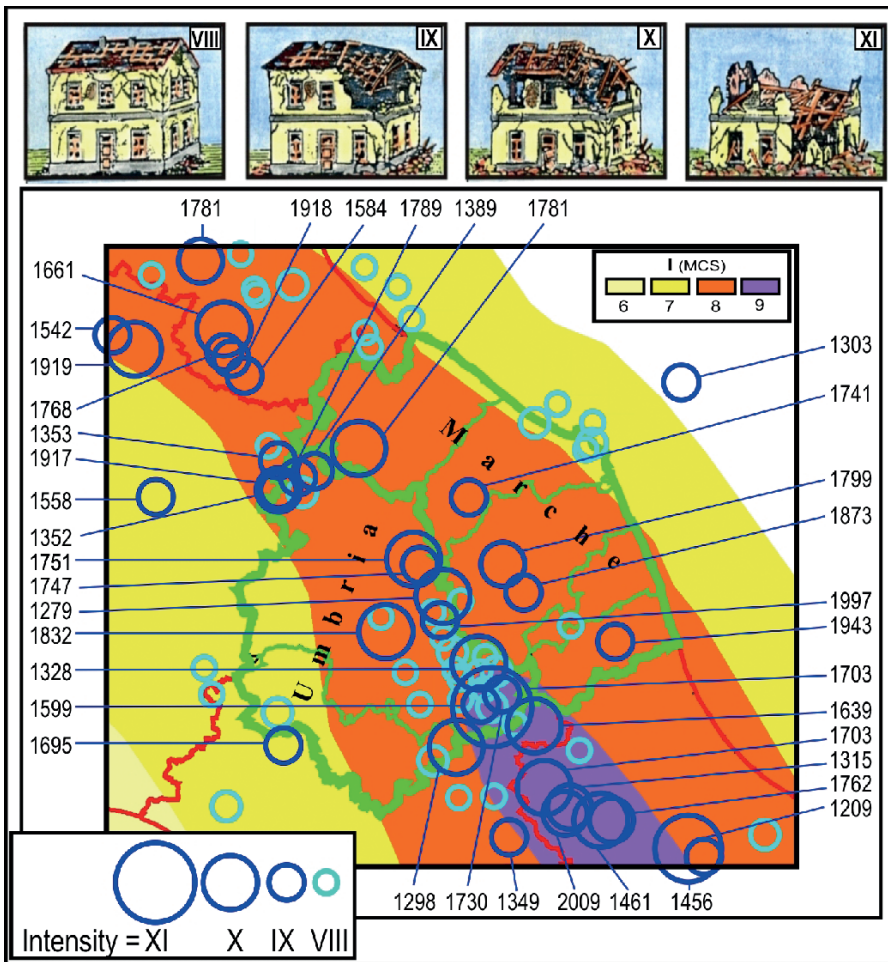


Fig. 1 – Pattern of the maximum intensity values (MCS scale) provided by the same procedure used for the elaboration of the presently adopted hazard map in Italy (Gomez Capera *et al.*, 2010). The colours indicate, in accord with the chromatic scale, the intensity values that are characterized by a probability lower than 10% of being overcome in the next 50 years. Circles identify the epicenters of the major shocks occurred since 1000 A.D. in the sector of northern Apennines enclosing Umbria and Marche (See tab. 1). The year of occurrence is indicated for the events with  $I \geq IX$  (blue). The pictures on the top aim at providing an idea about the damage associated with the highest intensity values for “normal” buildings.

of seismic ground shaking can reliably be estimated by the statistical analysis of the known seismic history. However, one must be aware that such method can hardly provide reliable results, since it is based on assumptions not compatible with the nature of earthquakes (e.g., Castanos and Lomnitz, 2002; Klugel, 2008; Mantovani *et al.*, 2011, 2012a, 2012b, 2013, 2014; Stein *et al.*, 2012), as synthetically recalled in the following.

