Seismic vulnerability assessment at urban scale: state of the art and perspectives

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Abstract

Italian territory is particularly sensitive to seismic actions. The Amatrice earthquake on August 24th 2016 confirmed this aspect. Such an event, nothing but extraordinary, has been able to cause huge and tragic damages. The direct knowledge of building features is the only prior measure to face seismic events. In order to get a realistic scenario of the urban damage distribution, the determination of useful seismic vulnerability assessment tools at urban scale becomes a priority. The widespread application of seismic vulnerability assessment sheets and the related data transformation into urban damage distribution plans is exactly what municipalities need. Main advantages are both in the chance of prior knowing the most affected areas to focus on for retrofitting interventions and in the possibility of organizing optimal emergency plans. In European framework, in the last decade, the Risk-UE project has played an important role. The Risk-UE project has proposed two methods for vulnerability assessment at urban scale: LM1 method (macroseismic) and LM2 method (mechanical). The two methods provide, with different approaches, seismic vulnerability assessment of existing buildings. In LM1, seismic input is simulated by a given seismic intensity. In LM2, seismic input is given by a predetermined response spectrum. On the basis of the two proposed methods, many countries have adjusted their evaluation forms. Seismic vulnerability assessment in Italy is carried out through the application of appropriate forms (level 0, level 1, level 2), prepared by GNDT. The three gradually more detailed forms provide all the core information for seismic assessment of analysed buildings. The two methods proposed by Risk UE project are particularly advanced and founded on solid theoretical basis. Their application over the last few years and, in particular, a recent detailed study on the reliability of the methods, carried out by Canton of Valais (Switzerland), together with local research centre Crealp, University of Genova and École Polytechnique Fédérale de Lausanne, have shown some nebulous aspects that deserve further studies. The paper deals with the main features of the two methods and tries to point out the aspects that need to be improved for a better reliability of results.

1. THE NEED OF VULNERABILITY ASSESSMENT AT URBAN SCALE

The Amatrice earthquake on August 24th 2016 and the following seismic events showed again the weakness of Italian territory. Consequently, vulnerability assessment at urban scale emerged again as a main issue. The Centre Italy earthquake (the hit area is in the middle of 4 regions: Lazio, Marche, Abruzzo, Umbria) showed how a medium-high magnitude seismic event can cause a lot of material damage and loss of human lives. From this viewpoint, the debate about the need of vulnerability assessment tools able to predict damage scenarios at urban scale has returned to the fore. Seismic vulnerability assessment at urban scale proves to be a useful tool for both prevention and management. First of all, the detection of the most hit areas gives an overview of priority buildings to intervene on to reduce material and human lives losses. Second, it ensures the organization of effective emergency management plans.

In particular, seismic vulnerability means the tendency of a structure, subject to possible seismic events, to suffer damage. Damage grade and damage type depend on the year and place of construction, on structural and material features and on the presence of nearby buildings.

After an earthquake, vulnerability assessment is an easy challenge. It is sufficient to identify the damage caused and to associate them to construction type and earthquake intensity. On the contrary, the assessment before a seismic event is more complex. Several methods have been developed, statistical and mechanical, and are the theoretical basis of vulnerability evaluation forms. Statistical methods are based on the observation of damage suffered by different construction types during past earthquakes. Mechanical methods, instead, make use of theoretical models that reproduce the main features of the buildings analysed.

Seismic vulnerability in Italy is carried out through the application of appropriate forms, gradually more detailed (level 0, level 1, level 2), prepared by GNDT[1]. The need of three increasing in-depth analysis is due to the impossibility to carry out detailed analysis on each building composing Italian vast real estate. The processing of the data provided by the vulnerability assessment forms and the related transformation into damage and emergency management scenario plans are often disregarded. The main consequence is that the information provided by the forms is useful only for the seismic assessment of the individual buildings without becoming useful at the urban scale.

Hence the need for an in-depth study about vulnerability assessment at urban scale arises as a central topic, especially for the so diversified Italian housing estate. In Centre Italy, in particular, there are a lot of small towns, everyone with different construction features. So it is impossible to refer to prevalent nationwide building types. One of the main qualities of the whole country is the great diversity of housing stock that it is structured in a lot of small-medium towns and villages with a huge presence of heritage buildings.

The preparation of seismic vulnerability urban plans requires a detailed knowledge of building construction features. The great fragmentation into a lot of small little towns implies a huge diversification of construction techniques with important differences, region by region, in the seismic performances offered.

2. DESCRIPTION OF MAIN DAMAGES OBSERVED IN AMATRICE

The post-earthquake survey, carried out in the municipality of Amatrice, has shown once again the strong correlation between the type of construction and the resulting damage. Masonry constructions made of irregular shaped stones, with poor quality ground soil mortar, proved to be particularly vulnerable. This typology showed important damages and an important amount of them has undergone a partial or a total collapse. Masonry buildings characterized by hewn stones regularly arranged in the construction presented a better behaviour. Mainly for isolated houses, reinforced concreate frame structure is widespread. Beyond some cases in which it showed non-structural elements damage, this typology offered a good seismic response. The survey has once again displayed how, mainly for masonry buildings, the construction technique, the accordance to the best practices and generally the quality in the realization proved to be the central issues in seismic response to horizontal actions. For masonry construction this refers in particular to the regular shape of stones, to their corner teething and to the mortar composition.

