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First remarks about the expected damage scenario following the 24th August 2016 earthquake in central Italy

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Abstract

Right after an earthquake the estimation the number of involved people, dead and the injured, missing people and homeless represent a topic issue in the emergency management, which is closely related to building damage scenario for the area of interest. To this end, in present work, different methodological approaches for seismic vulnerability assessment of buildings at large scale are used to derive damage scenarios for the Municipalities of Amatrice, Accumoli and Arquata del Tronto, which have been struck by the 24th August 2016 earthquake.

Seismic input characterization will be defined through the ShakeMap of the 24th August 2016 earthquake event, published by the Italian National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV).

Data about the number of inhabitant and involved buildings, and about their typological characteristics will be inferred from census data.

Damage scenarios according to various approaches, different in their conception (empirical or analytical methodologies) and/or simply in the choice of the required input parameters, will be derived. A detailed discussion about the reliability of results is carried out, through the comparison with the usability outcomes published by the Department of Civil Protection.

Keywords: Seismic fragility; Damage scenario; fragility curves; Damage States; Post-earthquake.

1. Introduction

In the first moments after an earthquake it is essential to assess the damage to the buildings stock, in order to estimate the number of involved people, the dead and the injured, the missing people and the homeless. Of course, this allows to define the resources necessary to proceed to the identification and the rescue of injured people, looking for missing people, to draw up the first measures of intervention in order to prevent further damage and/or collapse to damaged buildings resulting from aftershocks, but also to program structural interventions in the long term for the overcoming of the emergency condition.

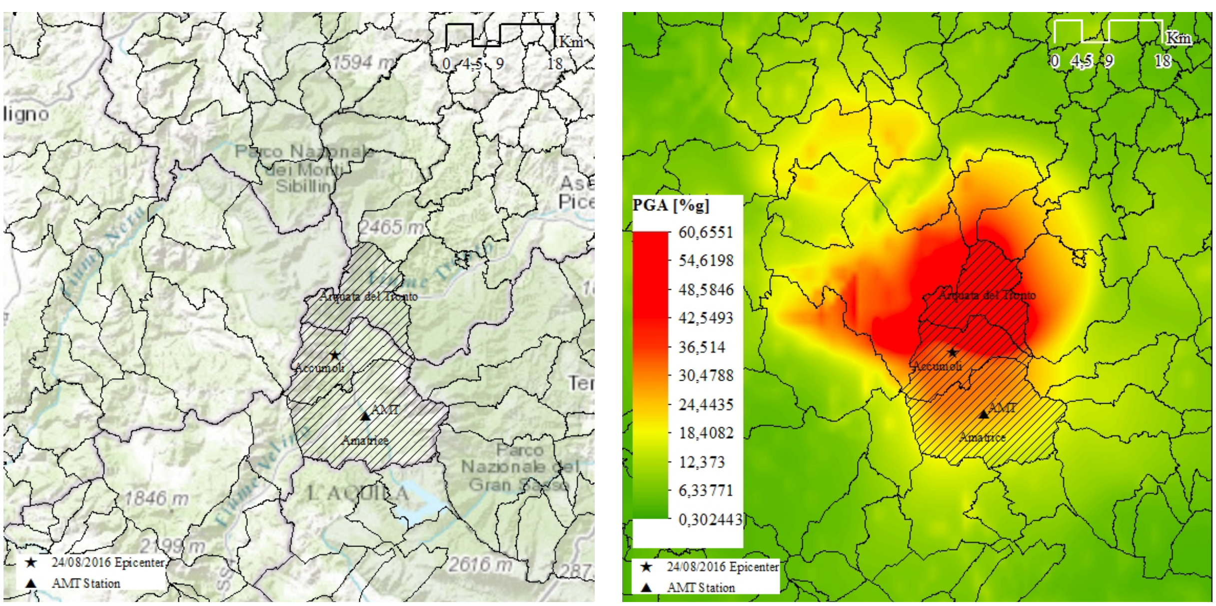
To this end, in the following an overview of the different methodological approaches for seismic vulnerability assessment of buildings at large scale is carried out in order to compare the difference in their results, but also in their conceptions. As a matter of fact, they may differ because they arise from different approaches (empirical or analytical methodologies) or simply in the choice of the required input parameters. In this work, the approaches of [1], [2] and [3] will be considered.

The municipalities considered in this study are those found within a radius of 10 km from the epicenter, namely Amatrice, Accumoli and Arquata del Tronto. Data about the number of inhabitant and involved buildings, and about their typological characteristics are inferred from [4].

The seismic input will be defined through the ShakeMap of the 24th August 2016 earthquake event, published by the Italian National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV).

2. Seismic input characterization

Soon after the 24th August 2016 earthquake that struck central Italy, the Italian National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV) published a ShakeMap of the event (http://shakemap.rm.ingv.it/shake/index.html). This was generated through the software package ShakeMap® developed by the U. S. Geological Survey Earthquake Hazards Program ([5]) specifically designed to obtain maps of the peak ground motion parameters (see [6]).



