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Seismic rehabilitation of residential buildings: an action plan for the urban centres in Val d'Agri, Italy

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ABSTRACT The paper deals with a highly seismic area located in the SW of the Basilicata region (southern Italy), along the valley of the Agri River. This area has a strategic role for Italy because about 70% of the Italian oil extraction derives from local deposits. Large quantities of oil have been extracted since the 1990s, making available large resources deriving from royalties. These sums of money could be used for an extensive strengthening program able to reduce the impact of future earthquakes. To this end, an action plan for the seismic risk mitigation of the residential building stock of 18 villages located in the Agri Valley is outlined, and specifically applied to the village of Viggiano. Starting from the available building-by-building inventory of the typological characteristics collected during previous research activities, the seismic vulnerability of the whole building stock is studied and the expected losses deriving from an earthquake scenario are determined. Some directions for an action plan, essentially based on the reduction of seismic vulnerability of buildings, are proposed in terms of needed costs and implementation timetables.

Key words: seismic hazard, building vulnerability, damage scenario, economic losses, mitigation strategy.

1. Introduction

Seismic risk mitigation in urban areas plays an increasing role because most of the world population lives in these areas (UNFPA, 2018). Setting up of emergency plans to face the immediate consequences of a damaging earthquake, development of methodologies aimed at assessing expected losses due to seismic events, and definition of sustainable solutions able to reduce the seismic vulnerability of residential buildings are crucial for medium-long term mitigation policies. To this end, damage scenarios related to suitably selected events provide relevant data on the seismic risk of urban systems in view of supporting civil protection activities.

Several studies have been devoted in past years to seismic risk and earthquake loss scenarios of urban areas, such as LESSLOSS (2004), RISK-UE (Mouroux and Le Brun, 2006), NERA (2014), FEMA (2015), and GEM [Global Earthquake Model (Silva *et al.*, 2018)]. As for Italy, the ENSeRVES Project (Dolce *et al.*, 2002), the DPC-INGV S3 Project (Chiauzzi *et al.*, 2012; Strollo *et al.*, 2012), and the PAGER Project (Wald *et al.*, 2006; Jaiswal and Wald, 2008) were focused on seismic risk assessment specifically considering the building stock of Potenza town (Basilicata region), assumed as representative of the Italian typological characteristics. A remarkable example of mitigation strategy in urban areas is the Community Action Plan for

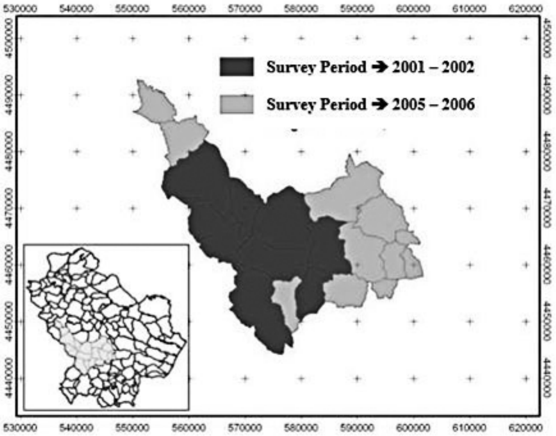
Seismic Safety (CAPSS) project developed by the Applied Technology Council (ATC) for the San Francisco Department of Building Inspection (ATC, 2010). The project was created to support city agencies and policymakers with an action plan able to reduce the earthquake risk in existing privately-owned buildings, and also to develop repair and rebuilding guidelines aimed at accelerating recovery after an earthquake. Further, Yakut *et al.* (2012) proposed a study for the seismic risk prioritisation at large scale of residential buildings in Istanbul with the objective of identifying the buildings that would be likely to sustain severe damage or suffer collapse during the expected Istanbul earthquake and, consequently, developing a rational risk reduction planning for minimising losses.

In this context, the present paper aims at defining an action plan to reduce the seismic risk of 18 villages located in Basilicata region (southern Italy), along the valley of the Agri River. This area was struck by severe earthquakes in the past and has currently a strategic role for the entire country because about 70% (referring to the year 2017; https://unmig.mise.gov.it) of the Italian oil extraction derives from local deposits. Moreover, studies on the seismic risk of this area have gained increasing importance due to the highly debated question about earthquakes possibly induced or triggered by the oil extraction process. The topic of induced seismicity has caught greater attention in the last years, especially as a consequence of some cases of seismicity related to processes involving high-pressure injection of fluids (McGarr *et al.*, 2002; Davies *et al.*, 2013; Klose, 2013; Bommer *et al.*, 2015).

In the past, studies on the Agri Valley aimed at estimating the seismic vulnerability of residential buildings were carried out (e.g. Masi *et al.*, 2014). To this purpose, typological data deriving by a building-by-building survey were collected. Starting from these data, in the present paper, an earthquake damage scenario by considering a seismic event with a 475-year return period has been prepared. Results have been analysed in terms of unusable buildings, human consequences (i.e. casualties) and repair costs. Further, a strategy based on seismic vulnerability reduction has been proposed and related costs have been estimated on the basis of data reported in past studies (e.g. Di Ludovico *et al.*, 2017a, 2017b). Finally, an action plan has been specifically developed for the village of Viggiano in terms of needed costs for structural strengthening and consequent implementation timetables.

2. Seismic vulnerability assessment

The area under study is located along the valley of the Agri River (SW of the Basilicata region) and has a total area of about 1,000 km^2 and a population of about 38,000 inhabitants (ISTAT, 2017). In the past, some studies were focused on the seismic risk of the Agri Valley area, such as Masi *et al.* (2007, 2014). The latter analysed the seismic vulnerability of the residential building stock belonging to 18 villages of the area on the basis of a building-by-building survey of typological characteristics. The survey was carried out by using a rapid inspection form named “Vulnerability Survey form in Peace-time” (VSP), derived from the post-earthquake damage and safety assessment inspection form AeDES (Baggio *et al.*, 2007). The VSP form enabled the collection of building data such as identification (name, address, cadastral unit, photographs), geometrical dimensions (average plan surface, number of stories, inter-storey height), use (property, function, percentage of use, number of dwellings and inhabitants), structural characteristics (materials, structural type, age of construction, strengthening interventions) and soil condition (geomorphology, landslide). The survey was carried out by trained technicians in two different periods, that are 2001-2002 and 2005-2006. The main collected data are summarised in the table attached to Fig. 1.



Number of villages	18
Number of buildings	17,500
Volume (m^3) of building stock	12×10^6
Number of retrofitted buildings	3,900
Percentage of retrofitted buildings	22%

Fig. 1 - On the left: map of the Agri Valley area displaying the villages surveyed during the first (dark grey) and the second (light grey) phase. On the right: summary of surveyed data.

Most of the buildings of the surveyed villages have masonry structure (75% of the building stock) while only 20% were built with reinforced concrete (RC) structure (other types amount to 5%). Instead, in terms of building volume a lower difference can be found, that is 42% and 51% for RC and masonry buildings, respectively. In terms of building height, about 77% of the surveyed buildings (65% in volume) can be classified as low-rise structures (i.e. buildings with a number of storeys in the range 1-3 for RC buildings and 1-2 for masonry and other types), while the other ones can be classified as mid-rise buildings (i.e. buildings with a number of storeys in the range 4-7 for RC buildings and 3-5 for masonry and other types). Very few buildings classified as high-rise structures are present in the area. About 60% of masonry buildings (45% in volume) were built before the Second World War (i.e. 1945), while RC buildings were built mostly after 1981 (15% and 30% in terms of number and volume, respectively), and, therefore, were designed using seismic criteria (the area under study was seismically classified after the 1980 Campania - Basilicata earthquake). Fig. 2 shows the distribution of buildings in terms of material (Fig. 2a), height (Fig. 2b) and period of construction (Fig. 2c).

