Damage scenarios in the Vittorio Veneto town centre (NE Italy)

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ABSTRACT A vulnerability model, based on the inventory of residential buildings given by ISTAT1991 data and corrected through the AeDES survey, has been applied to develop seismic damage scenarios in the most populated zone of the Vittorio Veneto municipality. The repetition of the 1936 Cansiglio event (magnitude 5.8) and of an event of magnitude 6.7 generated by an hypothetic seismic source located in the Montello area have been considered, taking into account amplification effects due to local soil conditions. Moreover, for the historic site of Serravalle, the scenarios have been refined considering a more detailed classification of the traditional masonry types, based on the application of mechanical approaches to a representative sample of buildings.

1. Introduction

The damage analysis described in the following has been carried out at a local scale, for the Vittorio Veneto municipality, considered representative of the situation of many towns in north-eastern Italy i.e. for its medium level of hazard and the vulnerability level of its building stock. The earthquake scenarios considered are based on the repetition of the 1936 Cansiglio event (magnitude 5.8) and on the predicted magnitude 6.7 Montello reference earthquake. The scenarios have been developed for two areas classified as medium-high seismic risk and located on the border of the provinces of Belluno, Treviso and Pordenone (Meroni *et al*., 2008). The hazard scenarios are calculated for rock conditions and are based on the analysis of Laurenzano and Priolo (2008, in the following referred to as PL) and on the analysis of Pettenati and Sirovich (2004) referred to as SP); local geotechnical amplification effects (Priolo *et al*., 2008) are included at a municipality scale, improving the resulting deterministic seismic ground shaking maps.

The elements considered at risk are the residential buildings and their inhabitants: data were obtained from the ISTAT (1995) census survey and they are gathered at the level of census sections. The vulnerability classification of the number and volume of building groups identified in each census section is obtained through a macroseismic methodology based on the EMS98 scale definition (Bernardini, 2004). The preliminary distributions in the 6 EMS98 vulnerability classes (decreasing vulnerability from A to F) have been successively corrected through a comparison of more reliable classifications of the buildings (surveyed by means of the national AeDES form) in a representative sample of census sections (Bernardini, 2008). Finally, the probabilistic damage assessment is evaluated by the implicit damage probability matrixes (DPMs) considered in the EMS98 scale (Grunthal, 1998).

Upper and lower bounds of the implicit DPMs and, also, a particular central "expected white" DPM have been identified through a fuzzy sets model of the linguistic definitions of the relative frequencies of damage grades in the different vulnerability classes conditional to the macroseismic intensity (Bernardini *et al*., 2008a). In the present work the binomial version of the DPMs was used.

Buildings are defined as unusable or collapsed and their quantification is based on the definition of different EMS98 damage level correlations (from D1 to D5), both in terms of numbers and volume of buildings. The collapsed buildings are defined as structures, with a high level of damage, that need to be demolished or to be strongly reinforced; the unusable buildings are structures not immediately usable in the first emergency phase.

The evaluation of the number of victims or homeless persons is carried out by using a modified correlation based on Italian data (Lucantoni *et al*., 2001).

In the following chapter 2, the risk indicators are defined and the numerical results of the expected damage, calculated in 51 census sections of the town, are presented.

In chapter 3, more detailed results for the historic site of Serravalle (corresponding to census sections n. 23 and 24) in the town of Vittorio Veneto are presented. The scenarios have been improved by considering a more accurate classification of the traditional masonry types based on the application of mechanical approaches to a representative sample of buildings.

2. Deterministic damage scenarios based on macroseismic vulnerability

Damage parameters are calculated as:

- collapsed buildings = all buildings with D5 level damage,
- unusable buildings = 40% of buildings with damage D3 + 100% of buildings with damage D4 or D5.

The expected number of victims (dead and injured) and homeless people are calculated as:

- victims = 30% of people residing in buildings with damage D5,
- homeless = 70% of people residing in buildings with damage D5 + 100% of those hit by D4 damage + 30% of those hit by D3.

To evaluate the number of residents in buildings of different classes from the total population in each census section, the number of inhabitants per building is assumed uniform.