(a) (b)

Fig. 1 – Shake map data (http://shakemap.rm.ingv.it/shake/index.html)

The data used to obtain the real-time maps are provided mainly by the INGV broadband stations, some of which paired with strong motion sensors, in addition to strong motion data obtained from the Italian Strong Motion Network (Rete Accelerometrica Nazionale, RAN). The peak ground motion parameters (e.g., PGA and spectral pseudo-acceleration for different periods of vibration) are determined through different Ground Motion Prediction Equations (GMPEs):

- for events with Mw≤5.5: three separate sets of equations GMPEs for six main regions are used, specifically determined using the largest number of available data for the area of interest.
- for events with Mw>5.5 (as in our case): the relations of [7] and [8] are used for PGA and PGV, respectively.

The procedure implemented by the INGV accounts for site effects through a nationwide 1:100000 geological map calibrated against the average shear wave velocity of the top 30 m of the subsurface profile (VS30).

In Figure 1 a general overview of the study area and the ShakeMap in terms of peak ground acceleration (PGA) of the event of 24th August 2016.

3. Analysis of building database for the municipalities of Amatrice, Accumoli and Arquata del Tronto

The need of producing damage scenario since the earliest instants following a seismic event, means that the only available data for the national territory are national census data. Hereinafter data from [4] have been used. More detailed data requires insights made by municipalities or authority in charge, that are not always available.

[4] provide information about inhabitants and/or about the typology, age of construction, number of storeys of buildings, although in aggregate form relative to smallest territorial unit that is the census cell.

The municipalities analyzed in this paper are those less than 10 km far from the epicenter: Amatrice, Accumoli and Arquata del Tronto. The municipalities analyzed involve a total population of 4586 inhabitants and 6197 residential buildings.

Hereinafter, data for each single municipality will be analyzed.

3.1 Amatrice

Amatrice has a total area of 174.4 square kilometers and a population of 2646 inhabitants. The number of buildings is equal to 5288, 4103 of which have a residential use, while the number of occupied dwellings by at least one inhabitant is equal to 1278. The 86% of residential buildings, is constituted by masonry buildings, 5% by RC buildings and 9% by buildings made of other materials. Furthermore, 27% of residential buildings were built before 1919, 18% between 1919 and 1945, 16% between 1946 and 1961, 27% between 1961 and 1981 and 12% after 1981. Lastly, 12% of residential buildings is characterized by a single storey, 47% by two-storeys, 39% by three storeys and the remaining 2% by buildings with at least four floors.

3.2 Accumoli

Accumoli has a total area of 87.3 square kilometers and a population of 653inhabitants. The number of buildings is equal to 1382, 849 of which have a residential use, while the number of occupied dwellings by at least one inhabitant is equal to 323. The 94% of residential buildings, is constituted by masonry buildings, 5% by RC buildings and 1% by buildings made of other materials. Furthermore, 36% of residential buildings were built before 1919, 23% between 1919 and 1945, 19% between 1946 and 1961, 12% between 1961 and 1981 and 9% after 1981. Lastly, 11% of residential buildings is characterized by a single storey, 45% by two-storeys, 42% by three storeys and the remaining 2% by buildings with at least four floors.

3.3 Arquata del Tronto

Arquata del Tronto has a total area of 92.2square kilometers and a population of 1287 inhabitants. The number of buildings is equal to 1315, 1245 of which have a residential use, while the number of occupied dwellings by at least one inhabitant is equal to 622. The 28% of residential buildings, is constituted by masonry buildings, 9% by RC buildings and 63% by buildings made of other materials. Furthermore, 32% of residential buildings were built before 1919, 31% between 1919 and 1945, 13% between 1946 and 1961, 20% between 1961 and 1981 and 4% after 1981. Lastly, 3% of residential buildings is characterized by a single storey, 26% by two-storeys, 57% by three storeys and the remaining 14% by buildings with at least four floors.

