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Site effects in Fabriano from post-earthquake typological and damage data collection

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Abstract - Post earthquake site effect evaluation is a necessary step in any reconstruction strategy. Although several approaches are available today, the time required for a detailed microzonation is not usually compatible with the reconstruction process. In this paper a probabilistic methodology able to estimate seismic intensity at any building location from post-earthquake building type and damage data, is proposed. The seismic intensity is evaluated by means of a Bayesian approach that requires previously assessed vulnerability functions and takes into account uncertainties in building type and building damage. An application for the town of Fabriano, hit by the 1997 Umbria-Marche earthquake is presented. Results are compared with the amplification of the ground motion predicted by the detailed microzonation.

1. Introduction

Just after the main shock of the 1997 Umbria-Marche sequence, damage surveys in epicentral areas and preliminary in situ tests (Capotorti et al., 1997) showed the importance of the site effects on the local seismic intensity. Other recent Italian, European and world wide earthquakes have confirmed the importance of the phenomenon.

At the end of the Umbria-Marche earthquake emergency, microzonation studies were carried out in order to evaluate the amplification of the ground motion to be used in the design to strengthen the buildings. However, the time required for the acquisition, harmonisation and analysis of the geological and geotechnical data is not, usually, acceptable in relation to the reconstruction process. The proposed solution for the Umbria-Marche reconstruction was a "quick" site effect evaluation based on geological, geomorphologic, hydrogeological and

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seismostratigrafic conditions at village level and on a numerical analysis on a reduced set of selected cases. The study regarded 465 centres and produced (CNR-IRRS, 2000), amplification values ranging from 1 to 2 and, in 86 % of the sites, from 1 to 1.5. A more detailed microzonation concerned the historic centres of Fabriano, Nocera and Sellano (Marcellini et al., 2001), two recently built districts of Fabriano and several localities near Nocera. The microzonation was based on soil properties, evaluated by means of geological and geotechnical data, and on seismic signal analysis. Damage to buildings was also taken into account by comparing the damage map with the map of soil properties. In this comparison, the building type is usually disregarded: the damaged buildings are just pinpointed on the map (Ambrosini et al., 1986), considering the damage simply as a direct measure of the seismic motion. However, for the damage to be an effective measure of the ground shaking, it has to be filtered by building type, since the vulnerability obviously affects the damage level. This has been done in the Fabriano, Nocera and Sellano microzonation. By using the typological and damage data collected in the post-earthquake survey, the observed damage level was transformed into the virtual damage level which was suffered at the same site by a building of a reference typological class, which, in this case, was the most vulnerable class. We now propose a different approach, where the macroseismic surveyed intensity in the analysed village is used as an initial estimate of the local intensity, defined as the seismic intensity experienced by each building. Using previously assessed vulnerability functions together with a Bayesian approach, the initial estimate has been updated and the distribution of the local intensity, for a given surveyed building type with a given damage level, evaluated. In the following, the proposed methodology is described in detail and an application for the town of Fabriano, which was struck by the Umbria-Marche 1997 earthquake is presented.

2. How to get seismic intensity from building damage

In order to estimate seismic intensity from observed building damage, in other words to estimate the cause (seismic intensity) that produced the effect (observed damage), an inverse problem should be solved. In the following, the building vulnerability, expressed by means of the observed damage d when building type T is affected by seismic intensity q, (see the explanation of the symbols in Table 1), will be supposed known and with the following expression:

$$d = f\,(T, q) \tag{1}$$

The function f gives the form of the cause-effect law and can be either a deterministic or a probabilistic relationship. For simplicity, seismic intensity will be considered a discrete variable. If detailed building data, according for example to II or III level inspection forms, are available, Eq. (1) is sometimes a deterministic relationship. This is the case of indirect vulnerability methods (Benedetti and Petrini, 1984), where T represents the vulnerability index. If Eq. (1) is also a one to one relationship, it can be inverted, once T is known, to obtain q. Generally,

Table 1 - Symbols.

C = binomial coefficient

d = observed building damage

d_m = mean non dimensional damage

d_s = damage to vertical bearing structures

d_t = damage to infill walls

D = surveyed damage levels

e = surveyed damage extension

f_{cr} = relative frequency of building collapse

I_c = a posteriori macroseismic intensity in the examined area

I_{co} = a priori macroseismic intensity in the area

I_o = 1997 Umbria-Marche epicentral macroseismic intensity

I_{ref} = reference macroseismic intensity in the area

$p\ (T,I)$, $g\ (T,I)$ = parameters of building vulnerability functions

q = seismic intensity

q_o = a priori seismic intensity experienced by one building

q_c = spatial average of the a posteriori seismic intensity in the area

q_{co} = spatial average of the a priori seismic intensity in the area

q_{ref} = seismic intensity in the reference site

q_{sb} = a posteriori seismic intensity experienced by one building

n = number of damage levels

N_{tot} = number of surveyed buildings in the area

T = building type

ε_I = error term affecting felt macroseismic intensity

ε = amplification of the seismic intensity

Γ = collapse distribution in vulnerability functions

$E\ [\ ]$ = expected value of [ ]