Starting from the above described typological data, Masi *et al.* (2014) assigned seismic vulnerability according to the four vulnerability classes, V_C (i.e. "A", "B", "C", and "D" relevant to high, medium, medium-low, and low seismic vulnerability, respectively) defined by EMS-98 scale (Grünthal, 1998). To this purpose, the criteria firstly introduced by Dolce *et al.* (2003) and also illustrated in Chiauzzi *et al.* (2012) were adopted, as shown in Table 1. Specifically, the vulnerability of masonry buildings was assessed on the basis of the most important structural characteristics that are horizontal and vertical structural type along the height, period of construction and/or retrofitting. For RC buildings, medium-low vulnerability (i.e. class "C") was assigned to structures without earthquake resistant design (i.e. built before 1980 as for the

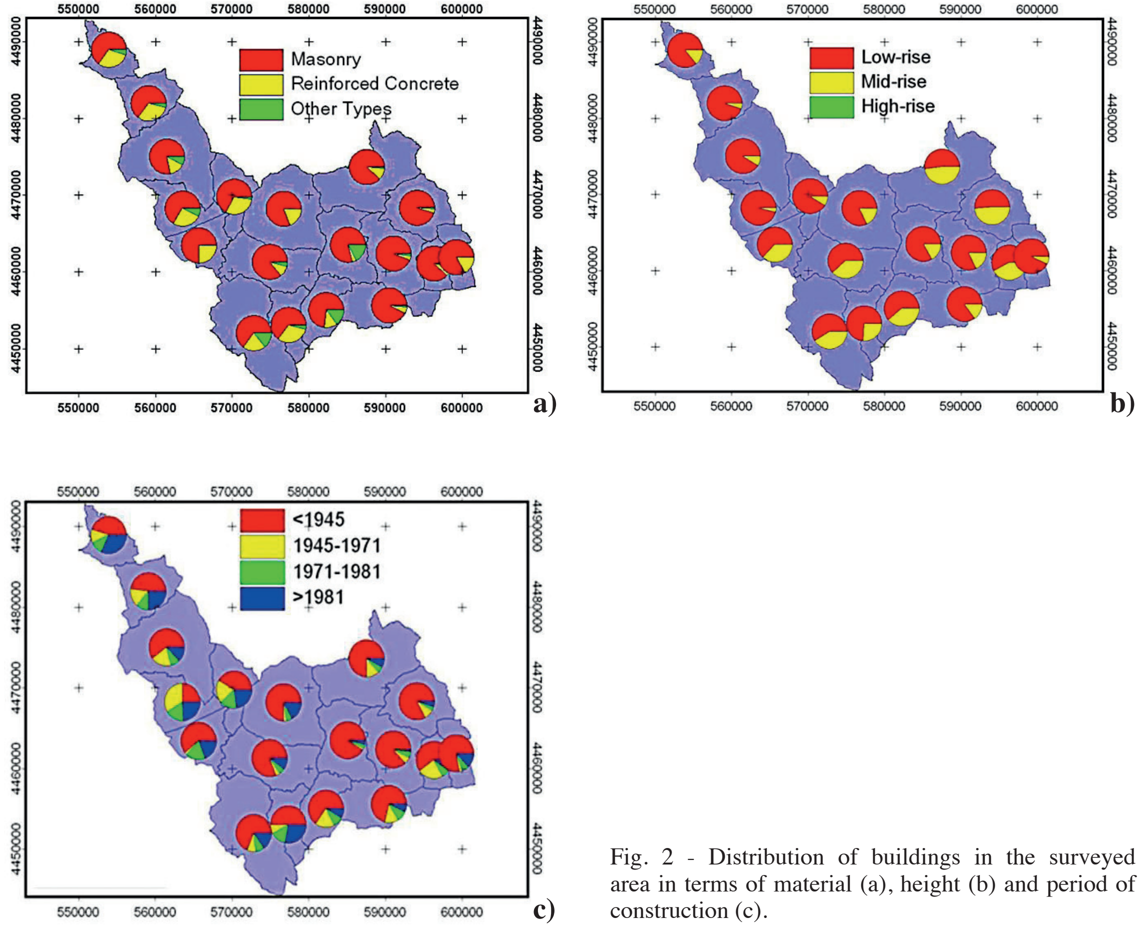


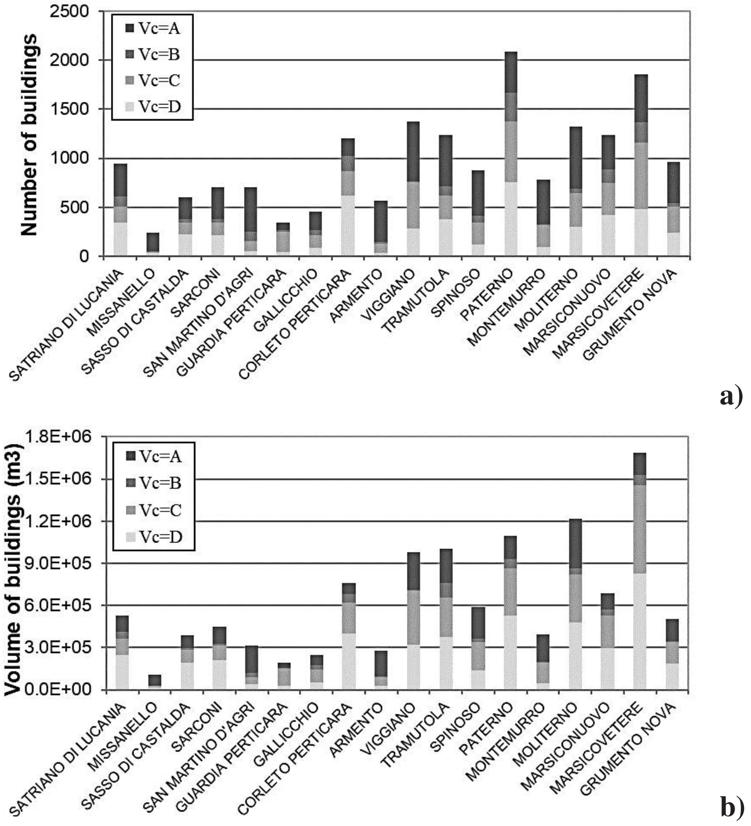
Fig. 2 - Distribution of buildings in the surveyed area in terms of material (a), height (b) and period of construction (c).

area under study), while the lowest vulnerability class (i.e. class "D") was assigned to buildings (both masonry and RC structures) designed according to modern anti-seismic criteria (i.e. built or retrofitted after 1980).

Table 1 - Criteria to assign vulnerability classes.

Horizontal Structures		**Vertical Structure**							
		Masonry Quality			Mixed	RC		Steel	Other
		Bad	Medium	Good		Frame	Wall		
Vaults	Without tie-beams	A	A	A	B	-	-	-	-
	With tie-beams	A	A	A	B	-	-	-	-
Floors	Deformable	A	A	B	C	C	C	C	C
	Semirigid	B	B	C	C	C	C	C	C
	Rigid, RC	B	C	C	C	C	C	C	C
Buildings retrofitted after 1980		D							
Buildings built after 1980		D							

Fig. 3 reports the distribution of building vulnerability for all 18 villages and the attached table shows the data related to entire area under study (see also Table 11 in the Appendix). Results show that the building stock is mainly characterised by low (class "D") and medium-low (class "C") vulnerability classes. Specifically, 39% of the building volume belongs to class "D" (27% in terms of number of buildings) while 31% belongs to class "C" (26% in terms of number). Nevertheless, it is worth highlighting that the percentage of the highest vulnerability class ("A") amounts to about 25% and 40% in terms of volume and number of buildings, respectively. The differences among vulnerability distributions in terms of volume and number of buildings are mainly due to the large difference in the average volume relevant to masonry and RC buildings. Specifically, it is about 500 m^3 for masonry buildings (which have generally higher vulnerability, i.e. V_C = A or B) and about 1000 m^3 for RC ones (which have lower vulnerability, i.e. V_C = C or D). As reported below, this result also influences loss scenarios.



	Total Number of buildings				Volume of buildings (m^3)			
	Vulnerability Classes (EMS-98)				Vulnerability Classes (EMS-98)			
	A	B	C	D	A	B	C	D
	6767	1409	4608	4718	2.9E+06	5.9E+05	3.6E+06	4.4E+06
%	39	8	26	27	25	5	31	39

Fig. 3 - Distribution of the vulnerability classes in terms of buildings' number (a) and volume (b) for each considered village and summary table for all the villages.

3. Seismic hazard

The Italian seismic catalogue CPTI15 (Rovida *et al*., 2016) reports several events that struck the Agri Valley in the past, the strongest one occurred on 16 December 1857, with epicentral intensity I_0 = XI MCS (M_W 7.1). According to the Italian seismic map (OPCM 3519, 2006) provided by the National Institute of Geophysics and Volcanology (http://www.ingv.it/it/) and adopted in the current Italian Building Code (NTC, 2018), for the 18 villages located in the Agri Valley, the expected values of peak ground acceleration (*PGA*) for an event with a 475-year return period (i.e. exceedance probability of 10% in 50 years) range between 0.143 and 0.262 g on stiff soil (V_{S30} > 800 m/s; cat. A), as displayed in Fig. 4.

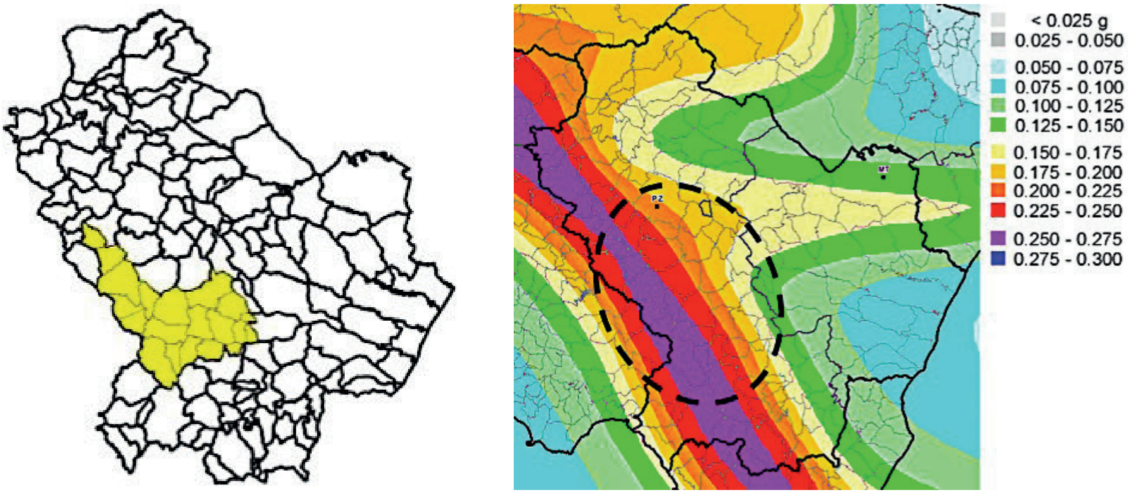


Fig. 4 - On the left: Basilicata region and the considered villages (yellow area). On the right: seismic hazard map of Basilicata region according to OPCM 3519 (2006) for an exceedance probability of 10% in 50 years, soil class A.

