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The L'Aquila 2009 earthquake: an application of the European Macroseismic Scale to the damage survey in the epicentral area

R. Azzaro[1], M.S. Barbano[2], S. D'Amico[1], T. Tuvè[1], L. Scarfì[1], A. Mostaccio[1]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Italy
[2] Dipartimento di Scienze Geologiche, Università di Catania, Italy

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ABSTRACT On April 6, 2009 a M_w 6.3 earthquake heavily damaged the city of L'Aquila, its suburbs and several localities along the Aterno valley. The extent of the damage was the result of several factors, among which the high vulnerability of the ancient buildings but in some cases also of the modern ones, the structure of the urban centres and the site effects deriving from local critical geological conditions. We present the results of the macroseismic investigation carried out in the epicentral area by using the European Macroseismic Scale (EMS), a more suitable scale than the Mercalli-Cancani-Sieberg (MCS) one in evaluating rather complex damage scenarios. The maximum intensity has been estimated for Onna (IX EMS), the historical centre of L'Aquila, and for Castelnuovo, Pettino and S. Elia (VIII-IX EMS). On the whole, some 30 localities within an area that extends for 35 km in a NW-SE direction suffered significant damage (VII-VIII EMS). Finally, we discuss the differences in the intensity assessment deriving from the interpretation of the MCS and EMS scales.

Key words: macroseismic survey, intensity assessment, EMS, vulnerability, Italy.

1. Introduction

On April 6, 2009, central Italy was hit by a M_w 6.3 earthquake with epicentre located near the town of L'Aquila, which produced more or less severe destruction and damage over a wide area of the Abruzzi region and caused 308 fatalities. This earthquake was the mainshock of a long-lasting seismic sequence of more than 10,000 events recorded from December 2008 till August 2009. Among the aftershocks, two earthquakes exceeded magnitude 5.0 (April 7 and 9, with M_w = 5.6 and 5.4 respectively), and some twenty had magnitude larger than 4.0. Seismological data acquired by the INGV seismic network (Chiarabba *et al.*, 2009) together with geological observations (EMERGEO Working Group, 2009; Falcucci *et al.,* 2009; Galli *et al.*, 2009) and geodetic satellite measurements (Anzidei *et al.*, 2009; Atzori *et al.*, 2009), reveal that the seismic source responsible for the seismic sequence may be identified with the NW-SE trending Paganica fault system, an about 30 km long normal fault segment that borders the Aterno valley to the NE.

Soon after the earthquake, the QUEST group (Quick Earthquake Survey Team) undertook a macroseismic survey with the aim of defining, for civil protection purposes, the damage scenario over the densely urbanised territory. During the first phase of the emergency the survey was elaborated in terms of the Mercalli-Cancani-Sieberg (MCS) macroseismic scale (Galli and

Camassi, 2009), and it soon became evident that damage was generally amplified both by the building vulnerability and the site effects.

In order to properly take into account the variability of the effects and the associated uncertainties in the intensity assessment, the survey continued with more detailed inspections of the most damaged areas by using the European Macroseismic Scale [EMS, Grünthal (1998)]. Here, we present the methodological approach and the results of the EMS application in the epicentral area, discussing the difference of intensity assessment deriving from the interpretation of both MCS and EMS scales.

2. Macroseismic survey

The EMS analysis started in the localities of the epicentral area already estimated by the MCS scale, with detailed field surveys aimed at a general verification of the damage effects and comprising smaller settlements that had not been considered previously. The investigation involved a working group with specific field experience in applying the EMS in cases of recent, damaging earthquakes (personnel from the INGV departments of Catania, Rome and Bologna, the University of Catania, the Agencija Republike Slovenije Za Okolje), and who operated according to a procedure that has been implemented, step by step, since the 1997-98 Umbria-Marche earthquakes (Camassi *et al.*, 2009).

For each locality, attention was focused on establishing the typology and number of buildings (masonry vs. reinforced concrete buildings), grade and typology of damage, percentage of damaged buildings and elements of specific vulnerability, namely all the basic information representing the diagnostics of the EMS. All the data collected were reported in a common field form, routinely used by the QUEST group during previous surveys, which was later used to assess intensity (Fig. 1).

The EMS survey allows one to have a more reliable point of view of the damage distribution with respect to the MCS approach, since the variability of building typology together with the high vulnerability and striking difference in damage between historical centres and more recent suburbs, make the assessment of macroseismic intensity problematic. This approach has produced a specific study focusing on the town of L'Aquila, that was examined in extreme detail (Tertulliani *et al.*, 2010), and the present analysis concerning some 70 localities of the epicentral area. The survey, lasting two months, has been extended to investigate also the transition from severe macroseismic effects to moderate ones, i.e., VII degree EMS, but some localities were discarded since repair/containment interventions altered the original damage scenario.

3. Intensity assessment: the European Macroseismic Scale

The damage scenario in the epicentral area appeared rather heterogeneous and complex to analyse, given the marked difference in seismic vulnerability presented by private and public buildings. Such differences are related not only to purely engineering factors - type of constructions and their state of maintenance - but also to geotechnical foundation features. Indeed, unfavourable geological conditions due to outcrops of terrains with poor mechanical properties such as sand, silt

Istituto Nazionale di GEOFISICA e VULCANOLOGIA

QUEST QUick Earthquake Survey Team

EARTHQUAKE: 6 April 2009 **HOUR (GMT):___01.32____**

LOCALITY:______**ONNA**______________ DISTRICT:_____**AQ**___________________ **Int. MCS IX-X**

SURVEY DATE :__**19/04/2009**________________ OPERATOR: **Barbano-Mostaccio-Tuvè-Cecic-Godec** **Int. EMS-98 IX**

