Vulnerability analyses in a sample of 18 municipalities in the Veneto-Friuli area (NE Italy)

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ABSTRACT Preliminary classifications of the number of buildings and their volumes in every census section based on "poor" data obtained from national statistics (ISTAT91), are verified through a first-level survey form (AeDES) with a sample of 18 municipalities selected so as to represent the residential building types in the total area of interest in the provinces of Belluno, Treviso and Pordenone (NE Italy). Criteria in the selection of the sample of municipalities and in every municipality of a representative sample of census sections are discussed. The numerical results allow us to evaluate the actual vulnerability, depending on the local historical developments of building types and moreover, on the criteria used in the past century for seismic classification of their territories.

1. The area of interest

The area object of this analysis (in the continuation area AS1) is the territory of the provinces of Treviso, Belluno and Pordenone (NE Italy) for which the National Seismic Service (SSN) proposed seismic classification in the year 2000, as a result of updating the previous proposal of reclassification agreed between GNDT and SSN in year 1998. Such area coincides nearly exactly with that inserted temporarily in zones 1, 2, or 3 by the recent decree of the Presidency of the Council (2003), even if the level of classification can be locally different. Some global parameters related to area AS1 are given in Tables 1 and 2.

The area surrounds the northern part of the Venetian plain (the northern zone of the Treviso province and the flat southern zone of the Pordenone province, containing many historical centers, well-documented during the Roman period due to the presence of rivers and spring waters and to the fertility of the grounds) and the higher pre-Alpine zone, incised by large valleys, particularly the valley of the Piave River whose direct line to the plain is impeded by the Fadalto barrier and the Alpago elevations, so it turns toward west to the Belluno high-plain and overtakes the low plain near to the Montello hills.

See Poli *et al.* (2008) for a presentation of the geology of the area and of the active faults explaining the historical seismicity, and therefore the present seismic classification of the municipalities displayed in Table 2.

However, seismic activity during the 20^{th} century was somewhat weak, and substantially restricted to the 1936 event (Alpago earthquake).

In fact, the first seismic classification of the territory followed that year [Belluno, Longarone, the municipalities in the Alpago plateau, Vittorio Veneto and a part of the low plain in the Treviso Province (Pieve di Soligo)]; however, a great part of the municipalities (for example Vittorio

Table 1 – Global values of residential constructions in the area AS1 according to ISTAT91 data. AREA= surface of the territory; VOLUME: built volume obtained by the estimated residential surface multiplied by mean interstorey height (3 m); MASONRY: percentage of volumes of masonry buildings with respect to the total volume; BUILDINGS: estimated from DWELLINGS in an indirect way (Meroni *et al.*, 2000). BL=Belluno, TV=Treviso, PN=Pordenone.

Regione	Area (km^2)	Volume (km^3)	Masonry (%)	Residents (10^3)	Dwellings (10^3)	Buildings (10^3)
Veneto (BL+TV)	5926	0.135	61	939	397	231
Friuli (PN)	2261	0.040	54	273	118	76
Total	8186	0.175	60	1211	515	307

Veneto) were subsequently declassified at the end of the Second World War, and only after the Friuli earthquake (1976) or (in a more extended and justified way) in the new century, was the classification based on systematic considerations of the historical seismicity and of the geological characteristics of the area.

Consequently during the period of intensive building reconstruction following the end of the Second World War and even more during the expansive economic phase of the second half of the last century, a greater part of the territory was not considered as subject to seismic risk: therefore a considerable percentage of the actual residential buildings have been designed or retrofitted without any consideration of rules for protection against earthquake action.

2. Criteria for selecting the sample municipalities

In the province of Pordenone, 3 municipalities were selected in zone classified 2 (medium seismicity), of which one in the plain area (Porcia), a second in the mountainous zone, less interested by the effects of the Friuli earthquake of 1976 (Claut), the third, in the hills, heavily struck by this earthquake and therefore, later reconstructed (Meduno). Unfortunately due to unexpected difficulties it was not possible to acquire the data of Meduno and therefore, the sample was reduced to two municipalities over a total of 50.

Table 2 – Population of the communes in the area AS1 for province and seismic hazard classification.

Province	S = 1	S = 2	S = 3	Total
Belluno	4	16	46	66
Treviso	0	33	62	95
Pordenone	3	35	12	50
Total	7	84	120	211

Table 3 – Joint frequencies and selected municipalities in the Veneto area. The selected municipalities with head-office of the COM are underlined.

Soil	Seismicity S	Vulnerability G	Frequency in the AS1 area	Selected Frequency	Selected Municipalities
2	3	G3	35	3	VALDOBBIADENE (TV12) GIAVERA DEL M. (TV6), SEDICO (BL3)
2	3	G2	17	2	S. ZENONE D. EZZ. (TV4), SAPPADA (BL9)
3	3	G2	15	1	MANSUE' (TV18)
2	2	G3	12	3	PONTE D. ALPI (BL1), PEDEROBBA (TV11) VITTORIO VENETO (TV15)
2	3	G4	12	0	
1	2	G3	10	1	QUERO (BL2)
1	3	G4	9	0	
3	3	G3	9	0	
2	2	G2	6	1	GODEGA DI S URBANO (TV16)
1	2	G4	6	1	VAS (BL2)
1	3	G3	6	1	FONTE (TV4)
2	2	G4	6	0	
1	2	G2	3	1	LONGARONE (BL5)
2	1	G3	2	1	PUOS D'ALPAGO (BL4)
3	2	G2	2	1	PIEVE DI SOLIGO (TV13)
3	2	G3	2	0	

As far as the area in the Veneto region is concerned, a representative sample (nearly 10%) of the pertinent population of 161 municipalities, taking into consideration the following parameters has been attempted:

a - subdivision of municipalities by province : 9 over 95 in the province of Treviso, 7 over 66 in the province of Belluno;

b - level of seismic classification [decreasing hazard with S = 1, 2, 3; Lucantoni *et al.* (2001)]: in this case the choice of municipalities with S = 1 or 2 (frequencies in the sample from 20 to 25% of the population) has been preferred with respect to S = 3 (from 5 to 8%), taking into account their greater relevance to seismic risk;

c - type of soil: 3 categories (1, 2, 3) corresponding respectively to rigid, middle, soft, according to the definitions of Eurocode 8 (Briseghella, 2001);

d - a judgment on the mean building vulnerability in every municipality evaluated by previous research; the index G = 1, 2, 3, 4, 5, 6 [however the classes G1, G5 e G6 are practically empty in the considered area; Zuccaro *et al.* (2000)] has been selected;

e - subdivision of municipalities in COM ("Centri Operativi Misti" established by the Civil Protection Office to manage the emergencies) defined by the Regione Veneto in the provinces of Treviso (19 COM) and Belluno (9 COM); in choosing of the sample, the

Table 4 - The sample municipalities and their main characteristics.