$P\ (\ )$ = probability of ( )

however, Eq. (1) is not a one to one relationship, because deterministic models predict the collapse (null damage) when buildings have experienced a seismic intensity greater than (inferior to) a given level. From the observed damage it is then impossible to estimate seismic intensities greater or less than the above mentioned limits. In other words, when the building is undamaged, all the intensities less than the lower limit are admissible, whereas, when the building has collapsed, all the intensities greater than the upper limit are admissible. The physical reason for the drawback described is that the instrument of measure, i.e. the building, is not sensitive enough to small seismic intensities in relation to the quantity that needs measuring, i.e. the observed damage. And, at the same time, the instrument saturates at high seismic intensity, when the building collapses. The upper and lower intensity thresholds clearly depend on building type. A pre-requisite for a greater chance of estimating the seismic intensity from the observed damage, is to have buildings with different vulnerabilities. Luckily, at least in Italy, earthquakes are not so destructive, while damage, due to high building vulnerability, is high. So, in many cases, the estimate of the seismic intensity from the observed damage can be effectively performed, although, from a methodological point of view, the above-mentioned difficulties still remain.

Going beyond the deterministic approach, the uncertainties in building behaviour are taken into account in Eq. (1) by introducing a probabilistic vulnerability function, that gives the observed damage distribution conditional upon building type and seismic intensity. The approach is commonly used when classes of structures are considered and post-earthquake I level typological and damage data are available. In this case, as seen in the inversion of Eq. (1), the distribution of the seismic intensity that affected the building can be obtained only with an additional hypothesis.

A complete probabilistic approach also requires the introduction of uncertainties on building type and observed damage. Generally, the building type can not be univocally determined, due to the lack of data and/or to uncertainties in the attribution of a specific vulnerability class. The damage classification can also be uncertain, in relation to the extension and to the intensity of the observed damage in the different building components. Being all the possible damage levels and all the possible building types a complete and disjointed set of events, making use of the total probability theorem (Benjamin and Cornell, 1970), one gets:

$$P\,(q) = \Sigma_T\,\Sigma_d\,P\,(q/d,\,T)\,P\,(d)\,P\,(T) \tag{2}$$

where $P(q)$ is the probability that a single building experienced a seismic intensity q and $P(q/d, T)$ is the same probability when the building type is T and the observed damage level is d. The uncertainties in damage and building type classification have been considered independent. Being related to the generic building, the local intensity will be reported as q_{sb}. From post-earthquake data collection (Braga et al., 1982) or via numerical analysis (Masi et al. 2001), Eq. (1) can be assessed as a probabilistic vulnerability function. It can be expressed as $P(q/d, T)$, representing the probability that building type T suffered damage level d when seismic intensity q occurs. If $P(q/d, T)$ is obtained from a statistical analysis on surveyed data, the survey should be complete at least in terms of d. Buildings with any damage level, including null damage and total collapse, should be surveyed if belonging to type T and subjected to intensity q. In practice, a suitable selection is made among the sites where the same intensity q has been felt, in order to reduce the buildings to be surveyed, while completeness in terms of d and T is maintained.

Similarly, in order to obtain $P(q/d, T)$, that is needed in Eq. (2), a complete survey at least in terms of q is required. Buildings of type T that suffered damage level d should be surveyed in all the sites with different felt intensity q. The latter requirement is essential also in order not to introduce any bias due to large building concentration in specific areas. Being a similar survey almost impossible to perform, if vulnerability function $P(d/q, T)$ is known, a Bayesian approach (Benjamin and Cornell, 1970) can be used to obtain $P(q/d, T)$. Because all the possible seismic intensities, q, experienced by each building are a complete and disjointed set of events, one has:

$$P\,(q/d,\,T) = P\,(d/q,\,T)\,P(q_o)\,/\,[\Sigma_i\,P\,(d/q_i,\,T)\,P\,(q_{oi})] \tag{3}$$

where the summation is to be performed over the $i = 1, ..., N_q$ discrete values of the seismic intensity introduced in the analysis. $P(q_o)$ is the a-priori probability that the generic building experienced a felt intensity q_o due to the earthquake and does not have, obviously, any hazard meaning. Being related to the generic building, it represents a local intensity distribution, but as an a-priori estimate it can be confused with the distribution of the seismic intensity in the whole analysed area, $P(q_{co})$. Then, by inserting Eq. (3) into Eq. (2), for each building one has:

$$P(q_{sb}) = \Sigma_d \, \Sigma_T P(d/q_{sb}, T) \, P(d) \, P(T) \, P(q_{co}) \, / \, [\Sigma_i P(d/q_i, T) \, P(q_{coi})] \tag{4}$$

The previous equation maps one distribution, the a-priori felt intensity in the area, into many distributions, the a-posteriori felt intensities, one for each building. The main drawback of the present approach is that the spatial correlation of the ground motion is neglected.