EFFECTS ON THE BUILDINGS

		VULNERABILITY CLASSES						GRADE OF DAMAGE				
TYPE OF STRUCTURE		**A**	**B**	**C**	**D**	**E**	**F**	**1**	**2**	**3**	**4**	**5**
	rubble stone, fieldstone	**X**									**50%**	**50%**
	simple stone		*X*							**40%**	**30%**	**20%**
	massive stone											
	unreinforced, with manufactured stone units											
	unreinforced, with RC floors											
	reinforced or confined											
REINFORCED CONCRETE (RC)	*frame without earthquake-resistent design (ERD)*											
	frame with moderate level of ERD				**X**				**10%**			
	frame with high level of ERD											
TOTAL NUMBER OF BUILDINNGS		**300**	**150**		**30**							

Quantitative Terms

Few	Many	Most
0-20%	10-60%	50-100%

Classification of damage

Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Negligible to slight damage (no structural damage, slight non-structural damage)	Moderate damage (slight structural damage, moderate non-structural damage)	Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Destruction (very heavy structural damage)

Fig. 1 - Example of field form used during the survey.

etc., have determined a higher concentration of damage in specific zones.

The main building typologies characterising the studied area include structures in rubble stone and fieldstone with very weak mortar (vulnerability class A in Fig. 1), and masonry edifices built with bricks (vulnerability class B). By comparison, the houses built with blocks are negligible. In general, the typical damage consisted of opening (failure) of corner walls, diagonal cracks in walls and widening of previous fissures also owing to the load action of the roofs. The most degraded buildings, in some cases abandoned or with evident lack of maintenance, suffered effects varying from the partial structural failure of roofs and floors, to total collapse. In practice, we faced the following situation:

i) houses restored only in the external parts looking like buildings of vulnerability class B,

Fig. 2 - Examples of variation of the vulnerability class associated to masonry buildings: a) class B house with external intervention, but the collapse reveals a wall structure typical of vulnerability class A; b) class B edifice (in the background) where the reinforcing prevented significant damage, so the effective vulnerability class becomes C (photo by A. Tertulliani); c) class B house elevated and restored using different materials that create heterogeneity in the structure and overloading; the final behaviour is like a building of vulnerability class A.

indeed having the internal structure of the walls typical of structures of class A (Fig. 2a);

ii) edifices with original vulnerability class B that, after a correct reinforcement intervention, behave better than class C buildings (Fig. 2b);

iii) class B edifices restored with interventions overloading the entire structure, that resulted in an increase of vulnerability to the class A and hence to collapses (Fig. 2c).

The newer quarters are formed by reinforced concrete (RC) frame buildings, that have been assumed to represent the vulnerability class D (moderate level of earthquake-resistant design, ERD), according to the seismic code in force in this area classified in the 2nd category. In fact, in most of the investigated localities, the seismic code was introduced between 1927 (following the 1915 Fucino earthquake) and 1962 (after the 1958 earthquake), and recently confirmed in 2003 (see Stucchi *et al.*, 2009). However, there are many buildings without ERD or with evident constructive defects (classes C and B, respectively). This means that, due to engineering factors but also to geotechnical ones, RC frame structures of class D (but also C) tend to behave like buildings with higher seismic vulnerability (i.e., C or even B) as indicated in the guidelines of the EMS (Grünthal, 1998).

In addition, the evaluation of the damage scenario was not simple because of the extension of some urban areas. As a result, damage appeared more concentrated in defined sectors and this could seem, at first sight, not fully representative of the overall urban territory (Figs. 3a and 3b).

In order to assess the intensity with the EMS, we integrated data collected in the field forms (Fig. 1) with other information available for the surveyed localities (photos, ISTAT data, technical documentation, etc.) and prepared tables where, for each intensity degree, the cumulative damage effects are reported according to EMS diagnostics. This approach simplified the process of intensity evaluation, facilitating the interpretation of data and allowing comparison of the effects in different localities. The examples of Onna, Monticchio, L'Aquila and localities in section 3.4, are hereinafter briefly discussed.

3.1. Onna

The village of Onna was almost completely destroyed (Fig. 4). The case of this locality is exemplificative in the EMS perspective since, due to its small area, it is simpler to analyse. It

Fig. 3 - Tempera: a) view of the village with several collapsed houses; b) inside the village, different damage grades depending on building typology.

consists of 477 buildings (ISTAT, 2001), of which about 300 are considered to have vulnerability class A, 150 with class B, and 30 are C/D types (Fig. 5).

The collected data are shown in Fig. 1 and summarized in Table 1. We detected grade 3 damage (i.e., moderate level of structural damage) on many ordinary buildings with vulnerability classes B and C, i.e., masonry structures and RC frame edifices probably built before the introduction of the seismic code (no ERD was adopted). Grade 4 damage (very heavy damage, including partial collapse) was observed on many buildings with vulnerability class A and B, but also on a few C buildings. Finally, a few buildings with vulnerability class B and many of class A suffered damage of grade 5 (total collapse). The latest effects match the diagnostics expected for intensity IX in the EMS, but other damage, typical of such a degree, concerning grades 2 and 3 in buildings with vulnerability class D was not detected. In conclusion, the observed effects in Onna are consistent with the damage scenario reported at degree IX EMS, although in general class D edifices seem to have suffered less damage than scheduled by the scale.

A very detailed survey of the village of Onna was also carried out by a team of technicians (DPC Working Group, 2009). This study, aimed at classifying the buildings and their level of damage according to the EMS guideline, has regarded only the so-called 'red zone' - the ancient nucleus - where the class A and B buildings predominate, and it was performed by a engineering analysis based on the classification of all the buildings into 'aggregates' and 'structural units'. As

Fig. 4 - Onna (photo by A. Tertulliani): aerial view showing destruction but also standing edifices (grades 2 and 3 of damage).

a result, they estimated the degree X EMS for Onna. However, such a value deriving from a very specialized approach cannot be compared, in our opinion, with the intensity assessment routinely performed by seismologists in macroseismic surveys.