Municipality	Province	Surface (km²)	Volume (m³)	Dwellings	Buildings	Residents	Soil	Seismicity	Vulnerability	COM
LONGARONE	BELLUNO	103.48	544,510	1,720	1,015	4,127	1	2	G2	BL05
PONTE NELLE ALPI	BELLUNO	58	1,078,300	3,506	2,355	7,556	2	2	G3	BL01
PUOS D'ALPAGO	BELLUNO	13.84	321,820	1,036	745	2,230	2	1	G3	BL04
QUERO	BELLUNO	28.25	330,610	1,067	732	2,054	1	2	G3	BL02
SAPPADA	BELLUNO	62.65	419,480	1,870	570	1,362	2	3	G2	BL09
SEDICO	BELLUNO	91.44	1,099,100	3,511	2,215	7,981	2	3	G3	BL03
VAS	BELLUNO	17.76	137,850	498	451	805	1	2	G4	BL02
FONTE	TREVISO	14.63	670,220	1,683	1,171	4,651	1	3	G3	TV04
GIAVERA DEL MONTELLO	TREVISO	19.91	549,940	1,432	1,041	3,795	2	3	G3	TV06
GODEGA DI SANT'URBANO	TREVISO	24.31	788,780	2,078	1,487	5,843	2	2	G2	TV16
MANSUE'	TREVISO	26.94	571,290	1,333	981	3,937	3	3	G2	TV18
PEDEROBBA	TREVISO	29.32	942,650	2,504	1,807	6,442	2	2	G3	TV11
PIEVE DI SOLIGO	TREVISO	19	1,375,700	3,682	2,525	9,284	3	2	G2	TV13
SAN ZENONE DEGLI EZZELINI	TREVISO	19.97	753,360	1,909	1,242	5,363	2	3	G2	TV04
VALDOBBIADENE	TREVISO	60.7	1,797,000	5,044	3,727	10,402	2	3	G3	TV12
VITTORIO VENETO	TREVISO	82.61	3,852,400	12,117	6,176	28,497	2	2	G3	TV15
CLAUT	PORDENONE	167.99	257,950	1,001	676	1,327		2	G4	
PORCIA	PORDENONE	29.89	1,539,300	4,711	3,047	13,083		2	G2	
Total		**870.69**	**17,030,260**	**50,702**	**31,963**	**118,739**				

greatest possible number of COM and in particular, the municipality with head-office of the COM was attempted. The municipality of Vittorio Veneto was chosen a priori because of particular interest for the general search.

Table 3 displays the joint frequencies (>1) of the parameters listed above at items b, c and d, and the selected municipalities (the municipalities with head-office of the COM are underlined).

In Table 4, the sample in the Veneto area is listed with the more significant parameters derived from ISTAT91 (ISTAT, 1995) data. In the same table, the two selected municipalities in the Friuli area are listed separately.

3. Criteria for selecting the representative census sections

Two criteria have been employed in the selection:

- nearly 10% of the number of buildings and their volumes;

