Spatial cluster analysis and site effects in San Giuliano based on building typology and damage data collected after the 2002 Molise earthquake

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ABSTRACT This paper describes the methodology used to evaluate site effects in San Giuliano, based on building typology data and building damage data collected after the 2002 Molise-Puglia earthquake. The analysis has been performed within the working group, established by the Italian Civil Protection Department, in order to define a microzonation map for the area of San Giuliano. Despite the necessary approximations within the proposed methodology and the data inaccuracies, results clearly show that, in the historical centre, the seismic intensity (MCS) has been significantly smaller (2 degree less) than in the new expansion area. In addition, spatial cluster analysis on the ground motion amplification highlights a clear-cut boundary between the stiff soil in the historical centre and the soft soil in the expansion area.

1. Introduction

After all recent Italian moderate earthquakes, such as 1997 Umbria-Marche (Capotorti *et al*., 1997), 1998 Pollino (Gullà and Sdao, 2001), 2002 Molise-Puglia (Casciello *et al*., 2003) and 2002 Etna (Goretti and De Sortis, 2003) earthquakes, damage surveys carried out in epicentral areas and in-situ tests have confirmed the worldwide-observed strong influence of soil conditions on the local seismic intensity.

Site effect evaluation involves the collection, harmonisation and analysis of a huge amount of data coming from several disciplines: topography, geology, seismology, geophysics and geotechnical engineering. Recently, one more discipline, namely structural engineering, has been introduced in the microzonation analysis and several methodologies have been proposed which make use of vulnerability and damage data collected a few months after the event.

Pioneering works in the field compared soil properties with the building damage distribution in Rome (Ambrosini *et al*., 1986), thus considering the damage as a direct measure of the seismic motion. Brambati *et al*. (1980) compared building damage, period of the first natural mode of vibration and soil stratigraphy in Tarcento. More recently (Goretti and Dolce, 2004a), each building has been considered as an instrument, where the quantity to be measured is the damage and the response curve of the instrument is the seismic vulnerability, which should be known in advance. Damage can be considered an effective measure of the ground shaking only when filtered by the building type. The main drawback of this approach is that a building is insensitive at low seismic intensity (null damage) and saturates at high intensity (collapse). Therefore, even in a deterministic approach, seismic vulnerability cannot provide a one-to-one relationship with the ground motion, due to the null damage and collapse thresholds.

Another issue to be taken into account is the high uncertainty of the seismic building vulnerability when dealing with classes of structures and/or 1st level accuracy data. A probabilistic approach considering uncertainties on surveyed building type and observed damage was presented by Goretti and Dolce (2004a). In order to reduce the computational demand of the model, which requires a non linear optimisation, a simpler methodology has been proposed (Goretti, 2004) within San Giuliano microzonation (AA.VV, 2003), later applied also to Laino Borgo (Goretti, 2005). An overview of recent Italian applications of the method is presented in Goretti and Dolce (2004b).

In the following, the evaluation of site effects in San Giuliano, based on typology and damage building data collected after the 2002 Molise-Puglia earthquake, will be presented. In addition, spatial cluster analysis based on the ground motion amplification is introduced, in order to provide information on the areas that can be considered homogeneous in terms of amplification.

2. Model description

In order to take into account the variability in building typology and damage and the spatial correlation of the ground motion, the seismic intensity experienced by every building will be evaluated by properly averaging the building typology and the building damage observed in a neighbourhood of the building itself. More formally, the observed damage distribution in the neighbourhood of a building i, $f_{d|i}$, is evaluated as:

$$f_{d|i} = \left(\sum_j w_{ij}(x,y) I_{dj}\right) / \left(\sum_j w_{ij}(x,y)\right) \tag{1}$$

where i is the building index, I_{dj} is 1 when building j experienced damage level d and 0 otherwise and $w_{ij}(x,y)$ is a spatial weighting function which depends on the distance D_{ij} between building i and j. Three weighting functions were included as a possible choice in the model: a) constant, b) linear and c) Gaussian (Goretti, 2004). From Eq. (1), the mean dimensionless damage around building i can be evaluated as $p_i = m_{d|i} / N_d = \sum_d d\, f_{d|i} / N_d$ where $N_d = 5$ is the number of damage levels different from zero. Note that the above approach is meaningful only if the survey is exhaustive, as in the case under study.

