THE ITALIAN CONTRIBUTION TO THE USGS PAGER PROJECT

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ABSTRACT

The USGS-PAGER Project is devoted to rapidly assess the consequences of severe earthquakes in the world. To improve the inventory and the vulnerability estimate, USGS made recourse to the EERI World Housing Encyclopedia (WHE) project, a web-based network of experts from around the world. A small group of experts, established by EERI, drafted a simple form to collect information at national level. For each country it was required to select the most significant construction types and to provide both the value of the collapse probability conditional upon seismic intensity and the fraction of population that lives and works in these construction types. Italy participated to the project and the Italian form was filled by the Seismic Risk Office-DPC. Several other research units accepted to participate to the project: RU-Genoa, RU-Naples, RU-Padua, RU-Pavia/Eucentre, RU-Potenza. The paper presents the contribution of the Italian Research Units to the PAGER project, providing an insight into the used methodologies and a comparison of the results.

KEYWORDS: Seismic vulnerability, RC, masonry, PAGER

1. INTRODUCTION

The USGS-PAGER Project (earthquake.usgs.gov/eqcenter/pager) is an automated system to rapidly assess the consequences of severe earthquakes in the world. To improve the inventory and the vulnerability estimate all over the world, USGS made recourse to the EERI World Housing Encyclopedia (WHE) project, a web-based network of experts from around the world who contribute standard information on housing construction types in their countries. A small group of experts, established by EERI, drafted a simple form to collect information at national level. The form contains information on the most significant construction types: the collapse probability conditional upon seismic intensity and the fraction of population that lives and works in these construction types.

The form was disseminated and several countries filled the form, some results being also available on the web. Italy participated to the project and the Italian form was filled by the Seismic Risk Office-DPC (SRO-DPC). It emerged quite soon that one of the crucial point was the reliability of the estimate. It was then decided to compare different estimates, based on different vulnerability models and/or on different geographical areas. The following research units accepted to participate on a volunteer basis to the project: Genoa-RU, Naples-RU, Padua-RU, Pavia/Eucentre-RU and Potenza RU. Each one of the above RU filled the EERI/PAGER form.

The paper provides an insight into the methodologies used by the Italian Research Units contributing to the PAGER project. The comparison has been made both in terms of building vulnerability and in terms of population involved in collapsed buildings. To evaluate the uncertainty of the estimate an homogenous event in the whole Italy was considered. The results were then compared with the ones derived with the SP-BELA procedure reported in Borzi *et al.* (2008a, 2008b). Results were also compared selecting building types and population in two Italian Regions: Liguria and Veneto, providing the uncertainty associated to the geographical extension of the estimate.

2. ITALIAN NATIONAL CENSUS ON POPULATION AND BUILDINGS

The main features of the Italian building stock at national and regional level have been provided by DPC to all participants. Information originated from 14th General Population Census and General Housing Census (Istat, 2001), which is currently performed to survey population, and to gather information about the consistency and the structural characteristics of dwellings. In 2001, for the first time, Istat has taken a census of buildings. Simultaneously to the census data processing, specific procedures were implemented to obtain vulnerability estimates at national level (Bramerini and Di Pasquale, 2008).

The national census is based on the Italian administrative organisation, in particular (from the less detailed to the most detailed level): Italy, geographical areas, regions, provinces and municipalities. For each municipality, inhabited places (“nuclei” and “centres”) are defined as aggregations of contiguous or close buildings with interposed streets, squares and the like. Each inhabited place is divided into elementary units (census sections), which, in municipalities having more than 30.000 inhabitants, coincide with the block. All buildings belonging to inhabited places have been classified as “urban”; the others are considered in rural area. For each building the following data were known: age (before 1919, 1919-1945, 1946-1961, 1962-1971, 1972-1981, 1982-1991, 1992-2001); structural type (masonry, RC, RC pilotis, mixt and others); number of storeys (1 storey, 2, 3, 4, 5, 6, 7, more than 7); seismic design (Y/N); area (urban or rural) and resident population. The national (regional) population joint distribution is obtained considering the population that lives in all the buildings that in the whole Italy (in each region) belong to the same building class (type of material, number of storeys, age of construction).

3. SRO-DPC APPROACH

In the SRO-DPC approach vulnerability has been considered in term of observed physical damage to the vertical bearing structures, measured, according to the MSK 76 (Medvedev, 1977) and EMS-98 (Grunthal, 1998) macroseismic scales, in a discrete scale ranging from 0, the null damage, to 5, the collapse of the building. According to the PAGER definition of collapse, 100% of the totally collapsed buildings and a fraction equal to 40% of the partially collapsed buildings has been included in the analysis.

The total and partially collapsed buildings have been estimated by means of a statistical procedure based on the observed damages and building types on more than 30.000 buildings inspected after the Irpinia 1980 earthquake (CNR-PFG, 1980). Empirical collapse probabilities (according to the definition of the PAGER project) were considered for masonry buildings (3 building types: Poor (Mas-A), medium (Mas-B) and good (Mas-C) quality) and RC buildings (2 building types according to the number of storeys (1-3 storeys and >3 storeys), being all the RC buildings stricken by the Irpinia earthquake designed only for gravity loads). In Goretti and Sarli (2006) the observed total and partial collapse probabilities were considered just for intensity I_{MCS}=IX. In this application, in order to extrapolate to higher intensities the observed collapse probabilities, P_c, conditional upon building type and intensity I, they have been expressed through the following relationship:

$$P_c = \left(\frac{I_{MCS} - I_o}{I_f - I_o} \right)^n \tag{3.1}$$

But P_c=0 if $I_{MCS}<I_o$ and P_c=1 if $I_{MCS}>I_f$. I_o, I_f and n are parameters depending on building type, that have to be obtained from the data. The MCS scale has been then converted in the MM scale according to the relationship:

$$I_{MM} = 0.806 I_{MCS} + 1.016 \tag{3.2}$$

obtained combining and averaging log(PGA)-I_{MM} and log(PGA)-I_{MCS} relationships proposed by several authors (Decanini *et al.*, 1995, Murphy and O’Brien, 1977, Faccioli and Cauzzi, 2006). Note that the adopted relationship provides similar I_{MM} and I_{MCS} values at lower intensities (I_{MM}=VI), and an I_{MM} value that is one degree higher than the I_{MCS} one at I_{MM}=IX. To obtain the collapse probability for RC buildings with (moderate) seismic design, we considered that according to theEMS98 macroseismic scale, the damage distribution for vulnerability class E and intensity I_{EMS} is similar to the one for vulnerability class D and intensity I_{EMS}-1. Assuming $I_{EMS}=I_{MM}$ one gets P_c(Class E, I_{MM})= P_c(Class D, I_{MM}-1). From eqn (3.2) one obtains P_c(Class E, $0.80I_{MCS}+1.01$)= P_c(Class D, $0.80I_{MCS}+1.01$). Recalling eqn (3.1) the following parameters for RC buildings with moderate aseismic design are found $n_E=n_D$, $I_{o,E}=I_{o,D}+0.80$, $I_{f,E}=I_{f,D}+0.80$. The obtained collapse probabilities are reported in Table 3.1 for masonry and RC buildings, together with the fraction of population that lives in that building types according to the data presented in the previous paragraph. Note that the proposed vulnerabilities are in good agreement with the EMS98 scale for what concerns masonry buildings. According to EMS98 macroseismic scale, the total collapse probabilities for I_{EMS}=IX and vulnerability class A and B are between 20-50% and ≤10% respectively, so that one can argue that including a fraction of the partially collapsed buildings, these percentage should increase and become similar to the proposed values. On the contrary the collapse probabilities for RC buildings are higher than the ones assumed in the EMS98 scale.

Table 3.1 Vulnerability and exposure for the whole Italy (%, DPC-SRO)

Building type	$Pc\|I_{MM}$=VI	$Pc\|I_{MM}$=VII	$Pc\|I_{MM}$=VIII	$Pc\|I_{MM}$=IX	Population in urban area	Population in rural area
Mas-A	0.0	2.8	20.9	61.2	13.5	2.0
Mas-B	0.0	0.0	4.8	16.0	13.8	2.0
Mas-C	0.0	0.0	0.0	5.0	22.1	2.8
RC-GLD ≤3 storeys	0.0	0.0	0.0	12.7	12.3	1.0
RC-GLD >3 storeys	0.0	0.0	1.2	20.6	19.5	0.1
RC-SD ≤3 storeys	0.0	0.0	0.0	1.4	5.4	0.8
RC-SD >3 storeys	0.0	0.0	0.0	7.4	4.7	0.1

4. GENOA-RU APPROACH

The macroseismic method (Lagomarsino and Giovinazzi, 2006) used in this application, was derived making reference to the European Macroseismic Scale EMS-98 (Grunthal 1998), which implicitly contains a model of vulnerability. The EMS-98 supplies, for each macroseismic intensity, the probability of occurrence of the five damage grades D_k (k = 1 to 5), in terms of Damage Probability Matrices (DPM) for the six vulnerability classes. The evident vagueness of the adjectives (the frequency of expected damage is defined by few, many or most) and incompleteness of the information (for each class and intensity at most the frequency of two damage grades is characterized) do not permit associating very precise numerical Damage Probability Matrices to the vulnerability classes. The complete description of the distribution of damage is obtained operating a reasonable linguistic complement of the definitions supplied by the scale, by means of a "fuzzy pseudo-partition" directly deducible from the EMS-98 (Bernardini *et al.*, 2007). Each vulnerability class is also associated with a specific central DPM called "white expected", which might be useful for a rapid determination of the most reliable expected value. With reference to the building typologies defined in the EMS-98, the associated Damage Probability Matrixes have been derived interpreting the correlation suggested by the scale with the vulnerability classes, in terms of relative frequencies of the classes. The macroseismic methodology described here allows one to calculate in a manner coherent with the conventional definitions of damage grade and macroseismic intensity supplied by the EMS-98 expected values of any functions of seismic damage to populations of ordinary buildings. With reference to the PAGER project, the percentage of collapsed buildings was calculated for EMS-98 typologies, that are very well correlated to the WHE typologies as shown in Table 4.1 (only one typology from EMS-98 was added, as it is relevant in Italy). Table 4.1 displays upper and lower values of the expected frequencies of collapsed buildings (considering a α-cut equal to 0.5 in the membership function), defined as the buildings with damage D5 and 40% of buildings with damage D4.

To evaluate the percentage of inhabitants exposed to risk from the data of the 14th Italian population census, percentage of occurrence of the typologies (building type shown in Table 4.1) in different age of buildings was defined, based on sample surveys, in particular made in Liguria Region Thus, frequencies of inhabitants in the different building typologies were evaluated. Table 4.1 shows the fraction of population that live in each building typology in Italy. Table 4.2 shows the same exposure information, referring only to Liguria Region

(North-west of Italy, on the border with France). These frequencies are quite similar in Italy and in Liguria; however, the vulnerability in Liguria is higher due to the high number of rubble stone masonry and RC designed only for gravity loads.