With a lack of accuracy and with a lack of in-depth analysis, masonry stone buildings are too often considered as an example of a good constructive practice and good structural behaviour. This evaluation can lead to overestimation of real structural performances. This approach results from an overly conservative trend in urban planning. Every stone construction, without any detailed analysis on the constructive values, is considered as best constructive practice building and so able to ensure optimum structural performances. In this way, conventional constructions are confused with virtuous examples that really characterize Italian housing estate.

In the pre-earthquake evaluation of damage distribution at urban scale, the main issue is the survey and the correct detection of the construction typology. Surveys at urban scale are not an easy and fast question and often a lot of uncertainties overcome. The presence of plaster and uncertainties linked to the real nature of floor (rigid or flexible) do not allow an immediate detection and categorization, slowing down the process.

3. RISK UE APPROACH

In last decade large scale seismic risk assessment framework, the European Risk-UE project[2], founded after big earthquakes occurred in Turkey and Greece in 1999, has played an important role (Mouroux and Le Brun 2006). Two methods were proposed for vulnerability assessment of existing buildings: a macroseismic-statistical model

[1] National team for earthquake protection .

[2] An advanced approach to earthquake risk scenarios with applications to different European towns.

Figure 1 - *Masonry building made of irregular shaped stones, with poor quality ground soil mortar, partially collapsed* (neighbouring of Amatrice, photo credits: Author 2016)

(method LM1), based on probabilistic understandings related to the behaviour of the different construction types found in past earthquakes, and a mechanical model (method LM2), where appropriate capacity curves, describing the structural behaviour of buildings, are subject to the seismic demand with the application of appropriate response spectra. Both methods refer to a framework of building typologies representative of European building stock, grouping together structures expected to behave similarly during an earthquake. The typology classification is based on an implementation of classes accepted in EMS-98[3] (Table 1). Compared to the EMS-98 classification, Risk UE methods introduce reinforced concreate dual system (RC3) and sub-categories according to: building height (_L=low, _M=medium, _H=high), the nature of the slabs (exclusively for masonry buildings M_w=wood slabs, M_v=masonry vaults, M_sm=composite steel and masonry slabs, M_ca= reinforced concreate), the seismicity of the region (_I=zone I, _II=zone II, _III=zone III)and the ductility class (-WDC=without ductility class, -LDC=low ductility class, -MDC=medium ductility class, -HDC=high ductility class) (Lagomarsino and Giovinazzi 2006).

Even more articulated than EMS-98, building typology classification remains the main limitation to operate on at the local scale to better describe local construction singularities.

On the basis of Risk-EU project assumptions, many European national Codes have oriented their seismic vulnerability assessment tools. Much the same occurs to Italy where data provided by level zero, one and two forms are useful to determine buildings vulnerability, according to one of the two approaches: marcosismic (probabilistic) or mechanical (analytical).

3. LM1 Method

The LM1 method is based on the observation of damage caused by past earthquakes on different construction types widespread in Europe. The aim is to use the macroseismic intensity scale introduced by EMS-98 (Grunthal 1998) and to elaborate appropriate vulnerability functions for each type based on probabilistic assumptions. The construction type is detected by an on-site survey together with irregularities and singularities classed as modifying elements.

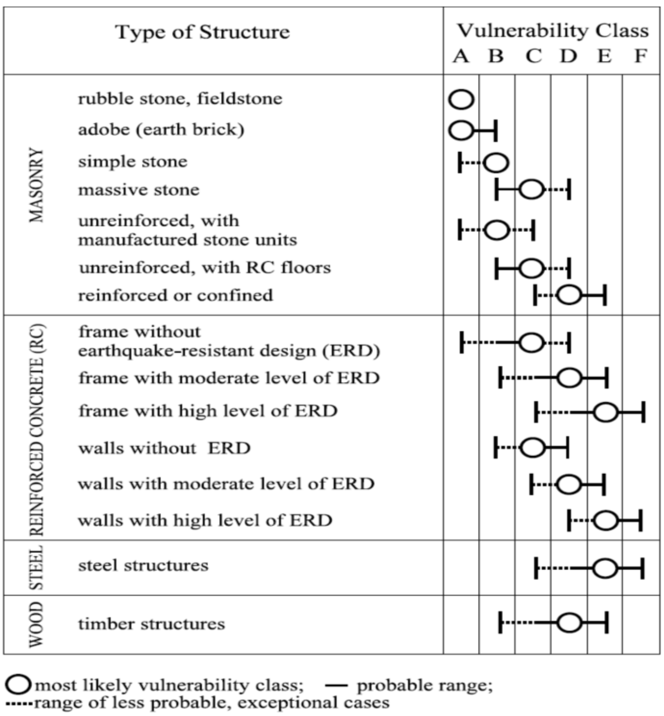
[3] EMS-98 : European Macroseismic Scale 1998.

Table 1 - *European building typology classification (exclusion of wood and steel constructions)*
[Table taken from: Lagomarsino and Giovinazzi 2006]

Typologies		Building types
Unreinforced Masonry	M1	Rubble stone
	M2	Adobe (earth bricks)
	M3	Simple stone
	M4	Massive stone
	M5	U Masonry (old bricks)
	M6	U Masonry – r.c. floors
Reinforced/confined masonry	M7	Reinforced/confined masonry
Reinforced Concrete	RC1	Concrete Moment Frame
	RC2	Concrete Shear Walls
	RC3	Dual System

Seismic vulnerability of the different classes are defined according to two index *V* and *Q*, respectively vulnerability and ductility index, both directly evaluated from the constructive features of the specific building type (Table 3, first two columns). Vulnerability index *V* for each typology has been established, in the first place, by Lagomarsino and Giovinazzi (2001) on the basis of EMS-98 vulnerability classes (Table 2). Subsequently, these values have been checked and calibrated by comparison with damage data found in previous seismic events. The implementation in numerical indices was carried out through the application of fuzzy set theory and in-depth probabilistic analysis.