The following caveats should be considered for the evaluation of the previous indicators:

(i) damage and victim assessment is based only on residential buildings,
(ii) time factors such as season or night/day conditions have not been considered, even if it could be assumed that the distribution of residents reflects the night-time condition,
(iii) induced risk factors (such as fires, landslides, ground breaking, etc.) have not been considered in evaluating the number of victims.

The evaluation of seismic damage for the Vittorio Veneto municipality takes 51 census sections into account, as shown in Fig. 1; they represent less than 43% of the total sections of the municipality and correspond to the most urbanized area of the town with 3,545 buildings (equal to 80% of the municipality building stock) and approximately 16,870 inhabitants. The considered area has an extension of 11.6 km^2 approximately and the total built volume is 3,777,490 m^3.

Both the Cansiglio and Montello events have been assumed as reference scenarios: the ground shaking values are calculated in MKS intensity degrees and they originate from the SP and PL simulations. In the case of the Cansiglio event, the SP scenario, for rock condition, provides grade VII MKS intensity for the entire municipality, while, according to the PL scenario, the felt intensity

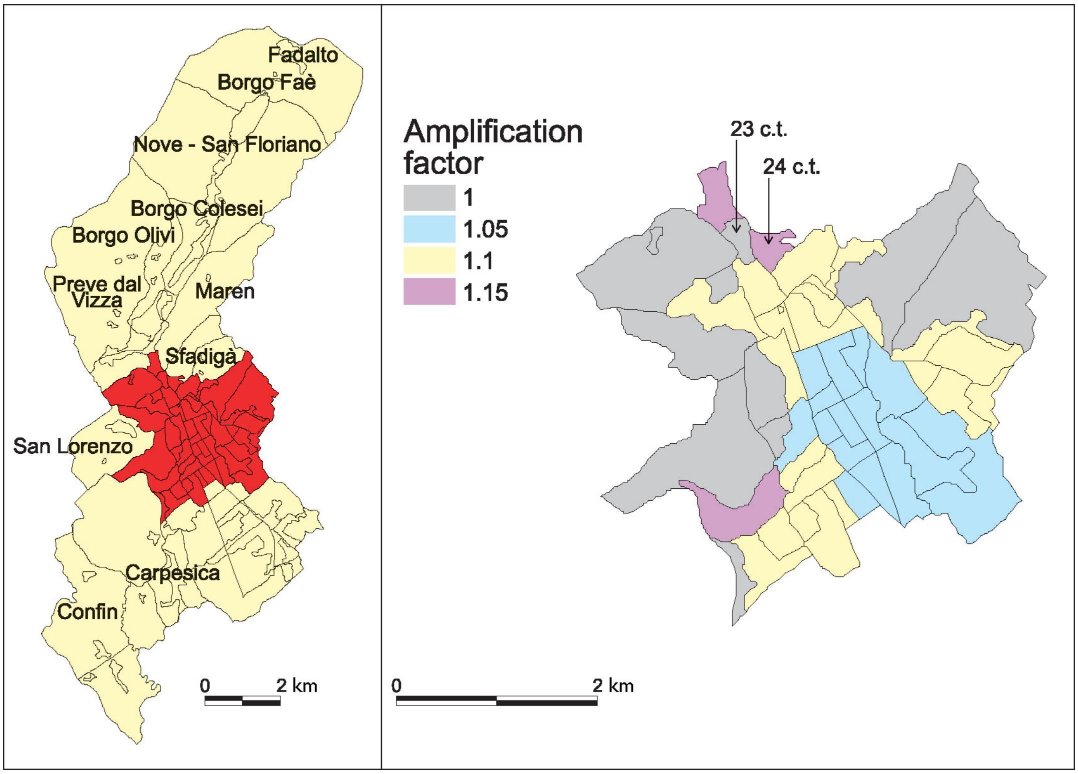

Fig. 1 - Location of the most populated census sections (red) of the Vittorio Veneto municipality investigated at a local scale, and (right) corresponding geo-morphological amplification factors adopted for the ground-shaking scenarios. Census sections n. 23 and 24 correspond to the historical site of Serravalle.

ranges from IV to VII (see maps of Meroni *et al*., 2008). In the case of Montello, the data used in this analysis are only from the PL simulation and the range of intensity values is larger (varying from VI to IX) because of the particular location of the seismic source.