The above-mentioned hazard values refer to the Life Safety limit state[1] (SLV) and, as will be explained later, have been adopted as seismic input in the present study. In order to take into account site effects, some results deriving from the seismic microzonation (SM) studies supported by the Basilicata Region (http://microzonazione.regione.basilicata.it/Microzonazione) have been considered. In accordance with the criteria given in the Italian Guidelines for SM (SM Working Group, 2015), three classes were qualitatively defined, that is "Stable zone", "Stable zone - susceptible to local amplifications" and "Unstable zone". Most of the Agri Valley was classified as "Stable zone but susceptible to local amplification", as specifically shown for the territory of Viggiano village in Fig. 5. Further, specific studies on the local amplification effects in some villages of the Agri Valley were carried out in the past within a research agreement between the Basilicata Region and the University of Basilicata (Mucciarelli, 2005). According to

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[1] Life Safety limit state (SLV) reported in NTC (2018) corresponds to Significant Damage limit state (SD) provided in EuroCode 8, Part 3 (CEN, 2004). This limit state requires that the structure preserves part of the vertical-load bearing capacity and some capacity against further horizontal actions although non-structural components suffer heavy damage up to collapse and structural components are significantly damaged.

the OPCM 3274 (2003) code [also consistent with EC8 (CEN, 2004) and NTC (2018)], soil class B-T1 (i.e. "deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth" and "no topographic amplification") was mainly assigned. Therefore, based on the results from the two available studies, soil class B-T1 has been assumed for all villages under study.

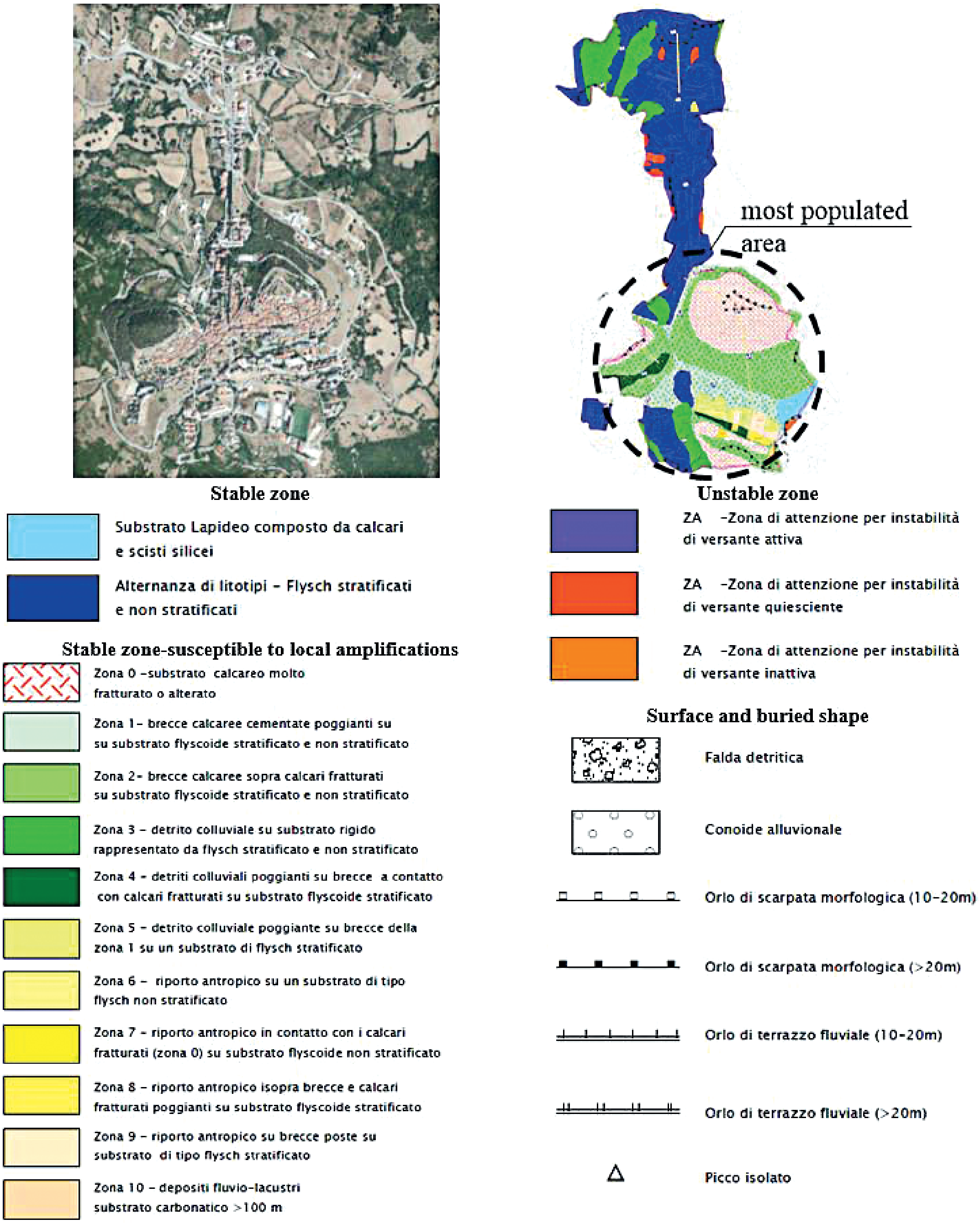

Fig. 5 - View of the Viggiano village and the corresponding SM map. The most populated area is highlighted.

Damage Probability Matrices (DPMs) (Braga *et al.*, 1982; Dolce *et al.*, 2003) have been adopted to compute seismic damage. Consequently, macroseismic intensities according to the EMS-98 scale, I_{EMS} (Grünthal, 1998) have to be evaluated to define the selected earthquake scenario. To this purpose, starting from the Italian seismic map and considering the greater capability of an integral parameter such as Housner intensity, I_H (Housner, 1952) to represent seismic severity (e.g. Masi *et al.*, 2015), the relationship developed by Masi *et al.* (2020) has been considered. Specifically, $I_{EMS\text{-}98}$ values given I_H values have been determined by the following equations:

$$I_{EMS-98} = 0.32 \cdot \ln (I_H) + 5.59 \qquad I_H < 0.15 \text{ m} \tag{1}$$

$$I_{EMS-98} = 1.64 \cdot \ln (I_H) + 8.08 \qquad I_H \geq 0.15 \text{ m.} \tag{2}$$

For each village, I_H values have been computed on the basis of pseudo-velocity response spectrum according to the Italian seismic map (OPCM 3519, 2006), as follows:

$$I_H = \int_{0.2}^{2.0} PVS(T,\ \xi = 5\%)dT \tag{3}$$

where $PVS\ (T, \xi)$ is the pseudo-velocity response spectrum, T is the vibration period and $\xi = 5\%$ is the fraction of critical damping.

For the considered event (i.e. exceedance probability of 10% in 50 years, $T_R = 475$ years, soil class B-T1), Table 2 reports the local values of PGA, I_H, and $I_{EMS\text{-}98}$.

Table 2 - Values of PGA and I_H for $T_R = 475$ years and class B-T1 obtained from the Italian seismic hazard map, and EMS-98 macroseismic intensities.

	Name of Villages	***PGA* (g)**	**I_H (cm)**	**I_{EMS-98}**
1	Armento	0.220	72	VIII
2	Corleto Perticara	0.206	71	VII
3	Gallicchio	0.183	65	VII
4	Grumento Nova	0.300	93	VIII
5	Guardia Perticara	0.183	66	VII
6	Marsico Nuovo	0.300	90	VIII
7	Marsicovetere	0.297	89	VIII
8	Missanello	0.172	63	VII
9	Moliterno	0.304	91	VIII
10	Montemurro	0.270	82	VIII
11	Paterno	0.299	90	VIII
12	San Martino D’Agri	0.255	79	VIII
13	Sarconi	0.303	91	VIII
14	Sasso di Castalda	0.297	89	VIII
15	Satriano di Lucania	0.296	89	VIII
16	Spinoso	0.285	86	VIII
17	Tramutola	0.302	91	VIII
18	Viggiano	0.290	87	VIII

4. Seismic risk assessment

In this section, expected losses in terms of unusable buildings, homeless, and casualties have been estimated. To this purpose, two seismic scenarios have been prepared by considering the building inventory in terms of either number or volume of buildings.