Table 2 - *Differentiation of structures (buildings) into vulnerability classes proposed by EMS-98 (increasing vulnerability classes from A to F)*
[Table taken from: Grunzhal 1998]



The LM1 method allows to estimate for each type, the damage average index μ_D on a scale of damage grades from 0 to 5 D_k $(k = 0,\dots,5)$ as prescribed by EMS-98: D_0 no damage D_1 slight damage D_2 moderate damage D_3 heavy damage D_4 very heavy damage D_5 destruction. The average damage index is expressed in function of seismic intensity I[4]:

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 6.25V - 13.1}{Q}\right)\right] \quad (1)$$

It allows determining, for each analysed type, detailed vulnerability curves (Figure 2).

The probability p_k that an analysed type performs a certain damage grade D_k is given by the binomial distribution as follow:

$$p_k = \frac{5!}{k!\,(5-k)!}\left(\frac{\mu_D}{5}\right)^k\left(1 - \frac{\mu_D}{5}\right)^{5-k} \quad (2)$$

For each typological class appropriate fragility curves can be defined. The fragility curve expresses probability distribution of the different damage grades as a function of earthquake intensity (Figure 3).

Values of table 3 (first two columns) are representative of average values of vulnerability index for given sub-types. Although referring to detailed subsets, generic values of *V* do not describe specific features of buildings, like irregularities in bearing structure or in building plan shape. Structure irregularities are introduced by index modifier ΔV_m, local features of the site by score modifier ΔV_s and specific regional construction techniques by ΔV_r. The overall vulnerability index is therefore defined by:

$$V_{Tot} = V + \Delta V_m + \Delta V_r + \Delta V_s \quad (3)$$

where *V* is the value taken from table 3. The chance to introduce local irregularities leaves screeners the freedom to vary the average vulnerability value of buildings analysed on the basis of particular features.

From output viewpoint, LM1 method allows a graphic plan layout at urban scale of the different buildings according to the average damage value μ_D obtained by (1) with the vulnerability index obtained by (3). In this kind of data output, probabilistic issues are not taken into account. For

[4] Seismic intensity *I* is related to vibrations amplitude found in a particular place and it is estimated on the basis of the effects seen. It is expressed according to a scale (as the EMS-98) that goes from I to XII. The magnitude *M* is instead connected to seismic energy released in the event. A same determined magnitude event can have different intensities in different places.

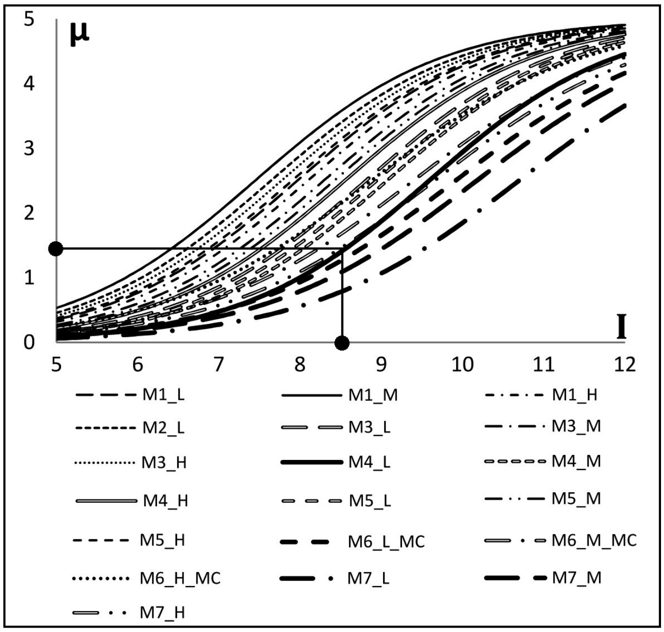


Figure 2 - *Vulnerability curves for different masonry building typologies. Average expected damage as a function of intensity. Expected damage* μ_D *=1.4 for M4_L typology when =8.5* [Figure adapted from: Lagomarsino and Giovinazzi 2006]

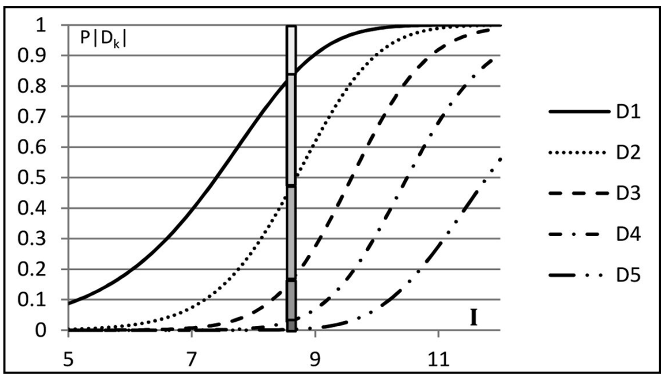


Figure 3 - *Fragility curves for building typology M4_L as a function of I Damage distribution for I =8.5* [Figure adapted from Lagomarsino and Giovinazzi 2006]

each building, a static damage value is considered. Further to this graphic output, there is the statistical output. In statistical output, probabilistic data related to a certain damage grade (obtained by (2)) for each typological subset, are multiplied by the number of respective buildings. This operation provides statistically buildings distribution according to the different damage grade.