In the case of deterministic building type classification, $P(T)$ should be set equal to 1 in Eq. (4) if T is the building type, while for deterministic damage classification $P(d) = 1$ if d is the damage suffered by the building. The expected local intensity for each building can be assumed as $E[q_{sb}] = \Sigma_j \, q_j \, P(q_{sbj})$, where, again, the summation is to be performed with respect to all the $j = 1, .., N_q$ discrete levels of seismic intensity.

3. The a-priori intensity distribution

The a-priori intensity distribution is an essential ingredient of the model and requires a deep analysis. If the surveyed buildings are sufficiently uniformly, spatially spaced and if they can be considered equally reliable, also the local seismic distributions $P(q_{sb})$ are uniformly, spatially spaced and equally reliable. So the a-posteriori distribution of the seismic intensity in the area can be assumed as the average distribution of the local intensities:

$$P(q_c) = \Sigma_b \, P(q_{sb}) \, / \, N_{tot} \tag{5}$$

where the summation is to be performed with respect to the $b = 1, .., N_{tot}$ buildings surveyed in the centre. Substituting Eq. (4) in Eq. (5) one gets:

$$P(q_c) = (1 / N_{tot}) \, \Sigma_b \, \Sigma_d \, \Sigma_T \, P(d/q, T) \, P(q_{co}) \, P(d) \, P(T) \, / \, [\Sigma_i \, P(d/q_i, T) \, P(q_{coi})]$$

The relative difference between $P(q_{co})$ and $P(q_c)$ is then:

$$[P(q_{co}) - P(q_c)] \, / \, P(q_{co}) = 1 - (1/N_{tot}) \, \Sigma_b \, \Sigma_d \, \Sigma_T \, P(d/q, T) \, P(d) \, P(T) \, / \, [\Sigma_i \, P(d/q_i, T) \, P(q_{coi})]$$

It seems reasonable to select $P(q_{co})$ to reduce the difference between the a-priori and the a-posteriori intensity distribution in the whole area as much as possible. $P(q_{co})$ should also take into account the strong motion registrations available in the area or the felt macroseismic intensity, the latter if macroseismic intensity is used as a measure of the seismic intensity. In this case, the felt intensity in the centre, I_c, can be assumed as the mean of the a-priori intensity distribution. The following integral constraint should be imposed on $P(q_{co})$: $E[q_{co}] = I_c \pm \varepsilon_I$, where ε_I is a possible error term associated to I_c. $P(q_{co})$ can then be evaluated as a solution for the following non linear constrained optimisation:

$$Min\ (\|1-(1/N_{tot})\Sigma_b\, \Sigma_d\, \Sigma_T\, P\,(d/q,\, T)\, P(d)\, P(T)\, /\, [\Sigma_i\, P\,(d/q_i,\, T)\, P(q_{coi})]\|)$$

$$P(q_{coi}) > 0, \qquad \Sigma_i\, P(q_{coi}) = 1, \qquad E\,[q_{co}] = I_c \pm \varepsilon_I$$

4. Site effects evaluation

Being $P(q_{sb})$ the distribution of the local seismic intensity that affected the generic building, it can be related to site effects. If q_{ref} represents the seismic intensity in a reference site (flat homogeneous stiff soil) the amplification of the seismic intensity, ε, in terms of seismic intensity q, can be assumed directly as $\varepsilon = q_{sb}/q_{ref}$. Being q_{sb} a random variable, also ε is a random variable. It can be characterised by its mean value, $m_\varepsilon = E\,[q_{sb}]\,/\,q_{ref}$, or by its modal value, $M_\varepsilon = M\,[q_{sb}]\,/\,q_{ref}$. If also q_{ref} is considered a random variable, then the mean and the modal amplification can be assumed as $m_\varepsilon = E\,[q_{sb}/q_{ref}]$ and $M_\varepsilon = M\,[q_{sb}/q_{ref}]$.

It is important to point out the difference between the a-priori intensity, q_{co}, and the reference intensity, q_{ref}. Both refer to the examined area, but the former includes site effects and it is used in the Bayesian approach to evaluate the a-posteriori intensities suffered by the buildings. The reference intensity, on the contrary, does not include site effects and it is needed only as a baseline in respect to which site effects are evaluated.

If q is assumed equal to the macroseismic intensity, $q = I$, and the amplification is required in terms of strong motion parameters, e.g. PGA, we have to resort to conversion laws. For the purpose of the present study, it seems reasonable to use Margottini et al. (1987) local relationship, $log_{10}\,(\text{PGA}) = a + bI$, where $b = 0.22$. In this case one gets $\varepsilon = 10^{b\,(q_{sb}-q_{ref})}$ and $m_\varepsilon = E\,[10^{b\,(q_{sb}-q_{ref})}]$. It is not pointless to note that the variance of the seismic intensity in the centre, $Var\,[q_c]$, is a measure of the variation of the seismic amplification in the analysed area. When site effects are uniform in the area, the variance of the seismic intensity in the centre is expected to be small, while, when different amplifications of the ground motion occurred, the variance of the seismic intensity in the centre is expected to be high.