Table 4.1 Vulnerability and exposure for the whole Italy (%, Genoa-RU)

Building type	Pc|I_{MM}=VI	Pc|I_{MM}=VII	Pc|I_{MM}=VIII	Pc|I_{MM}=IX	Popul. in urban area	Popul. in rural area
Rubble Stone Masonry (WHE1)	0.04-0.08	1.51-6.08	9.81-35.90	30.01-68.04	5.93	1.05
Simple Stone Masonry lime mortar	0.00	0.11-0.54	1.85-8.52	10.45-38.49	7.67	1.11
Massive Stone Masonry (WHE2)	0.00	0.00	0.27-1.35	2.85-12.44	1.76	0.17
UR Brick Masonry (WHE7)	0.00	0.11-0.54	1.79-8.25	10.10-37.09	14.40	2.05
UR Brick Masonry RC floors (WHE9)	0.00	0.00	0.27-1.35	2.85-12.44	13.46	2.04
RC-GLD (WHE14)	0.00	0.11-0.54	1.08-4.68	5.35-18.11	25.04	1.02
RC-SD (WHE15)	0.00	0.00	0.11-0.54	1.08-4.68	11.96	0.97
RC - Walls cast in situ (WHE21)	0.00	0.00	0.11-0.54	1.63-7.44	10.79	0.59

Table 4.2 Exposure for the only Liguria Region (%, Genoa-RU)

Building type	Fraction of population	
	urban areas	rural areas
Rubble Stone MAsonry (WHE1)	11.53	1.10
Simple Stone Masonry in lime mortar	9.77	0.85
Massive Stone Masonry (WHE2)	2.71	0.15
UR Brick Masonry (WHE7)	10.21	0.93
UR Brick Masonry with RC floors (WHE9)	5.85	0.72
RC-GLD (WHE14)	37.57	1.17
RC-SD (WHE15)	4.73	0.64
RC - Walls cast in situ (WHE21)	11.55	0.53

5. NAPLES-RU APPROACH

In this application only RC buildings have been considered. Fragility curves for classes of structures have been computed according to the methodology proposed in Iervolino *et al.* (2007), were the class is arbitrarily defined as the ensemble of buildings sharing the same structural type, global shape, number of storeys, design code and construction practice at age of construction; i.e., 4 storeys rectangular RC frames built in Italy after the Second World War for gravity loads only. Only the rectangular shape is considered so far; number of storeys ranges from 2 to 8; the design options are (1) gravity loads only and (2) obsolete seismic code. Structures considered are 3D bare frames, e.g., no infills are considered. The approach to the fragility of the class is analytical/numerical, and it is probabilistic for what concerns both the seismic capacity and demand. The capacity of each class includes variability of material properties and, most importantly, variability of building global (plan) dimensions, and variability of structural system given the global dimensions (this variability is found to dominate in respect to that of materials). Uncertainty of materials is characterized by appropriate probabilistic distributions developed by the same researchers in other studies. Variability of dimensions and structural system is accounted for as follows: (i) a certain number of buildings (defined by global dimensions) is considered for each class, these buildings should be chosen according to the frequency distribution of the of the buildings' dimensions in a specifically surveyed area (the structural system of each building is unknown at this stage); (ii) to each building a number of possible structural systems compatible with the global dimensions is

designed according to the code enforced at time of construction; (iii) seismic capacity for each of the considered structures is computed via non linear static procedures (see next paragraph); (iv) multiple regression of the results for the analyzed structures (similar to response surface) is used to obtain capacity as function of global dimensions, structural configuration and materials (e.g., class scale capacity is obtained as function of parameter determining a specific building within the class).
The seismic demand is obtained via the capacity spectrum method (CSM) modified to include variability of the elastic spectral ordinates (obtained by means of probabilistic seismic hazard analysis) and variability of the elastic to inelastic spectral modification factor. Montecarlo simulation is employed to compute fragility for the class. In each run a building of the class (i.e. dimensions, structural system and material properties) is extracted. For that structure the seismic demand is computed via the CSM as described. Then, the performance of the structure is assessed. Reporting the fraction of collapses as a function of the peak ground accelerations, or PGA, (although other ground-motion characteristic may be considered, i.e. spectral accelerations or displacements) gives the fragility for the class. The analysis is carried out for each of the two directions of the building.
The peculiar feature of the approach is the simulated design of structures, which leads to a lumped plasticity model for each of the two principal horizontal directions of the 3D buildings (Cosenza *et al*. 2005). For gravity load designed classes only two frames are associated to the transverse (short) directions, conversely a frame is considered for each bay in the longitudinal (long) direction. Collapse is defined as first component failure, that is, when an element reaches ¾ of its ultimate rotation. Static push-over is used to assess the seismic capacity, which is defined in terms of three parameters: (1) effective period; (2) inelastic strength; (3) displacement capacity. This step allows to associate an equivalent bilinear SDOF curve to each structure. Therefore the class capacity defined above is actually a three components vector.
According to the population census, in RC-MRF-GLD and RC-MRF-SD buildings lives about 70% of the population that lives in RC buildings.