A detailed study in the last few years, carried out by IMAC[5] Lab (EPFL, Lausanne, Switzerland) in cooperation with Crealp[6] and University of Genova, investigated the reliability of different Risk UE methods and of different output procedures on some Swiss cities.

In low seismicity regions where it is not possible to introduce a high intensity *I* level, a clear homogeneity of results at very low damage grades is shown. For high seismicity regions, such as Canton de Valais, wide-ranging results are shown with a consequent hierarchy in damage grades for different areas. Results obtained for the city of Sion are shown in figure 4.

3.2 LM2 method

The LM2 method is based on a mechanical approach. The method is based on an enhancement of the capacity spectrum method adopted by HAZUS (FEMA 1999), particularly widespread in the US. This approach leads to evaluate the expected seismic performance of buildings hit by an earthquake by the comparison between the capacity curve and the response spectrum. The capacity curve describes the structural behaviour of the building to horizontal seismic actions while the response spectrum is defined as the earthquake demand curve (Cattari *et al.*, 2004).

As in the case of the LM1 method, even in this case the starting point of the whole process is the correct detection of the building type. The behaviour of the building is described by the capacity curve through three parameters: the fundamental period of vibration of the structure *T* (indicating the slope of the curve in figure 5), the yield strength F_y (which is the limit value from elastic to plastic behaviour) and the ultimate displacement d_u that the structure can stand. These three values allow the determination of the relative capacity curve (Figure 5).

The capacity curve, through a transformation into spectral coordinates (ADRS – acceleration displacement response spectrum), can be directly compared with seismic demand spectrum. The comparison between capacity curve and seismic spectrum admit the determination of the "performance point". The performance point is the displacement required by a specific seismic event which the structure is supposed to suffer (Figure 6). Depending on the performance point location on the capacity curve, the corresponding damage grade that the structure should suffer can be detected. The damage limit states $S_{d,k}$ (k =1,…,4) are identified directly on the capacity curve as a function of the yielding displacement d_y and the ultimate displacement d_u according to:

$$\begin{cases} S_{d,1} = 0.7 d_y \\ S_{d,2} = 1.5 d_y, \\ S_{d,3} = 0.5(d_y + d_u), \\ S_{d,4} = d_u \end{cases} \quad (4)$$

In Europe and within Risk UE project, the true value of the displacement of performance pointt (S_d^*), is obtained by the application of the N2 method (Fajfar 2000):

[5] IMAC : Informatique et mécanique appliquées à la construction (École Polytechnique Fédérale de Lausanne).

[6] Centre de Recherche sur l'environnement alpin de Sion (Suisse).

$$S_d^* = \begin{cases} \left[1 + \left(\frac{S_{ae}(T)}{a_y} - 1\right)\frac{T_C}{T}\right] d_y, & T < T_C \text{ and } \frac{S_{ae}(T)}{a_y} > 1, \\ \frac{S_{ae}(T)}{a_y} d_y, & T_C \le T < T_D \text{ or } \frac{S_{ae}(T)}{a_y} d_y \le 1, \\ \frac{S_{ae}(T_D){T_D}^2}{4\pi^2}, & T \ge T_D \end{cases} \quad (5)$$

Where T, a_y, μ are parameters defining building capacity and $S_{ae}(T)$, T_C, T_D parameters related to seismic demand. In the US, the determination of the performance point is based on different theoretical background (ATC 2005, Lin and Miranda 2008). The capacity curves for each typology are determined starting from T, a_y, μ values introduced by Lagomarsino and Giovinazzi (2006) and listed in table 3 (starting from the third column). The considered building types are the same already introduced in LM1 method as widespread across Europe.

The LM2 method estimates the probability of exceeding the damage state thresholds $S_{d,k}$ with respected to the performance point displacement S_d^*. This probability is obtained by the use of a lognormal cumulative function:

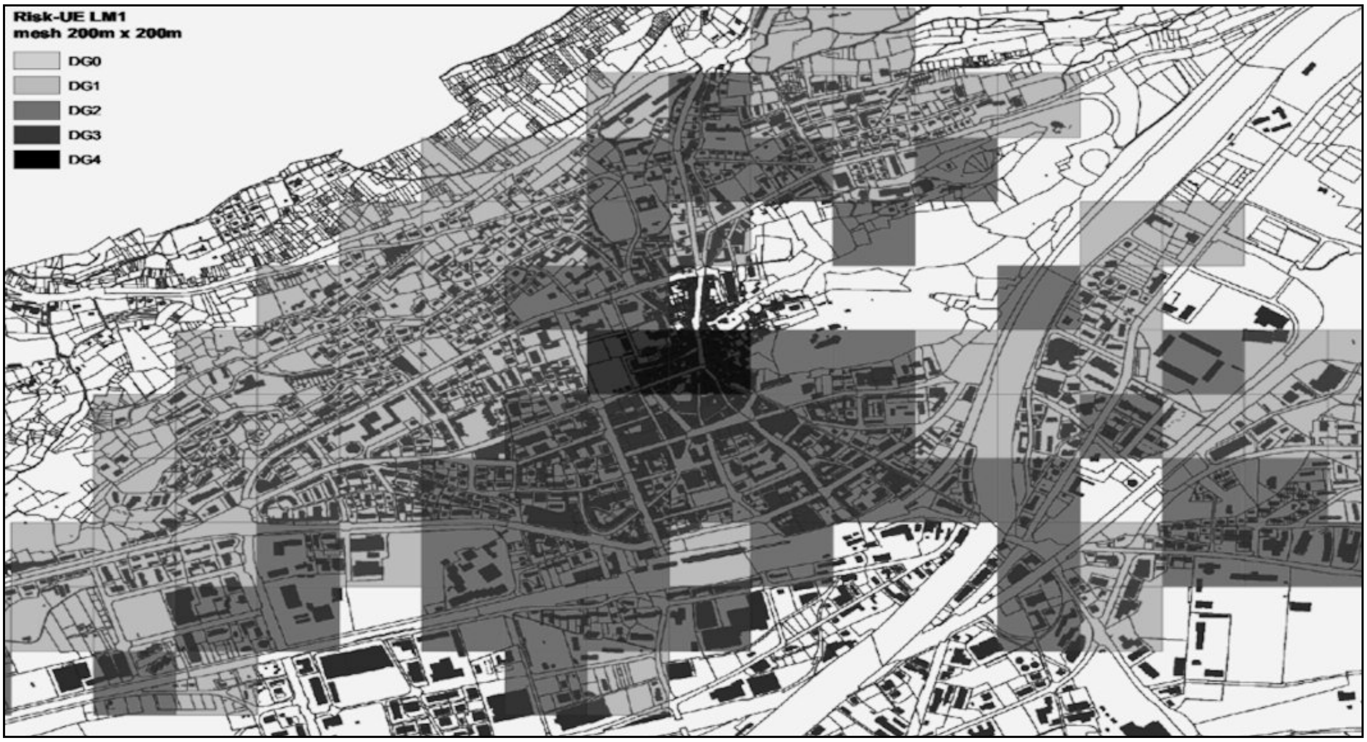


Figure 4 - *Method LM1: results for the city of Sion for macroseismic intensity I_{EMS} =7.19, with average damage grades for a mesh of 200 m x 200 m* [Figure taken from: Lestuzzi *et al.*, 2016A]

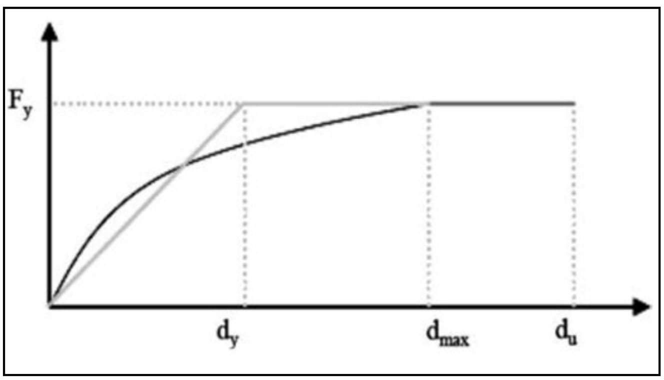


Figure 5 - *Idealised elasto-perfectly plastic capacity curve related to a force-displacement curve* [Figure taken from: Lagomarsino and Giovinazzi 2006]

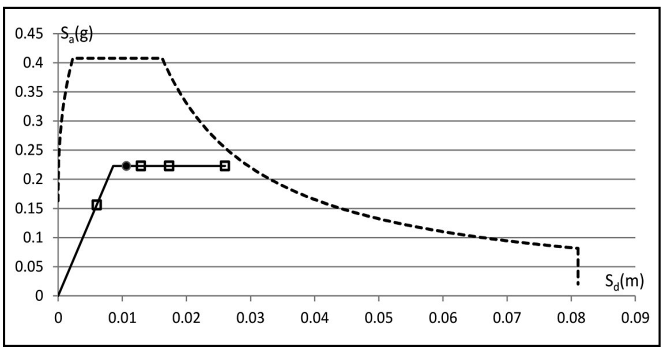


Figure 6 - *Capacity curve for M4_H typology, EC8 elastic response spectrum for a_g = 0.15 and soil A. Performance point (black bold circle) is related to a damage grade 1* [Figure adapted from Lagomarsiono and Giovinazzi 2006]

$$P[D_{Sk}|S_d^*] = \Phi\left[\frac{1}{\beta} ln\left(\frac{S_d^*}{S_{d,k}}\right)\right] \quad (6)$$

where Φ is the normal cumulative distribution function and β the normalised standard deviation of the natural logarithm of the displacement threshold $S_{d,k}$ (Lagomarsino and Giovinazzi 2006).

Also in this case, appropriate fragility curves can be defined, for each construction typology, able to express the probability distribution of the different damage grades as a function of the seismic input defined such as the PGA (peak ground acceleration) (Fig. 7).