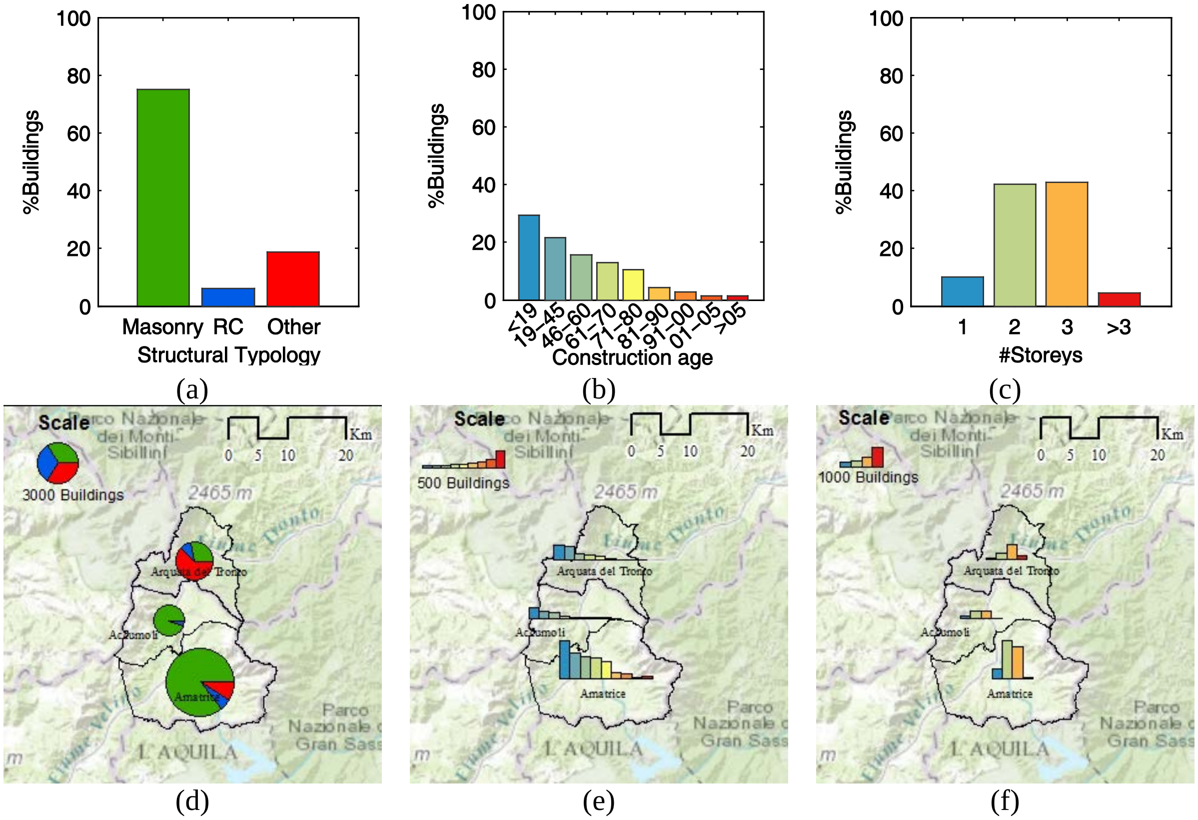


Fig. 2 – Distribution of structural typology (a, d), age of construction (b, e) and number of storeys (c, f).

Fig. 2a-f, reporting distribution about structural typology, age of construction, number of storeys for the whole sample of 6197 buildings, show that:

- with reference to the structural typology, on average 75% of buildings is constituted by a load-bearing masonry structure, 6% by RC buildings and 19% from buildings made of other materials;
- with reference to the age of construction, there is a decreasing trend with the passing of the year, with 29% built before 1919, 22% between 1919 and 1945, 16% between 1946 and 1961, 23% between 1961 and 1981 and 10% thereafter;
- with reference to the number of storeys, on average 10% of buildings is characterized by a single storey, 42% by two-storeys, 43% by three storeys and the remaining 5% by buildings with at least four floors;
- the percentage of buildings a.c. present in the three municipalities is very similar to that for the whole sample; the percentage of masonry buildings for the municipality of Amatrice and Accumoli is respectively 10% and 19% higher, while for the municipality of Arquata del Tronto is 48% lower than the average value. Conversely for buildings made of other materials;
- the distribution of age of construction for the Municipality of Amatrice is very similar to that of the whole sample, while Accumoli and Arquata del Tronto have a (10%) higher percentage of buildings dating from before 1961 against a lower percentage of buildings constructed thereafter;

- the distributions of the number of storeys for Amatrice and Accumoli is very similar to that of the whole sample, while Arquata del Tronto has a (respectively 7% and 17%) lower percentage of 1- and 2-storeys buildings and conversely a (respectively 14% and 10%.) higher percentage of 3- and 4-storeys buildings.

Hereinafter the methodology that allows to derive distributions of vulnerability classes for the study area starting from [4], according to the classification of [9], is presented.

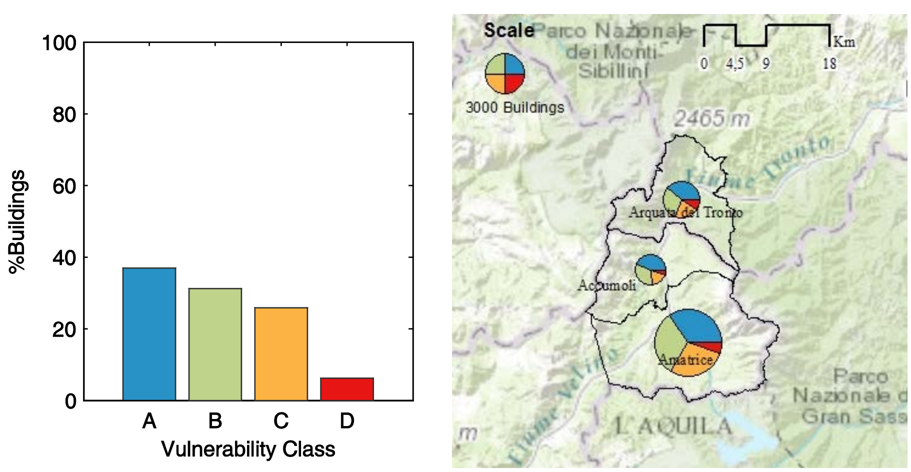
The latter identifies the vulnerability classes, firstly, in relation to the structural typology (masonry, RC, steel or wood buildings) and, secondly, to the layout and quality of the bearing structures for masonry buildings and to the level of seismic action for RC buildings. In particular, the study area is classified in II seismic zone: Amatrice and Accumoli since 1927 through the [10] and Arquata del Tronto later with the [11] (ECSit software available http://www.reluis.it/software to link). In this work, it is assumed that the RC buildings might be considered as EMS class "D" buildings.