Table 5.1 Vulnerability and exposure for the only RC building in Italy (%, Naples-RU) (RC-MRF-SD refers to the only buildings built before 1980)

Building type	$Pc\|I_{MM}$=VI	$Pc\|I_{MM}$=VII	$Pc\|I_{MM}$=VIII	$Pc\|I_{MM}$=IX	Popul. in urban area	Popul. in rural area
RC-MRF-GLD, 1-2 st.	2.64	17.56	51.55	84.51	4.69	0.53
RC-MRF-GLD, 3 st.	1.74	14.23	47.23	82.36	4.03	0.16
RC-MRF-GLD, 4 st.	1.90	15.79	50.82	85.29	3.78	0.03
RC-MRF-GLD, 5-7 st.	1.36	14.06	49.60	85.53	3.30	0.007
RC-MRF-GLD, ≥8 st.	0.77	10.08	42.17	80.61	3.52	0.002
RC-MRF-SD, 1-2 st.	2.42	15.65	47.15	80.69	3.07	0.49
RC-MRF-SD, 3 st.	1.84	13.73	44.88	79.72	2.89	0.17
RC-MRF-SD, 4 st.	1.03	10.92	42.21	79.52	2.03	0.05
RC-MRF-SD, 5-7 st.	0.57	8.39	38.48	77.80	1.19	0.02
RC-MRF-SD, ≥8 st.	0.37	6.46	33.68	73.72	0.56	0.0008

6. PAVIA/EUCENTRE-RU APPROACH

The proposed empirical fragility curves have been directly derived from observed post-earthquake damage data, collected after the main Italian events of the last 30 years, i.e. Irpinia (1980), Abruzzo (1984), Umbria-Marche (1997), Pollino (1998) and Molise (2002). The main advantage of empirical fragility curves, directly derived from observed data, is that they allow to take into account all the elements affecting damage, such as for example site effects and contribution of non structural components to the seismic response, which are implicitly included in the vulnerability description. Fragility curves have been derived for selected building typologies, typical of the Italian building stock and defined based on the information available from the different survey forms (Rota *et al*., 2007). The severity of ground motion has been expressed both in terms of PGA and Housner intensity. The damage scale of the EMS-98 (Grunthal, 1998) has been used, which includes 5 levels of damage, plus the case of no damage. A single value of ground motion severity has been defined for each affected municipality, using the attenuation relationship of Sabetta and Pugliese (1987), on rock, with the characteristics of the earthquake affecting such municipality. Since the survey forms used after the 5 considered events were different from each other, the available information have been homogenised into the selected damage scale and building typology matrix. The issue of completeness of the survey has been accounted for, by defining an extended set of data, containing data from all municipalities surveyed for at least 60% of the buildings, as compared to the 2001 census data. The experimental damage probability matrices have been processed in order to infer the parameters of lognormal distributions, through an advanced nonlinear regression procedure. The bootstrap technique has been used to take into account the relative reliability of each point and determine appropriate weights.

The PGA-I_{MSK} law proposed by Margottini *et al.* (1987) has been used to convert PGA values to macroseismic intensities and to obtain damage estimates. Although vulnerability curves were available for 16 masonry typologies and 4 RC building typologies, in this project, results were delivered for 2 masonry building typologies (1-2 storeys and ≥3 storeys), 2 RC building types (1-3 storeys and ≥4 storeys) and 2 mixed (masonry + RC) typologies. For each of these wider typologies, a minimum and a maximum value of collapse probability have been derived from the obtained fragility curves; however, in comparing the results, only the average value of this interval has been used, which reduces significantly the variability obtained from empirical post-earthquake observations.

A general feature of most of the proposed fragility curves, except for those derived for reinforced concrete structures, is the presence of a very steep branch (nearly vertical) close to the origin. This very high probability of slight damage even for very low values of PGA is partly related to the selected analytical expression, i.e. the lognormal distribution. However it is mainly due to the fact that the most vulnerable types of masonry structures show a slight level of damage (typically of grade DS1) even for very low values of PGA, and possibly even in the absence of an earthquake. This pre-existing damage is due to the particular conditions of many bad quality masonry buildings in Italy, which lack proper maintenance and hence show some endemic damage also before the earthquake strikes.

Moreover, curves derived from post-earthquake observed data are strongly influenced by the very high concentration of observations at low values of ground motion, for the lower damage states. Since the weights used in the nonlinear regression procedure are somehow proportional to the size of the sample for each PGA value, such large data sample at low PGA significantly conditions fragility curves. This effect is less pronounced for the higher damage levels, since observed collapses have occurred for higher values of ground motion. This result could also somehow depend on the survey completeness, although this problem has been carefully considered.

Table 6.1 Vulnerability and exposure for the whole Italy (%, Pavia/Eucentre-RU)

Building type	$Pc\|I_{MM}$=VI	$Pc\|I_{MM}$=VII	$Pc\|I_{MM}$=VIII	$Pc\|I_{MM}$=IX	Popul. in urban area	Popul. in rural area
Masonry, ≤2 storeys	0.7-11.1	1.4-16.2	2.4-22.5	4.0-30.1	20.8	5.0
Masonry, >2 storeys	0.2-6.9	0.6-11.2	1.8-18.3	4.9-28.6	16.2	0.9
Mixt, ≤2 storeys	2.8	4.3	6.4	9.1	5.6	1.0
Mixt, >2 storeys	1.9	3.5	6.0	9.7	6.9	0.2
RC, GLD, ≤2 storeys	0.00	0.20	0.90	3.30	17.5	1.8
RC, GLD, >2 storeys	0.00	0.10	1.70	13.20	24.0	0.1

7. PADUA-RU APPROACH

The following analyses provide the expected relative frequencies of heavily damaged buildings, and of the corresponding exposed population, conditional to the macro-seismic intensity of a hypothetical earthquake in Italy and more particularly in Veneto Region in Norh-Eastern area of Italy.