3.2. Monticchio

The village of Monticchio is located just 2 km from Onna. The historical centre suffered slight damage, mainly of grade 2 (Fig. 6a) in a few edifices of classes B and C, and grade 3 in a few class A buildings. Since damage percentages are less than expected for intensity VII EMS, we preferred to consider the uncertainty and assess the degree VI-VII EMS. There is a very different situation for the industrial district, located a few hundreds of metres from the heart of the village on the road from L'Aquila to Monticchio. Here, some recent constructions such as prefabricated trading centres and factory buildings (classes D-E), showed heavy non-structural and moderate structural damage (grade 3, Fig. 6b), diagnostics scheduled in the degree IX. From the structural point of view, Menegotto (2009) suggests an apparent lack of connection between columns, beams and infill walls, that in practice means a higher vulnerability class (B-C). In our opinion, this is insufficient to account for such a marked damage difference in a very short distance. An important cause can be ascribed to a site amplification effect, because the industrial centre is located on the soft terrain of the alluvial plain while the old village of Monticchio stands on stiff

Fig. 5 - Onna, examples of damaged buildings with different vulnerability: a) class A, total collapse (grade 5); b) class C, slight damage (grade 2); c) class D, undamaged.

Table 1 - Summary of damage observed at Onna (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

Onna **Damage**	**VI** **Building quantity**	**VII** **Building quantity**	**VIII** **Building quantity**	**IX** **Building quantity**	**X** **Building quantity**
grade 1	many of class A many of class B a few of class C	a few of class D			
grade 2	a few of class A a few of class B	many of class B **a few of class C**	many of class C **a few of class D**	many of class D a few of class E	many of class E a few of class F
grade 3	no	many of class A a few of class B	**many of class B** a few of class C	**many of class C** a few of class D	many of class D few of class E
grade 4	no	a few of class A	**many of class A** a few of class B	**many of class B** **a few of class C**	many of class C a few of class D
grade 5	no	no	a few of class A	**many of class A** **a few of class B**	most of class A many of class B a few of class C

Fig. 6 - Monticchio, examples of damaged buildings with different vulnerability: a) historical centre, class B, slight damage (grades 1 and 2) (photo a, on the right by I. Cecic); b) industrial district, classes D-E, moderate damage (grade 3) (photo b, on the left by M. Godec).

rocks at the footwall of the Bazzano fault. However, given the peculiarity of these building typologies, we did not assign the intensity.

3.3. L'Aquila

The town of L'Aquila, a moderate-sized city (about 70,000 inhabitants), has shown a rather composite damage scenario. At a larger scale, the urban territory can be considered divided into different but homogeneous sectors according to: i) different geotechnical conditions in contiguous quarters and ii) diverse building typologies in the historical centre – mainly ancient houses with vulnerability classes A and B – with respect to the new districts, largely formed by edifices with vulnerability classes C and D. In detail, each neighbourhood has presented special aspects that deserve appropriate consideration such as the construction features of buildings, conditions of maintenance, age, etc. As a consequence, the level of damage was quite different throughout the old town and its modern suburbs.

The historical centre was heavily hit by the earthquake, not only for the high vulnerability of the poor building typologies but also for the presence of monumental buildings - by their very nature more vulnerable - as well as for the urban structure of the old town. Several churches, including the Cathedral, St. Augustine and the Collemaggio basilica, suffered partial or total

Fig. 7 - L'Aquila, historical centre, examples of damaged buildings with different vulnerability: a) ancient edifice with unsatisfactory maintenance; b) detail, the height of the building has recently been raised by one storey; c) church of St. Maria Paganica; d) restored and well-maintained houses coexist with abandoned ones, sharing lateral load-bearing walls.

collapses of tympanums, vaults and perimetral walls, and in general other important damage. A large part of the historical centre consists of an agglomerate of edifices that are not separated from each other, sharing lateral load-bearing walls, where abandoned or even disrepaired houses (class A) stand next to well-maintained ones (classes B and C) (Figs. 7a and 7d). Most buildings have been raised by 1-2 stories and modified using different materials which create heterogeneity in the structures and overloading (Fig. 7b). All these situations have generally determined an increase of the vulnerability scheduled in the EMS for a given building typology, that in practise

Table 2 - Summary of damage observed at the historical centre of L'Aquila (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

L'Aquila historical centre Damage	VI Building quantity	VII Building quantity	VIII Building quantity	IX Building quantity	X Building quantity
grade 1	many of class A many of class B a few of class C	a few of class D			
grade 2	a few of class A a few of class B	**many of class B** a few of class C	**many of class C** a few of class D	many of class D a few of class E	many of class E a few of class F
grade 3	no	**many of class A** a few of class B	**many of class B** a few of class C	**many of class C** a few of class D	many of class D few of class E
grade 4	no	a few of class A	**many of class A** **a few of class B**	many of class B **a few of class C**	many of class C a few of class D*
grade 5	no	no	**a few of class A**	many of class A **a few of class B**	most of class A many of class B a few of class C

*declassified to C

has to be taken into account by declassifying the involved buildings to a lower class as suggested by Grünthal (1998) in the guidelines on the scale usage. Finally, the historical centre also hosts a relatively small number of RC constructions, scattered throughout the old area; most of them were built in 1960s-1970s and may indeed be associated with low or moderate levels of earthquake-resistant design (ERD, classes C and D).

The results of the macroseismic survey in the ancient part of the town are shown in Table 2. The heaviest damage is found on the buildings of vulnerability class A, that in many cases suffered damage of grade 4 and in some others damage of grade 5. Regarding buildings with vulnerability class B, many of them suffered damage of grade 3, and few damage of grade 4.