On the other hand, [4] does not allow to define detailed information on layout and quality of the masonry bearing structures. Hence, definition of vulnerability classes for masonry buildings will be derived hereinafter according to the correlation table derived by [12] between the vulnerability class and the age of masonry buildings through a statistical study of a sample of about 50000 dwellings after the 1980 Irpinia M 6.9 earthquake.

Table 1 – Vulnerability classes vs. age for masonry buildings. (from [12]).

Epoca di costruzione	Classe di Vulnerabilità		
	A	B	C
<1919	0,74	0,23	0,03
1919 - 1945	0,52	0,40	0,08
1946 - 1960	0,25	0,47	0,28
1961 - 1971	0,04	0,31	0,65
1972 - 1991	0,02	0,19	0,79

Ultimately, it can be observed from Fig. 5a that, respectively 37%, 31% and 26% of the buildings is characterized by a Vulnerability Class "A", "B", "C", while only 6% to a Vulnerability Class "D". Amatrice has a distribution similar to that for the study area. Accumoli and Arquata del Tronto had a higher percentage of vulnerable class "A" buildings (average of 5-7%) and a correspondgly lower percentage of "C" class. These circumstances may be related to trends of age of construction and structural typology previously analyzed for the municipalities.



(a) (b)

Fig. 3 – Distribution of vulnerability classes according to the classification of European Macroseismic Scale (Grünthal, 1998).

4. Seismic damage scenarios at urban scale: the case of municipalities of Amatrice, Accumoli and Arquata del Tronto

In the first moments after an earthquake it is essential to assess the damage to the buildings stock, in order to estimate the number of involved people, the dead and the injured, the missing people and the homeless. Of course, this allows to define the resources necessary to proceed to the identification and the rescue of injured people, looking for missing people, to draw up the first measures of intervention in order to prevent further damage and/or collapse to damaged buildings resulting from aftershocks, but also to program structural interventions in the long term for the overcoming of the emergency condition.

To this aim, an overview of the different methodological approaches for seismic vulnerability assessment at large scale is presented. In particular, the approach of [1], [2] and [3] will be used for the derivation of damage scenarios relating to the present case study. The results will be widely discussed in relation to the assumption made for their derivation and compared with observed damage.

In particular, it has been shown in #4 how to obtain for each building the corresponding vulnerability class from [4]. At the same starting from the fragility curves / DPMs proposed by [1], [2] and [3] for building typological classifications different from one approach to another, it will be shown how to derive *average* fragility curves for the defined vulnerability classes. It would probably be more accurate deriving *weighted* fragility curves for each vulnerability class, derived as a function of the occurrence of building typology, defined in each approach, in each vulnerability classes. Nevertheless, [4] does not provide data with a level of detail, such as to allow it.

4.1 Rota et al. (2008)

[3] provide fragility curves derived from data on structural damage from a large database of about 150000 buildings collected after different Italian earthquakes (Irpinia 1980, Abruzzo 1984, Molise 1997, Pollino 1998, Molise 2002). The outcomes of post-earthquake inspection forms are collected and processed in order to obtain the Damage Probability Matrices (DPMs) and fragility curves for typological classes typical of Italian building stock through non-linear regression. The authors provide fragility curves for reinforced concrete, masonry and mixed buildings.

Fragility curves for RC buildings have been derived as a function of the class of height (1≤Nstoreys<4) or (Nstoreys≥4), and with or without seismic design; nevertheless, due to the reduced amount of data, fragility curves are not provided for RC buildings with seismic design and Nstoreys≥4. Nevertheless, two to the reduced amount of data, fragility curves are not provided for RC buildings with seismic design and Nstoreys≥4. For this reason, in the following the curves for RC buildings without seismic design will be used.

Regarding masonry, in addition to number of storeys (1≤Nstoreys<3) or (Nstoreys≥3), the type of horizontal structure (rigid and flexible floors), the layout and quality of masonry (regular or irregular masonry) and the presence or absence of tie rods and tie beams have been considered in order to derive specific class fragility curves.