*Earthquakes are casual and independent events.* This assumption contrasts with the fact that seismic activity is closely connected with the ongoing tectonic processes and that each strong shock causes a significant change of the strain field in the zone involved, which may influence the probability of future events. In particular, there is a growing awareness that seismogenic faults may have long-term and long-range interactions, in contrast with the hypothesis of complete independence of seismic sources (e.g., Scholz e Gupta, 2000; Freed, 20005; Luo e Liu, 2010). Very significant examples of seismicity pattern which strongly support the existence of a close

connection between major earthquakes in the periAdriatic regions are given in a number of papers (e.g., Mantovani *et al.*, 2012a, 2012b, 2013, 2014; Viti *et al.*, 2012, 2013).

*The available data set (a seismic history of some hundreds of years) can be considered representative of the future behaviour of seismicity.* This assumption is clearly unreliable, since the spatio-temporal distribution of main shocks depends on the progressive development of tectonic processes, whose temporal scale is much longer than the known seismic history. However, the earthquake catalogues available for the Italian region are reliable and satisfactorily complete for the last centuries at most (e.g., Gruppo di Lavoro MPS, 2004). This time interval is much shorter than the duration of the present seismotectonic setting, presumably started in the Middle Pleistocene (e.g., Mantovani *et al.*, 2009). The shortness of the available seismic history may crucially affect the results of probabilistic procedures, as pointed out by Swafford and Stein (2007).

*Seismic activity in the study area can be considered as the effect of a number of seismogenic zones.* This idea could be reasonable, but one must be aware that it makes the results of this approach very dependent from the proposed seismogenic zoning. In this regard, it has been pointed out that the zones adopted for elaborating the present hazard map are scarcely compatible with the seismotectonic setting in the northern Apennines. For the Italian region, the detailed ZS4 model [80 zones: Meletti *et al.* (2000)] has been replaced by the much simpler ZS9 model [36 zones only: Meletti *et al.* (2008)]. This choice has favoured the statistical analysis, since in average each new, larger zone includes more earthquakes. On the other hand, the new seismic zoning is less realistic with respect to the seismotectonics context in the Italian area. For instance, the Apennine chain is currently subdivided in few, very long belts, which heavily affect the resulting hazard estimates. However, the distribution of historical seismicity (Fig. 1) shows that the real seismic sources are not uniformly distributed within the adopted seismogenic zones (Mantovani *et al.*, 2011, 2012b, 2013).

Thus, considering the scarce reliability of its basic assumptions, the results obtained by the Cornell's approach can hardly be used to exclude the occurrence of earthquakes with intensity values  $I > VIII$  in the two Regions here considered during the next 50 years.

The need of having a more realistic evaluation of seismic risk has led the Toscana and Emilia-Romagna Regions to promote further studies based on more reliable approaches. The results of such investigations (Mantovani *et al.*, 2011, 2012b, 2013) are presently utilized by the above Regions to manage the initiatives for seismic risk mitigation in the respective territories. In the next section we describe the results of an analogous study carried out for the Marche and Umbria Regions.

**A novel seismic hazard assessment for Umbria and Marche.** The profound difference between the methodology here proposed and the Cornell's approach is that we do not try to estimate the probability of future earthquakes (and related seismic shaking), since we are aware that such evaluation would be affected by unknown uncertainty. Thus, our primary interest is defining the highest values of intensity ever felt in each commune, by the analysis of the available macroseismic data set (DBMI11, Locati *et al.*, 2011), and tentatively recognizing the zones that, in spite of the fact that were not hit by strong events in the past, may be prone to major events. This last result has been tentatively achieved by exploiting the detailed reconstruction of the present tectonic setting we have achieved during a long and accurate analysis of a huge amount of observations in Earth Sciences (e.g., Mantovani *et al.*, 2009; Viti *et al.*, 2011).