Information about the inventory of buildings and related population derive from ISTAT 2001 census data, presented in a previous paragraph, that made available the percentages of resident population separately for 4 types (masonry buildings, regularly infilled RC buildings, pilotis RC buildings and other, i.e. generally mixed masonry and RC buildings), and for different ages of construction and number of storeys.

Buildings with the same type, age and number of storeys have been classified in the EMS vulnerability classes (from A to F) (Grunthal, 1998) according to some rules derived with some necessary modifications from a proposed methodology (Bernardini, 2005) for the vulnerability analyses of the building inventory in the

Veneto-Friuli area, described by ISTAT 1991 data.

Damage Probability Matrixes (DPM) for each vulnerability class have been recognised from the qualitative definitions of relative frequencies and damage degrees from D0 (no damage) to D4 (partial collapse) and D5 (total collapse), suggested by the EMS98 macro-seismic scale (Bernardini, 2005; Bernardini *et al.*, 2007). A convex family of numerical DPM can be assumed as compatible with the definitions, giving upper and lower bounds of each expected frequency. However in the present application only a precise "central" DPM has been used ("White expected DPM" according to the theory of the random sets (Bernardini, 2005)).

In the PAGER project the collapse of a building has been considered as corresponding to a reduction over 50% of the original volume due to partial collapses. It has been assumed here that collapsed buildings are buildings with damage D5 and 40% of buildings with damage D4. Table 7.1 displays, for each EMS98 vulnerability class, the upper, lower and white values of the expected relative frequencies, and hence the uncertainty inherent in the analyses.

Table 7.1 – Probability of damage according to PAGER project for EMS98 vulnerability classes

	V	VI	VII	VIII	IX	X	XI	XII
A_LOW	0	0	0	0,06	0,25	0,67	1	1
A_UP	0	0	0,06	0,37	0,73	1	1	1
A_WHITE	0	0	0,03	0,215	0,49	0,835	1	1
B_LOW	0	0	0	0	0,06	0,25	0,67	1
B_UP	0	0	0	0,06	0,37	0,73	1	1
B_WHITE	0	0	0	0,03	0,215	0,49	0,835	1
C_LOW	0	0	0	0	0	0,06	0,31	0,97
C_UP	0	0	0	0	0,06	0,37	0,73	1
C_WHITE	0	0	0	0	0,03	0,215	0,52	0,985
D_LOW	0	0	0	0	0	0	0,06	0,82
D_UP	0	0	0	0	0	0,06	0,37	1
D_WHITE	0	0	0	0	0	0,03	0,215	0,91
E_LOW	0	0	0	0	0	0	0	0,67
E_UP	0	0	0	0	0	0	0,06	1
E_WHITE	0	0	0	0	0	0	0,03	0,835
F_LOW	0	0	0	0	0	0	0	0,52
F_UP	0	0	0	0	0	0	0	1
F_WHITE	0	0	0	0	0	0	0	0,76

In this analysis the following classes of structures have been considered: Masonry, RC w/o pilotis, RC w pilotis, Mixt. They will be indicated with T_{PAGER}. In order to obtain the collapse probabilities of these classes of structures from the corresponding collapse probabilities of the EMS98 classes (from A to F), named T_{EMS}, the theorem of total probabilities has been adopted:

$$P(collapse \mid I, T_{PAGER}) = \sum_{j} P(collapse \mid I, T_{EMS,j}) P(T_{EMS,j} \mid T_{PAGER}) \tag{7.1}$$

The building conditional distribution $P(T_{EMS}|T_{PAGER})$ is not known. However it is known the same distribution in terms of population. Since the mean value of residents in each building is clearly different for different number of storeys, and probably also different types, age of construction, urban context, an approximate linear correlation for each type to a numerical parameters joined to the vulnerability classes (A = 1, to F = 6) has been derived by the available joint frequencies of number of classified buildings and population in the vulnerability analyses of the Veneto-Friuli area based on ISTAT 1991 data (Bernardini, 2004). For RC buildings $y=0.051x+1.086$, while for masonry buildings $y=0.171x+0.375$ where y is the mean number of inhabitants per building of vulnerability class x, (from x(A)=1, to x(F)=6) over the average number of inhabitants independently of building type. Using the corresponding corrective factors the "white" expected relative frequencies of collapse displayed in Table 7.2 (Italy) and Table 7.3 (Veneto) have been computed.

Observe that collapse frequencies are quite similar in Italy and in Veneto, due to the combination of two opposite factors: in the Veneto area the percentage of masonry buildings is much higher (and the percentage of RC buildings is lower) than in Italy; however both masonry and RC buildings in Veneto seem less vulnerable than, in the mean, in Italy.

Table 7.2 Vulnerability and exposure for the whole Italy (%, Padua-RU)

Building type	$Pc\|I_{MM}$=VI	$Pc\|I_{MM}$=VII	$Pc\|I_{MM}$=VIII	$Pc\|I_{MM}$=IX	Population in urban area	Population in rural area
Masonry	0.0	0.0	2.1	14.2	36.97	5.80
RC w/o pilotis	0.0	0.0	0.0	1.7	37.32	1.86
RC w pilotis	0.0	0.0	0.7	7.1	4.23	0.10
Mixt	0.0	0.0	0.7	7.6	12.47	1.23

Table 7.3 Vulnerability and exposure for the only Veneto Region (%, Padua-RU)

Building type	$Pc\|I_{MM}$=VI	$Pc\|I_{MM}$=VII	$Pc\|I_{MM}$=VIII	$Pc\|I_{MM}$=IX	Population in urban area	Population in rural area
Masonry	0.0	0.0	1.2	10.5	47.7	11.0
RC w/o pilotis	0.0	0.0	0.0	1.2	20.4	1.6
RC w pilotis	0.0	0.0	0.5	5.9	2.1	0.1
Mixt	0.0	0.0	0.4	5.6	14.9	2.2

8. POTENZA-RU APPROACH

Two different methods have been adopted to evaluate the vulnerability of RC and masonry buildings.