Table 2 shows how to assign different vulnerability classes ("A", "B", "C") for masonry buildings, based on vertical and horizontal structure, presence of ties or tie beams, according to the classification given in Baggio et al. (2008). The grey shades present in table (dark gray, light gray and white) indicate increasing levels of vulnerability. In this way *average* fragility curves as a function of vulnerability classes can be derived.

Table 2 – Definition of vulnerability class in relation to vertical and horizontal structure, presence of ties or tie beams for [3]

	Irregular layout or bad quality (stones, pebble,...)		Regular layout or good quality (hewn stones, bricks,...)	
	Without ties or tie beams	With ties or tie beams	Without ties or tie beams	With ties or tie beams
Vaults	IMA4/IMA8	IMA3/IMA7	RMA4/RMA8	RMA3/RMA7
Flexible floors	IMA2/IMA6	IMA1/IMA5	RMA2/RMA6	RMA1/RMA5
Semirigid floors	IMA2/IMA6	IMA1/IMA5	RMA2/RMA6	RMA1/RMA5
Rigid floors	IMA4/IMA8	IMA3/IMA7	RMA4/RMA8	RMA3/RMA7

4.2 Lagomarsino and Giovinazzi (2006)

[2] combine a “macroseismic” and a “mechanical” method. In both cases, the adopted building typological classification essentially corresponds to the [9] proposal. Following the macroseismic approach, vulnerability and fragility curves, respectively providing the expected (mean) damage grade for each building class and the probability of having each discrete damage grade as a function of macro-seismic intensity, are derived from the DPMs implicitly defined by [9]. The mechanical approach is based on CSM, employing bilinear Single Degree of Freedom (SDoF) capacity curves representative of each building class, which are derived from seismic design code lateral-force design requirements, factors like redundancies and conservatism, and the true strength of materials rather than the nominal ones. Hence, fragility curves are derived from the comparison between demand and capacity, the latter defined as a function of capacity curve.

The authors provide fragility curves as a function of building typologies (masonry or reinforced concrete buildings), the classes of height, the type of horizontal structure (wood slabs, masonry vaults, composite steel and masonry slabs, reinforced concrete slabs) for masonry buildings, the level of seismic action depending on seismicity and the ductility class for RC buildings.

Table 3 shows how to assign different vulnerability classes ("A", "B", "C") for masonry buildings, based on vertical and horizontal structure, presence of ties or tie beams, according to the classification given in Baggio et al. (2008). The grey shades present in table (dark gray, light gray and white) indicate increasing levels of vulnerability. The following classes will be considered: Rubble stone (M1), Simple stone (M3), e Unreinforced Masonry (M5) and Unreinforced Masonry with RC floors (M6). In particular, the authors do not provide information about the presence of ties or tie beams. For this reason, in the absence of such information, the lower vulnerability class will be assigned to the building considering or not the presence of ties and tie beams (see Table 3). Therefore, by choosing the lowest vulnerability class between the two, the resulting damage scenarios will represent an upper bound, that is certainly the worst scenario that could be expected.

It is worth noting, that the methodology does not generate fragility curves for the class Rubble stone with composite steel and masonry slabs (M1_sm) and reinforced concrete slabs (M1_rc). In this way *average* fragility curves as a function of vulnerability classes can be derived.

Table 3 – Definition of vulnerability class in relation to vertical and horizontal structure, presence of ties or tie beams for [2]

	Irregular layout or bad quality (stones, pebble,...)	Regular layout or good quality (hewn stones, bricks,...)
	Without ties or tie beams	Without ties or tie beams
Vaults	M1_v	M3_v/M5_v
Flexible floors	M1_w	M3_w/M5_w
Semirigid floors	-	M3_sm/M5_sm
Rigid floors	-	M6

4.3 Zuccaro & Cacace (2009)

In Zuccaro & Cacace (2009) the DPMs based on Italian observational data are reported. The DPMs account for four different vulnerability classes from A to D, and six damage levels (D0 – no damage, D1 – slight damage, D2 – moderate damage, D3 – heavy damage, D4 – very heavy damage, D5 collapse in accordance with [9]. The DPMs derived in terms of macroseismic intensity (MI), are referred in this study to PGA value according to the formulation of [13]:

$$MI = \frac{\log(PGA)}{0.22} - 2.388 \tag{1}$$

4.4 Comparison between the fragility curves

Figure 5 reports the comparison of fragility curves from [1], [2] and [3] methodologies for the different classes of vulnerabilities (from "A" to "D" class).

The fragility curves of [2] show very little changes varying vulnerability classes.