Similarly, the observed building type distribution in the neighbourhood of building i, $f_{T|i}$, is evaluated as:

$$f_{T|i} = \left(\sum_j w_{ij}(i,j) I_{Tj}\right) / \left(\sum_j w_{ij}(i,j)\right) \tag{2}$$

where I_{Tj} is 1 when building j belongs to vulnerability class T, and 0 otherwise.

The felt macroseismic intensity is then estimated by comparing the observed and the expected mean dimensionless damage in the neighbourhood of every building. The latter one, considering the observed building type distribution, $f_{T|i}$, in the building neighbourhood can be expressed as:

$$g_i(I_{MCS}) = \sum_T h(I_{MCS}, T) f_{T|i} \quad (3)$$

where $h(I_{MCS}, T)$ is the expected dimensionless mean damage when intensity I_{MCS} affects building type T and represents the vulnerability of the building stock. In the following, $h(I_{MCS}, T)$ will be supposed to be known, for each building type, from post-earthquake surveys in similar regions or from numerical analyses on similar building types.

By equating the expected dimensionless mean damage, g_i, to the observed dimensionless mean damage, p_i, the felt intensity in the neighbourhood of building i, I_{MCSi}, can be obtained. In other words, the felt intensity is the intensity for which the mean expected damage matches the mean observed damage. For the sake of simplicity, the subscript MCS will be omitted from now on.

Site effects in terms of seismic intensity are then obtained comparing the felt intensity, I_i, with the reference intensity, I_{ref}. The latter is the intensity expected at San Giuliano in the case of flat and stiff soil. The increment of intensity, experienced by each building, is then evaluated as:

$$\Delta I_i = I_i - I_{ref} \quad .$$

This increment is entirely due to site effects, since the contribution of building vulnerability has already been removed.

In Goretti and Dolce (2004a), I_{ref} has been deduced from a probabilistic attenuation law. In this case, there was geological and geotechnical evidences (AA.VV., 2003) of the presence of stiff soil, although it was not really flat, where the historical centre was located. Two alternative hypotheses were then considered: the first one assumes I_{ref} as the spatial average of intensities associated to buildings located in the whole historical centre; the second one considers an average intensity on buildings located in a pre-selected region, where stiff soil was assumed. In both cases, I_{ref} can be cast in the form:

$$I_{ref} = \sum_i I_i / N_R$$

where $i = 1,.., N_R$ refers to the buildings located on the reference soil.

In order to quantify site effects in terms of strong motion parameters, such as EPA, PGA, etc., empirical conversion laws have been used. In general, if Y is the strong motion parameter to be estimated from the seismic intensity I, conversion laws are cast in the form of $\log_{10}(Y) = a+bI$, where a and b are parameters depending on the assumed law. The amplification in terms of Y, associated to each building, F_{ai}, can be expressed as:

$$F_{ai} = Y_i / Y_{ref} = 10^{b(I_i - I_{ref})} = 10^{b\Delta I_i}$$

and strongly depends on the b-value of the attenuation law, which is reported in Table 1 for several ground motion parameters (PGA, PGV, EPA, I_H).

Table 1. *b*-value for several ground motion parameters.

Parameter	PGA	PGA	PGA	EPA	EPV	IH
Author	Margottini *et al.* Local (1987)	Margottini *et al.* Global (1987)	Petrini and Guagenti (1989)	Decanini *et al.* (2002)	Decanini *et al.* (2002)	Decanini *et al.* (2002)
b	0,220	0,179	0,202	0,197	0,225	0,290

The amplification in terms of ground motion parameters, due to the increment of macroseismic intensity, is then reported in Fig. 1.