For what concerns RC buildings, a specific procedure was set up (Masi, 2003) where structures widely present in the Italian building stock and representative of low- mid- and high-rise building types designed for gravity loads only, are considered. The procedure is made up of five main steps:

- structural types of RC buildings, typical of the period and of the region under examination, are selected;
- the structural types are carefully designed taking into account only vertical loads, on the basis of the codes in force, of the available handbooks and of the current practice of the period (simulated design);
- seismic response is calculated through nonlinear dynamic analyses with artificial and natural accelerograms;
- the seismic resistance is evaluated by means of damage vs. intensity relationships relevant to some structural and non-structural damage parameters (drift, ductility demands, etc.);
- the vulnerability class of each type, according to the European Macroseismic Scale 1998 (Grunthal, 1998) is assigned, taking into account the increasing damage degrees computed by applying increasing seismic intensities. Classes A, B, C and D have been considered, where class A corresponds to the highest vulnerability and D to low vulnerability (e.g. building structures seismically designed or retrofitted).

A mechanical approach is used to obtain the intensity vs. damage relationship for each structural type. An accurate model is adopted modelling all the structural elements with their actual mechanical characteristics (stiffness, strength, deformation capacity). Whereas collaboration of non structural elements (NSE) with the primary RC structure in the seismic dynamic response is usually neglected, possible damage to NSE is considered in the procedure and their contribution is carefully taken into account. In fact it is often crucial to consider the effects either for the survival of a building (increase of lateral resistance) or for its anticipated collapse (e.g. soft story, plan irregularities - torsion). Both positive and negative collaboration effects are considered, even though as for the negative effects, only the presence of irregularities in elevation is presently considered. Non linear dynamic analyses are carried out by using both artificial and natural accelerograms (Masi *et al.*, 2008). For simplicity sakes, taking into account the major role of masonry infills on the seismic behavior of GLD buildings, only three types, beyond the buildings designed with seismic features, have been considered in the present paper, that is Moment Resisting Frames without infills (BF type), regularly infilled (IF type), and with pilotis (PF type). Results provided in (Masi, 2003) show that a high vulnerability can be assigned to the pilotis frames (PF). On the contrary, a low vulnerability (class D of EMS98) is shown by the frames with regularly arranged good quality masonry infills (IF). In this case the failure probability can be considered unlikely also after strong earthquakes. An intermediate behaviour (vulnerability class B-C of EMS98) is shown by the frames without infills or with ineffective infills (BF).

For what concerns masonry buildings, vulnerability evaluation is based on the Damage Probability Matrices (DPMs) set up by Braga *et al.* (1985) after the 1980 Southern Italy earthquake. Besides the vulnerability classes A, B and C of the MSK-scale, class D of the EMS98 scale, typically pertinent to earthquake-resistant structures, has been considered (Dolce *et al.*, 2003). Vulnerability class is assigned taking into account the following characteristics: vertical structural type; horizontal structural type; eventual retrofitting; age (before or after the seismic classification of the area. For simplicity sakes only two construction types, beyond the buildings designed with seismic features or retrofitted (widely present in some areas of Italian territory), have been considered. A high vulnerability has been assigned to buildings with bad quality masonry (rubble stone with vaults or wooden slabs), and a medium vulnerability (class C of EMS98) has been assigned to the buildings with good quality masonry (massive stone or brick with RC slabs).

Table 8.1 Vulnerability and exposure for the whole Italy (%, Potenza-RU)

Building type	Pc|I_{MM}=VI	Pc|I_{MM}=VII	Pc|I_{MM}=VIII	Pc|I_{MM}=IX	Popul. in urban area	Popul. in rural area
Masonry - Bad quality	1.0	5.0	35.0	70.0	7.0	1.0
Masonry - Good quality	0.0	0.0	3.0	10.0	9.0	3.0
Masonry - SD	0.0	0.0	1.0	6.0	4.0	1.0
RC-MRF-GLD Pilotis	1.0	4.0	25.0	53.0	20.0	0.0
RC-MRF-GLD Bare	0.0	0.0	8.0	23.0	10.0	1.0
RC-MRF-GLD Infilled	0.0	0.0	1.0	6.0	22.0	2.0
RC-MRF-SD	0.0	0.0	0.0	2.0	13.0	2.0

9. COMPARISON

To provide a more complete picture of the vulnerability models, in the comparison of the previous estimates, the vulnerability SP-BELA approach by (Borzi *et al.*, 2008a; Borzi *et al.*, 2008b) will be also included. This method estimates the vulnerability of the building stock from capacity (simplified pushover) and demand (spectral displacements anchored to a given value of PGA). In order to use the Modified Mercalli Intensity (I_{MM}) values provided by PAGER, the relationship between I_{MM} and PGA proposed by Decanini et al. (1995) has been selected. In the following results of this model will be referred as SP-BELA

Before proceeding to the comparison of the estimates, it is useful to analyze the vulnerability models adopted by each RU. The different methodologies can be summarized in terms of Strong Motion Parameter used, vulnerability model and building types considered. Both I_{MM} and PGA are well represented in the sample. Similarly both mechanical models, macroseismic models and models based on observational data have been used. All RUs addressed both masonry and RC buildings with the only exception of Naples-RU that addressed the only RC building vulnerability.