As for RC edifices, they generally suffered more damage (grades 3 and 4) than observed in the new quarters of L'Aquila, with the extreme cases of the collapses (grade 5) of the *Casa dello studente* and *via Campo di Fossa* buildings in which the role of construction defects and hence of the declassification (from D to C), may be determinant.

In conclusion, the surveyed effects in the historical part of L'Aquila are fully consistent with intensity VIII EMS, but there are also some diagnostics reported at degree IX. For this reason we have estimated the intensity as VIII-IX EMS, a value equal to that obtained by Tertulliani *et al.* (2011) using a very detailed survey.

For the new suburbs built in the plain below, the damage scenario emerging from the survey was not homogeneous, with significant differences even between adjacent neighbourhoods. Given the size of the urbanised area, we chose to mainly investigate the zones where particular situations of damage were present, so the sectors north and west of the historical centre have not been considered in our analysis (Fig. 8). In the NW sector of L'Aquila, namely Casantessa, buildings with vulnerability classes C and D (Fig. 9a) suffered damage of grades 3 and 2 respectively (Table 3). As for the few buildings of class A, located along the main street, just one house suffered the collapse of the roof (grade 4). As a result, since heavy damage to classes A-B buildings is lacking, we estimated the intensity VII-VIII EMS.

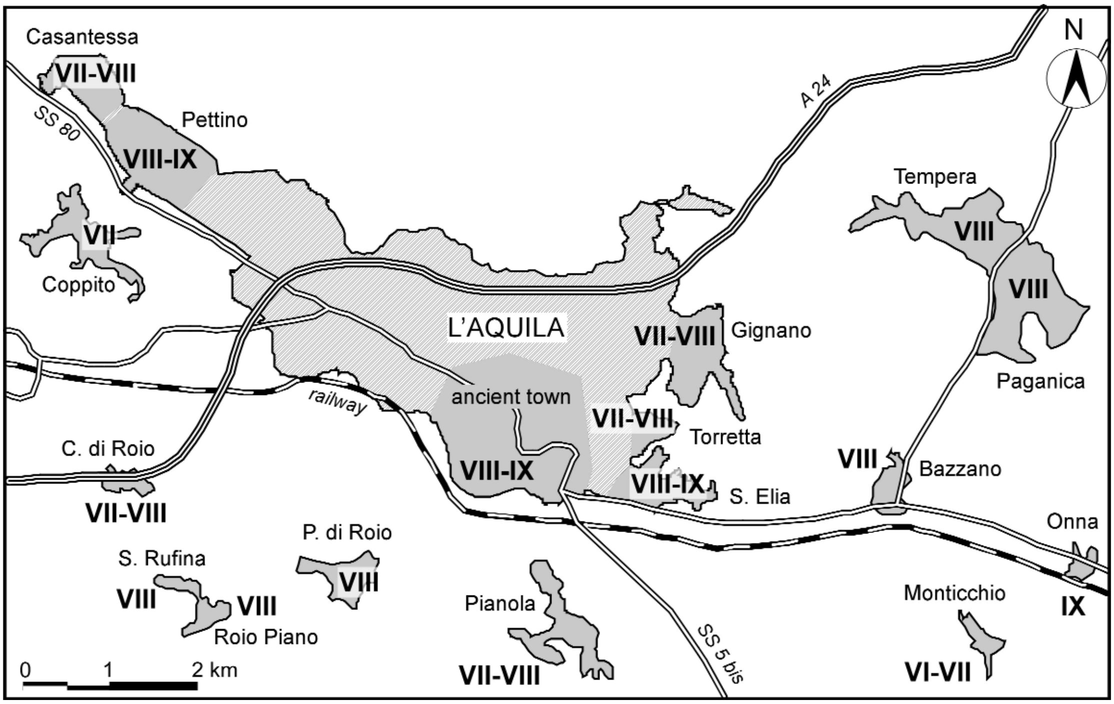

Fig. 8 - Different distribution of intensity at L'Aquila and its suburbs. The hatched grey area was not considered in the study.

By contrast, the nearby neighbourhood of Pettino suffered the heaviest damage. The most striking effect was observed in some very recent buildings of class D, i.e.,, the collapse of the ground floor (soft-storey) compressed from the load of the overlying storeys (Fig. 9b). The other damage is summarised in Table 4, where it is evident that most of the effects are distributed

Table 3 - Summary of damage observed at Casantessa (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

Casantessa Damage	VI Building quantity	VII Building quantity	VIII Building quantity	IX Building quantity	X Building quantity
grade 1	many of class A many of class B a few of class C	a few of class D			
grade 2	a few of class A a few of class B	many of class B a few of class C	**many of class C** **a few of class D**	many of class D a few of class E	many of class E a few of class F
grade 3	no	many of class A a few of class B	many of class B **a few of class C**	many of class C a few of class D	many of class D few of class E
grade 4	no	**a few of class A**	many of class A a few of class B	many of class B a few of class C	many of class C a few of class D
grade 5	no	no	a few of class A	many of class A a few of class B	most of class A many of class B a few of class C

Fig. 9 - a) Casantessa, examples of damage of grade 3 in buildings with vulnerability classes C and D; b) Pettino, via Dante Alighieri, damage of grade 4-5 in buildings with 'theoretical' vulnerability class D (to be declassified to C).

between degrees VIII and IX EMS. The asterisk indicates the formal position of the aforementioned class D edifices in the diagnostics of degree X that is, if compared with the overall effects, clearly indicative of problems due to either construction defects (Cosenza *et al.*, 2009) or a different site response. For this reason, we have declassed them to class C buildings, thus estimating intensity VIII-IX.

Two kilometres SW, at Coppito, the seismic scenario was once again different. In this suburb, damage was slighter and less widespread: we have indeed observed effects of grade 2 both in A and B buildings, grade 3 in a few edifices of class B and, finally, damage of grade 4 in a few buildings of class A. The intensity was estimated to be VII EMS.