The three ground shaking scenarios have been integrated with the amplification factors (Fig. 1, right) due to local geological and morphological effects, evaluated in each census section by means of detailed geo-technical analysis carried out in the area (Priolo *et al.,* 2008). The corresponding amplified hazard scenarios, derived for PL and SP simulations, are shown in Fig. 2.

Seismic losses have been evaluated with the method previously illustrated and the values of the expected damage indicators are summarized in Table 1 for different hazard scenarios.

The comparison of damage indicators illustrates their strong dependence on the seismic hazard scenario: there is a substantial discrepancy between the Montello and the Cansiglio scenario, because of the different magnitude of the events, but, within the same reference Cansiglio earthquake, different values of the damage indicators are obtained depending on the chosen simulation.

Maps of estimated damage for the 51 census sections of the Vittorio Veneto municipality have been elaborated in terms of collapsed or unusable buildings, victims and homeless. The distribution of victims and homeless for the three simulations are shown in Figs. 3 and 4, respectively.

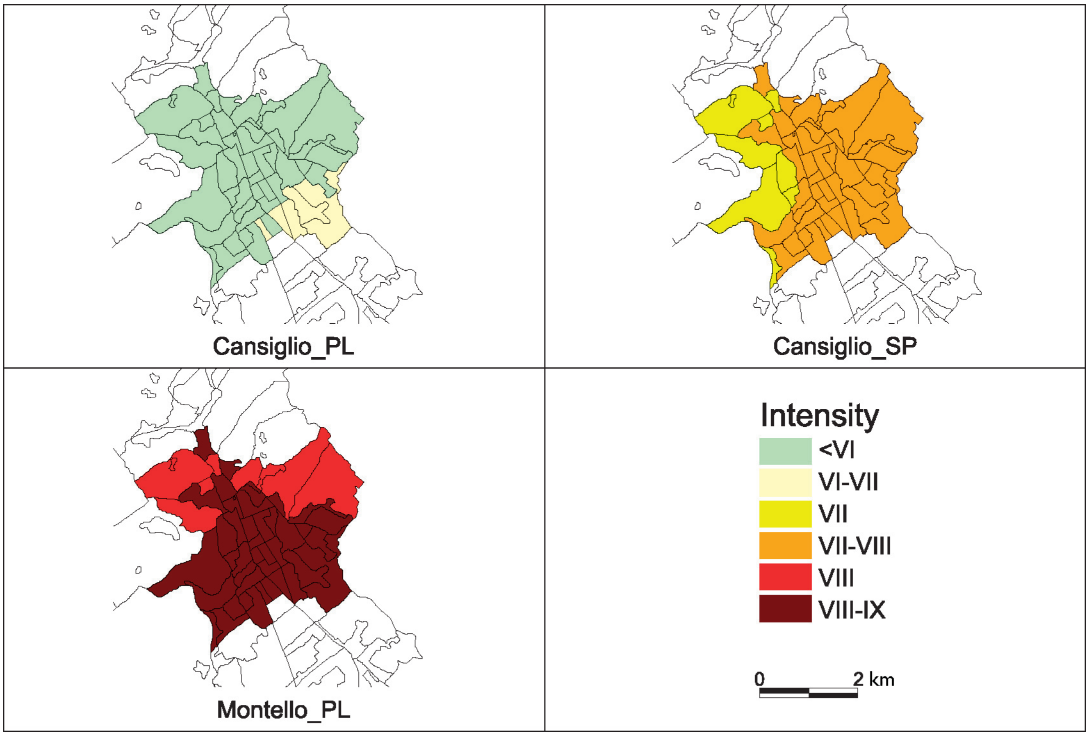

Fig. 2 - Ground shaking maps in the Vittorio Veneto municipality, according to PL and SP simulations, for the Montello and the Cansiglio reference events. Local soil effects are considered in the intensity MKS values.

3. Refined damage scenarios in Serravalle

A substantial influence on the values of the indicators obtained in the damage scenarios is also played by the vulnerability model adopted. Specifically, correlating a much more accurate measure of the vulnerability of the traditional masonry buildings performed for Serravalle and described in Bernardini *et al*. (2008b) with the EMS98 classification obtained by means of the macro-seismic

Table 1 - Absolute values of damage index for the Cansiglio and Montello scenarios, in the central area of the Vittorio Veneto municipality.