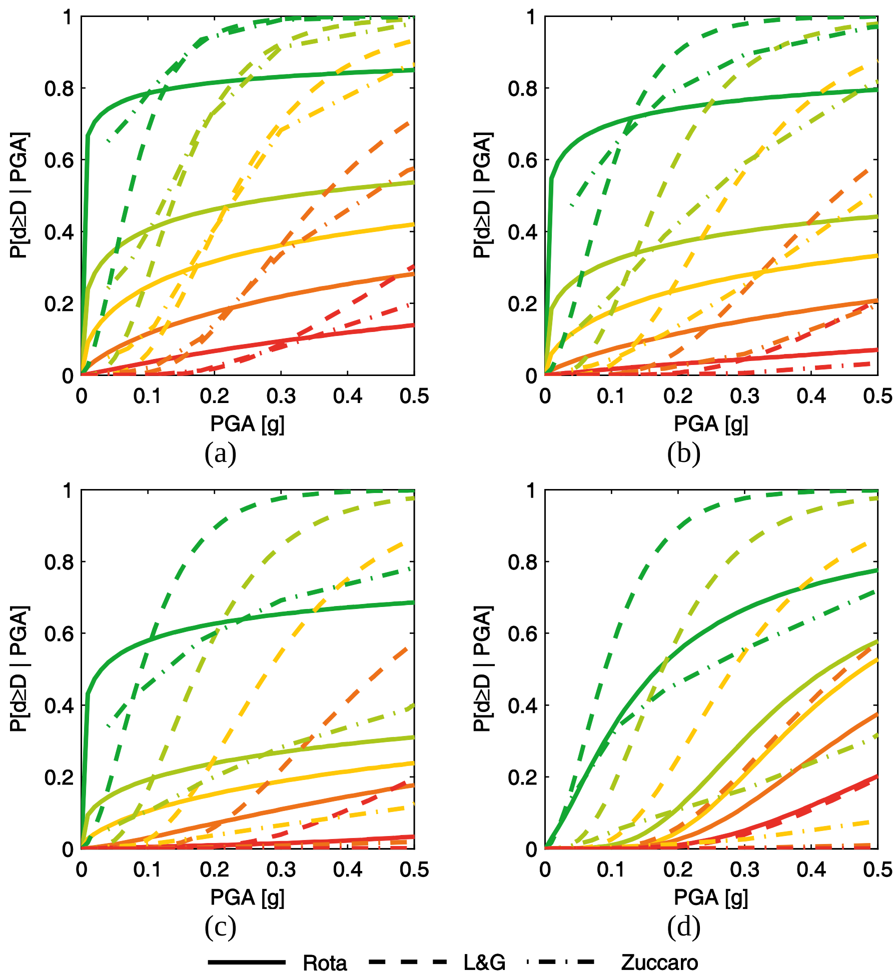


Fig. 4 – Fragility curves for [1], [2] and [3] for different vulnerability classes from “A” to “D”.

Similarly, the curves of [3] are slightly variable for vulnerability "A" and "B” classes. Compared to the curves of [2] they are more vulnerable at low values of PGA (<0.10g) and less vulnerable for higher PGA. The curves for "C" class are less vulnerable than "A" and "B” classes. Altogether these curves have very high values of logarithmic standard deviation that causes a general trend characterized by an elbow for very low PGA values and a pseudo-constant branch thereafter. The vulnerability curves for class "D" show a flatter general trend than “A” to “C” classes. Compared to the curves of [2] they are systematically less vulnerable.

Fragility curves from [1] are derived from DPMs, thereby they are defined for discrete values of IEMS between 5 and 12 (corresponding to a PGA range between 0.04g and 1.33g according to Eq.1). Curved for vulnerability class “A” are very similar to the curves provided by [2], while curves for classes “B” and “C” are intermediate between the curves provided by [2] and by [3] (except for DS4 and DS5, for which they provide a lower estimate of the expected fragility). For the vulnerability class “D” the fragility curves by [1] provide the lowest fragility estimate, compared to the remaining authors.

4.5 Evaluation of damage scenario for the case study

Damage scenarios for the whole database are derived starting from fragility curves for different vulnerability classes.

The reference unit of the procedure is the single building.

In particular, a simulation technique has been implemented, which for each building and for each single run, assigns a realization of number of storeys, structural typology and age of construction from the corresponding distribution of census cell obtained from [4]. The corresponding vulnerability class is derived according to #4 and hence the corresponding vulnerability curves for each approach (Fig. 4).

The PGA value for the building is provided by the ShakeMap of the event for the spatial centroid of census cell. Finally, the damage distribution for the building is derived from the intersection between fragility curves and the calculated PGA value.

The damage distribution of the census cell or for the Municipality is derived summing up the damage distribution of all buildings within the corresponding administrative boundary.

When dealing with post-earthquake damage assessment, the concept of “usability” has to be considered. The definition of usability is linked to the possibility of using the building right after the seismic event, with a reasonable degree of safety against significant damage to people. Usability is defined in [14]”:

“[…] usability may be related to the need of using the building during the seismic emergency, being reasonably safe from the risk of significant damage to people. For this reason, the usability assessment does not aim at safeguarding the construction from further damages, but only at preserving the life of occupants”.