Finally, the south-eastern suburbs of L'Aquila, Torretta and Gignano, have generally suffered more or less moderate damage, undoubtedly less than the old town two kilometres away. A synthesis of the surveyed effects is reported in Table 5: a few buildings of vulnerability classes C and D were affected by damage of grade 2, while a few of vulnerability classes B and C suffered damage of grade 3 (Fig. 10). Although relevant diagnostics of degree VIII have been observed, heavy damage to classes A-B buildings is lacking; therefore we estimate intensity VII-VIII EMS for both neighbourhoods.

Table 4 - Summary of damage observed at Pettino (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

Pettino Damage	**VI Building quantity**	**VII Building quantity**	**VIII Building quantity**	**IX Building quantity**	**X Building quantity**
grade 1	many of class A many of class B a few of class C	**a few of class D**			
grade 2	a few of class A a few of class B	**many of class B** a few of class C	many of class C **a few of class D**	many of class D a few of class E	many of class E a few of class F
grade 3	no	many of class A a few of class B	**many of class B** a few of class C	**many of class C** **a few of class D**	many of class D few of class E
grade 4	no	a few of class A	**many of class A** a few of class B	many of class B **a few of class C**	many of class C a few of class D*
grade 5	no	no	**a few of class A**	many of class A a few of class B	most of class A many of class B a few of class C

*declassified to C

3.4. Other localities

In addition to Onna, L'Aquila-historical centre and Pettino, we estimated intensity VIII-IX EMS also at Sant'Elia and Castelnuovo, whereas about fifteen surrounding localities that suffered heavy damage, have been evaluated as degree VIII (see the Appendix). In brief, in all these localities we observed many buildings of vulnerability class A with damage of grade 4, some with damage of grade 5; many buildings of vulnerability class B with damage of grade 3, a few with damage of grade 4; a few buildings of vulnerability of class C with damage of grades 2 and 3. As an example, Table 6 reports the damage scenario surveyed at Fossa. In some cases, we also observed displaced tombstones or overturned monuments (Fig. 11), diagnostics explicitly

Table 5 - Summary of damage observed at Torretta-Gignano (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

Torretta-Gignano Damage	**VI Building quantity**	**VII Building quantity**	**VIII Building quantity**	**IX Building quantity**	**X Building quantity**
grade 1	many of class A many of class B a few of class C	a few of class D			
grade 2	a few of class A a few of class B	**many of class B** a few of class C	**many of class C** **a few of class D**	many of class D a few of class E	many of class E a few of class F
grade 3	no	many of class A **a few of class B**	many of class B **a few of class C**	many of class C a few of class D	many of class D few of class E
grade 4	no	**a few of class A**	many of class A a few of class B	many of class B a few of class C	many of class C a few of class D
grade 5	no	no	a few of class A	many of class A a few of class B	most of class A many of class B a few of class C

Fig. 10 - Different damage of grade 2 in buildings of vulnerability class C and D and damage of grade 3 in one building of type B: a) Gignano; b) Torretta.

scheduled in the EMS scale for intensity VIII.

Finally, the EMS survey has also been extended to many other damaged localities around the epicentral area. In general, we observed effects with percentages up to 20% concerning the grades 2 and 3 of damage on buildings with vulnerability classes A, B and C (including masonry and declassed RC frame structures together); the heaviest situations of grade 4 affected only some buildings with vulnerability class A. Depending on grade and typology of damage with respect to the vulnerability of the involved edifices, we have assigned intensities VII or VI EMS. The complete distribution of the macroseismic effects estimated by the EMS is shown in Fig. 12 and the locality inventory listed in the Appendix. As already highlighted by the MCS scale survey (Galli and Camassi, 2009), the distribution of the effects in the near field (I≥VII-VIII EMS) shows a pattern lengthened in the NW-SE direction, with the localities most hit lying on the hangingwall of the Paganica Fault along the coseismic deformation zone (EMERGEO Working Group, 2009; Falcucci *et al.*, 2009; Galli *et al.*, 2009). In this frame, the site effects responsible for local amplification of the ground shaking seem to have contributed to enhancing damage, such as in the cases of Onna and Castelnuovo (Cultrera and Luzi, 2009; Dolce and Naso, 2009).

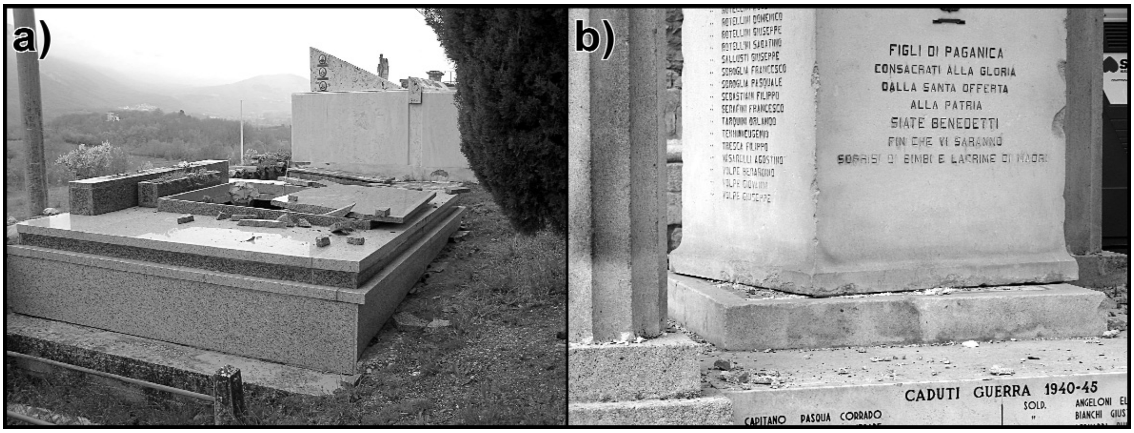

Fig. 11 - a) San Demetrio cemetery, overturned tombstone (photo by I. Cecic); b) Paganica, rotated war memorial.