	Cansiglio scenario PL	***Cansiglio scenario SP***	***Montello scenario PL***
collapsed bldgs	0	6	48
unusable bldgs	3	125	480
collapsed volume (m^3)	0	4.327	40.369
unusable volume (m^3)	2.762	108.519	462.607
victims	0	7	64
homeless	14	547	2.111

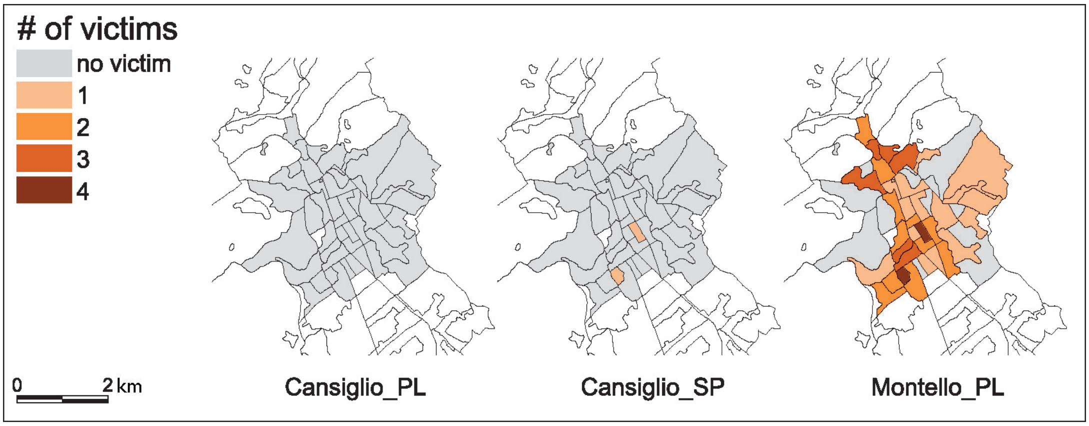

Fig. 3 - Distribution of the number of victims in each census sections, for the three hazard scenarios considered.

method, allows us to refine the damage scenarios in this area (census sections 23 e 24 in Fig. 1) with greater reliability. Here, all existing buildings were surveyed using the AeDES form and the scenarios for both the Montello and Cansiglio earthquake were again considered.

Moreover, two samples of masonry buildings representing the local typology (via Roma sample in section 23; via Casoni sample in section 24) were more accurately surveyed and their EMS98 vulnerability class evaluated using fragility curves obtained through an independent application of two mechanical methodologies [VULNUS and FaMIVE; as described in more detail in Bernardini *et al*. (2008b)]. The vulnerability class of each building as suggested by the mechanical model (either FaMIVE or VULNUS) can be compared with the class, sometime coincident but in many cases different, suggested by the macroseismic method based on the AeDES survey classification, modified by taking into account the more pessimistic judgement associated with the adverse effect

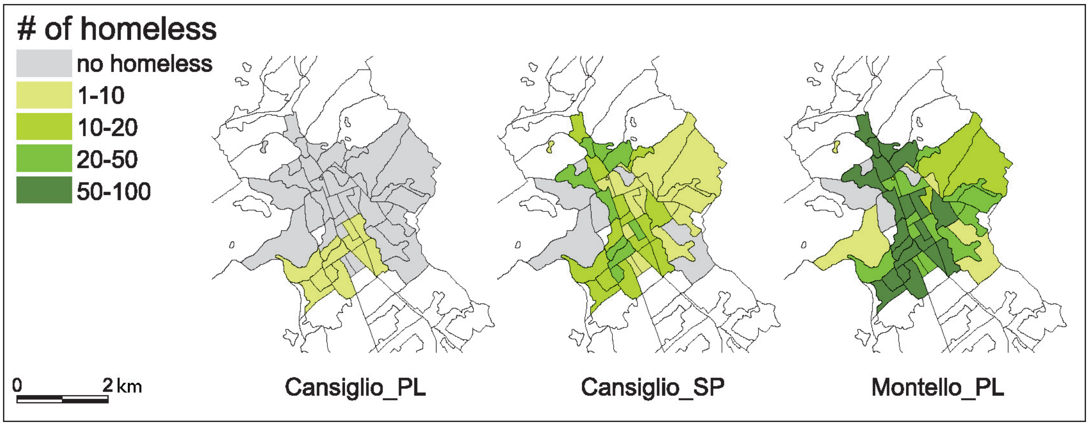

Fig. 4 - Distribution of the number of homeless in each census sections, for the three hazard scenarios considered.