The present methodology can also be applied to evaluate a unique value of amplification for the whole centre. In this case the buildings do not even need to be geo-referred. The average value of the mean local intensity can be compared with the reference intensity, in order to get $\varepsilon = (1\,/\,N_{tot})\ \Sigma_b\, E\,[q_{sb}]\,/\,E\,[q_{ref}]$, where the use of a posteriori seismic intensity instead of the a priori intensity improves the estimate of the intensity as a result of the building damage analysis.

In the above site effect evaluation, the assessment of q_{ref} is reputed to be crucial. If one assumes the reference intensity as the average value of the mean local intensities, $q_{ref} = (1\,/\,N_{tot})\ \Sigma_b\, E\,[q_{sb}]$, one will inevitably get sites with amplification and others with deamplification. This is evidently not realistic as a general rule. If one assumes the reference intensity as the minimum of the mean local intensities, $q_{ref} = min\,(E\,[q_{sb}])$, one will get only amplification factors. Again, although sites able to amplify can be more frequently encountered, this result cannot be considered a general rule. Moreover, the effective amplification can be totally different if the minimum intensity did not occur on a normal site. The determination of q_{ref} also requires some consideration on the attenuation laws to be used together with the amplification factors, at least in Italy, since attenuation laws for macroseismic intensity are evaluated without any consideration of site conditions. Being the amplification, in a mean sense, already present in the attenuation laws, any evaluation of the site effects will consider them twice. The situation becomes clearer when strong motion parameters are used, as attenuation laws, in this case, are usually different for bedrock and deep or shallow alluvium soil (Sabetta and Pugliese, 1987). Due to drawbacks mentioned, in order to evaluate q_{ref} we usually have to resort to geophysical, geological or geotechnical considerations.

In the following application, the seismic intensity will be measured by macroseismic intensity and, for the sake of simplicity, the distribution of the reference intensity, I_{ref}, will be assumed as the one obtained by the probabilistic attenuation proposed by Magri et al. (1994): $P(I_{ref} / I_o, D) = x / (1 + x)$, where $x = e^{a + b \ln(D)}$, D is the distance of the site from the epicentre and a and b are parameters depending on I_{ref} and I_o, reported in Albarello and D'Amico (2000).

5. Vulnerability and damage assessment

In the following, the physical damage caused by an earthquake will be assumed as the observed damage to the vertical bearing structures measured, according to the MSK 76 Medveder (1977) and EMS 98 Grünthal (1998) macroseismic scales, in a discrete scale ranging from 0, the null damage, to 5, the collapse of the building. Buildings will be grouped into 4 vulnerability classes, A, B, C_1 and C_2, where A, B and C_1 are representative of masonry buildings of poor, medium and good quality and C_2 is representative of RC buildings. Only the approach in terms of macroseismic intensity will be developed. The damage distribution, given vulnerability class T and macroseismic felt intensity I, has been assumed as:

$$P(d = k / T,I) = \{C(n,k)\, p(T,I)^k [1 - p(T,I)]^{(n-k)} + \Gamma(k)\, g(T,I)\} / [1 + g(T,I)] \qquad (6)$$

where $k = 0, .., n$, $n = 5$, $T = A, B, C_1, C_2$, $\Gamma = \{0\ 0\ 0\ 0\ 0\ 1\}$, $C(n,k) = n! / [k!\,(n\text{-}k!)]$. Eq. (6) sums a binomial distribution and a collapse distribution. The latter is not a null distribution only in the damage level that corresponds to the building collapse. This approach permits to accurately represent the damage distributions observed after the Italian destructive earthquakes, where the building collapse frequency is higher than the collapse frequency obtained from the only binomial distribution fitted with the mean observed damage. From Eq. (6), the mean damage in a scale ranging from 0 to 1, d_m, and the collapse frequency, f_{cr}, for the generic felt intensity and building type, are:

$$\begin{aligned} d_m(T,I) &= \Sigma_k\, k\, P(d = k / T,I) / n = [p(T,I) + g(T,I)] / [1 + g(T,I)] \\ f_{cr}(T,I) &= P(d_5 / T,I) = [p(T,I)^n + g(T,I)] / [1 + g(T,I)]. \end{aligned} \qquad (7)$$

From the previous expressions it is possible to evaluate the two parameters of the damage distribution, $p\,(T,I)$ and $g\,(T,I)$, once the mean damage and the collapse frequency are known. The latter, obtained by means of a statistical procedure based on the observed damage and building type of more than 30,000 buildings inspected after the Irpinia 1980 earthquake (CNR-PFG, 1980), are reported in Table 2.