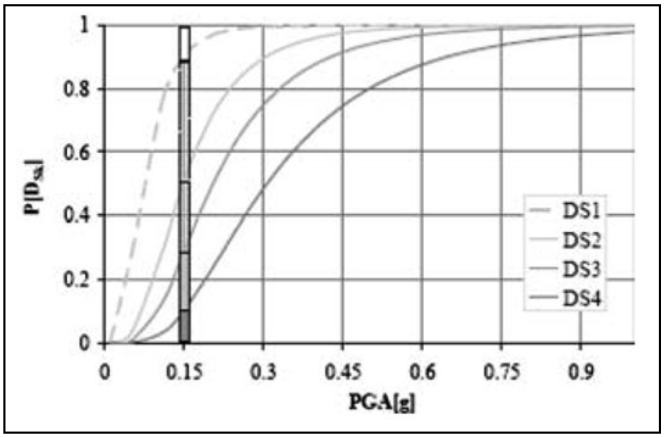


Figure 7 - *Fragility curves $P[D_{Sk}]$ for M6_M-PC typology for a Soil A and PGA = 0.15* [Figure taken from: Lagomarsino and Giovinazzi 2006]

As previous for LM1 method, there are two kinds of output data. First of all, there is the graphical plan layout at urban scale. Here, buildings are shown for their own damage grade according to (4) and (5). It is worth noting that, in this kind of output, probabilistic distributions are not taken into account. Unlike LM1, in this case it is not possible to take into account specific behaviour modifiers like discontinuities in the structural system or irregular shape of the plan. All the buildings belonging to the same construction typology behave in the same way and thus perform the same damage grade. The second type of results output is the statistical one in which the probabilistic distribution obtained for a given type is multiplied by the number of buildings, similar to LM1 method.

With regard to the graphical plan layout at urban scale, there is a clear general overestimation of the damage grade distribution achieved by the LM2 method than the one obtained with LM1. With regard to that, Figure 8 shows the damage distribution at urban scale for the city of Sion obtained by LM2 method. It can be easily appreciate the damage overestimation in comparison with the damage distribution of LM1 method (Figure 4).

4. PERSPECTIVES AND IMPROVEMENTS

Methods analysis and their application on different cities have shown some elements that need further reflections. In general, LM2 method is more significant due to the displacement performance determination procedure. The performance point is calculated by a mechanical approach that is able to consider non-linear behaviour of the structure after the elastic limit threshold. During an earthquake, important displacements are reached that lead the structure beyond its linear behaviour. So, for vulnerability assessment at urban scale, LM2 method is preferable for in-depth analysis with regards to the structural behaviour during the seismic event.

Compared to LM2 method, the LM1 method is more related to probabilistic issues and does not enter into structural considerations. However, the results provided are reliable. In addition, it is worth noting that with LM1 method it is possible to modify the average vulnerability index introducing score modifiers related to specific building features.

As mentioned earlier, the LM2 method is preferable because of the theoretical basis of greater reliance and for the direct connection to more properly seismic issues. Some aspects, however, need further reflections, for an improvement of the method in the near future.

1) Proper capacity curves determination

For a seismic vulnerability assessment at urban scale, it seems to be necessary for more reliable distributions, to provide consistent capacity curves for each single territorial unit. This aim is very important especially in Italy where the building stock is so heterogeneous and where it is possible to find different construction techniques from region to region. To reach this goal, a detailed study on construction techniques is due. Only through an in-depth knowledge, assessment and modelling on building stocks, reliable tools able to prevent earthquake disasters can be prepared. The study on Sion and Martigny, previously mentioned, introduced additional construction types with special capacity curves, in order to best describe building stock features in two major Swiss cities.

An important part of the building stock resulted in fact excluded from the classification of building types introduced by Lagomarsino and Giovinazzi (2006) for Risk UE project. New introduced typologies are: unreinforced masonry buildings (URM) with basement floor in reinforced concrete (RC) and stiff slabs in full reinforced concrete; buildings with mixed URM-RC along the height with stiff slabs; buildings with external masonry shear walls and internal RC pillars with stiff slabs; buildings with RC pillars in the base floor and shear walls at higher levels with stiff slabs (Lestuzzi *et al.*, 2016B). The new capacity curves have been created by a mechanical model introduced by Luchini (2016) and then verified with appropriate pushover analysis (Luchini and Podestà 2015). These types seem to better describe the overall behaviour of Swiss building stocks. As regards the Italian building stock, typologies introduced by Lagomarsino and Giovinazzi (2006) well describe general buildings features. However, according to local characteristics, typologies