4. Comparison with the MCS scale

The analysis of the collected data shows that the application of the EMS may explain some apparent anomalies in the distribution and typology of damage inside a settlement, which cannot be taken into account by the MCS scale. The comparison between the intensities obtained by applying both the scales is shown in Fig. 13, while the Appendix reports the couples of the EMS-MCS values assessed for each locality. A first consideration regards the evaluation of the maximum effects ($I \geq$ VIII EMS), EMS intensities resulting in some cases (e.g., Castelnuovo, San Gregorio, Tempera) one degree ($\Delta I = 1$) lower with respect to the MCS values. This result can be ascribed to the concentration of highly vulnerable buildings - ancient and often disrepaired edifices - that is interpreted in the end by the MCS diagnostics as an extremely severe damage

Table 6 - Summary of damage observed at Fossa (in bold) compared with the general definition of grade of damage vs. building vulnerability in the EMS.

Fossa **Damage**	**VI** **Building quantity**	**VII** **Building quantity**	**VIII** **Building quantity**	**IX** **Building quantity**	**X** **Building quantity**
grade 1	many of class A many of class B a few of class C	a few of class D			
grade 2	a few of class A a few of class B	**many of class B** **a few of class C**	many of class C a few of class D	many of class D a few of class E	many of class E a few of class F
grade 3	no	many of class A a few of class B	**many of class B** **a few of class C**	many of class C a few of class D	many of class D few of class E
grade 4	no	a few of class A	**many of class A** **a few of class B**	many of class B a few of class C	many of class C a few of class D
grade 5	no	no	**a few of class A**	many of class A a few of class B	most of class A many of class B a few of class C

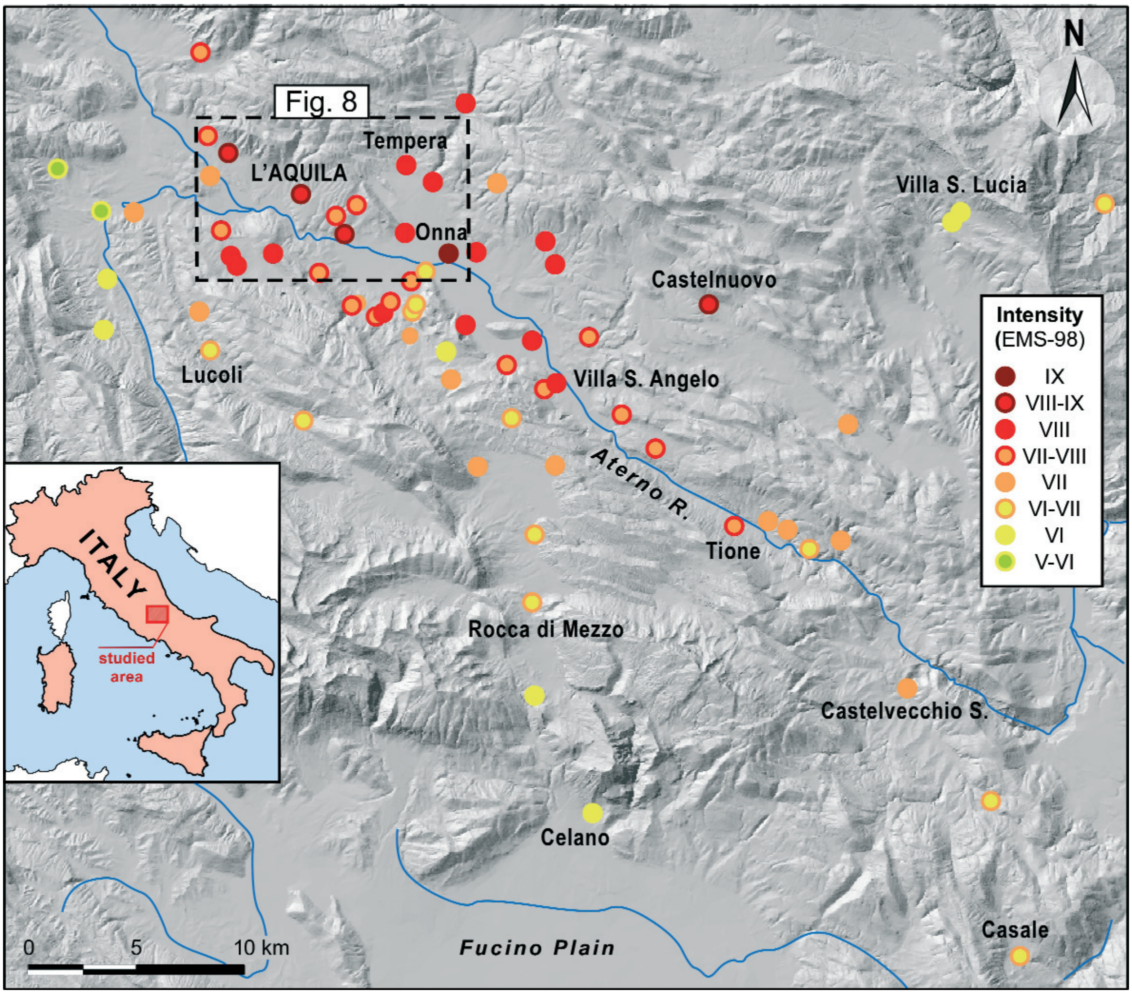

Fig. 12 - EMS intensity map of the April 6, 2009 L'Aquila earthquake.

scenario. By contrast, from the EMS perspective, notwithstanding that the villages appeared almost completely destroyed, major striking damage (grades 4 and 5) has affected only buildings with vulnerability classes A and sometimes B.