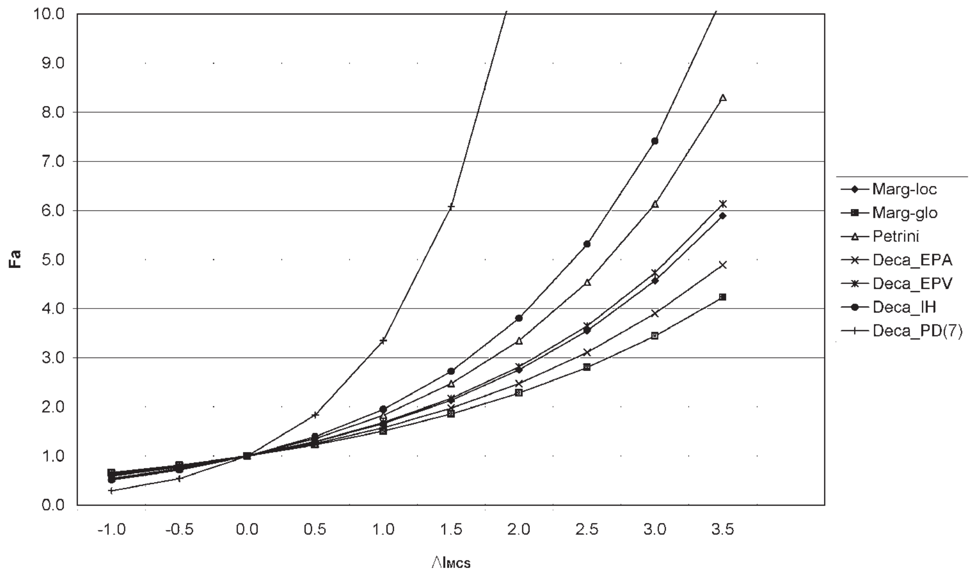

Fig. 1 - Amplification in terms of ground motion parameters. PD(7) is the amplification in terms of Destructive Potential (Decanini *et al.*, 2002) evaluated for I_{MCS} = VII).

3. Building vulnerability

Building vulnerability has been quantified through a relationship between mean damage, building typology and macroseismic felt intensity. According to all recent macroseismic scales, such as MSK 76 (Medvedev, 1977) and EMS 98 (Grunthal, 1998), observed physical damage to vertical bearing structures has been classified in a scale ranging from 0 (null damage) to 5 (building collapse).

The mean damage has been evaluated from the damage distribution observed after the 1980 Irpinia earthquake, when more than 30,000 buildings were inspected (CNR-PFG, 1980). Buildings have been grouped into 5 vulnerability classes, following Braga *et al*. (1982), based on the description of vertical and horizontal building structures. Mas-A, Mas-B and Mas-C refer to masonry buildings of poor, medium and good quality, RC to reinforced concrete buildings and Mixed to buildings with both masonry and reinforced concrete vertical-bearing structures.

Macroseismic intensities, assigned right after the earthquake, have been re-evaluated by the working group created with the aim of updating the building vulnerability distribution in Italy (Angeletti *et al*., 2002). The mean damage observed after the 1980 Irpinia earthquake has been converted into a dimensionless quantity, dividing it by the maximum level of damage (i.e. 5); the values obtained are reported in Table 2.

Table 2 - Empirical mean dimensionless damage in terms of macroseismic intensity (after the Irpinia 1980 earthquake).

T \ I_{MCS}	**VI**	**VI-VII**	**VII**	**VII-VIII**	**VIII**	**VIII-IX**	**IX-X**
Mas-A	0.209	0.245	0.296	0.372	0.396	0.506	0.725
Mas-B	0.124	0.174	0.198	0.230	0.266	0.285	0.426
Mas-C	0.030	0.093	0.104	0.102	0.094	0.076	0.185
Mixed	0.075	0.123	0.120	0.215	0.225	0.225	0.288
RC	0.023	0.035	0.062	0.067	0.091	0.060	0.267

The dimensionless mean damage curves have been then smoothed and extrapolated to levels of intensity higher than what was felt in the 1980 Irpinia earthquake. The solid lines reported in Fig. 2 have been obtained, with circles representing the values observed in Irpinia. Extrapolation to intensities greater than I_{MCS} = IX-X was based on expert judgement and on the MCS macroseismic scale.