Starting from the results of the building vulnerability assessment (see Section 2), for each village the number/volume of buildings suffering a certain damage level L_d due to the considered seismic input has been computed as follows:

$$N(L_d) = \sum_{V_C=\mathrm{A}}^{\mathrm{D}} \left[N_{V_C} \cdot DPM(L_d, V_C, I_{EMS}) \right] \qquad (4)$$

where L_d is the damage level as provided in EMS-98 scale, ranging between 0 and 5 ($L_d = 0$ means total absence of damage, while $L_d = 5$ means collapse), N_{V_c} is the number/volume of buildings for each vulnerability class V_C (i.e. "A", "B", "C" and "D"), DPM (L_d, V_C, I_{EMS}) provides the probability of obtaining a damage level L_d given a macroseismic intensity I_{EMS} and a vulnerability class V_C. Table 3 reports the coefficients of the DPM (L_d, V_C, I_{EMS}), for all the vulnerability classes and for the EMS values VII and VIII considered in the proposed scenario (Dolce *et al.*, 2003).

Table 3 - DPM for buildings of vulnerability classes A, B, C and D and macroseismic intensity equal to VII and VIII (adapted from Dolce *et al.*, 2003).

Vulnerability class (V_C)	**Intensity (I_{EMS})**	**Damage Level (L_d)**					
		0	1	2	3	4	5
A	VII VIII	0.064 0.002	0.234 0.020	0.344 0.108	0.252 0.287	0.092 0.381	0.014 0.202
B	VII VIII	0.188 0.031	0.373 0.155	0.296 0.312	0.117 0.313	0.023 0.157	0.002 0.032
C	VII VIII	0.401 0.131	0.402 0.329	0.161 0.330	0.032 0.165	0.003 0.041	0.000 0.004
D	VII VIII	0.715 0.401	0.248 0.402	0.035 0.161	0.002 0.032	0.000 0.003	0.000 0.000

Fig. 6 shows the expected damage distribution in terms of number (on the left) and volume (on the right) for each damage level (i.e. from $L_d = 0$ to $L_d = 5$). As can be seen, about 25% of the building stock (about 15% in terms of volume) would suffer a damage level $L_d \geq 4$ (heavily damaged and collapsed buildings).

Results obtained from Eq. 4 have been also analysed in order to evaluate unusable buildings, homeless, and casualties. Specifically, unusable buildings have been calculated by using the percentages provided for the different vulnerability classes by Masi *et al.* (2007) and Chiauzzi *et al.* (2018) on the basis of surveyed data after past earthquakes (Table 4). The percentages of unusability refer to severely damaged buildings with rating "E" according to the AeDES form.

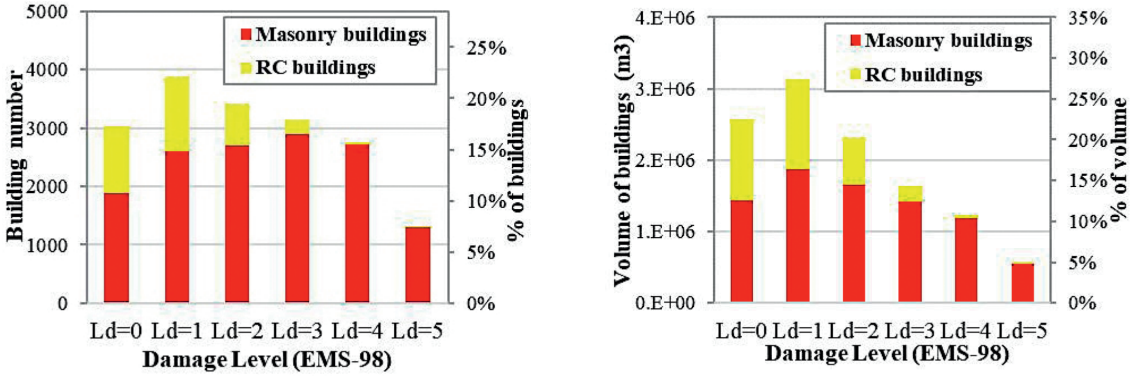

Fig. 6 - Expected damage levels in terms of number (on the left) and volume (on the right) of buildings. The damage distribution has been split into RC (in yellow) and masonry/other type (in red) buildings.

Table 4 - Percentage of unusable buildings as a function of damage level and vulnerability class.

Vulnerability Classes	Damage Level (EMS-98)					
	$L_d = 0$	$L_d = 1$	$L_d = 2$	$L_d = 3$	$L_d = 4$	$L_d = 5$
A	0%	10%	30%	82%	100%	100%
B	0%	5%	23%	75%	100%	100%
C, D (masonry buildings)	0%	2%	18%	64%	100%	100%
C, D (RC buildings)	0%	0%	14%	38%	100%	100%

As for the homeless number, it has been estimated by multiplying the number/volume of unusable buildings and the average number of inhabitants per building/unit of volume. Possible differences in terms of average number of inhabitants per building located in the periphery with respect to the historic centre have been neglected.

Starting from the results reported in Fig. 3 (i.e. distribution of the building vulnerability classes), Table 5 summarises the number of unusable buildings and homeless for each vulnerability class as a function of both number and volume of buildings.

In order to address a seismic intervention strategy, it is worth noting that the larger percentages refer to buildings with high vulnerability. Specifically, the percentage of unusable buildings with class “A” is equal to 31% of the whole building stock (20% in terms of volume), while the number of homeless amounts to 30% and 20% of inhabitants, respectively for scenario in terms of number and volume of buildings. The percentages of unusable buildings related to each vulnerability class are equal to about 80% (for V_C = “A”), 45% (for “B”), 14% (for “C” and “D”, masonry buildings) and 5% (for “C” and “D”, RC buildings).

With respect to casualties’ estimation, the approach proposed by Coburn and Spence (2002) has been adopted, whose parameters have been calibrated in order to calculate the minimum-maximum number of estimated victims.

Tables 6 and 7 summarise the expected losses for all villages of the Agri Valley, respectively for the scenario in terms of number and volume of buildings. It is worth underlining that, as a consequence of the selected seismic input, the results have to be intended as the maximum expected losses for each single village, while it is very unlikely that they occur simultaneously.

Table 5 - Number and percentage of the expected unusable buildings and homeless for each vulnerability class. Results from damage scenarios in terms of both number and volume of buildings are reported. For unusable buildings, the percentage related to each vulnerability class (%V_C) has been reported.

Vulnerability Classes V_C	***Scenario in terms of number of buildings***				***Scenario in terms of building volume***			
	Unusable buildings		**Homeless**		**Unusable buildings**		**Homeless**	
	Number	**%**	**Number**	**%**	**Volume (m^3)**	**%**	**Number**	**%**
A	5510	31	11530	30	2.3E+06	20	7410	20
B	640	4	1400	4	2.7E+05	2	905	2
C, D (masonry buildings)	840	5	1880	5	6.5E+05	6	2170	6
C, D (RC buildings)	200	1	445	1	1.9E+05	2	645	2
All	7190	41	15255	40	3.4E+06	30	11130	29

Table 6 - Distribution of I_{MD}, number of unusable buildings, homeless and casualties for all 18 involved villages of the Agri Valley area (damage scenario in terms of buildings' number).

Village	**Expected consequences (scenario in terms of number of buildings)**					
	I_{MD}	**Number of unusable buildings**	**% of unusable buildings**	**Number of homeless**	**% of homeless**	**Casualties**
Satriano di Lucania	0.43	385	41	955	41	15-25
Missanello	0.36	85	35	200	35	0
Sasso di Castalda	0.43	245	40	335	40	5-10
Sarconi	0.47	330	47	665	47	15-25
San Martino d'Agri	0.60	460	65	495	65	10-20
Guardia Perticara	0.22	50	15	80	15	0
Gallicchio	0.27	100	22	195	22	0
Corleto Perticara	0.17	130	11	270	11	0
Armento	0.62	390	69	415	69	10-20
Viggiano	0.48	640	46	1550	46	30-55
Tramutola	0.46	555	45	1365	45	30-50
Spinoso	0.53	480	55	780	55	20-35
Paterno	0.37	660	32	1055	32	15-30
Montemurro	0.54	445	57	685	57	15-30
Moliterno	0.49	650	49	1915	49	40-75
Marsico nuovo	0.41	460	37	1490	37	15-30
Marsicovetere	0.41	680	37	2020	37	30-55
Grumento nova	0.47	445	46	785	46	15-25
All villages	**0.43**	**7190**	**41**	**15255**	**40**	**265-485**

In order to obtain a synthetic estimation of the global building damage, the mean damage index (I_{MD}) (Dolce *et al.*, 2003) has been computed through the following expression:

$$I_{MD} = \sum_{i=1}^{n} \left(\frac{L_{d_i} \cdot f_i}{n} \right) \tag{5}$$

where L_{di} is a generic damage level (i.e. from $L_d = 1$ to $L_d = 5$), n is the number of damage levels and f_i is the relevant frequency of occurrence. As a consequence, I_{MD} can vary from 0 to 1, where $I_{MD} = 0$ means total absence of damage and $I_{MD} = 1$ refers to total destruction.