What was unexpected is that, for some localities, the EMS estimation is greater than the corresponding MCS value. This is the case, for example, of Pettino (VIII-IX EMS vs. VII MCS) or Casantessa (VII-VIII EMS vs. VI-VII MCS) and other localities, which are marked with a negative difference ($\Delta I = -1$) in the Appendix. At a glance, they do not appear so heavily damaged because there are less class A buildings than in the oldest villages or in the historical centre of L'Aquila. However, the new C and D edifices have been moderately or heavily damaged in sometimes greater percentages than in the localities where almost all the class A and B buildings were destroyed. This behaviour is also observed for lower values of intensity corresponding to the damage threshold.

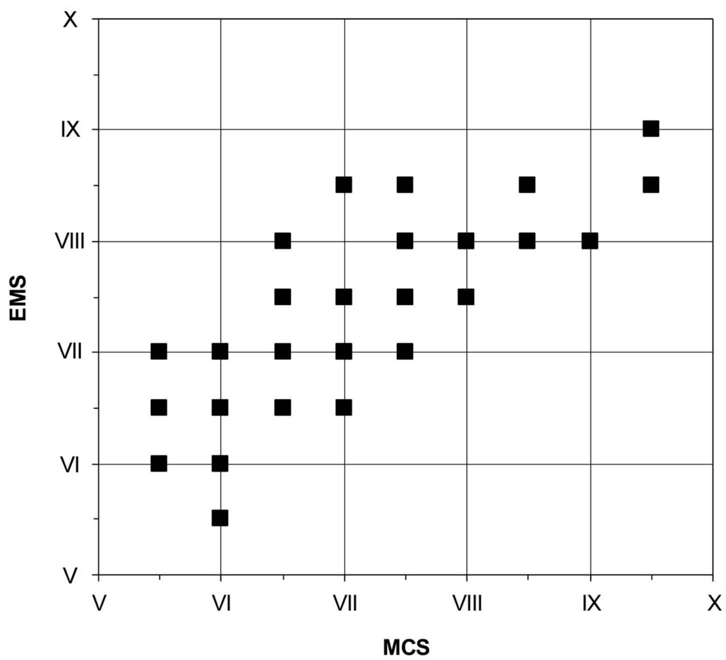

Fig. 13 - Comparison between the intensities estimated in the near-field using the EMS (this study) vs. MCS scale [data from Galli *et al.* (2009)].

5. Conclusions

The macroseismic effects of the April 6, 2009 L'Aquila earthquake have been investigated by a first emergency survey aimed at defining, also for civil protection purposes, the general earthquake damage scenario according to the MCS scale (Camassi *et al.*, 2009; Galli and Camassi, 2009; Galli *et al.*, 2009). Nevertheless, the variability of the effects within the same urban area and the uncertainties deriving in assessing the intensity, prompted us to carry out a more detailed survey in some 70 localities of the epicentral area and environs, with the aim of applying the EMS (Grünthal, 1998). The use of this scale, enabling detailed considerations on the vulnerability of buildings and their grade of damage, has provided a more coherent evaluation of the intensity also in the case of settlements made up of very different building typologies.

The maximum intensities have been estimated for the village of Onna (IX EMS), the historical centre of L'Aquila, Castelnuovo, Pettino and Sant'Elia (VIII-IX EMS), while numerous localities along the valley of the Aterno River, a few tens of kilometres apart from each other, suffered severe damage (VIII EMS). By contrast, other villages within this area have had lower than 1-2 degree intensities (e.g., Coppito, Monticchio, San Panfilo d'Ocre). Finally, among the factors which have contributed to a higher concentration of damage in some specific zones, the following can be noted:

- extremely different conditions of building seismic vulnerability, also in the same locality;
- problems of engineering nature, such as adopted construction techniques and quality of materials;
- local seismic response, leading to site amplification effects for unfavourable geological

conditions;
- coseismic deformation and source directivity effects along the Paganica fault system.

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Corresponding author: Raffaele Azzaro
Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania
Piazza Roma 2, 95123 Catania, Italy
Phone: +39 095 7165821; fax: +39 095 7165826; e-mail: azzaro@ct.ingv.it

Appendix

List of localities investigated by this study, assigned intensities and comparison between the EMS and MCS intensities [MCS data from Galli *et al.* (2009)].