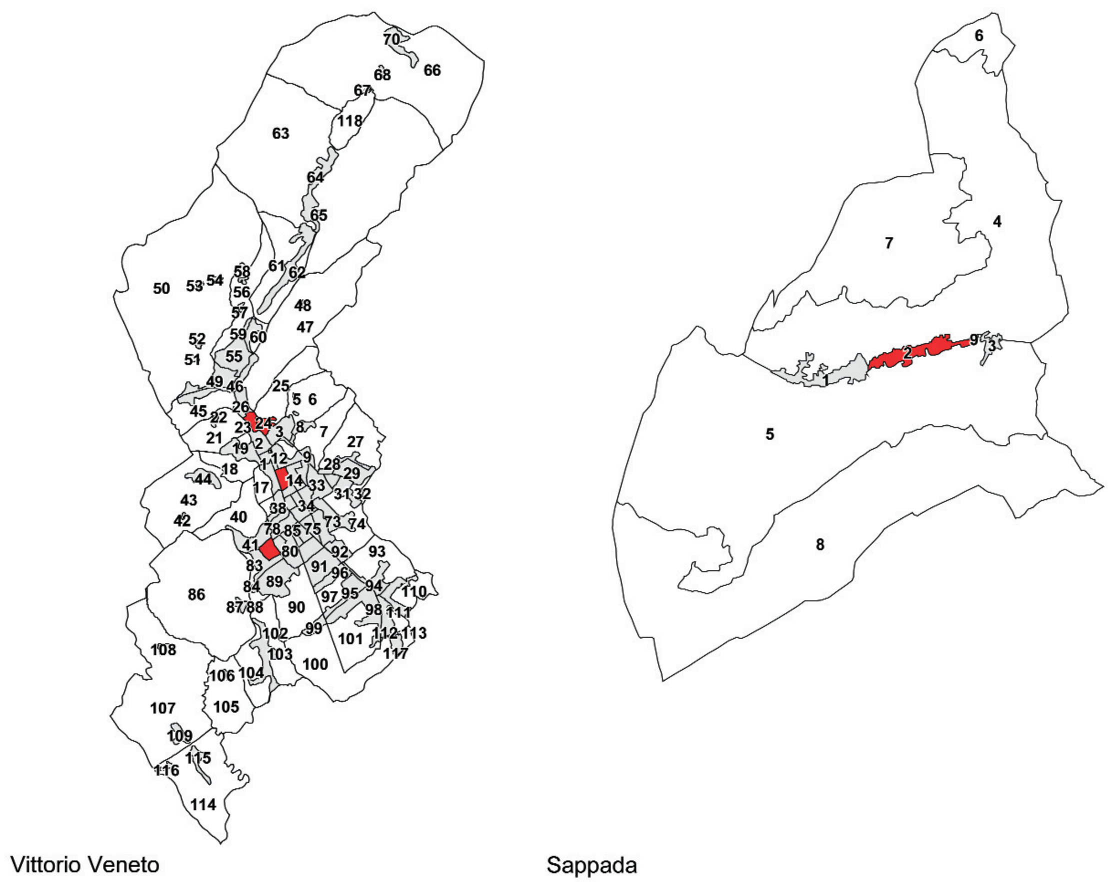

Fig. 1 - Maps of census sections and those selected (in red) for survey in the municipalities of Vittorio Veneto (TV) (left) and Sappada (BL) (right); with a considerable density of residential volumes (in grey the census).

- quantitatively, at best, the histograms of the relative frequencies of the uncorrected EMS98 (Grunthal, 1998) classifications of the whole municipality should be respected in the sample of selected census sections; the classifications are based on ISTAT91 data with the criteria presented in Bernardini *et al.* (2008);
- qualitatively the different types of buildings deriving from the historical development of each municipality should be represented in the sample.

An accurate analysis of historical, political and administrative vicissitudes has been carried out on each municipality separately to better evaluate and classify the existing construction type of residential buildings and their distribution in the census sections; moreover, the physical, topographical, geological characteristics of the territory and its historical seismicity have been considered. The history of the progressive development of buildings, villages and town centres has been reconstructed, and in particular, existing buildings constructed or retrofitted when rules of seismic protection were in force have been identified. The conclusions of these analyses have been used in choosing the census sections to be inspected, by compiling and recording the survey form AeDES (Bernardini, 2000) for all existing buildings in the years 2002-2003. See Bernardini

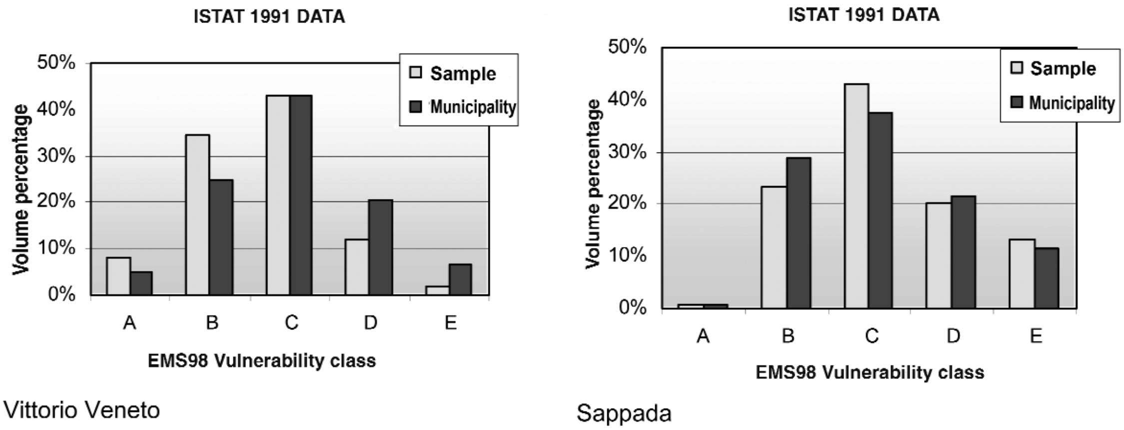

Fig. 2 - Percentage of residential volumes in the EMS98 vulnerability classes in the selected sample of census sections and in the total municipalities of Vittorio Veneto (left) and Sappada (right). Classifications from ISTAT91 data.

and Baldin (2005), Bernardini and Biscontin (2005a, 2005b), Bernardini and De Nard (2005), Bernardini and De Vecchi (2005), Bernardini and Fattor (2005a, 2005b), Bernardini *et al.* (2005a to 2005h) for details separately reported for each municipality.

In Fig. 1, for example, the subdivisions of census sections and those selected (in red) for the survey among those with a considerable density of residential volumes (in grey) are displayed in the municipalities of Vittorio Veneto (Treviso province) and Sappada (Belluno province). In Fig. 2, the distributions of the percentage of residential volumes in the EMS98 vulnerability classes of the selected sample of census sections in the same municipalities are compared with the corresponding distributions of the total municipality. Finally, in Fig. 3, the comparison is extended, separately, for the different construction types (MUR: masonry; TEL+MIX: r.c. or mixed masonry/r.c. buildings).

In Vittorio Veneto, the residential buildings are substantially grouped into nearly 50 census sections in the historical middle-age town centres of Serravalle and Ceneda, and moreover, in the more recent developments after the unification into the new municipality (1866), particularly in the area around the new municipal residence. Two census sections (23 e 24) were selected in the historical centre of Serravalle, one (82) in a zone of modern development around the town of Ceneda and finally, one (15) in the modern zone built up after the second world war with high-rise r.c. building types.

In Sappada, the residences are grouped into 3 census sections around the traditional villages along the main national road. In any case, the existing types are traditional masonry/timber constructions, generally well maintained and retrofitted according to seismic rules after the Friuli earthquake (1976) and the consequent seismic classification of the municipality. In this case, section 2 was selected for the survey.