Several authors have collected data on buildings damaged by past earthquake events in order to establish a relationship between the building damage and the usability outcome. In this study, the approach proposed by [15] is adopted. This approach is based on a dataset of about 80.000 buildings surveyed after the 2009 L’Aquila earthquake. According to the authors, the number of “Usable”, “Temporary or Partially Unusable” and “Unusable” buildings can be estimated starting from the damage to the buildings, assuming that:

- the number of Usable buildings is equal to the number of undamaged buildings (DS0) plus the 60% of the buildings with slight damage (DS1);
- the number of Temporary or Partially Unusable buildings is equal to the 40% of the buildings with slight damage (DS1) plus the 20% of the buildings with moderate or heavy damage (DS2 and DS3);
- the number of Unusable buildings is equal to the 80% of the buildings with moderate or heavy damage (DS2 and DS3) plus the buildings with very heavy or collapse damage (DS4 and DS5).

Figure 7 reports damage scenarios for the considered methodologies. The damage scenario derived from [3] shows the majority of buildings with no damage (24.8%) or slight damage (35.8%), and lower and almost uniform percentages of buildings with heavier damage (on average about 10%). This trend can be explained by the fragility curves for vulnerability classes “A”, “B” and “C”, for which the DS1 curve is significantly distant from the remaining curves. Secondly, as highlighted previously, very high values of logarithmic standard deviation lead to sub-horizontal fragility curves, following very low PGA values. Following the approach by [15], this damage scenario leads to a number of Usable, Temporary or Partially Unusable, and Unusable buildings equal to 46.2%, 18.9%, and 34.9%, respectively.

The damage scenario derived according to [2] is characterized by a "pseudo-normal" trend with a mean estimated damage between DS2 and DS3. Compared to [3], the scenario is significantly conservative. In this case, the number of Usable, Temporary or Partially Unusable, and Unusable buildings is equal to 11.9%, 16.5%, and 71.5%, respectively.

According to [1], the mean estimated damage is between DS1 and DS2. The number of Usable, Temporary or Partially Unusable, and Unusable buildings is equal to 33.5%, 19.4%, and 47.1%, respectively. Note that, even starting from significantly different estimated damage scenarios, the approach by [15] provides quite similar usability scenario compared to [3]. This is due to the specific combination of the estimated percentages of buildings in damage states DSi (with i = 0,…,5).

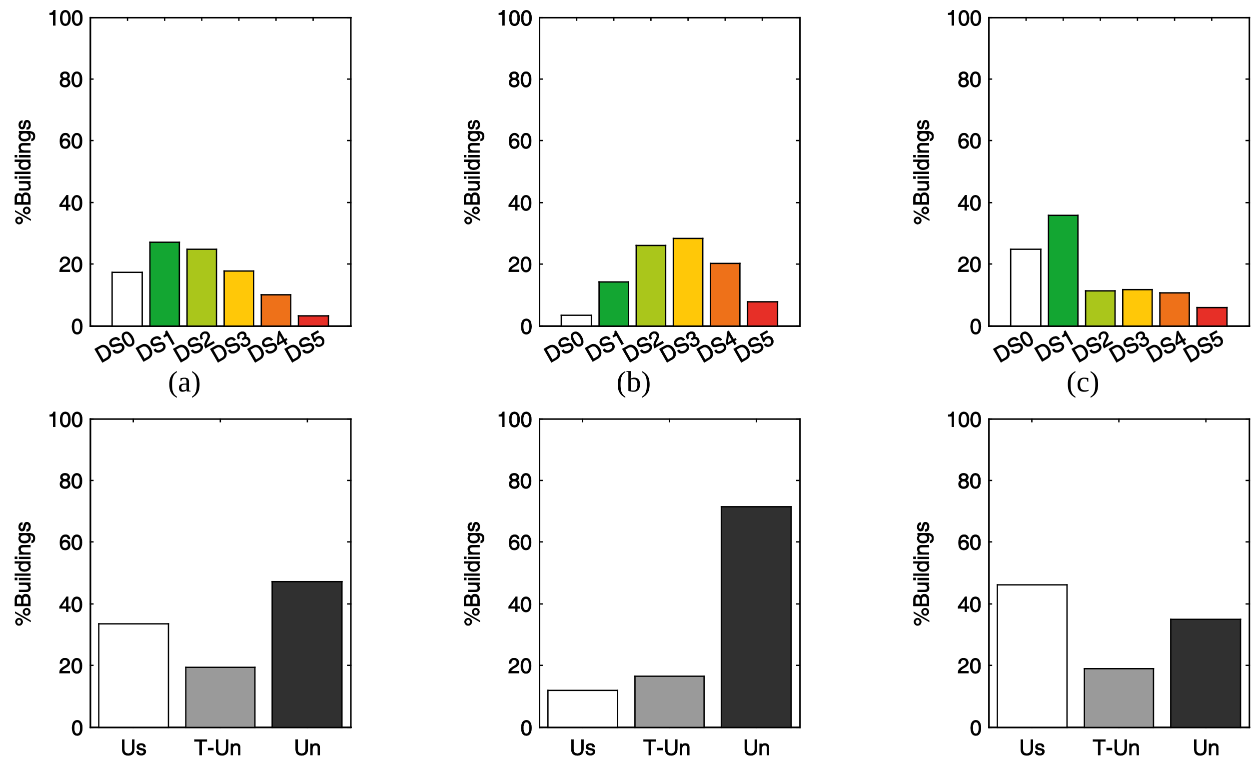


Fig. 5 – Damage scenarios for different DSs, usability outcomes obtained from [1] (a-d), [2] (b-e), [3] (c-f)