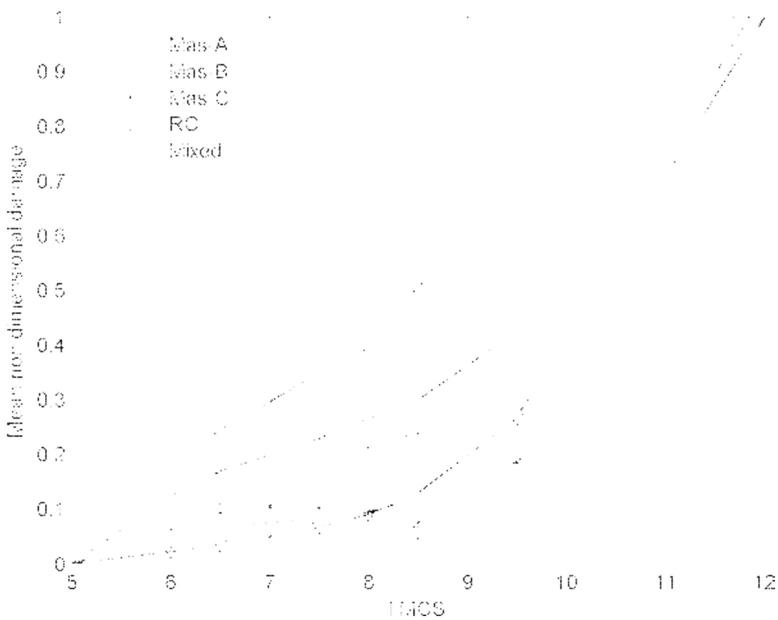

Fig. 2 - Relationship between dimensionless mean damage, vulnerability class and macroseismic intensity. Solid lines are adopted values, circles are values observed after 1980 Irpinia earthquake.

The vulnerability assumed, based on data observed after the Irpinia earthquake, and reported in Fig. 2, has been then compared with the vulnerability level implicit in the MCS scale. The damage percentages reported in the MCS scale have been attributed to class B masonry buildings, although this assumption is not always accepted. The mean dimensionless damage has been then obtained with the additional hypothesis of binomial damage distribution.

In Fig. 3, MCS (dashed line) and Irpinia (solid line) observed vulnerability are reported, in terms of mean dimensionless damage, for class B masonry buildings. In the same figure, the mean dimensionless damage observed in 2002 Molise earthquake (squares) is presented.

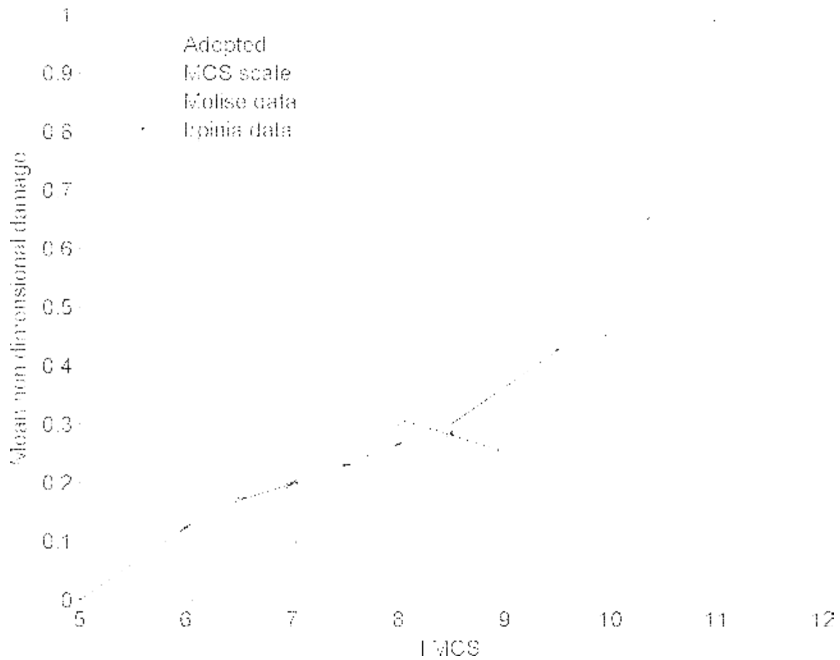

Fig. 3 - Dimensionless mean damage versus macroseismic intensity for class B Masonry buildings: solid lines = assumed, dashed line = implicit in MCS scale, stars = observed after the 1980 Irpinia earthquake, squares = observed after the 2002 Molise earthquake.