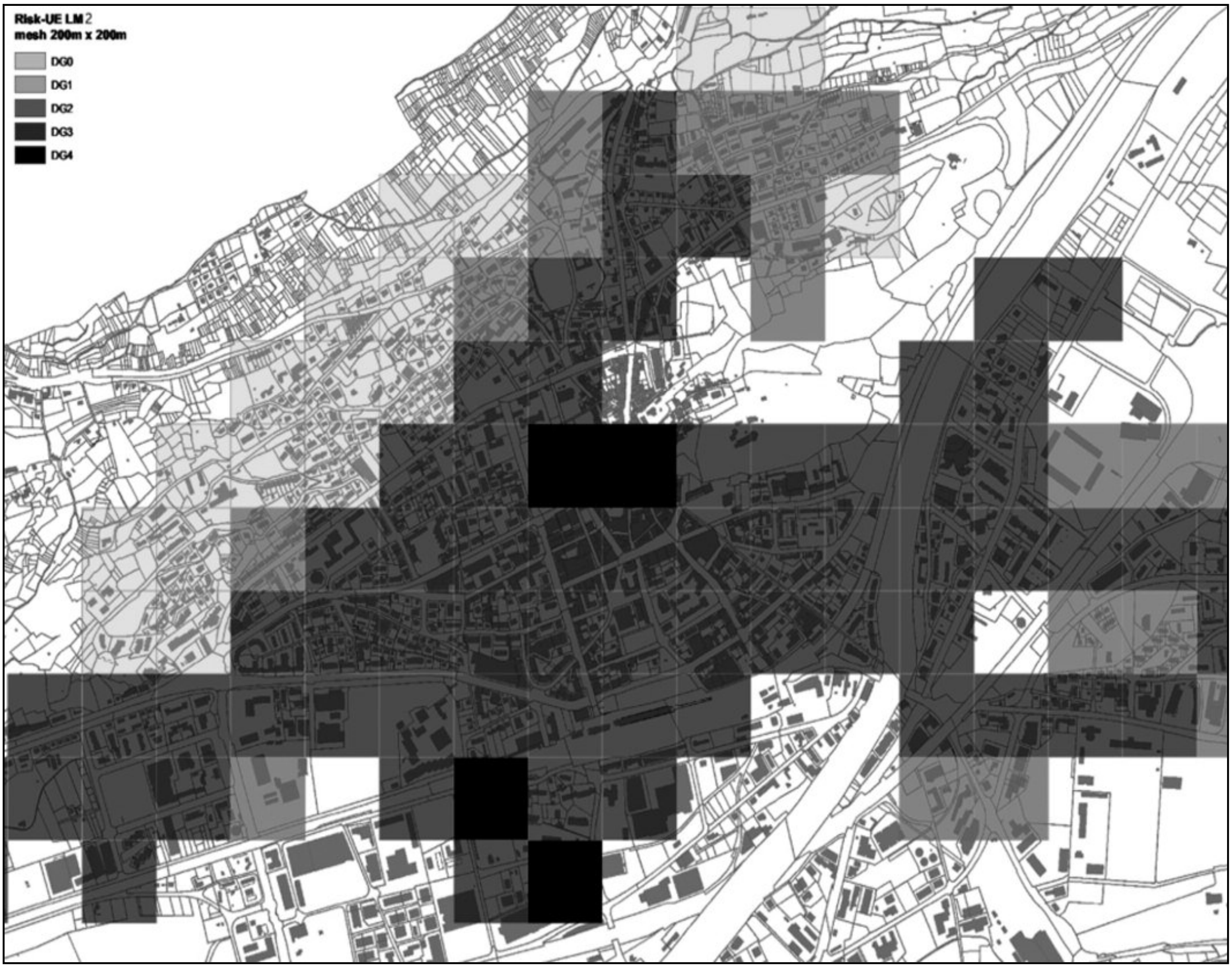


Figure 8 - *Method LM2: results for the city of Sion, with* $A = 1.6 m/s^2$ *with average damage grades for a mesh of 200 m x 200 m* [Figure taken from: Lestuzzi *et al.*, 2016A]

may be recalibrated to generate new capacity curves more consistent with the real seismic behaviour.

Thus the in-depth knowledge of building stock and construction techniques shows up as the central issue for a reliable seismic vulnerability assessment at urban scale.

2) Graphic results output

From output viewpoint, graphic plan layout is surely the most impacting one as easy to understand and direct for the determination of most affected areas. With this kind of graphic layout, however, all considerations about damage probability distributions are excluded. For every building belonging to a given typology, the same damage grade is assumed. In this context, an implementation is due: appropriate graphic layouts, taking into account probability element of attending a well-defined damage grade, should be considered.

3) Irregularities evaluation

The LM2 method is considered, as previously said, more reliable than LM1 for non-linear aspects analysed. Nevertheless, it does not take into account issues related to structural irregularities that may concern several buildings belonging to the same type. This evaluation is slightly possible in macroseismic method LM1 for the presence of score modifiersΔV_i. As it concerns LM2 method, the evaluation of irregularities score modifiers is not currently scheduled. To face this central issue, new subtype should be introduced able to describe building with similar irregularities. At urban scale in fact, some

Table 3 - *Masonry building typologies: parameters for vulnerability and capacity curves*
[Table taken from: Lagomarsino and Giovinazzi 2006]