4.6 Comparison of predicted and observed damage scenarios

The Department of Civil Protection organized usability assessment surveys since the very first days right after the event. Fig. 6 reports the outcomes of these surveys, carried out between 10th September and 23rd September. In this period, a number of buildings close to the building population of the above analyzed Municipalities has been surveyed. Based on these data, on 21st September, out of 6651 surveyed buildings, the percentages f Usable, Temporary or Partially Unusable, and Unusable buildings are equal to 51.2%, 15.5%, and 33.4%, respectively.

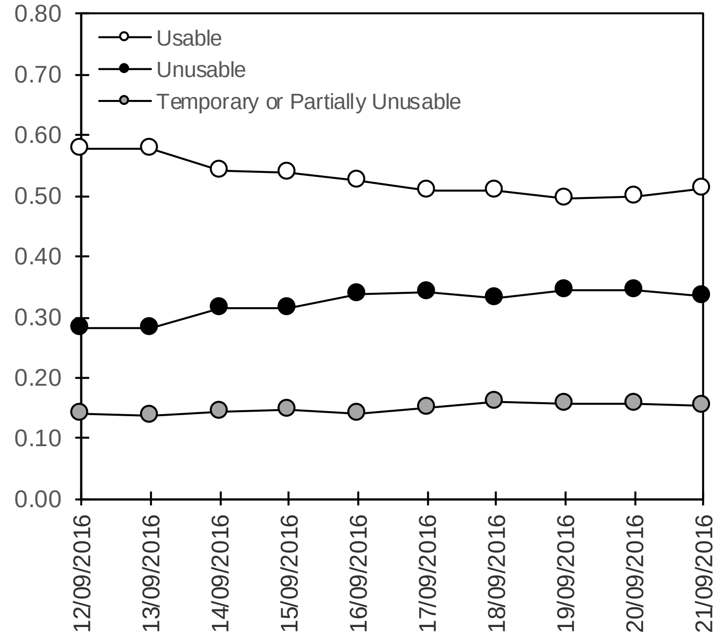


Fig. 6 - Usability outcomes reported by Italian Department of Civil Protection

The comparison with the usability scenarios evaluated above shows that the scenario derived from [2] is the most conservative, whereas those from [3] and [1] allow a quite good usability prediction, even though obtained from different predicted damage scenarios.

5. Conclusion

In this work, a comparison between the damage observed during 24th august 2016 earthquake, which struck central Italy, and the damage scenario predicted by [1], [2], [3] methodologies has been shown.

Seismic input characterization has been defined through the ShakeMap of the 24th August 2016 earthquake event, published by the Italian National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV).

The municipalities considered in this study are those found within a radius of 10 km from the epicenter, namely Amatrice, Accumoli and Arquata del Tronto. Data about the number of inhabitant and involved buildings, and about their typological characteristics has been inferred from [4], from which a vulnerability class has been derived according to the classification of [9].

The fragility curves / DPMs proposed by [1], [2] and [3] for building typological classifications different from one approach to another, have been used to derive *average* fragility curves for the vulnerability classes defined according to [9].

The reference unit of the procedure is the single building. A simulation technique has been implemented, which for each single run, assign a realization of number of storeys, structural typology and age of construction from the corresponding distribution of census cell obtained from [4] and allows to derive a vulnerability class. The PGA value for the building is provided by the ShakeMap of the event for the spatial centroid of census cell. Finally, the damage distribution for the building is derived from the intersection between fragility curves and the calculated PGA value. The damage distribution of the census cell or for the Municipality is derived summing up the damage distribution of all buildings within the corresponding administrative boundary.

The procedure is repeated by using *average* fragility curves / DPMs proposed by [1], [2] and [3] for the different vulnerability classes in order to derive damage scenario and usability outcomes obtained using the relationship proposed by [15].

The comparison with the usability scenarios reported by a bulletin of The Department of Civil Protection published on 21st September 2016, regarding a number of buildings close to the building population of the above analyzed Municipalities, shows that the scenario derived from [2] is the most conservative, whereas those from [3] and [1] allow a quite good prediction, even though obtained from different predicted damage scenarios. Damage scenario derived from [3] shows the majority of buildings with no damage or slight damage, and lower and almost uniform percentages of buildings with heavier damage. Damage scenario derived according to [2] is characterized by a "pseudo-normal" trend with a mean estimated damage between DS2 and DS3. On the other hand, the mean damage predicted by [1] is between DS1 and DS2 and damage distribution shows a "lognormal" trend.

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