Considering the damage scenario in terms of number of buildings (Table 6), a mean value of I_{MD} equal to 0.43 has been computed for the whole area. Further, a total number of about 7,000 unusable buildings (about 40% of the total building stock), about 15,000 homeless (about 40% of the inhabitants) and 265-485 casualties have been estimated. The scenario prepared in terms of volume (Table 7) reveals a lower percentage of expected losses. Specifically, an I_{MD} equal to 0.36, about 11,000 homeless (about 29% of the total building stock) and 175-300 casualties have been evaluated. The differences among earthquake loss scenarios are mainly due to the different distributions of the seismic vulnerability in terms of volume and number of buildings. Specifically, as shown at Section 2, the building stock of the considered area is characterised by a large number

Table 7 - Distribution of I_{MD}, unusable volume, number of homeless, and casualties for all 18 involved villages of the Agri Valley area (damage scenario in terms of buildings' volume).

Village	Expected consequences (scenario in terms of building volume)					
	I_{MD}	Unusable Volume (m³)	% of Unusable Volume	Number of Homeless	% of Homeless	Casualties
Satriano di Lucania	0.36	1.6E+05	30	700	30	10-15
Missanello	0.34	3.5E+04	33	185	33	0
Sasso di Castalda	0.35	1.1E+05	29	240	29	5-10
Sarconi	0.37	1.4E+05	31	445	31	10-15
San Martino d'Agri	0.57	1.9E+05	61	460	61	10-15
Guardia Perticara	0.20	2.6E+04	13	70	13	0
Gallicchio	0.24	4.6E+04	18	165	18	0
Corleto Perticara	0.15	6.4E+04	8	215	8	0
Armento	0.57	1.7E+05	62	370	62	10-15
Viggiano	0.39	3.2E+05	33	1110	33	20-35
Tramutola	0.38	3.3E+05	33	1005	33	15-30
Spinoso	0.45	2.5E+05	43	610	43	15-25
Paterno	0.32	2.7E+05	24	810	24	10-20
Montemurro	0.51	2.1E+05	52	630	52	15-25
Moliterno	0.39	4.1E+05	34	1325	34	25-45
Marsico nuovo	0.34	1.9E+05	27	1090	27	10-15
Marsicovetere	0.30	3.3E+05	20	1090	20	10-20
Grumento nova	0.40	1.8E+05	36	610	36	10-15
All villages	**0.36**	**3.4E+06**	**30**	**11130**	**29**	**175-300**

of masonry buildings having higher vulnerability (mainly V_C = A). On the contrary, in terms of volume, RC buildings (for which lower vulnerability classes have been assigned, i.e. V_C = C or D) prevail due to the higher average volume per building with respect to masonry ones. Therefore, the large amount of buildings with high vulnerability (i.e. masonry buildings) inappropriately influences loss results when preparing the scenarios in terms of number of buildings. On the contrary, in case of scenarios in terms of volume, loss results reduce due to the higher volume of RC building stock having a lower vulnerability. In general, results from scenarios in terms of volume should be considered more accurate because building dimensions (such as volume and surface) are better correlated to both repair/reconstruction cost and exposure data.

5. Estimation of direct economic losses

Direct economic losses associated with repair of post-earthquake damage of residential buildings are one of the most important indicators to consider in planning seismic risk mitigation strategies. Different approaches can be used to estimate repair costs, frequently referred to data drawn from past earthquakes. Di Pasquale and Goretti (2001) analysed more than 50,000 damaged buildings after the Umbria-Marche 1997 and the Pollino 1998 events, and proposed repair cost functions for different damage levels. Specifically, for each damage level, repair cost curves were defined in terms of an economic damage index $C_{r,r}$ evaluated as the ratio between the cost of repair and the cost of reconstruction, thus ranging between 0 and 1. A standard normal distribution of $\mathrm{C}_{\mathrm{r,r}}$ was assumed in defining the repair cost curves. Starting from the results obtained by Di Pasquale and Goretti (2001), Masi *et al*. (2002) and Dolce *et al*. (2006) developed curves of the relative repair cost, $C_{r,r}$, by adopting the standard Beta distribution. The related cumulative distribution functions for the damage levels considered in the EMS-98 scale are displayed in Fig. 7.

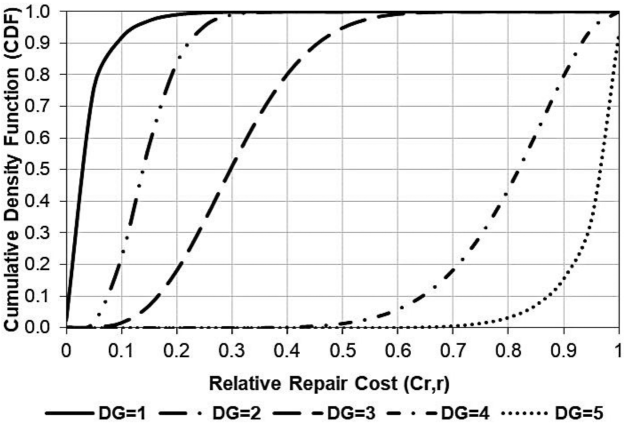

Fig. 7 - Relative repair cost functions proposed by Masi *et al*. (2002) and Dolce *et al*. (2006).

For a given macroseismic intensity I_{EMS}, the relative repair cost can be computed by convolving the DPMs (probability to observe different damage levels L_d for each vulnerability class V_C, given a seismic intensity I_{EMS}) with the standard Beta distribution of the relative cost (probability to observe a value of $C_{r,r}$ for each damage level L_d), as follows:

$$\mathrm{Prob}\left[C_{r,r}\middle|\ \mathrm{I}\right] = \sum_{L_d=1}^{5}\sum_{\mathrm{V=A}}^{\mathrm{D}} \mathrm{Prob}_{Ld}\left[C_{r,r}\middle|\ L_d\right] \cdot \mathrm{Prob}_{\mathrm{V}}\left[L_d\middle|\ \mathrm{V,I}\right]. \qquad (6)$$

Eq. 6 has been applied to the current study in order to evaluate the total repair costs (direct economic losses) caused by the considered seismic scenario. Specifically, by assuming an average reconstruction cost equal to 1,225 €/m^2 and a total volume of the building stock equal to about $12{\cdot}10^6$ m^3 (i.e. a total area equal to about $4{\cdot}10^6$ m^2, assuming an average story height equal to 3.0 m), the estimated value of total repair cost T_{Cr} is about 1,100 M€ (millions of euro). The considered reconstruction cost has been assumed on the basis of the Basilicata Regional law DGR n.1942/2011, which provides a basic cost of 720 €/m^2 for new public housing, plus 55% for overheads and 10% for VAT. The costs are defined per square metre of the total gross area of the building.

Fig. 8 shows the direct economic losses related to each considered vulnerability class in all 18 villages. As expected, the higher percentage values of direct economic losses are related to the buildings with high vulnerability, i.e. class A, whose repair cost amounts to about 62% of the total repair cost. For Viggiano village, for which an action plan has been specifically defined as described below, the direct economic losses are about 103 M€.

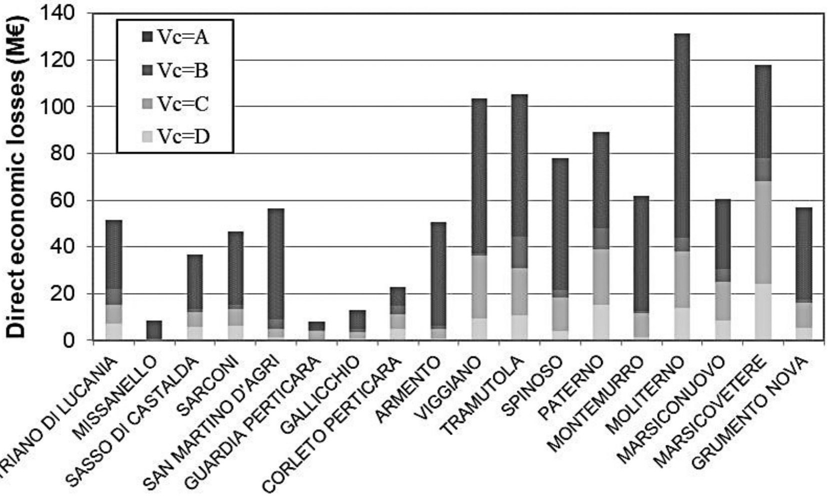

Fig. 8 - Direct economic losses for each considered vulnerability class, computed for each village.