From Fig. 3, it can be noticed that, for intensities I_{MCS} = VI and VII, the MCS scale assumes damage levels that are lower than those observed in Irpinia and in Molise. This is presumably due to several issues: a) the MCS description of I = VI (Molin, personal communication); b) the fact that inspections from outside often do not allow to detect slight damage, which is instead more visible from inside; c) the inspector's tendency to overestimate the damage.

In addition, the assumed vulnerability probably underestimates the mean dimensionless damage for high intensity, I_{MCS} > X, and hence gives, in this range, for the same observed damage, a higher estimate of the felt intensity.

4. San Giuliano case study

The municipality of San Giuliano was affected by the 2002 Molise earthquake, suffering intensity I_{MCS} = VIII-IX (Galli and Molin, 2004). The collapse of the elementary school, built outside the historical centre, killed 27 children and 1 teacher (Foster and Kodama, 2004).

During the post-earthquake safety inspections, building damage and building-type data were collected for each building. Local authority and National Civil Protection technicians produced a Geographic Information System (GIS) of the urban area, where the collected data were associated to the polygons representing the area of the inspected buildings. The GIS validation required additional building inspections, performed a few months after the earthquake. The collapsed buildings, which had not been inspected during the damage survey, were also included in the GIS at this stage.

Data were collected using the release 05.2000/bis of the AeDES form (Baggio *et al*., 2000). The damage classification and the building-type classification have been based on the final report of the working group which created the AeDES form. In Table 3, the vulnerability classification which has been used is reported (Mas-A, Mas-B, Mas-C and RC), based on the seismic performance of the buildings. In case of unknown building type, vulnerability class A was assigned to the building.

Table 3 - Vulnerability classification and structural elements performance.

Vertical structures	**MASONRY**				**RC**
	Irregular layout or bad quality, (rubble stone, pebbles, HCB)		Regular layout and good quality (squared stone, bricks)		
Horizontal structures	Without iron ties or beam ties	With iron ties or beam ties	Without iron ties or beam ties	With iron ties or beam ties	
Vaults without ties	A	A	A	B	
Vaults with iron ties	A	B	A	B	
Flexible floors	A	B	A	B	
Semi-rigid floors	A	B	B	C	
Rigid floors	B	B	C	C	RC

Following Dolce *et al*. (1999) and Di Pasquale and Goretti (2001), the physical damage has been assumed as an appropriate combination of damage grade and damage extension to vertical bearing structures:

$$d = \sum_i d_i e_i$$

where d_i and e_i are determined from the conversion rules in Table 4. Damage grade (*D0, D1, D2-D3, D4-D5*) and damage extension *E* are observed values, reported in section 4 of the AeDES form. Summation is extended to all the damage levels in the building. The result is then rounded off to the nearest greater integer and then converted into a dimensionless quantity, diving it by the maximum level of damage (i.e. N_d = 5).

Table 4 - Classification of damage to vertical bearing structures.

Level	Observed	*D0*	*D1*	*D2 - D3*	*D4 - D5*
	Assumed	d = 0	d = 1	d = 2.5	d = 4.5
Extension	Observed		$E < 1/3$	$1/3 < E < 2/3$	$E > 2/3$
	Assumed		e = 0.166	e = 0.500	e = 0.834

Figs. 4 and 5 show the distribution of building typology and observed building damage in San Giuliano. The historical centre is located SE, where buildings are closely spaced, while the new expansion area is located NW. The damage map, even without the vulnerability filtering, highlights an area of more severe effects outside the historical centre. The boundary is approximately a straight line oriented WNW-ESE.

According to the proposed methodology, the intensity felt in the neighbourhood of any building was then evaluated for several choices of the model parameters. Once the reference intensity was estimated, the felt intensity increment and the amplification in terms of ground motion parameters was evaluated.

Results of the model, in terms of the spatial average of the intensity, I, and amplification, F_a, over the whole urban area, are reported in Table 5. R is the radius of the area where local averages [Eqs. (8) and (9)] are performed, w_{ij} is the weighting function in R, I_{ref} is the reference intensity, E[I] and σ give mean value and standard deviation.