In the 18 municipalities a total of 46 census sections were selected. The surveyors observed and recorded 5928 buildings, of which 3752 useful for the comparison with ISTAT91 data [because constructed before 1991 and used totally or partially (to the date of the survey: from

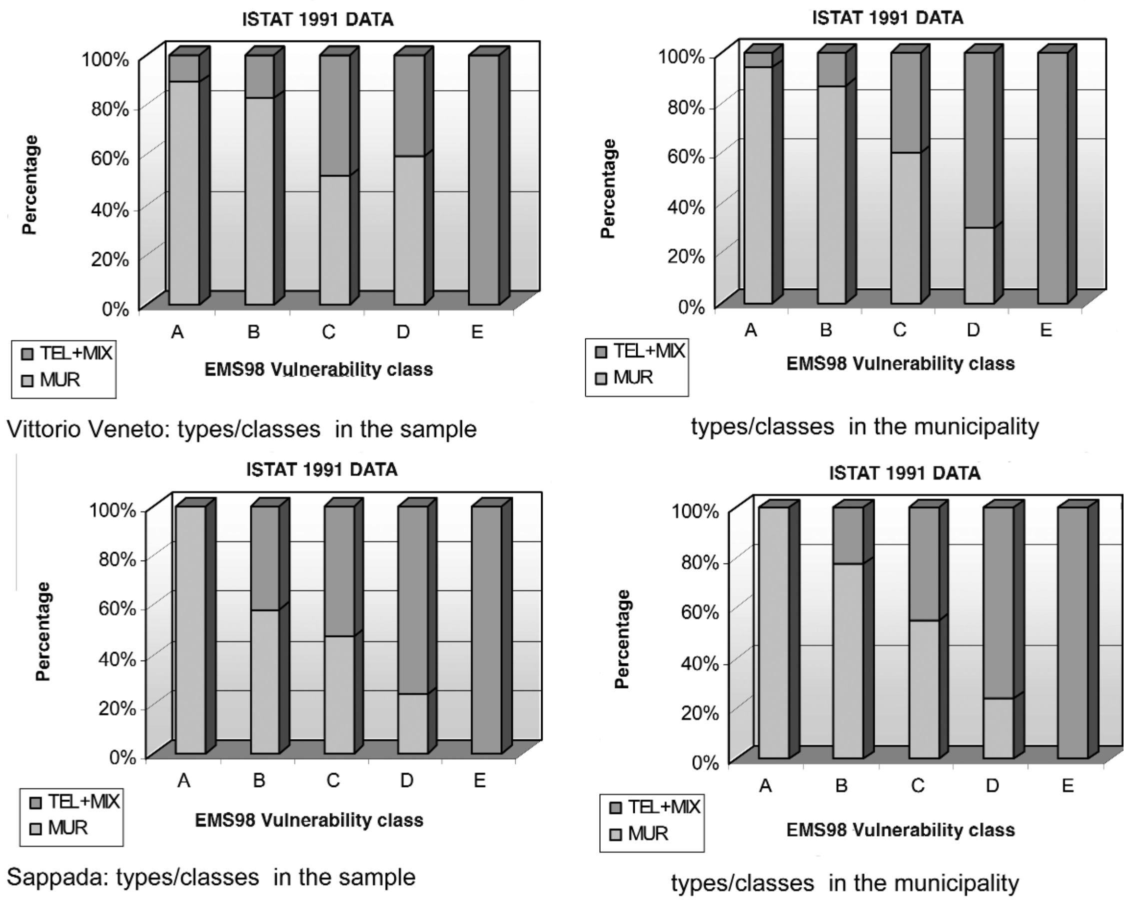

Fig. 3 - Percentage of the different construction types (MUR: masonry; TEL+MIX: r.c. or mixed masonry/r.c. buildings) in the sample (left) and in the total municipalities (right) of Vittorio Veneto (upper) and Sappada (lower). Classifications from ISTAT91 data.

2002 to 2004) for residential activity].

The EMS98 vulnerability class of each building has been attributed according to the criteria specified in Bernardini (2004) and Bernardini *et al.* (2008). The hypothesis CR (the more pessimistic one, but probably the most reliable) has been assumed to take into account the influence of retrofitting on vulnerability.

4. Numerical results

4.1. Comparison between ISTAT91 and AeDES classifications and corrective coefficients

In Figs. 4, 5 and 6, for example, the distributions in the EMS98 classes of the absolute number of buildings and volumes (thousands of m^3), based respectively on ISTAT91 data and AeDES survey, are displayed for the sample of census sections in some of the selected municipalities of the 3 Provinces [Fonte, Giavera del Montello and Vittorio Veneto (Treviso); Longarone, Puos