The geometries of the zones finally adopted are shown in Fig. 2. For each zone it is defined a maximum intensity ( $I_{max}$ ), on the basis of the seismic history and of the tectonic setting and it is assumed that at any time an event of the proposed  $I_{max}$  can take place anywhere in that zone. Taking into account the implications of the seismogenic zones considered and the documented damages, a value of  $I_{max}$  is proposed for each commune of Umbria and Marche.

The information acquired during the study is synthesized in provincial tables, of the type shown in Tab. 2. For each commune, the table reports the  $I_{max}$  value we propose on the basis of

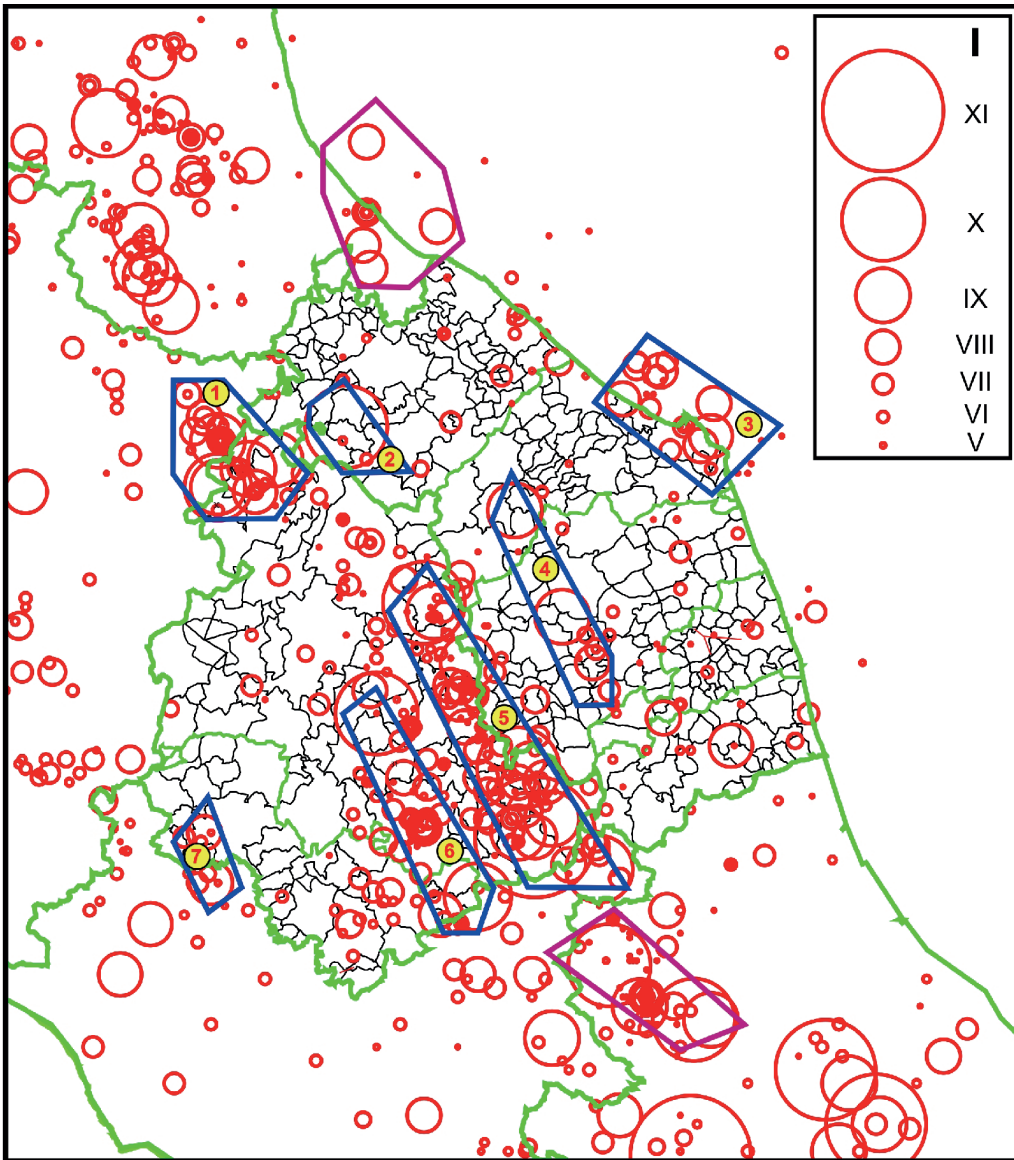


Fig. 2 – Geometries (blue contours) of the seismogenetic zones adopted in the analysis. Circles indicate the major earthquakes (I>V, MCS). 1) Alta Valtiberina, 2) Cagliese, 3) Anconetano, 4) Dorsale Marchigiana, 5) Dorsale Umbra, 6) Valle Umbra, 7) Orvietano. The two zones contoured by violet lines (Riminese ed Aquilano) are located outside the Regions considered, but have been characterized by strong shocks that have produced appreciable effects in Umbria and/or Marche.

all the information acquired, and the  $I_{max}$  value that would instead result by only considering the data given by the DBMI11 catalog. Also, to allow an assessment of the possible robustness of the data set used to define the proposed  $I_{max}$  values, the numbers of macroseismic observations available for the most relevant intensity classes are also given in Tab. 2.

The result of this study, synthetized in the coloured map of Fig. 3, provides an information on the expected damage for the communes of the two Regions considered, which is compatible