Locality	Municipality	District	Lat. N (°)	Lon. E (°)	EMS	MCS	ΔI
Onna	L'Aquila	AQ	42.327	13.480	IX	IX-X	0.5
Castelnuovo	San Pio delle Camere	AQ	42.295	13.628	VIII-IX	IX-X	1.0
L'Aquila centro	L'Aquila	AQ	42.356	13.396	VIII-IX	VIII-IX	0.0
Pettino	L'Aquila	AQ	42.375	13.355	VIII-IX	VII	-1.5
Sant'Elia	L'Aquila	AQ	42.338	13.420	VIII-IX	VII-VIII	-1.0
Bazzano	L'Aquila	AQ	42.337	13.455	VIII	VIII	0.0
Camarda	L'Aquila	AQ	42.391	13.494	VIII	VII-VIII	-0.5
Fossa	Fossa	AQ	42.296	13.487	VIII	VII-VIII	-0.5
Paganica	L'Aquila	AQ	42.358	13.473	VIII	VIII	0.0
Poggio di Roio	L'Aquila	AQ	42.331	13.378	VIII	VIII-IX	0.5
Poggio Picenze	Poggio Picenze	AQ	42.320	13.541	VIII	VIII-IX	0.5
Roio Piano	L'Aquila	AQ	42.327	13.357	VIII	VIII	0.0
San Benedetto	L'Aquila	AQ	42.303	13.440	VIII	VII-VIII	-0.5
San Gregorio	L'Aquila	AQ	42.327	13.496	VIII	IX	1.0
San Martino	Barisciano	AQ	42.330	13.536	VIII	VI-VII	-1.5
Santa Rufina	L'Aquila	AQ	42.331	13.354	VIII	VIII	0.0
Sant'Eusanio Forconese	Sant'Eusanio Forconese	AQ	42.288	13.525	VIII	IX	1.0
Tempera	L'Aquila	AQ	42.366	13.458	VIII	IX	1.0
Villa Sant'Angelo	Villa Sant'Angelo	AQ	42.269	13.538	VIII	IX	1.0
Arischia	L'Aquila	AQ	42.419	13.342	VII-VIII	VII-VIII	0.0
Bagno Grande	L'Aquila	AQ	42.307	13.422	VII-VIII	VII-VIII	0.0
Casantessa	L'Aquila	AQ	42.383	13.344	VII-VIII	VI-VII	-1.0
Casentino	Sant'Eusanio Forconese	AQ	42.278	13.510	VII-VIII	VIII	0.5
Civita di Bagno	L'Aquila	AQ	42.308	13.445	VII-VIII	VII-VIII	0.0
Colle di Roio	L'Aquila	AQ	42.342	13.349	VII-VIII	VIII	0.5
Fagnano Alto (Vallecupa)	Fagnano Alto	AQ	42.254	13.575	VII-VIII	VII-VIII	0.0
Gignano	L'Aquila	AQ	42.350	13.428	VII-VIII	VII-VIII	0.0
Pedicciano	Fagnano Alto	AQ	42.239	13.593	VII-VIII	VII	-0.5
Pianola	L'Aquila	AQ	42.322	13.404	VII-VIII	VII	-0.5
San Demetrio ne' Vestini	San Demetrio ne' Vestini	AQ	42.288	13.558	VII-VIII	VI-VII	-1.0
Sant'Angelo	L'Aquila	AQ	42.302	13.436	VII-VIII	VII-VIII	0.0
Tione degli Abruzzi	Tione degli Abruzzi	AQ	42.204	13.636	VII-VIII	VII	-0.5
Torretta	L'Aquila	AQ	42.346	13.416	VII-VIII	VII-VIII	0.0
Tussillo	Villa Sant'Angelo	AQ	42.267	13.531	VII-VIII	VIII	0.5
Bagno Piccolo	L'Aquila	AQ	42.308	13.426	VII	VII	0.0

Appendix - Continued

Locality	Municipality	District	Lat. N (°)	Lon. E (°)	EMS	MCS	*ΔI*
Castelvecchio Subequo	Castelvecchio Subequo	AQ	42.130	13.731	VII	VII	0.0
Civitaretenga	Navelli	AQ	42.245	13.705	VII	VII	0.0
Colle di Lucoli	Lucoli	AQ	42.308	13.334	VII	VII-VIII	0.5
Coppito	L'Aquila	AQ	42.366	13.344	VII	VI-VII	-0.5
Pescomaggiore	L'Aquila	AQ	42.356	13.510	VII	VII-VIII	0.5
Rocca di Cambio	Rocca di Cambio	AQ	42.235	13.490	VII	VI	-1.0
Roccapreturo	Acciano	AQ	42.195	13.697	VII	VII	0.0
San Felice d'Ocre	Ocre	AQ	42.293	13.455	VII	VII-VIII	0.5
San Lorenzo	Acciano	AQ	42.205	13.656	VII	VI	-1.0
San Martino d'Ocre	Ocre	AQ	42.273	13.477	VII	VII	0.0
Sassa	L'Aquila	AQ	42.352	13.299	VII	VI	-1.0
Succiano	Acciano	AQ	42.201	13.667	VII	VI	-1.0
Terranera	Rocca di Mezzo	AQ	42.234	13.535	VII	V-VI	-1.5
Beffi	Acciano	AQ	42.192	13.679	VI-VII	VI	-0.5
Carpineto della Nora	Carpineto della Nora	PE	42.333	13.860	VI-VII	V-VI	-1.0
Casale	Cocullo	AQ	42.013	13.787	VI-VII	VI	-0.5
Casamaina	Lucoli	AQ	42.259	13.391	VI-VII	VI-VII	0.0
Castiglione della Valle	Colledara	TE	42.550	13.676	VI-VII	VI	-0.5
Cavalletto	Ocre	AQ	42.306	13.459	VI-VII	VI-VII	0.0
Collimento	Lucoli	AQ	42.291	13.339	VI-VII	VI-VII	0.0
Fonteavignone	Rocca di Mezzo	AQ	42.255	13.511	VI-VII	VI	-0.5
Goriano Sicoli	Goriano Sicoli	AQ	42.080	13.775	VI-VII	VII	0.5
Monticchio	L'Aquila	AQ	42.320	13.466	VI-VII	VI	-0.5
Rocca di Mezzo	Rocca di Mezzo	AQ	42.205	13.521	VI-VII	VI	-0.5
Rovere	Rocca di Mezzo	AQ	42.176	13.517	VI-VII	VI	-0.5
Valle d'Ocre	Ocre	AQ	42.303	13.457	VI-VII	VI	-0.5
Carrufo	Villa S. Lucia degli Abruzzi	AQ	42.329	13.772	VI	V-VI	-0.5
Celano	Celano	AQ	42.084	13.546	VI	V-VI	-0.5
Ovindoli	Ovindoli	AQ	42.136	13.516	VI	VI	0.0
Palombaia	Tornimparte	AQ	42.324	13.282	VI	VI	0.0
San Nicola	Tornimparte	AQ	42.302	13.278	VI	VI	0.0
S. Panfilo d'Ocre	Ocre	AQ	42.285	13.475	VI	VI	0.0
Villa S. Lucia degli Abruzzi	Villa S. Lucia degli Abruzzi	AQ	42.333	13.777	VI	VI	0.0
Civitatomassa	Scoppito	AQ	42.353	13.280	V-VI	VI	0.5
Scoppito	Scoppito	AQ	42.372	13.256	V-VI	VI	0.5