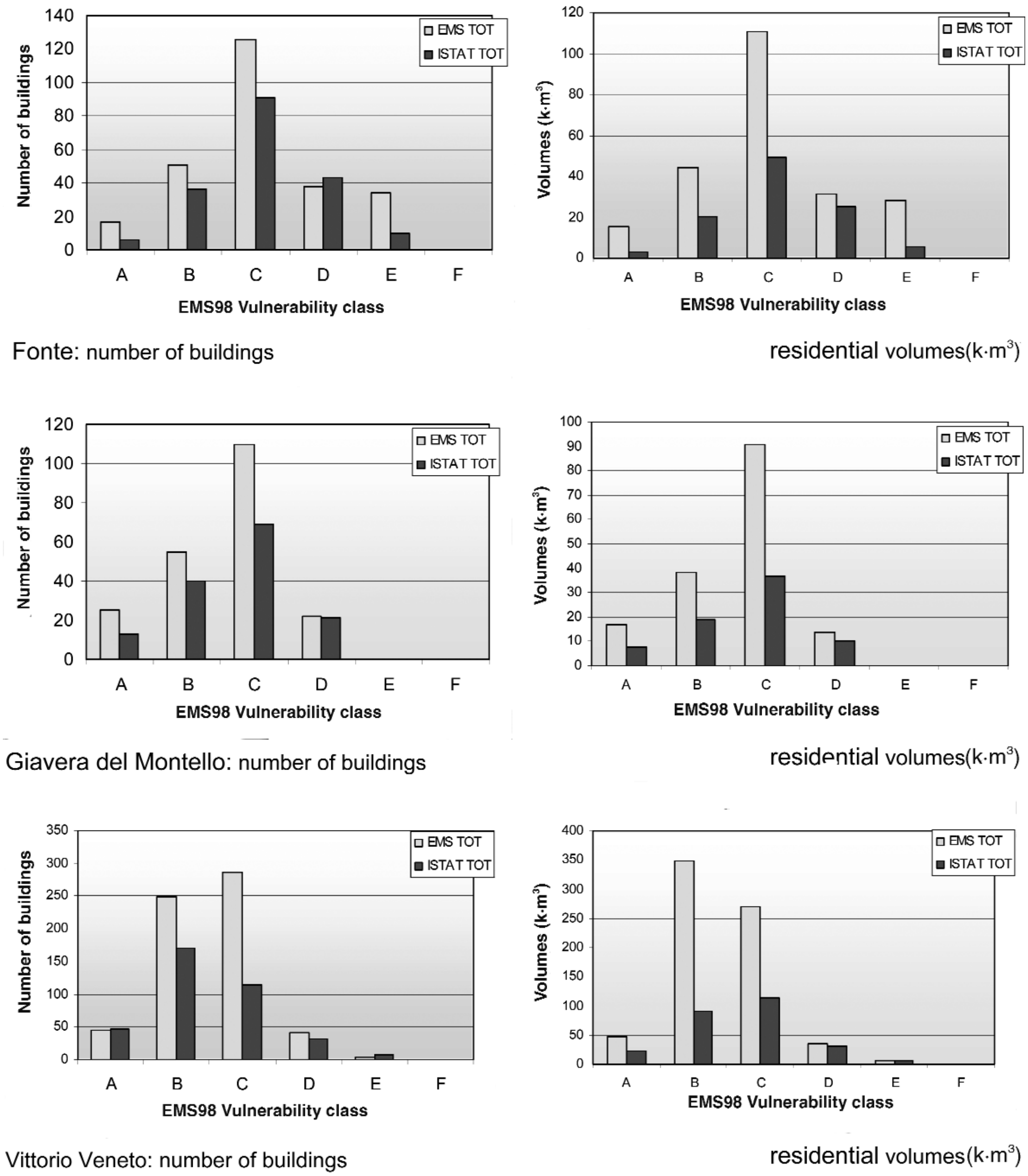

Fig. 4 - Comparison of ISTAT91 and AeDES EMS98 classifications in the sampled census sections in 3 municipalities of Treviso province.

d'Alpago and Sappada (Belluno); Claut and Porcia (Pordenone)].

As clearly displayed in the figures, although percentages in the original ISTAT91 distributions are substantially respected in the surveyed sections, the differences in their absolute values are frequently very great, particularly in the volumes. The volumes both global and subdivided into

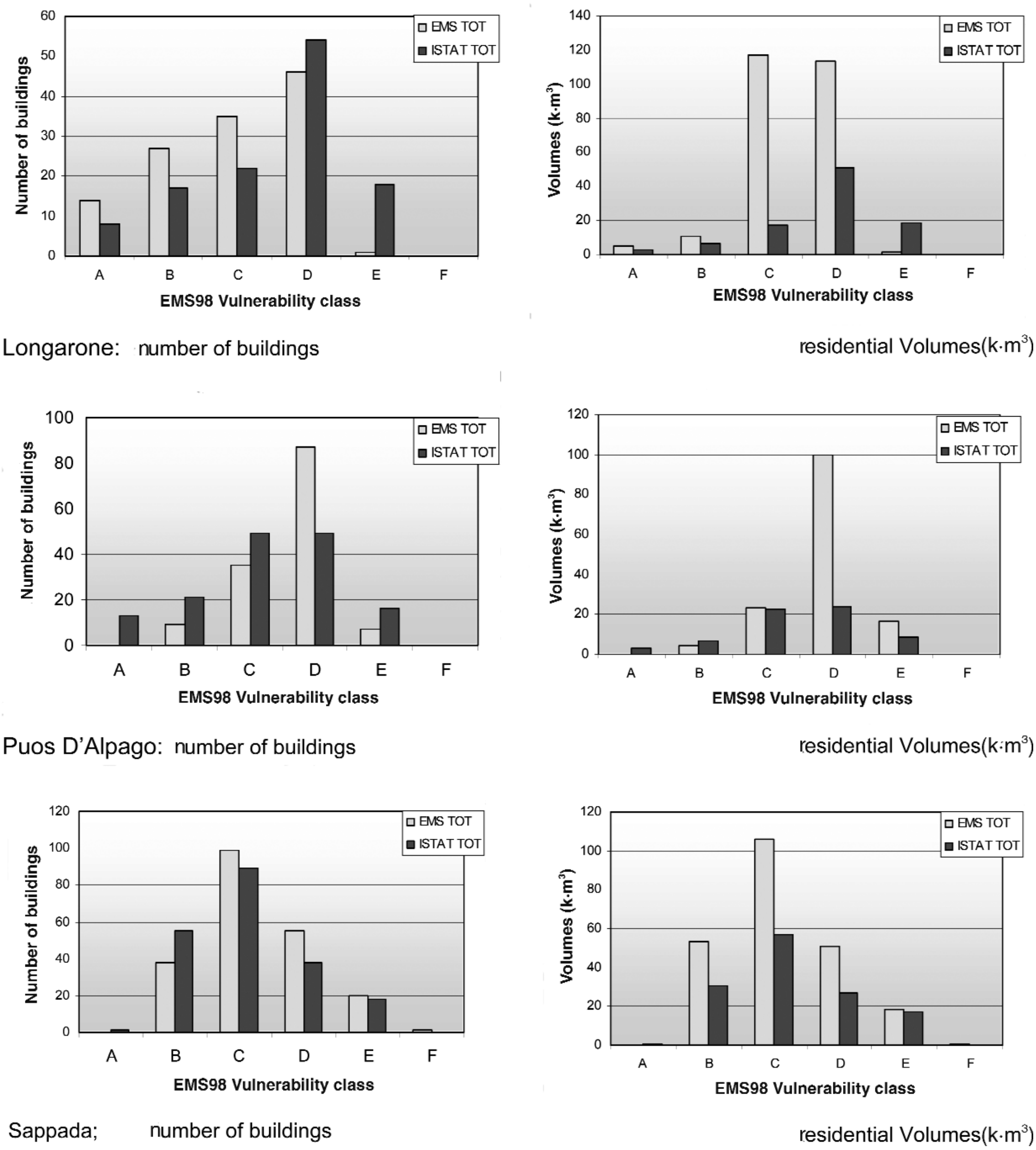

Fig. 5 - Comparison of ISTAT91 and AeDES EMS98 classifications in the sampled census sections in 3 municipalities of Belluno province.

the class values derived by ISTAT91 data are generally lower with respect to the corresponding values recorded in the AeDES form in the years 2002-2003.