6. Estimation of seismic strengthening costs

In order to mitigate the seismic risk of the considered area, a strategy based on vulnerability reduction has been proposed and its relevant costs have been estimated. As reported in the previous sections, most of the expected losses are due to buildings having high- and mid-vulnerability. Therefore, strengthening interventions are primarily devoted at enhancing the seismic performance of buildings belonging to vulnerability classes “A” and “B”. As better discussed later, the seismic capacity of strengthened buildings has been set equal to 60% of the capacity currently required for new buildings (referred to the SLV).

In order to assign the required strengthening costs, data from past studies on the reconstruction process after the 2009 L'Aquila earthquake have been considered (Dolce and Manfredi, 2015; De Martino *et al*., 2017; Di Ludovico *et al*., 2017a, 2017b; Fico *et al*., 2019). This choice is based on the fact that the seismic hazard of L'Aquila area is comparable to the one under study and the target of the strengthening intervention adopted for the post-earthquake reconstruction is the same as mentioned above (i.e. at least 60% of the capacity required for the SLV).

Specifically, the costs have been evaluated considering the two funding classes (FCs) defined by the Italian government in order to refund the "heavy damage" repair costs of unusable private buildings, that are:

- FC_E, involving unusable buildings (i.e. with usability rating "UR_E") due to heavy structural and non-structural damage;
- $FC_{E\text{-}B}$, involving unusable buildings (i.e. "UR_E") but having damage consistent with the usability rating "UR_B" (i.e. temporarily unusable buildings, mainly due to heavy non-structural damage and slight structural damage).

A methodology has been properly defined in order to link the FCs to the considered vulnerability classes. First of all, on the basis of the data collected after the L'Aquila earthquake through the AeDES form (Masi *et al*., 2016) and adopting the criteria reported in Table 1, the distribution of the usability ratings as a function of the vulnerability classes has been analysed, as shown in Fig. 9a. In order to better highlight the results for the two vulnerability classes considered in the strengthening strategy, Fig. 9b shows the usability rating only for classes "A" and "B" (note also that the rating corresponding to the usable buildings, i.e. rating "UR_A", has been omitted).

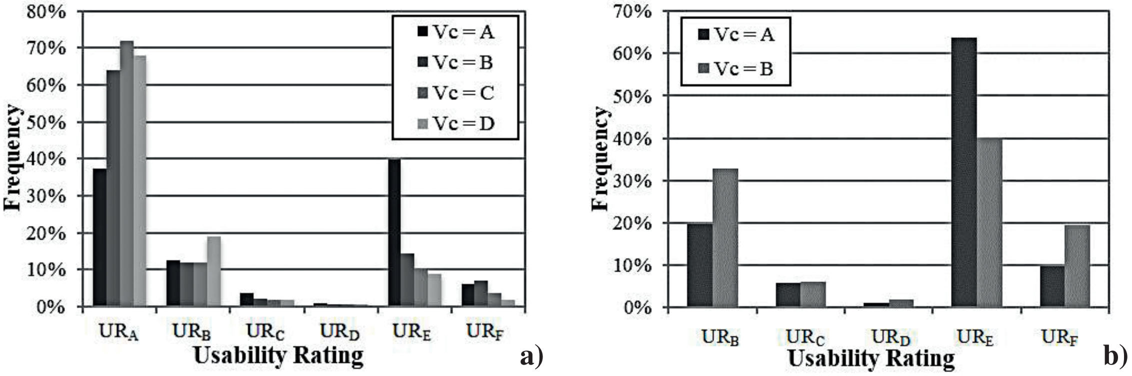

Fig. 9 - Usability rating of the buildings surveyed after the 2009 L'Aquila earthquake for all vulnerability classes (a) and only for "A" and "B" classes (b).

Fig. 9b shows that the usability rating "UR_E" was assigned to most of buildings with vulnerability class "A" (about 65%). On the contrary, in case of the vulnerability class "B", the usability ratings "UR_E" (about 40%) and "UR_B" (about 32%) were mainly assigned. Therefore, in the paper the strengthening costs for the buildings with vulnerability class "A" have been derived from the ones of buildings having usability rating "UR_E" and belonging to "FC_E". As for buildings with vulnerability class "B", the costs have been obtained from the funding class of the unusable buildings having damage consistent with "UR_B", i.e. "$FC_{E\text{-}B}$". Specifically, the costs for buildings with vulnerability classes “A” and “B” have been estimated equal to 530 €/m^2 and 255 €/m^2, respectively (VAT is equal to 10%). These values have been evaluated from the L’Aquila reconstruction process, as reported by Di Ludovico *et al*. (2017b). They originally take into account: i) strengthening intervention [able to increase seismic capacity at least up to 60% of the New Buildings Standard (NBS)], ii) energy efficiency upgrading, iii) structural/geotechnical tests, and iv) damage repair. Regarding this latter cost, since the paper deals with a prevention strategy, no prior damage on the considered buildings has been assumed. Therefore, a rate equal to 20% of repair cost evaluated in the L’Aquila reconstruction process has been considered to take into account finishing works to be made as an unavoidable consequence of strengthening interventions (Del Vecchio *et al*., 2020).

It is also worth noting that, according to the L’Aquila “heavy damage” reconstruction process, the costs associated to “FC_{E-B}” also derive from local strengthening interventions, for which no analyses related to the building safety reached after the intervention were required. For this reason, for types belonging to V_C = “B” (always masonry buildings), it has been assumed that local strengthening interventions are able to achieve the required safety level.

By considering the inventory of residential buildings (as reported in Fig. 3 in terms of volume) and assuming an average height of dwellings equal to 3.0 m, Table 8 reports the total strengthening costs estimated for each village and the mean values for building with V_C = “A” and V_C = “B”.

Table 8 - Seismic strengthening costs for each village and the mean value for each building with V_C = “A” and “B”.

Village	**Estimated cost of seismic strengthening**		
	Total cost (M€)	**Mean value for building with V_c = ”A” (€)**	**Mean value for building with V_c = ”B” (€)**
Satriano di Lucania	25	63,000	39,000
Missanello	14	74,000	36,000
Sasso di Castalda	18	75,000	24,000
Sarconi	24	70,000	31,000
San Martino d’Agri	37	75,000	29,000
Guardia Perticara	8	86,000	34,000
Gallicchio	16	77000	44000
Corleto Perticara	20	77,000	36,000
Armento	33	76,000	39,000
Viggiano	48	78,000	70,000
Tramutola	53	85,000	92,000
Spinoso	43	89,000	31,000
Paterno	36	71,000	20,000
Montemurro	36	79,000	38,000
Moliterno	67	99,000	78,000
Marsico nuovo	25	61,000	26,000
Marsicovetere	35	59,000	30,000
Grumento nova	29	67,000	32,000
All villages	**567**	**75,000**	**35,000**

As can be seen, the strengthening cost for the whole area is about 570 M€, while the mean value per single building is equal to about 75,000 € for vulnerability class "A" and 35,000 € for vulnerability class "B". For each village, the mean values for single building have been evaluated as ratio between the total cost related to V_C= "A" and V_C= "B" and the corresponding number of buildings with V_C= "A" and V_C= "B" (see Table 9). Therefore, these mean values are dependent on the average volume of buildings with V_C= "A" and V_C= "B".

Table 9 - Distribution of the vulnerability classes in terms of buildings' number and volume for each considered village.

Village name	Number of buildings				Volume of buildings (m^3)			
	Vulnerability Classes (EMS-98)				Vulnerability Classes (EMS-98)			
	A	B	C	D	A	B	C	D
Satriano di Lucania	332	110	158	346	1.2E+05	5.0E+04	1.2E+05	2.5E+05
Missanello	187	9	14	31	7.7E+04	3.8E+03	8.4E+03	1.8E+04
Sasso di Castalda	227	37	120	221	9.5E+04	1.0E+04	8.8E+04	2.0E+05
Sarconi	325	35	128	213	1.3E+05	1.3E+04	1.0E+05	2.1E+05
San Martino d'Agri	457	93	100	54	1.9E+05	3.2E+04	5.3E+04	3.8E+04
Guardia Perticara	82	13	208	44	3.9E+04	5.2E+03	1.2E+05	3.1E+04
Gallicchio	184	52	136	83	7.9E+04	2.7E+04	9.2E+04	5.3E+04
Corleto Perticara	185	148	256	615	8.0E+04	6.3E+04	2.2E+05	4.0E+05
Armento	423	20	87	39	1.8E+05	9.1E+03	5.8E+04	3.1E+04
Viggiano	612	11	474	281	2.7E+05	9.1E+03	3.8E+05	3.2E+05
Tramutola	520	95	237	382	2.4E+05	1.0E+05	2.8E+05	3.7E+05
Spinoso	458	72	227	117	2.3E+05	2.7E+04	2.0E+05	1.4E+05
Paterno	417	289	623	755	1.7E+05	6.9E+04	3.3E+05	5.3E+05
Montemurro	451	13	222	94	2.0E+05	5.8E+03	1.5E+05	4.6E+04
Moliterno	637	46	341	301	3.5E+05	4.2E+04	3.5E+05	4.8E+05
Marsico nuovo	351	135	328	421	1.2E+05	4.1E+04	2.3E+05	3.0E+05
Marsicovetere	495	204	678	481	1.6E+05	7.2E+04	6.3E+05	8.3E+05
Grumento nova	424	27	271	240	1.6E+05	1.0E+04	1.5E+05	1.9E+05

7. An application of mitigation strategy: the action plan for Viggiano village

Based on the results described in the previous sections, an application is developed outlining a mitigation strategy on the building stock of Viggiano village (Fig. 10). Specifically, an action plan aimed at the reduction of residential buildings' vulnerability has been defined in terms of costs and implementation timetable.