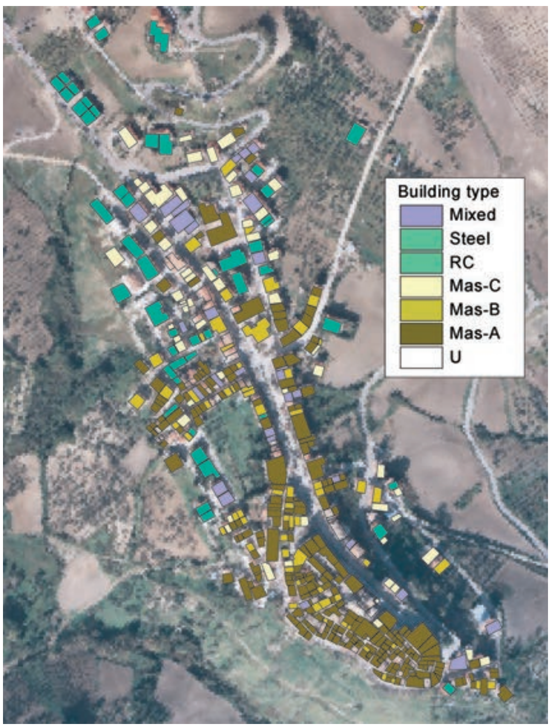

Fig. 4 - Building type distribution in San Giuliano.

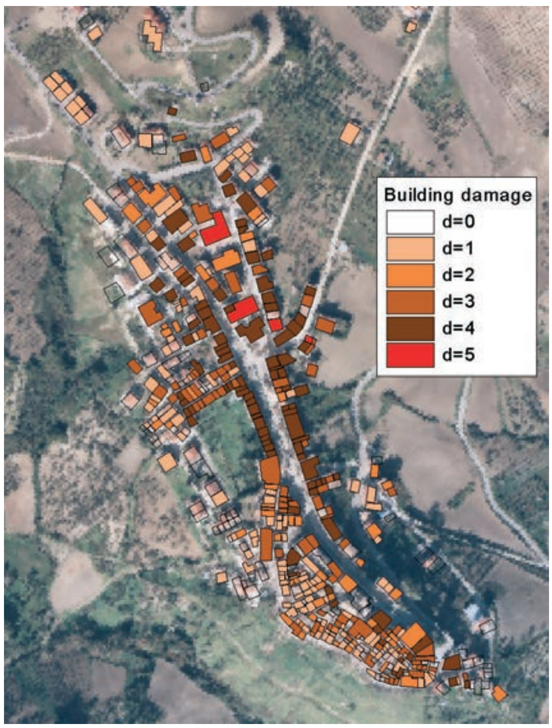

Fig. 5 - Observed building damage in San Giuliano.

Table 5 - *Fa* in terms of PGA using Margottini *et al.* (1987)local intensity conversion law.

R (m)	w_{ij}	I_{ref}	E [*I*]	σ_I	E[F_a]	σ_{Fa}
25	Linear	6.98	8.06	1.88	2.60	2.22
25	Uniform	7.02	8.10	1.78	2.49	2.04
50	Linear	7.10	8.19	1.65	2.37	1.76
50	Uniform	7.15	8.22	1.60	2.29	1.62
100	Linear	7.27	8.29	1.46	2.14	1.40
100	Uniform	7.43	8.36	1.38	1.99	1.24

It can be deduced that the mean value of *I* increases as *R* increases and/or when the weighting function is assumed to be uniform rather than linear. On the contrary, the standard deviation of *I* reduces as *R* increases, obviously vanishing for extremely large values of *R*. The trend of the mean F_a value is strictly related to the trend of E[*I*] and I_{ref}, and, similarly, σ_{Fa} is strongly correlated to σ_I. A large value of σ_{Fa} identifies areas with different amplification within San Giuliano.