Such differences derive only in a few cases from the buildings constructed in the years after 1991: in most cases, the explanation seems to clearly indicate inconsistencies or errors in the

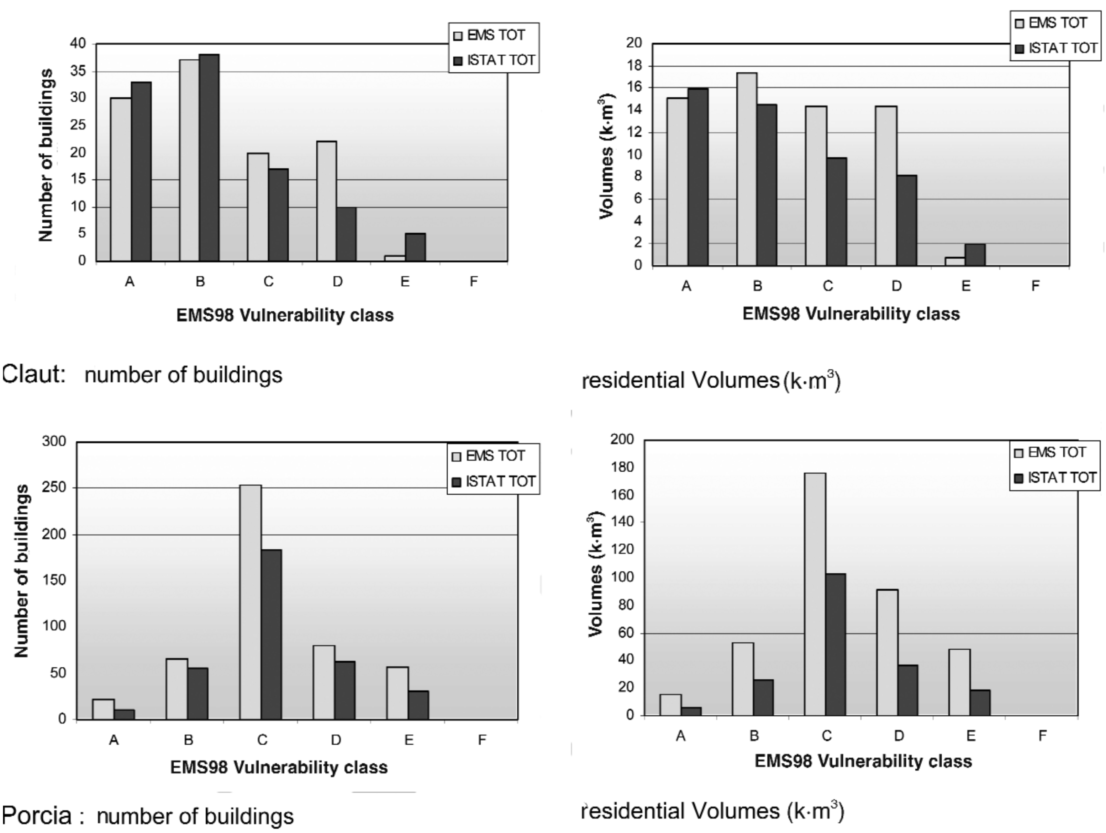

Fig. 6. - Comparison of ISTAT91 and AeDES EMS98 classifications in the sampled census sections in two municipalities of the Pordenone province.

original ISTAT91 data or are introduced by the approximations in estimating, the number of buildings and their volumes from the original data.

Therefore, it seems necessary to make some corrections of the original classifications based on ISTAT91 data, to better evaluate the present vulnerability of the total population of census sections in the area of interest. In Bernardini *et al.* (2004, 2008) alternative statistical criteria are discussed and final corrective parameters of simple or robust linear regression are suggested for uniform application in the total area, both for CR and RR hypotheses.

4.2. Corrected ISTAT91 classifications

In Fig. 7, the corrected ISTAT91 classifications are shown for the municipalities of Vittorio Veneto (Treviso), Puos (Pordenone), Longarone (Belluno) and Giavera del Montello (Treviso). Moreover, in the same figure, the corrected frequencies are displayed separately for masonry buildings and r.c plus mixed r.c/masonry buildings. The comparison of different municipalities allows us to appreciate the greater vulnerability when a considerable quantity of historical masonry buildings actually still exists (for example Vittorio Veneto) with respect to municipalities that were particularly developed in the second half of the last century.