	BTM	V	Q	T	a_y	μ	d_y	d_u
M1	M1_L	0.79	2.3	0.211	0.168	4.79	0.0019	0.0089
	M1_M	0.87	2.3	0.355	0.133	3.25	0.0042	0.0135
	M1.w_L	0.77	2.3	0.211	0.178	4.79	0.0020	0.0094
	M1.w_M	0.85	2.3	0.355	0.141	3.25	0.0044	0.0143
	M1.v_L	0.87	2.3	0.211	0.132	4.79	0.0015	0.0070
	M1.v_M	0.95	2.3	0.355	0.105	3.25	0.0033	0.0107
M2	M2_L	0.84	2.3	0.268	0.146	3.98	0.0026	0.0104
	M2.w_L	0.82	2.3	0.268	0.155	3.98	0.0028	0.0111
	M2.v_L	0.92	2.3	0.268	0.116	3.98	0.0021	0.0082
M3	M3_L	0.66	2.3	0.192	0.248	5.17	0.0023	0.0117
	M3_M	0.74	2.3	0.322	0.196	3.48	0.0051	0.0176
	M3_H	0.82	2.3	0.437	0.142	3.00	0.0067	0.0202
	M3.w_L	0.64	2.3	0.192	0.263	5.17	0.0024	0.0124
	M3.w_M	0.72	2.3	0.322	0.208	3.48	0.0054	0.0187
	M3.w_H	0.80	2.3	0.437	0.151	3.00	0.0071	0.0214
	M3.v_L	0.74	2.3	0.192	0.196	5.17	0.0018	0.0093
	M3.v_M	0.82	2.3	0.322	0.155	3.48	0.0040	0.0140
	M3.v_H	0.90	2.3	0.437	0.112	3.00	0.0053	0.0160
	M3.sm_L	0.60	2.3	0.192	0.296	5.17	0.0027	0.0140
	M3.sm_M	0.68	2.3	0.322	0.234	3.48	0.0060	0.0210
	M3.sm_H	0.76	2.3	0.437	0.170	3.00	0.0080	0.0241
M4	M4_L	0.54	2.3	0.173	0.358	5.63	0.0026	0.0149
	M4_M	0.62	2.3	0.290	0.283	3.76	0.0059	0.0222
	M4_H	0.70	2.3	0.393	0.223	3.03	0.0086	0.0260
	M4.w_L	0.52	2.3	0.173	0.379	5.63	0.0028	0.0158
	M4.w_M	0.60	2.3	0.290	0.300	3.76	0.0063	0.0235
	M4.w_H	0.68	2.3	0.393	0.237	3.03	0.0091	0.0276
	M4.v_L	0.62	2.3	0.173	0.283	5.63	0.0021	0.0118
	M4.v_M	0.70	2.3	0.290	0.223	3.76	0.0047	0.0176
	M4.v_H	0.78	2.3	0.393	0.177	3.03	0.0068	0.0206
M5	M5_L	0.64	2.3	0.173	0.263	5.63	0.0019	0.0110
	M5_M	0.72	2.3	0.290	0.208	3.76	0.0044	0.0164
	M5_H	0.80	2.3	0.393	0.165	3.03	0.0063	0.0192
	M5.w_L	0.62	2.3	0.201	0.279	4.97	0.0028	0.0140
	M5.w_M	0.70	2.3	0.338	0.221	3.36	0.0063	0.0211
	M5.w_H	0.78	2.3	0.459	0.152	3.00	0.0080	0.0239
	M5.v_L	0.72	2.3	0.192	0.208	5.17	0.0019	0.0098
	M5.v_M	0.80	2.3	0.322	0.165	3.48	0.0043	0.0148
	M5.v_H	0.88	2.3	0.437	0.119	3.00	0.0057	0.0170
	M5.sm_L	0.58	2.3	0.192	0.314	5.17	0.0029	0.0148
	M5.sm_M	0.66	2.3	0.322	0.248	3.48	0.0064	0.0223
	M5.sm_H	0.74	2.3	0.437	0.180	3.00	0.0085	0.0256
M6	M6_L-PC	0.57	2.3	0.211	0.324	4.79	0.0036	0.0171
	M6_M-PC	0.65	2.3	0.355	0.256	3.25	0.0080	0.0260
	M6_H-PC	0.73	2.3	0.481	0.168	3.00	0.0097	0.0290
	M6_L-MC	0.49	2.6	0.211	0.358	5.98	0.0040	0.0236
	M6_M-MC	0.57	2.6	0.355	0.283	3.96	0.0088	0.0350
	M6_H-MC	0.65	2.6	0.481	0.186	3.63	0.0107	0.0387
M7	M7_L	0.37	2.6	0.153	0.508	7.85	0.0030	0.0233
	M7_M	0.45	2.6	0.258	0.401	5.07	0.0066	0.0336
	M7_H	0.53	2.6	0.350	0.317	4.00	0.0096	0.0386

irregularities can be found in several buildings, allowing the introduction of new subtypes. New typologies can be introduced for buildings with reinforced concrete pillars in the base floor (*piano piloties*) or for masonry buildings with vertical walls interrupted by store openings at the ground floor or for masonry buildings with obvious vertical discontinuity.

4) Performance point determination

The performance point displacement determination is evaluated according to N2 method, introduced by Fajfar in 2000. The N2 method estimates the behaviour of structures in the non-linear field. This assessment is not simple: the more the elastic field threshold is overpassed, the more hardening and local yielding appear. Several studies (Michel *et al.*, 2014) have shown, through a comparison of results obtained with N2 method and those obtained through a more accurate non-linear simulation, that for certain structures N2 method proved to be wrong. The results provided by N2 method so are unsatisfactory. Structures that especially showed wrong performance point determination are those with low fundamental period. Overestimations in damage determination may be welcomed for seismic evaluation of individual buildings, as in favour of security. In seismic vulnerability assessment at urban scale this trend may lead to untrue final results. In some special conditions, the method also tends to dangerous damage underestimation. Some ongoing studies (Diana L., A. Manno, Lestuzzi P.) are considering an optimization of N2 method formula so that it can give results close to the real ones.

5) Performance evaluation of historical urban centres

The main element that the LM1 and LM2 methods fail to describe is the seismic vulnerability assessment of historical urban centres. In this context, it becomes important the evaluation of the interactions between buildings which, due to the contiguity, can generate indirect consequences on the nearby constructions. More than the single construction, the whole aggregate features results decisive for the general seismic behaviour. The aggregate behaviour is determined by many factors: the relationship with the urban morphology, the irregularities of its plan, the relationship with the surrounding aggregates, the elevation of the aggregate itself, its typological composition, the presence of typological and structural alterations and the presence of stratifications and changes that occurred over the years (D'Amico 2016). These elements escape from evaluations performed on individual buildings with traditional LM1 and LM2 methods. The introduction for the seismic vulnerability assessment of historical urban centres of finest and more reliable methods becomes a main priority.

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