In RC buildings, the damage to external walls usually occurs before the damage to vertical bearing structures and it can be significant also when the latter one is null. It has been shown (Masi et al., 2000) that the damage distribution to external walls in RC buildings is very similar to the damage distribution to vertical structures in good quality masonry buildings, at least up to an intensity of about VII MSK. For higher intensities, the main parameter in RC buildings description becomes the damage to vertical structures. To take into account the aforesaid phenomenon, the following relationship has been introduced in case of RC buildings $P(d) = \alpha P(d_t) + (1\text{-}\alpha)\ P(d_s)$, where d_s is the damage to vertical structures, d_t is the damage to external walls. The proposed damage distribution represents a continuous shifting from the damage distribution to external walls to the damage distribution to vertical structures. The parameter α, on which the shifting is based, should be, in principle, based on the seismic intensity. However, being the damage a consequence of the seismic intensity, the parameter α will be assumed a function of the damage to vertical structures, $\alpha = [1.0\ 0.9\ 0.5\ 0.2\ 0.1\ 0.0]$ when $E\,[d_s] = [0\ 1\ 2\ 3\ 4\ 5]$. Consequently, also the vulnerability function must shift from the vulnerability of good quality masonry buildings to the vulnerability of RC buildings. This is achieved assuming $P(T = C_1) = \alpha$ and $P(T = C_2) = 1\text{-}\alpha$.

The building vulnerability classification has been based, according to Braga et al. (1982), on the description and performances of the vertical and horizontal building components, v and h. In general, the classification is uncertain both for a non deterministic building classification once vertical and horizontal components are known and for the frequent lack of information about the building components. With this in mind, the probability that a surveyed building belongs to vulnerability class T can be expressed as:

$$P(T) = \Sigma_{hv}\, P(T\,/\,h,v)\, P(h,v) = \Sigma_{hv}\, P(T\,/\,h,v)\, P(h\,/\,v)\, P(v) \qquad (8)$$

where $T = A$, B, C_1 or C_2 and $P(T\,/\,h,v)$ is the probability that a building with vertical component v and horizontal component h belongs to class T. It will be assumed that $\Sigma_T\, P(T\,/\,h,v) = 1$ for every set of v and h, and consequently also $\Sigma_T\, P(T) = 1$, i.e. the building vulnerability classification is a complete set of events. $P(h,v)$ is the joint probability to observe, in a given

Table 2 - Observed values of d_m and f_{cr} (after the Irpinia 1980 survey).

	d_m				f_{cr}			
Class \ I	**VI**	**VII**	**VIII**	**IX**	**VI**	**VII**	**VIII**	**IX**
A	0,210	0,300	0,400	0,620	0,001	0,007	0,032	0,210
B	0,120	0,200	0,270	0,360	0,000	0,004	0,006	0,037
C1	0,030	0,070	0,094	0,130	0,000	0,000	0,000	0,009
C2	0,023	0,061	0,091	0,163	0,000	0,000	0,0075	0,037

building, vertical component v and horizontal component h. It has been expressed as $P(h / v)\, P(v)$, that is as the conditional probability to observe horizontal component h, given the vertical component v, times the probability to observe vertical component v. In this way uncertainties can be reduced when only vertical components are known in a given building. $P(h / v)$ and $P(v)$ can easily be obtained by simple statistical analysis on the post-earthquake building component collected data. Obviously $P(v)$ is set equal to one when the vertical component v is really observed in the building and $P(h / v)$ is set equal to one when horizontal component h is really observed in the building, independently of v. With the above representation, $P(T / h,v)$ is due to intrinsic uncertainty in vulnerability classification when building components are known, while $P(h / v)$ and $P(v)$ take into account the epistemic uncertainty due to the lack of information.

6. An application to the municipality of Fabriano

The described methodology will be applied to the town of Fabriano stricken by the 1997 Umbria-Marche earthquake. In the Fabriano municipality, and in general in the whole Marche Region, the 1997 post-earthquake damage and usability survey was performed with a preliminary draft of the form at present used by the Italian National Civil Protection. A completeness analysis concerning the whole building database is reported in Cherubini et al. (1999). Considering only the Fabriano municipality, nearly all the buildings present typological and damage data, while addresses or land register codes, required to georefer the buildings, are almost nil. It must be noted that during the writing of this work, the updated, validated and georeferred Fabriano database was not available. The analysis of the typological data has led to typological distributions, $P(v)$ and $P(h / v)$, reported in Table 3.

The observed damage to the vertical bearing structures has been analysed. The resulting mean damage for each of the vulnerability classes is quite high if compared with the values obtained from other Italian post-earthquake surveys, e.g. Irpinia 1980. The result was already pointed out in Dolce et al. (1999), although with reference only to the historical buildings. In that

Table 3 - Building distribution in Fabriano, P (h/v) × 100.