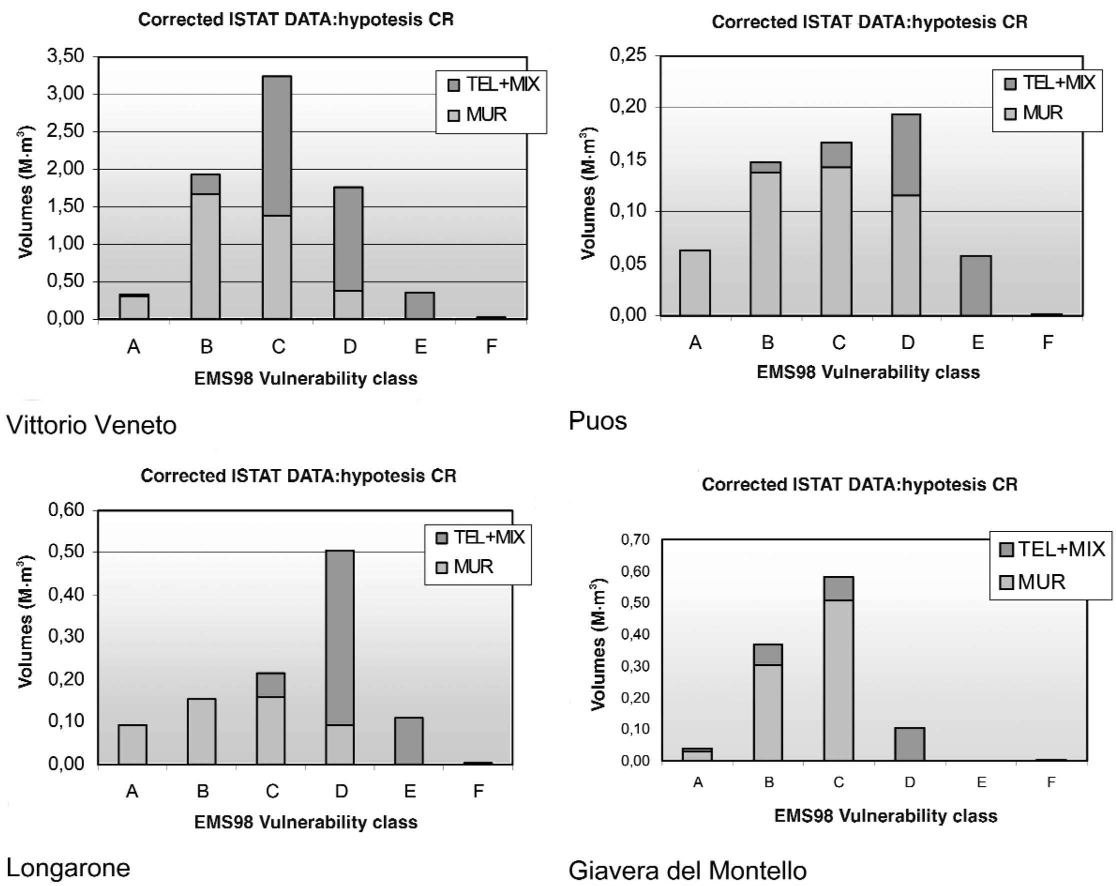

Fig. 7 - Corrected volumes (milion of m^3) in the municipalities of Vittorio Veneto (TV), Puos (PN), Longarone (BL).

Moreover, it allows us to appreciate the higher vulnerability of municipalities only very recently (2003) classified seismic zones (Giavera del Montello), with respect to municipalities classified as such since 1936 (immediately after the Alpago earthquake) and not declassified later (Puos), or also municipalities with a considerable quantity of new buildings built after extensive destruction due to catastrophic events (Longarone).

4.3. Damage scenarios for prescribed uniform intensities

The different vulnerability of the municipalities can be appreciated by observing the consequent expected damage conditional to the local earthquake intensity, supposed uniform here along the total area of the municipality.

For example, in Figs. 8 and 9, for the four municipalities considered in the previous chapter the expected number of buildings with damage > D2 (unusable buildings) after an earthquake of EMS98 macroseismic intensity VII and respectively IX are displayed and compared with the total, corrected number of buildings. The forecasting is obtained using the fuzzy damage

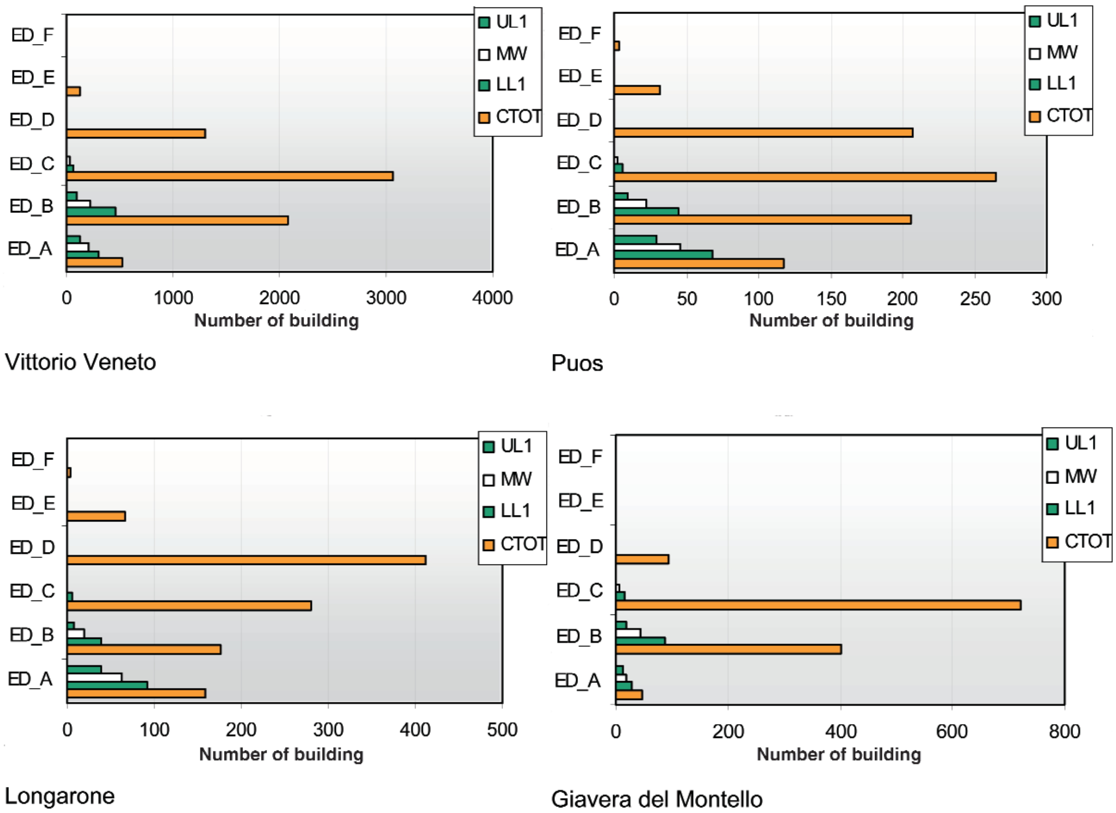

Fig. 8 - EMS98 macroseismic intensity VII: scenarios of damage >D2 for the corrected buildings in the municipality of Vittorio Veneto (TV), Puos (PN), Longarone (BL) and Giavera del Montello (TV). Hypothesis CR. MW: expected white binomial; UL1 and LL1: upper/lower bounds of uncertainty at level α = 1; CTOT: total number of buildings.

probability matrices implicit in the EMS98 scale, proposed and justified in Bernardini *et al.* (2004, 2008).