Results of the model (Goretti, 2004), in terms of macroseismic intensity, are reported in Fig. 6 for a suitable choice of the parameters: *R*=100 m, uniform weighting function within *R* and I_{ref} as the spatial average of intensities only within the historical centre and on firm soil (which means excluding the buildings located on stiff soil inside Area 1). Results show that, in the area of most severe effects, the felt macroseismic intensity has been approximately 2 degrees (MCS scale)

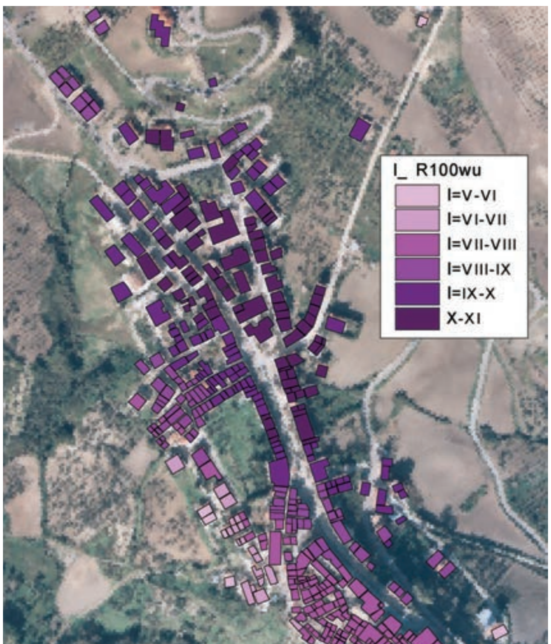

Fig. 6 - Map of felt macroseismic intensity (MCS scale).

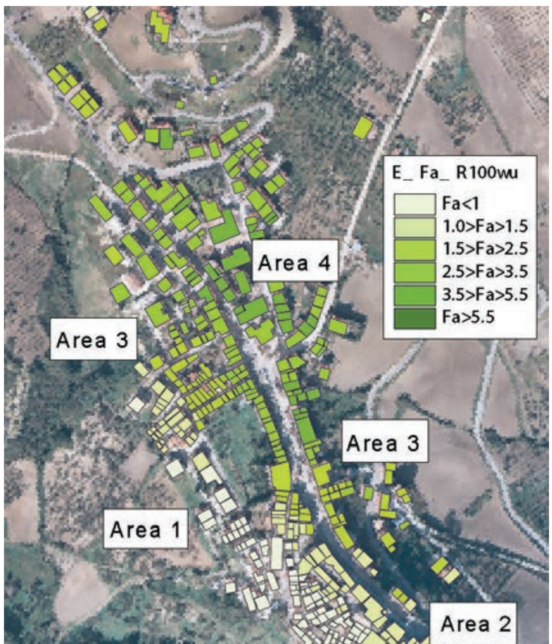

Fig. 7 - Amplification map in terms of EPA.

larger than in the historical centre. Fig. 7 reports the amplification map in terms of EPA. Several areas with different amplification can be highlighted. A small area with slight deamplification is located at the upper left side of the historical centre (Area 1). Moreover, a small area of slight amplification is located at the right side of the historical centre (Area 2). Since this area is located on firm soil and at the top of the hill, amplification can be due to topographic effects. A larger area with considerable amplification starts from the historical centre and moves upward on the left and on the right sides of the new expansion area (Area 3). Finally, the area with the strongest amplification is located outside the historical centre, along the main road, in the middle of the new expansion area, just where the school was located (Area 4). A spatial averaging of the amplification within the above areas gives the values reported in Table 6.

Table 6 - Spatially averaged *Fa* values within amplification Areas 2, 3 and 4.

F_a	*R* = 50 m			*R* =100 m		
	Mean	**Std.dev**	**CoV**	**Mean**	**Std.dev**	**CoV**
Area 2	1.34	0.27	19.85	1.13	0.09	7.55
Area 3	2.16	0.74	34.12	2.03	0.61	29.85
Area 4	3.36	0.77	22.86	3.20	0.37	11.69

The above results are compared with the amplification provided by in-situ measurements and numerical analyses on a 2D soil model (Baranello *et al.*, 2004). In both cases, the amplification was defined as $F_a = SI/SI_{ref}$, where $SI = \int PSV(T)\mathrm{d}T$ is the spectral intensity and SI_{ref} is the same quantity measured or evaluated on a reference site (in this case the historical centre). PSV(T) are 5% damped pseudovelocity response spectra as a function of period T. The integral has been evaluated between 0.1 and 0.5 s, in order to include the natural periods typical of most of the buildings. For what concerns the in-situ measurements, six seismometric stations, S#, were installed after the main shock. The location of the stations is reported in AA.VV. (2003). The results obtained are summarized in Table 7, where F_a values have been averaged in the areas previously defined. On the other hand, numerical analyses on a 2D soil linear equivalent model, subjected to a moderate magnitude earthquake, provided F_a values on several points of the soil surface (Baranello *et al.*, 2004). The point locations are reported in Baranello *et al*. (2004). Again, local F_a values are averaged over the same areas as above and reported in Table 7.