Vertical structures	**Masonry**				**RC**
	Irregular layout, poor quality i.e. field stone		**Regular layout, good quality i.e. bricks**		
Floors	**Without ties and ring beams**	**With ties or ring beams**	**Without ties and ring beams**	**With ties or ring beams**	
Vaults	11.1	13.0	12.5	15.6	
Wodden	61.8	40.2	46.9	18.6	
Steel and vaulted ma	9.6	8.6	16.7	8.5	
Steel and masonry	7.1	11.8	9.1	8.9	
RC.	10.4	26.4	14.8	48.4	100
Surveyed buildings	729	118	945	308	284

case, on the basis of the mean damage index in Fabriano, an intensity greater than I = VII MSK was assigned, significantly greater than the surveyed intensity, I = VI-VII MCS (Camassi et al., 1997).

In order to obtain a reliable database, it has been considered more efficient to perform a new survey rather than to complete and/or modify the post-earthquake survey, thus also achieving more homogeneous information. 883 buildings were surveyed (Larotonda and Dolce, 1999), located in the Fabriano historic centre, where masonry buildings prevail, and in the districts of Spina Serraloggia and Borgo, where recent RC buildings prevail. All the buildings have been georeferred by means of the land register code. In the survey, sections 1, 3 and 4 of the 6.98 version of the Italian post-earthquake damage and usability form have been completed. In the form, the vertical structures are classified as Masonry (regular layout, good quality and irregular layout, poor quality), RC (frame, shear walls or both), Steel and Mixed. With respect to the form used in the post-earthquake survey, the descriptions of the horizontal structures has been replaced by their performance and the roof and the external walls have been included in damageable components, while stairs have been excluded. Null damage has been introduced for all the building components.

The inspections have been performed only from outside, due to the obvious difficulty of entering the damaged buildings a long time after the event. This aspect has in some way underestimated the damage, as many wall separations can be observed only from inside, and this has also been responsible for an incomplete floor identification. When data were missing, the typological distribution reported in Table 3 has been assumed.

The buildings where grouped into four different vulnerability classes, according to the description of the horizontal and vertical structures. The building attribution to one of the vulnerability classes, $P(T)$, is reported in Table 4. The damage distribution in each building, $P(d)$, has been assumed as in Table 5, depending on the damage level, $D0$,.., $D5$, and damage extension, $e1$: $e < 1/3$, $e2$: $1/3 < e < 2/3$; $e3$: $e > 2/3$, observed in the building. Any non present value in the damage distribution in Table 4 is to be assumed null.

Table 4 - Building attribution to vulnerability classes.

Vertical structures	**Masonry**				**RC**
	Irregular layout, poor quality i.e. field stone		**Regular layout, good quality i.e. bricks**		
Floors	**Without ties and ring beams**	**With ties or ring beams**	**Without ties and ring beams**	**With ties or ring beams**	
Vaults without ties	$A = 1.0$	$A = 1.0$	$A = 1.0$	$A = 0.5$ $B = 0.5$	
Vaults with ties	$A = 1.0$	$A = 0.5$ $B = 0.5$	$A = 0.8$ $B = 0.2$	$B = 0.8$ $C_1 = 0.2$	
Flexible	$A = 1.0$	$A = 0.5$ $B = 0.5$	$A = 0.8$ $B = 0.2$	$B = 0.8$ $C_1 = 0.2$	
Semi-rigid	$A = 1.0$	$B = 1.0$	$B = 1.0$	$C_1 = 1.0$	
Rigid	$A = 0.5$ $B = 0.5$	$B = 0.8$ $C_1 = 0.2$	$C_1 = 1.0$	$C_1 = 1.0$	$C_2 = 1.0$

Table 5 - Surveyed damage levels and damage distribution.

Level	***D*0**	***D*1**			***D*2-*D*3**			***D*4-*D*5**		
Extens.		***e*1**	***e*2**	***e*3**	***e*1**	***e*2**	***e*3**	***e*1**	***e*2**	***e*3**
$P(d)$	$P(d_0)$=1	$P(d_1)$=1	$P(d_1)$=1	$P(d_1)$=1	$P(d_2)$=1	$P(d_2)$=0.5	$P(d_3)$=1	$P(d_4)$=1	$P(d_4)$=0.9	$P(d_5)$=1
						$P(d_3)$=0.5			$P(d_5)$=0.1	

The analysis has been limited to the following intensities I = [VI VII VIII IX] MCS. The felt macroseismic intensity in Fabriano has been assumed as I_c = VI-VII MCS, with a possible error of $\varepsilon_I = 0.25$. The following a priori intensity distribution has been obtained as a result of the constrained optimisation: $P\,(I_{co})$ = [0.541 0.405 0.000 0.054], from which $E\,[I_{co}] = 6.56$ MCS. The distribution of the reference intensity in Fabriano has been evaluated by means of the previously reported probabilistic attenuation law for the following parameters: D = 25 km and I_o = VIII-IX MCS. We obtained $P\,(I_{ref})$ = [0.633 0.291 0.069 0.007], from which $E\,[I_{ref}] = 6.45$ MCS. Making use of the above a priori intensity, I_{co}, the macroseismic intensity felt by each building was obtained. By comparison with the reference intensity, the increment of macroseismic intensity was obtained for each building and then converted into PGA amplification. The distribution of the mean amplification in terms PGA is reported in Fig. 1. For 93.3% of the buildings, the mean amplification is not greater than 1.5, maximum value assigned in the Fabriano microzonation (Marcellini et al., 2001). The mean value of the amplification turned out to be 1.20 and its variance 0.149, so that CV = 32.2%. The analysis of the amplification in different areas of Fabriano produced the following results: Historic core:

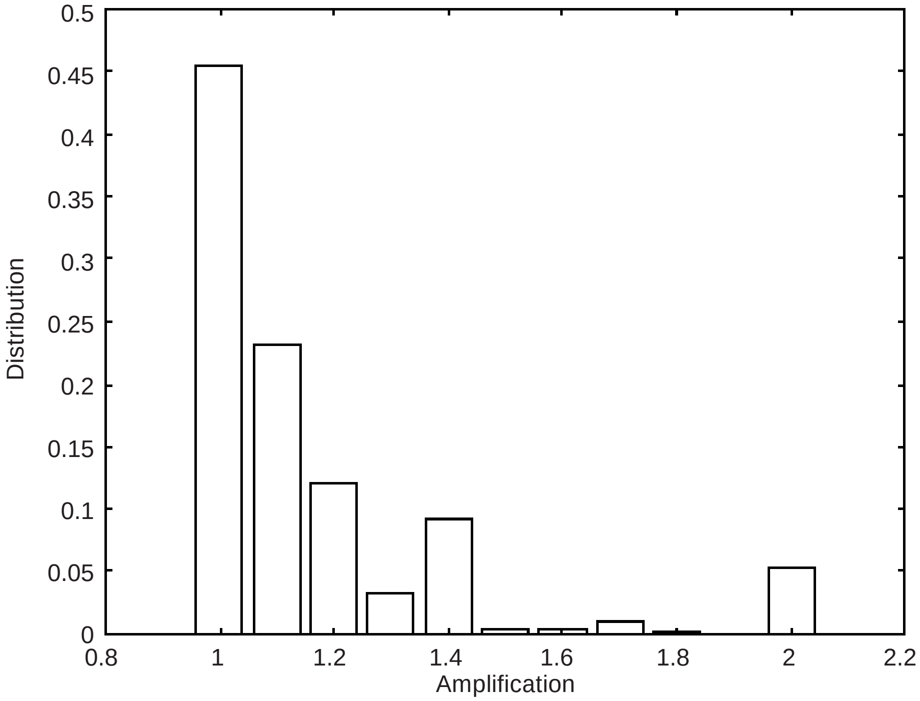

Fig. 1 - Distribution of mean value of PGA amplification for the buildings.

$m_\varepsilon = 1.16$, $CV = 24.1\%$ (816 buildings); Borgo $m_\varepsilon = 2.15$, $CV = 44.1\%$ (8 buildings); Spina Serraloggia $m_\varepsilon = 1.80$, $CV = 43.2\%$ (59 buildings). In the detailed microzonation of Fabriano (Marcellini et al., 2001) an amplification factor $Fa = 1.5$ was assigned to the new districts of Borgo and Spina Serraloggia, while in the historic core amplification values ranging from 1.1 to 1.3 were assigned, depending on the local soil properties. In particular, in the SW part of downtown $Fa = 1.1$, while in the NE part $Fa = 1.2$. $Fa = 1.3$ (Fig. 2) only along the riverbed. Results from the damage analysis seem then in good agreement with the microzonation results, especially in the historic core. But in Borgo and Spina Serraloggia as well if one takes into account the fact that a) not all the buildings in these districts have been surveyed and b) *Fa* refers to a 475-year return period earthquake, while the present analysis refers to the Umbria Marche earthquake, of moderate magnitude. When buildings in the Fabriano historical core are grouped according to *Fa* values, one gets a) 350 buildings located in the area where $Fa = 1.1$,