Viggiano was affected by several earthquakes in the past (Locati *et al.*, 2016), particularly the 16 December 1857 earthquake (M_W 7.1, local intensity X MCS) and, more recently, the 1980 Irpinia earthquake (M_W 6.9, local intensity VI MCS). According to the Italian seismic zonation adopted in the OPCM 3274 (2003), Viggiano is classified as highly seismic zone (SZ 1). As reported in Table 2, for events with exceedance probability of 10% in 50 years (and soil class B-T1), the values of *PGA*, I_H, and macroseismic intensity evaluated for Viggiano are equal to

Fig. 10 - Built environment of Viggiano village.

0.29 g, 87 cm, and VIII EMS, respectively. The building stock of Viggiano is made up of about 1,400 buildings, and 10^6 m^3 in terms of volume. Most of them (about 80% in terms of number of buildings and 56% in terms of volume) have masonry structure, while the other 20% (about 44% in terms of volume) are RC structures. As for building age, about 75% of buildings (about 52% in terms of volume) were built before 1945 (essentially masonry buildings), and only 17% (about 31% in terms of volume) after 1981 (mainly RC buildings) when the area was classified as seismic.

According to the procedure described at Section 2, about 39% of volume of Viggiano buildings belongs to class "C" and 33% belongs to class "D". The percentage of buildings with high vulnerability (class "A") is equal to 27%, as shown in Fig. 11.

In the previous sections, expected losses for the considered scenario earthquake and strengthening costs (related to a seismic capacity able to reach at least NBS = 60%) have been determined for the vulnerability classes "A" and "B". In order to perform a new damage scenario after the strengthening interventions, the vulnerability class of the retrofitted buildings (i.e. building with NBS = 60%) needs to be assessed. To this purpose, starting from the results obtained

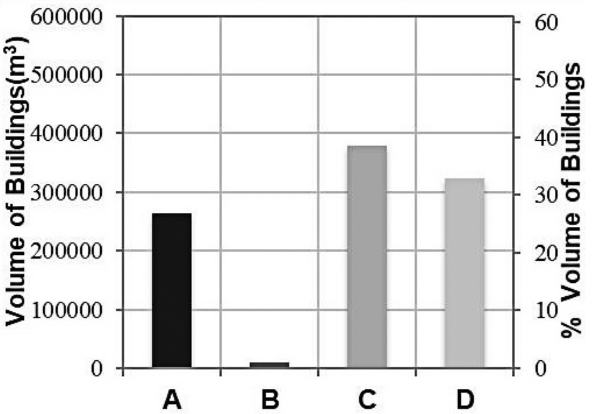

Fig. 11 - Distribution of Viggiano building stock for each vulnerability class.

by Lagomarsino and Cattari (2014) on a wide set of masonry building types, the following step-by-step procedure has been set up:

1) according to the criteria reported in Table 1, the seismic vulnerability class of all 10 types considered by Lagomarsino and Cattari (2014) is assigned;
2) based on the fragility curves provided by Lagomarsino and Cattari (2014), the median *PGA* value (i.e. 50% of exceedance probability, PGA_{LS}) is evaluated for each type with respect to Damage State 3 (DS3) (Fig. 12);
3) comparing the definitions of DS3 given in EMS98 and of SLV given in EC8 (CEN, 2004) and NTC (2018), DS3 is assumed as representative of a Life Safety condition;
4) for each vulnerability class evaluated at step 1, the mean value $PGA_{LS,med}$ is calculated averaging the PGA_{LS} values referred to the related building types;
5) the ratio between $PGA_{LS,med}$ and the value referred to the scenario event (i.e. 475-year return period, PGA_{475y}) is determined for each vulnerability class;
6) among all the vulnerability classes having $PGA_{LS,med}/PGA_{475y}$ ratio values equal or greater than 0.6 (i.e. the threshold value of the strengthening intervention), the one with the lower $PGA_{LS,med}/PGA_{475y}$ value is assumed as representative of the strengthened buildings.

For all types considered in Lagomarsino and Cattari (2014) and described in detail in the Appendix, Table 10 reports the corresponding vulnerability classes and PGA_{LS} values. For each vulnerability class, the mean $PGA_{LS,med}$ value and the $PGA_{LS,med}/PGA_{475y}$ ratio values are also reported (the PGA_{475y} value for Viggiano is equal to 0.29 g). According to the above described procedure, the lower $PGA_{LS,med}/PGA_{475y}$ value equal to 0.80 (among those equal or greater than 0.6) is referred to the vulnerability class "C".

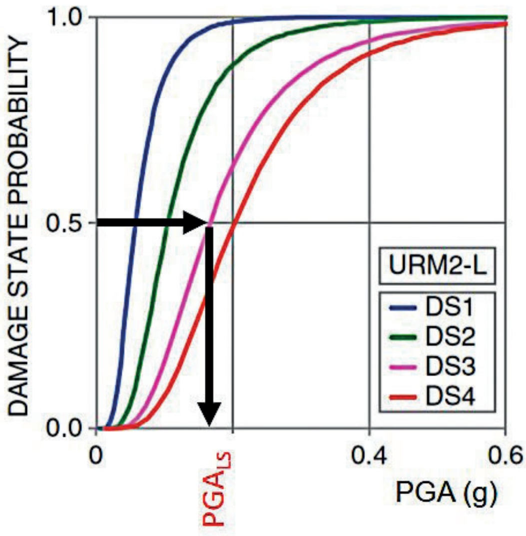

Fig. 12 - *PGA* median values for DS3 obtained from the fragility curves provided by Lagomarsino and Cattari (2014).

As a consequence, the buildings in Viggiano village having originally vulnerability class "A" or "B" after a strengthening intervention aimed at achieving at least NBS = 60% (requiring the costs estimated in section 6) can be assigned vulnerability class "C" ($PGA_{LS,med}/PGA_{475y} > 60\%$).

It is worth noting that this assumption is consistent with the results found by Di Ludovico *et al.* (2017b) for the L'Aquila reconstruction process. Specifically, for masonry buildings, the mean

Table 10 - Vulnerability classes V_C and PGA_{LS} values for all masonry types considered by Lagomarsino and Cattari (2014). For each V_C, the mean values $PGA_{LS,med}$ and the corresponding values of the ratio $PGA_{LS,med}/PGA_{475y}$ (assuming PGA_{475y} = 0.29 g) are also reported.

Masonry building type	V_C	PGA_{LS}	$PGA_{LS,med}$	$PGA_{LS,med}/PGA_{475y}$
URM1-L	A	0.13	0.13	0.45
URM2-L	B	0.17	0.16	0.52
URM2-M	B	0.14		
URM3-M	C	0.25	0.23	0.80
URM3-H	C	0.25		
URM3-M-IR	C	0.22		
URM3-H-IR	C	0.22		
URM4-M	C	0.23		
URM4-H	C	0.23		
URM5-M	D	0.40	0.40	1.38

value of the capacity/demand ratio (with respect to the SLV) after the strengthening intervention was found equal to about 70%.

Finally, a damage scenario has been prepared considering the changes in the building vulnerability. Specifically, after the strengthening interventions, the percentage related to vulnerability class “C” increases from about 39% to 67%.

Table 11 summarises the results of the new damage scenario. The unusable buildings (in terms of volume) decrease from $3.2 \cdot 10^5$ to $1.5 \cdot 10^5$, while the expected casualties are in the range 0-5 instead of 20-35 (referred to the before strengthening condition). In terms of direct economic losses, the value decreases from 103 M€ (before strengthening, see Fig. 8) to 55 M€ (after intervention), with an economic loss reduction equal to 48 M€, which is practically coincident with the costs required for the adopted strengthening interventions (see Table 8).

Table 11 - Expected losses for Viggiano before and after the strengthening program.

Expected loss	Before strengthening	After strengthening
Unusable buildings [m³]	3.2E+05	1.5E+05
Homeless	1110	525
Casualties	20-35	0-5
Direct economic losses (M€)	103	55

Accounting for the high number of buildings to be strengthened and the amount of the related costs, the action plan has been defined also in terms of implementation timetables. An annual financial investment equal to 5 M€ has been considered in order to reduce the seismic vulnerability of “A” and “B” classes, thus requiring a total implementation time of 10 years. This investment appears to be compatible with the amount of royalties annually assigned to Viggiano for the oil extraction activities. Indeed, in Italy, hydrocarbons deposits are public unavailable property and, consequently, private companies that produce hydrocarbons have to pay royalties to the State, the regions and the involved municipalities. From 2008 to 2018 an average value of royalties equal to about 110 M€/year was paid by Eni S.p.A. and Shell Italia E&P S.p.A. to Basilicata Region. In the same period, the municipality of Viggiano received an average value equal to 13 M€/year.