It can be observed that the epistemic uncertainty is greater for a middle/low intensity earthquake (VII EMS98) than for a high intensity one (IX EMS98) and, for equal intensity, greater for the intermediate vulnerability classes (B,C, D) than for the extreme ones (A, E).

5. Conclusions

The extensive on-site investigations in 18 municipalities sampled in the north-eastern zone of Italy, subject to a considerable level of seismic hazard, and the employment of an empirical model for the classification of buildings based on the criteria and definitions of the EMS98 macroseismic scale, allow ys to give some global measure and the distribution on the territory of the seismic vulnerability of residential constructions, showing the influence of the different

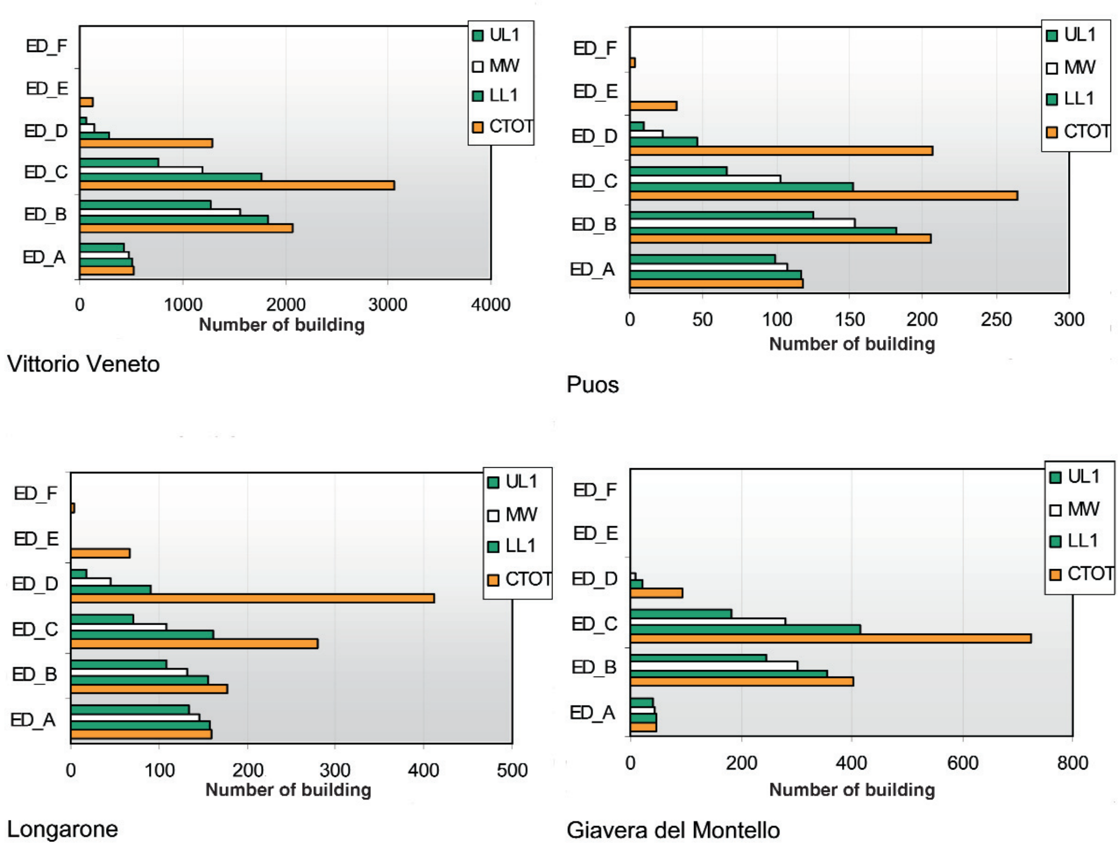

Fig. 9 - EMS98 macroseismic intensity IX: scenarios of damage >D2 for the corrected buildings in the municipality of Vittorio Veneto (TV), Puos (PN), Longarone (BL) and Giavera del Montello (TV). Hypothesis CR. MW: expected white binomial; UL1 and LL1: upper/lower bounds of uncertainty at level $\alpha = 1$; CTOT: total number of buildings.

construction types and moreover, of the different political choices on the seismic classification of the territory in the last century.

The survey demonstrates the low reliability of classifications based uniquely on national ISTAT91 data, but the possibility of evaluating corrective coefficients statistically justified for the 18 municipalities exists and therefore, indirectly possible for the overall area of interest.

The numerical results indicate, in a great part of the area, but particularly in the municipalities where traditional masonry buildings prevail and/or seismic rules for design and retrofitting were not enforced by law in the last century (at least until 1982 or in some cases until 2003), a prevailing percentage of existing buildings in the three more vulnerable classes A, B and C, and therefore, benefit and allows us to give priority for eventually planned programs of systematic retrofitting of the building stock.

The database on the vulnerability, implemented in the geographical system at the discrete level of the census sections, can be combined with information on local intensities and the set of damage probability matrices proposed in the ambit of the present research to evaluate probabilistic maps of seismic risk or scenarios of the expected damage due to deterministic reference earthquakes.

Some caution regarding the reliability of the final results seems, however, appropriate taking into account the only qualitatively justified sampling criteria in the choice of the selected municipalities and, in each one of the selected municipalities, of the census sections to be surveyed. Further research seems useful in future applications of the proposed procedure (hopefully based on the ISTAT 2001 data when available) to improve sampling criteria, and moreover, to increase the statistical confidence of both the corrective relations and of the classification criteria of the different construction types.

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