The fraction of population that lives in the considered building types is reported in table 9.1. In most of the cases all the population has been associated to building types. In some cases mixt buildings have been explicitly considered (Pavia/Eucentre and Padua), in the remaining cases they have been grouped with the masonry buildings. This explains some discrepancies among the RUs on the population that lives in masonry buildings.

Table 9.1 Fraction of population that lives in the considered building types (%)

	Masonry Buildings	RC	Other	Total considered
DPC	56.2	43.9	0.0	100
GENOA-RU	49.6	50.4	0.0	100
SP-BELA	43.8	43.5	0.0	86.3
PAVIA/EUCENTRE-RU	42.9	43.4	13.7	100
PADUA-RU	42.8	43.5	13.7	100
NAPLES-RU	0.0	30.5	0.0	30.5
POTENZA-RU	70.0	25.0	0.0	95.0

Coming to vulnerability estimates, from the previous tables a quite large scatter appears on the collapse probabilities, ranging for intensity I_{MM}=IX from few percent to more than 90 percent. The comparison is more complicated than the one on the population due to the fact that some RUs considered very detailed building types (Naple-RU differentiated RC buildings even for a one storey difference), even if characterised by small differences in collapse probabilities, while other RUs considered few building types (Padua-RU grouped together all masonry building). In the latter case the scatter in collapse probability may be very large. This is the reason why some RUs provided, instead of a single value, a range of collapse probabilities (Genoa-RU and Pavia/Eucentre-RU), given building type and seismic intensities. In these cases, in the following, for sake of simplicity the mean value of the collapse probability has been considered. For the same reason it is not possible to compare the collapse probability of a specific building type, being meaningless to compare the behaviour of a 7-storey GDL-RC buildings with the behaviour of a generic RC building. As an example, in figure 1, the collapse probability for all types of RC buildings is reported. The dashed line represents the average vulnerability. To overcome the mentioned difficulties, it has been reputed more interesting to group together several building types and compare, for each RU, the weighted average of the collapse probabilities, P_{cg}, assuming the weights proportional to the fraction of population that lives in the grouped building types.

$$P_{c,g} = \sum_{i=1}^{Ng} P_{c,i} Pop_i \Big/ \sum_{i=1}^{Ng} Pop_i \tag{9.1}$$

The index i ranges from 1 to N_g, the number of building types that, within each RU, one wants to group and average, e.g. all masonry building types. Note that the above quantity is also equal to the fraction of population involved in collapse with respect to the total population that lives in the grouped building types. If the grouped building types are representative of a quite broad building class (Masonry, RC, …), the results should be independent from the number of building types considered by each RU, so that the differences should be only related to the different methodology used. To this end building types have been grouped in i) masonry and mixt buildings, ii) GLD-RC buildings and iii) SD-RC buildings. Results are reported in Figure 2 and 3