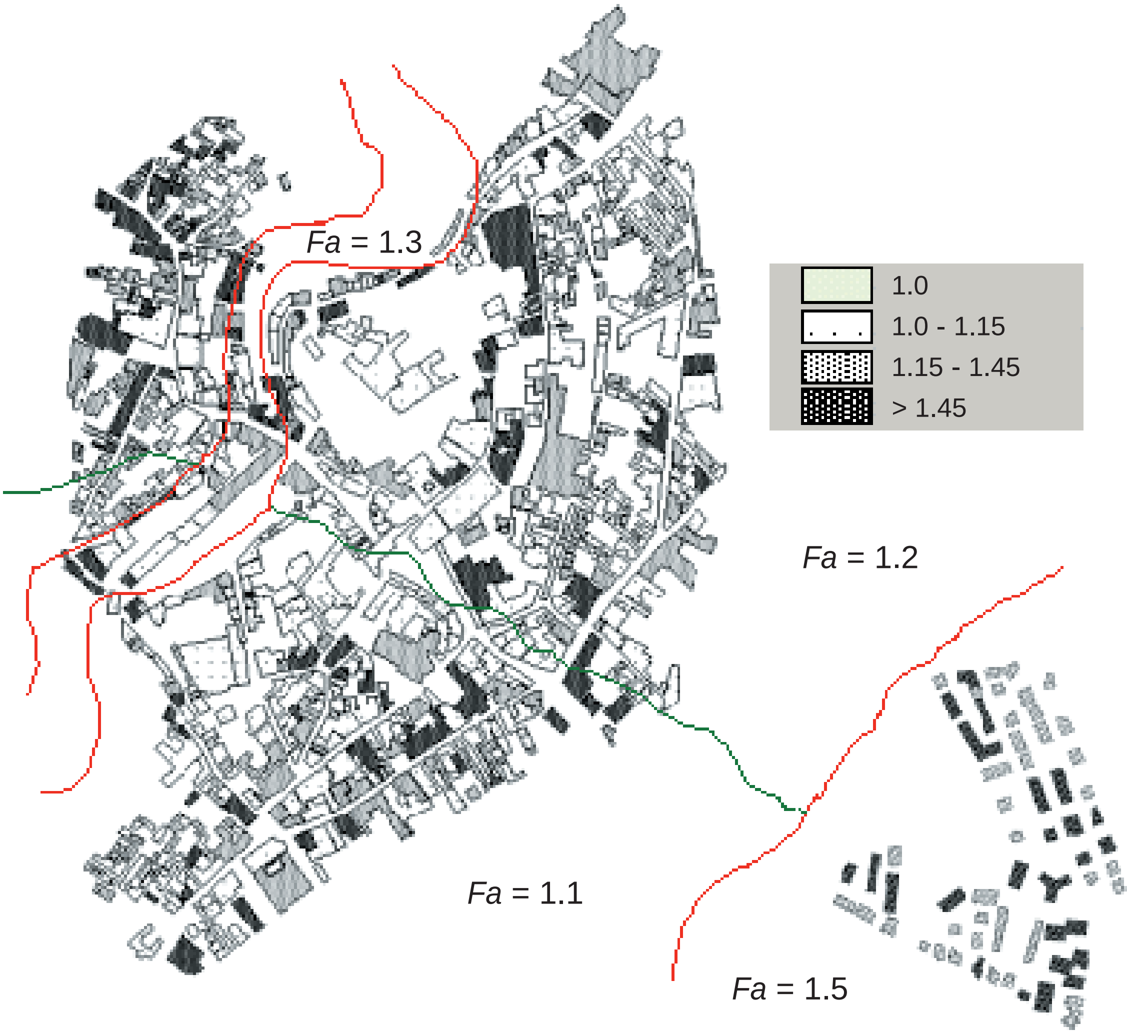

Fig. 2 - Map of the mean amplification factor in the Fabriano historic core and Spina Serraloggia district. *Fa* refers to amplification factors as a result of the Fabriano detailed microzonation (Marcellini et al., 2001).

m_ε = 1.15 and b) 464 buildings located in the area where Fa = 1.2, m_ε = 1.17. Hence our model does not predict any significant difference in ε within the Fabriano historical core. From Fig. 2 it is also evident that spatial dispersion of the mean amplification does not permit to clearly select areas with different amplifications. These results can be due to the lack of spatial correlation in the a priori intensity distribution as well as in building data inaccuracies. The average value of amplification on large areas seems then to be more representative than the local values. This can redirect the analysis towards the definition of a non local intensity obtained with a proper spatial averaging of the local intensities.

7. Conclusions

Post-earthquake site-effect evaluation is a necessary step in any reconstruction strategy. Although several approaches are available today, the time required for a detailed microzonation analysis is not usually compatible with the reconstruction process. A methodology, aimed at a possible measurement of seismic intensity from collected data of post-earthquake buildings, is then proposed. The felt macroseismic intensity in the analysed area is used as an initial estimate for the local intensity, defined as the seismic intensity experienced by each building. Using previously assessed vulnerability functions together with a Bayesian approach, it has been possible to update the initial estimate and to evaluate the distribution of the local intensity for a given surveyed building with a given damage level. Uncertainties in building type and building damage are also taken into account.

An application to the town of Fabriano, struck by the 1997 Umbria-Marche earthquake is presented. The historical town centre, where the older masonry buildings are located, and the districts where reinforced concrete buildings have been damaged by the earthquake, have been included in the analysis. Results are in good agreement with the amplification of the ground motion predicted by the detailed microzonation recently performed.

As in all the Bayesian approaches, results depend on the a priori intensity distribution. In the proposed methodology, however, the a priori distribution is not assigned by the user but evaluated by the model, on the basis of the overall building damage and the felt macroseismic intensity. The evaluation turned out to be well constrained, giving reliable results.

On the other hand, the major drawback in the methodology seems the lack of any spatial correlation in the a priori intensity estimate. As a consequence spatially averaged amplification values are more representative than local values. Finally, the proposed methodology would be more reliable if uncertainties in vulnerability functions and/or in vulnerability classification were significantly reduced.

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