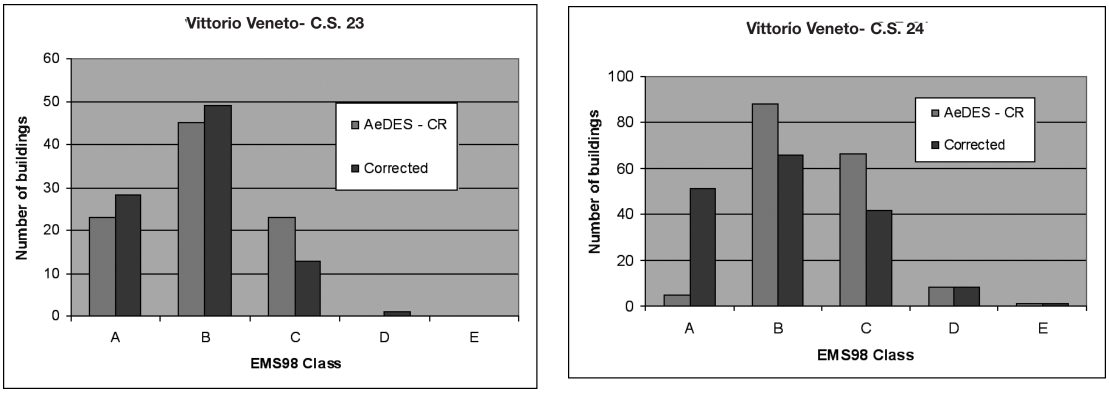

Fig. 5 - Uncorrected and corrected distribution of number of buildings per EMS98 vulnerability class respectively in the census sections 23 (via Roma) and 24 (via Casoni).

of past structural alterations [CR hypothesis: see Bernardini (2008) and Bernardini *et al.* (2008a)]. Such comparison yields a matrix of joint relative frequencies for every couple of macro-seismic and mechanical classes for each sample of buildings.

The mean values of the relative frequencies determined separately by applying VULNUS and FaMIVE to each sample are then assumed as joint probability of each couple of EMS98 vulnerability classes, for the total population of masonry buildings in the census sections of Serravalle. Therefore, corrected marginal distributions of masonry buildings in the EMS98 classes A, B, C and D can be derived from the uncorrected marginal distributions obtained with the AeDES survey, and further combined with the distribution of the more recent r.c. building types to refine the vulnerability distributions in the two sections (Fig. 5).

Finally, in Figs. 6 and 7, the refined damage scenarios for the assumed earthquakes of Montello and Cansiglio are displayed for the total area of Serravalle (census sections 23 and 24).

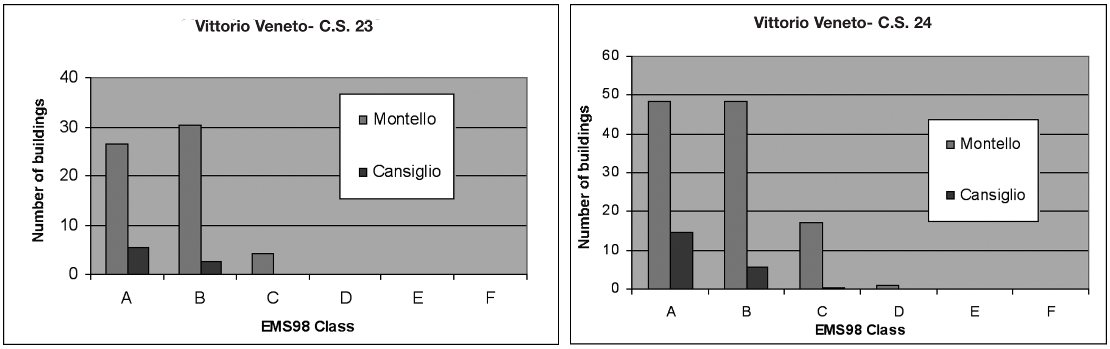

Fig. 6 - Refined damage scenarios in Serravalle (census sections 23 and 24). Macroseismic vulnerability by AeDES (CR hypothesis) corrected through VULNUS/FaMIVE procedures. DPM: binomial "expected white". Local Intensities: mean of the values given separately by SP and PL.