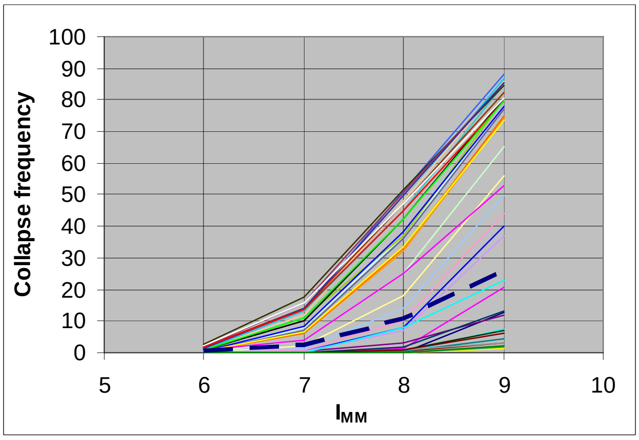

Figure 1 Collapse frequency - All RC building types and all RUs

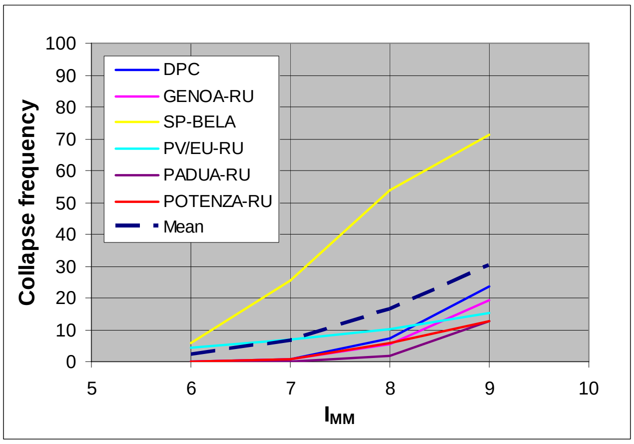

Figure 2 Collapse frequency – Masonry and mixt buildings

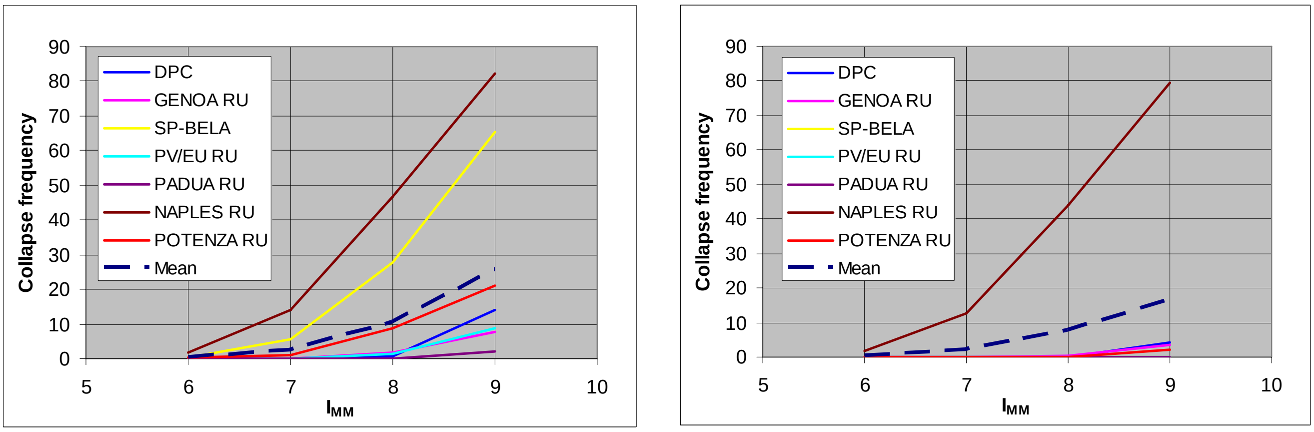

Figure 3 Collapse frequency – Left: GLD-RC buildings, Right SD-RC buildings

From the previous figures appears that purely mechanical models (SP-BELA and Naples RU) might overestimate the building vulnerability. This is due to the fact that mechanical models are an idealization of the actual building behaviour. In addition they are often based on the seismic code, that is generally on the safe side. The overestimate is more pronounced for SD-RC concrete buildings than for GLD-RC buildings. Masonry buildings appear to be in an intermediate condition. On the contrary empirical collapse frequencies represent observed values, that include all the variability due to material type, failure modes, etc. Since this application deals with the only collapse estimate, the well known damage overestimation of the empirical models at lower intensities did not introduce any significant bias in the estimate. However the extrapolation of the collapse frequencies to intensities higher than the felt ones and to Regions far from the affected ones may be questionable. The macroseismic models produced on average lower estimated. This is due to the assumption $I_{MM}=I_{EMS}$ and to the damage distribution reported in the EMS-98 scale.

Table 9.3. Fraction of population involved in the collapse of the buildings.

	Area \ Intensity	VI	VII	VIII	IX
Genoa RU	Italy	0.0	0.2-0.7	1.5-6.2	6.9-22.6
Genoa RU	Liguria Region	0.0	0.3-1.1	2.1-8.4	8.6-26.2
Padua RU	Italy	0.0	0.0	1.02	8.09
Padua RU	Veneto Region	0.0	0.0	0.78	7.51

The percentages shown in Table 4.1, 4.2, 7.2 and 7.3 may be also used to compare the number of inhabitants that would be involved in the total or partial collapse of the buildings at the national and regional level. Table 9.3 shows the results of this evaluation for different values of macroseismic intensity. The variability of the estimate in the considered Regions may be quite high in percentage (up to 50%), if the fraction of involved population is small. When the fraction of involved population is greater than 5% the variability ranges from 7% to 35% with an average value of 20%. Finally note that in Liguria Region the fraction of population involved in collapses is greater than in the whole Italy, while the opposite occurs in Veneto Region.

10. CONCLUSIONS

The paper presented the contribution of the Italian Research Units to the PAGER project, where DPC-SRO participated together with the following research units: Genoa-RU, Naples-RU, Padua-RU, Pavia/Eucentre-RU and Potenza RU. The PAGER project required the collapse probabilities of the most representatives building types and the fraction of population that lives and works, in urban and rural areas, in that building types.

The methodologies used by the different RUs have been summarized and the results presented and compared. It appears a large scatter in the estimate due to several reasons: i) the different vulnerability models used (empirical, macroseismic, mechanical), ii) the different criteria used to select the considered building types (one RU considered 2 RC building types, another considered 10 RC building types), iii) the different seismic action considered (I_{MM} or PGA), iv) the different conversion relationship used (I_{MM}-I_{MCS}, I_{MM}-PGA, I_{MM}-I_{EMS}, etc).

The previous sources of uncertainties cannot be easily quantified, so that it is quite difficult to evaluate their relative influence on the collapse probabilities. Each one of them may have a significant impact on the results. As an example, according to the DPC-SRO approach should one uses the I_{MM}-I_{MCS} conversion obtained combining the I_{MCS}-PGA Decanini (2005) and the I_{MM}-PGA Wald *et al.* (1999) relationships, the collapse probability for poor quality masonry building and intensity I_{MM}=IX would rise from 61% to 100%. In order to reduce the variability due to building types, a weighted average vulnerability has been considered for Masonry, GLD-RC and SD-RC buildings. The scatter in the estimates decreases, however it still remains significant. Regional variability has also been addressed in the paper, considering two Italian Regions: Liguria and Veneto. Differences in the order of 20% appeared in the fraction of population involved in building collapses.

One of the conclusions that can be drawn from this application is that the variability of the results may be very large, mainly in relation to the used methodology. Attention should then be paid to the use of the results. One possible solution is to highlight the associated uncertainty, evaluating the possible range of variability, as some RU did. In the future, in order to reduce the variability of the estimate, specific building types will be selected in advance and the RUs will be asked to provide the collapse probability for these building types.

We envisage that the PAGER project and the world-wide real-time estimates of fatalities due to earthquakes will benefit from this application.

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