Fig. 13 shows the trend of the expected direct economic losses as a function of the vulnerability reduction over ten years.

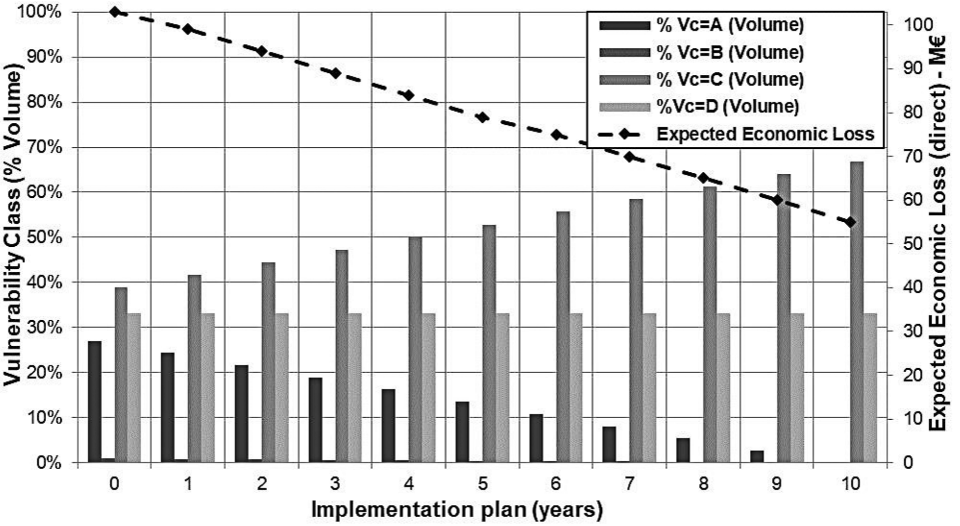

Fig. 13 - Vulnerability and economic loss reduction as a result of the action plan proposed for Viggiano.

Despite the slight economic advantage deriving from the adopted strategy, it is worth highlighting the remarkable reduction in terms of both social and human losses (see Table 10), which appear as key elements in judging the benefits of a risk mitigation plan. Moreover, the indirect economic losses related to population assistance (Mannella *et al.*, 2017) or business interruption (Benson and Clay, 2004) need to be strongly considered, even more in an area with a strategic role due to oil extraction.

8. Final remarks

An earthquake damage scenario for the residential building stock of 18 villages located in the Agri Valley (south of the Basilicata region, Italy) has been prepared. A seismic event with an exceedance probability of 10% in 50 years (475-year return period) and a building vulnerability distribution based on an accurate building-by-building inventory have been considered.

Heavy consequences in terms of human, social, and economic losses, mainly due to masonry buildings with high and medium vulnerability (classes "A" and "B" according to EMS-98 scale), have been estimated. Specifically, about 7,000 unusable residential buildings (40% of the building stock), about 15,000 homeless (40% of the inhabitants) and 265-485 casualties have been estimated for the 18 villages. Moreover, the direct economic losses (i.e. the total repair cost) amount to about 1,100 M€.

A seismic risk mitigation strategy has been defined which aims to the seismic strengthening of the residential buildings with high- and medium-vulnerability (i.e. classes “A” and “B”) in order to reach a safety level essentially equivalent to a percentage of 60% of that one required by the Italian code for new buildings at the SLV. In order to evaluate the strengthening costs, the data from the reconstruction programme after L’Aquila 2009 earthquake have been used. To this end, a methodology based on the usability ratings (and the corresponding funding classes) as a function of the vulnerability classes, has been purposely set up.

An application to the village of Viggiano has been carried out to compare the expected consequences before and after the strengthening interventions. A new seismic scenario, where the vulnerability class of the strengthened buildings re-evaluated through an *ad hoc* methodology based on studies available in the literature, has been prepared. Results show that a significant reduction of human, social and economic losses would derive from the strengthening program. Specifically, considering a total investment of 50 M€ over 10 years, the action plan defined for Viggiano village would allow about 50% reduction of the expected direct economic losses and, most importantly, a reduction of the expected number of casualties and homeless. As for the homeless reduction, it should be emphasised that applying the proposed risk mitigation plan would enable also to reduce the indirect economic losses related to population assistance and business disruption, which are generally important and even more crucial in an area with a strategic role on the Italian national energetic policy due to oil extraction. Moreover, the prevention strategy could contribute to prevent a negative phenomenon frequently detected in the aftermath of past Italian earthquakes, where a certain share of the affected population moves away from the stricken territory, also because of the long intervention times. Finally, regarding the financial backing, it is worth highlighting that Viggiano annually receives, for the oil extraction activities from deposits located in the area, an amount of royalties that could cover the entire cost of the seismic vulnerability reduction program.

Although the above described action plan has been defined for a small village, the proposed methodology can be generally applied to larger areas. Further studies are required, and are currently in progress, to better define the selected seismic scenario and to more accurately estimate the expected economic losses.

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Appendix: Masonry building classes (Lagomarsino and Cattari, 2014)

In the following, the description of the ten classes of masonry buildings according the SYNER-G taxonomy (Lagomasino and Cattari, 2014) has been reported. Each class is described by a string of codes, separated by slashes and hyphens. Slashes indicate the main categories of the taxonomy: Force Resisting Mechanism (FRM); Force Resisting Mechanism Material (FRMM); Plan (P); Elevation (E); Cladding & Openings (CO); Detailing & Maintenance (DM); Floor System (FS); Roof System (RS); Height Level (HL) and Code Level (CL). Within each category, the list of possible options is defined by proper acronyms and, for some category options, a more detailed classification is defined and indicated by separating the list of codes by hyphens.

1) **URM1-L**: BW-IP/URM-HS-RU-LM/R/R/x/LQD-WoT-WoRB/F-T/P-T/L/PC
   Bearing Walls - In plane / Unreinforced Masonry - Hard Stone - Rubble - Lime mortar / Regular (plan) / Regular (elevation) / x / Low quality details - Without tie rods - Without ring beams / Flexible - Timber / Peaked - Timber / Low-rise / Pre-code.
2) **URM2-L**: BW-IP/URM-HS-UC-LM/R/R/x/LQD-WT/F-T/P-T/L/PC
   Bearing Walls - In plane / Unreinforced Masonry - Hard Stone - Uncut - Lime mortar / Regular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Flexible - Timber / Peaked - Timber / Low-rise / Pre-code.
3) **URM2-M**: BW-IP/URM-HS-UC-LM/R/R/x/LQD-WT/F-T/P-T/M/PC
   Bearing Walls - In plane / Unreinforced Masonry - Hard Stone - Uncut - Lime mortar / Regular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Flexible - Timber / Peaked - Timber / Mid-rise / Pre-code.
4) **URM3-M**: BW-IP/URM-FB-LM/R/R/x/LQD-WT/R-S/P-RC/M/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Regular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Rigid - Steel / Peaked - Reinforced Concrete / Mid-rise / Pre-code.
5) **URM3-H**: BW-IP/URM-FB-LM/R/R/x/LQD-WT/R-S/P-RC/H/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Regular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Rigid - Steel / Peaked - Reinforced Concrete / High-rise / Pre-code.
6) **URM3-M-IR**: BW-IP/URM-FB-LM/IR/R/x/LQD-WT/R-S/P-RC/M/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Irregular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Rigid - Steel / Peaked - Reinforced Concrete / Mid-rise / Pre-code.

7) **URM3-H-IR**: BW-IP/URM-FB-LM/IR/R/x/LQD-WT/R-S/P-RC/H/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Irregular (plan) / Regular (elevation) / x / Low quality details - With tie rods / Rigid - Steel / Peaked - Reinforced Concrete / High-rise / Pre-code.
8) **URM4-M**: BW-IP/URM-FB-LM/R/R/x/HQD-WRB/R-RC/P-RC/M/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Regular (plan) / Regular (elevation) / x / High quality details - With ring beams / Rigid - Reinforced Concrete / Peaked - Reinforced Concrete / Mid-rise / Pre-code.
9) **URM4-H**: BW-IP/URM-FB-LM/R/R/x/HQD-WRB/R-RC/P-RC/H/PC
   Bearing Walls - In plane / Unreinforced Masonry - Fired brick - Lime mortar / Regular (plan) / Regular (elevation) / x / High quality details - With ring beams / Rigid - Reinforced Concrete / Peaked - Reinforced Concrete / High-rise / Pre-code.
10) **URM5-M**: BW-IP/URM-HC-CM/R/R/x/HQD-WRB/R-RC/P-RC/M/MC
   Bearing Walls - In plane / Unreinforced Masonry - Hollow clay tile - Cement mortar / Regular (plan) / Regular (elevation) / x / High quality details - With ring beams / Rigid - Reinforced Concrete / Peaked - Reinforced Concrete / Mid-rise / Moderate (0.1-0.3 g).