Tab. 2 - Example of synthetic table, related to the Perugia province. IP = Maximum intensities here proposed for the respective communes. IDB = Maximum intensity deduced from the catalog DBMI11 (Locati *et al.*, 2011). N=Number of macroseismic observations available for various intensity classes.

PROVINCE of PERUGIA								
COMMUNES	I <sub>MAX</sub>		N					
	I <sub>P</sub>	I <sub>DB</sub>	10 ≤ I ≤ 11	9 ≤ I < 10	8 ≤ I < 9	7 ≤ I < 8	6 ≤ I < 7	5 ≤ I < 6
Assisi	10	9		1	15	7	17	33
Bastia Umbra	9-10	9		1	3	5	3	10
Bettona	9-10	8			1	2	2	6
Bevagna	10	9		1		2	6	8
Campello sul Clitunno	10	8			2	5	6	12
Cannara	10	10	1	1	1		2	12
Cascia	10-11	10-11	18	14	43	57	14	13
Castel Ritaldi	10	8			4		2	11
Castiglione del Lago	7	5						4
Cerreto di Spoleto	10	9		7	7	27	14	9
Citerna	9-10	9		1		2	2	7
Città della Pieve	7	7				1	1	6
Città di Castello	9-10	9		4	11	21	33	21
Collazzone	9	7-8				3	1	6
Corciano	7-8	6					2	7
Costacciaro	8	7-8				1	4	12
Deruta	9	8			1	2		12
Foligno	10	10	1	1	29	51	22	18
Fossato di Vico	9-10	8-9			2	1	6	6
Fratta Todina	8-9	5						3
Giano dell'Umbria	9-10	6-7					5	8
Gualdo Cattaneo	9-10	7				1	3	7
Gualdo Tadino	10	10	6	11	10	10	17	12
Gubbio	8-9	8			1	33	17	13
Lisciano Niccone	7	6					3	4
Magione	7	6					1	3
Marsciano	8	7				1	6	5
Massa Martana	9	7				2	6	6
Monte Castello di Vibio	8-9	5-6						3
Monte Santa Maria Tiberina	9-10	9		3	4		1	10
Montefalco	10	8			5	1	5	9
Monteleone di Spoleto	10	10	2	2		5	1	7
Montone	8-9	7-8				3	5	4
Nocera Umbra	10	9		1	8	17	23	17
Norcia	11	11	8	19	31	28	12	12
Paciano	7	6					1	1
Panicale	7	6-7					3	4
Passignano sul Trasimeno	7	5-6						5

Tab. 2 - continued.