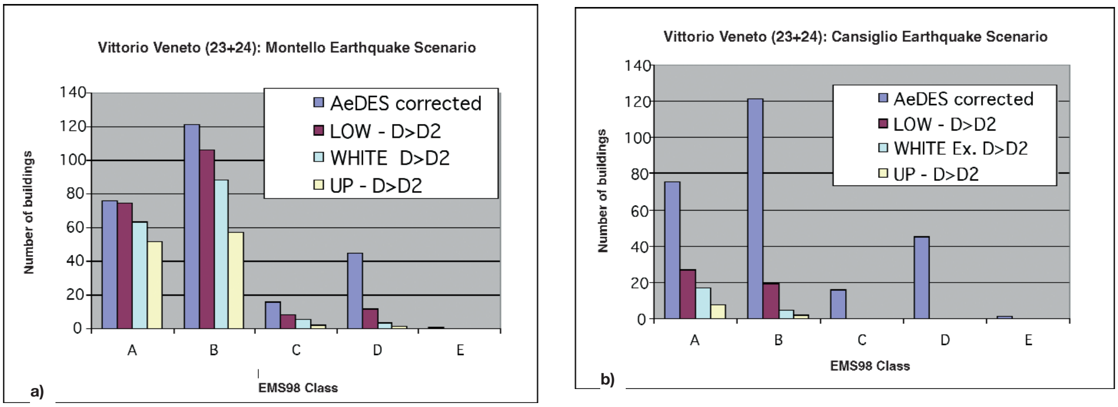

Fig. 7 - Damage scenarios in Serravalle (census sections 23 and 24) due to the Montello (a) and Cansiglio (b) earthquakes. The corrected attribution of buildings to EMS98 class is compared with the forecasted expected number of buildings with damage > D2 respectively evaluated with the "white" DPM implicit in the EMS98 scale and the bounds of the fuzzy sets measuring the linguistic frequencies (Bernardini *et al.,* 2008a).

The scenarios forecast the expected number of buildings with damage >D2, assuming the mean value of the *PGA* in every section given for each earthquake by PL and SP respectively, and multiplied by the local soil amplification factor. The correlation suggested by Slejko *et al.* (2008) is used to evaluate the local EMS98 macroseismic intensity from the *PGA*.

In Fig. 6, the "expected white" DPM has been used to give a mean central value of the expected number of buildings.

On the other hand, Fig. 7 displays a remarkable scatter with respect to these central values of the number of damaged buildings, due to the uncertainty on the effective implicit EMS98 DPM: the upper and lower bounds are shown corresponding to the alfa-cuts obtained for $\alpha= 0$ ed $\alpha= 1$ of the fuzzy sets measuring the linguistic frequencies in the scale (Bernardini *et al.*, 2008a). This scatter however does not take into account the further uncertainty related to the assumed local intensities. It can be, moreover, noted that the prediction improves substantially when the intensity of the earthquake is closer to the higher structural damaging intensity associated to the EMS98 classes. This explains the better forecast obtained for the Montello event, with respect to the Cansiglio event, for classes A and B.

4. Conclusions

The vulnerability analyses and the seismic damage scenarios with intensity level congruent with the historical seismicity and the local geological evidence of the active sources, confirm the remarkable seismic risk of the residential buildings in Vittorio Veneto where rules imposed by seismic protection codes have been applied only to structures built after 1937.

In this work, the fragility of the highly valuable historic site of Serravalle has been displayed.

However, the scatter with respect to the central estimates of the damage obtained on the basis of the available inventory of the buildings [ISTAT (1995) data; AeDES survey of a sample of census sections; accurate survey of samples of masonry buildings] is generally very high, especially for buildings in the most populated, intermediate vulnerability classes (B, C, D) and for low to medium values of earthquake intensities.

Further research is therefore recommended to reduce the scatter, both by refining the inventory [e.g. on the basis of ISTAT 2001 data, when available] and by better calibrating the employed macroseismic and mechanical vulnerability models.

In any case, the available evidence is reliable enough to recommend systematic retrofitting programs, particularly to reduce the actual vulnerability of the oldest masonry constructions.

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