Perugia	8	8			3	15	21	32
Piegaro	7-8	6-7					2	2
Pietralunga	9	9		1		4	5	9
Poggiodomo	10	9		2	3	11	4	4
Preci	10	10	3	2	28	33	14	10
San Giustino	9-10	9		2	9	8	7	3
Sant'Anatolia di Narco	10	6-7					6	6
Scheggia e Pascelupo	8	8			1	2	7	9
Scheggino	10	7				4	4	10
Sellano	10	10	1	1	7	29	18	17
Sigillo	8-9	8			1		3	4
Spello	10	8-9			4	3	7	6
Spoletto	10	8			5	13	17	23
Todi	8-9	8			1	1	4	10
Torgiano	9	6-7					2	5
Trevi	10	8			9	5	10	13
Tuoro sul Trasimeno	7	5-6						1
Umbertide	8-9	7				3	5	9
Valfabbrica	9-10	7-8				7	14	11
Vallo di Nera	10	8			1	1	10	3
Valtopina	10	8			1	3	2	15

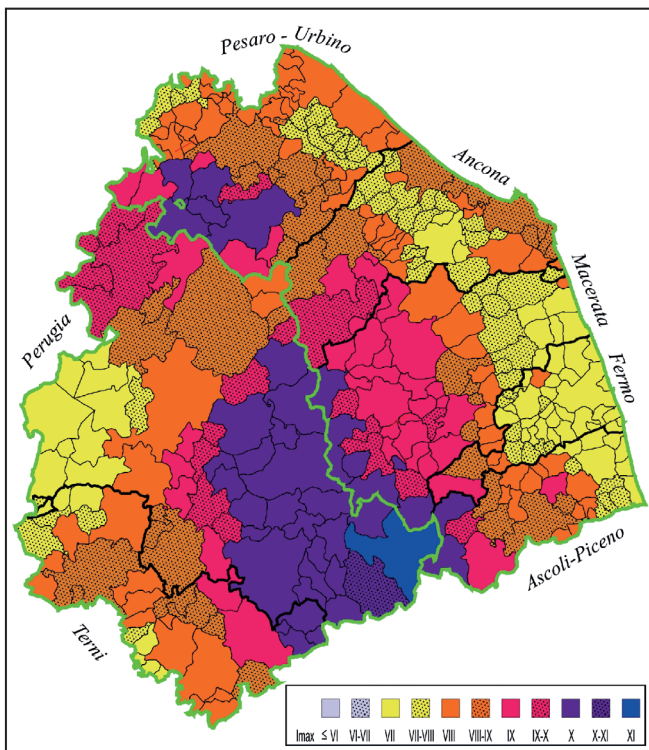


Fig. 3 – Map of the expected maximum intensities for the communes of the Marche and Umbria Regions, resulting from the study carried out by the Dipartimento di Scienze Fisiche, della Terra e dell’Ambiente, Università di Siena (Mantovani *et al.*, 2014). Colours correspond to I<sub>max</sub> values, as indicated in the scale.

with the seismic history and the tectonic setting of the study area. This contrasts with the present PSHA hazard map (Fig.1), where the effects of the adopted statistical approach have considerably altered the meaning of the basic Intensity data. The largest differences concern the Umbria Region, where the expected intensities are much higher (up to XI) than the ones predicted by the PSHA map ( $I \leq VIII$  almost everywhere).

**Conclusions.** It can hardly be accepted that the defense policy from earthquakes in the Umbria and Marche Regions relies on a hazard map elaborated by a procedure based on unreliable assumptions. In the event that one of the strong shocks that occurred in the past, reaching intensity XI (Tab.1), occur again in the next future (a possibility that can hardly be ruled out or taken as unlikely), the preventive measures based on the map shown in Fig. 1 would be inadequate, up to be dramatically insufficient in some zones of Umbria. This problem is considerably mitigated by the map here proposed, where the expected intensities are much more consistent with the observed damages. The results briefly described in this note and fully described by Mantovani *et al.* (2014) have been made available to the authorities of the Marche and Umbria Regions.

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