Table 7 - Average amplification in Areas 2, 3 and 4.

	In situ recordings	**Numerical analysis**	**This model**
Area 2	2.3 [1]	1.05 [a]	1.13
Area 3	2.5 [2]	2.20 [b]	2.03
Area 4	3.7 [3]	2.87 [c]	3.20

[1] S7; [2] S3, S6, S8, S9; [3] S10, S11.
[a] Point A; [b] Points B, C, G, H; [c] Points D, E, F.

Considering that a) recordings and numerical analyses provide F_a local values, while the proposed methodology provides averaged F_a values; b) in each approach, a different seismic intensity was considered (aftershocks in recordings, moderate magnitude earthquake in soil numerical analyses and main shock in damage analysis) and c) building damage and building typology data were only at the first level accuracy data, results from damage analysis are deemed to be in good agreement with other discipline results. However, issue b) is considered to have the most significant influence on the scatter of the results, due to the different soil behaviour in case of different seismic input energy.

The above results are also in good agreement with the seismological analysis of Cara *et al*. (2005). By analysing 130 aftershocks, the Authors located the strongest amplification area in the middle of the new expansion area (Area 4 in this analysis), and found a 10 second-long ground motion amplification in a range of frequency (4-7 Hz) close to the natural frequencies of the most common building types in the area.

Fig. 8 - Group location from spatial cluster analysis on ground motion amplification.

In order to have a more rational evaluation of areas with homogenous amplification, a spatial cluster analysis is then performed, where the number of groups is established a priori. Each spatial group is defined by the coordinates of its centroid, x_c and y_c. Each building is then assigned to the group with minimum geometrical distance between the group's centroid and the building, that is:

Buildings j belongs to group k if $D_{ki} = \min_i(D_{ij})$, where $D_{ij}^2 = (x_j - x_{ci})^2 + (y_j - y_{ci})^2$

The coordinates of the centroids are evaluated with a non linear optimisation procedure, in which the objective function is the minimum amplification variance within the groups:

$$\sum_i Var[F_a]_i = \min \qquad Var[F_a]_i = E_j[F_a^2] - (E_j[F_a])^2 \qquad \text{if building } j \in \text{ group } i$$

Since the results strongly depend on the initial conditions, the procedure is repeated many times, randomly selecting the initial position of the centroids. The case with minimum variance within groups is then retained. The statistics obtained for the case of 3 centroids and 2000 different initial conditions, are shown in Table 8 and the group's location is shown in Fig. 8.

Table 8 - Amplification obtained within groups from spatial cluster analysis.

Group	**E[F_a]**	**Var[F_a]**	**CoV[F_a]**
A	1.02	0.13	35%
B	2.71	1.02	37%
C	0.47	0.008	18%

Although the assumed cluster analysis has some limitations in the geometry of the groups, i.e. it will not easily provide concentric areas, a clear-cut boundary between stiff and soft soil appears from the analysis. This result is in very good agreement with geological evidence (AA.VV., 2003). The groups are also very similar to the ones reported in Fig. 7, and intuitively defined: Group A corresponds to the historical centre and includes Area 2, Group B includes both Area 3 and Area 4 and Group C corresponds to Area 1.

From Table 8, it appears that the average amplification values within Area A and B are in good agreement with the average amplification values within Area 2, 3 and 4 reported in Table 7. Deamplification values within Area 1 were not computed and reported in Table 7, as there were no recordings or results from numerical analyses to be compared with results of the proposed model. From cluster analysis, it turns out that deamplification can halve the ground motion in Area C. When considering these results, some issues should be kept in mind: i) the small number of buildings in Area C, ii) the inaccuracy of the model in case of negligible ground motion which does not trigger the building damage, iii) the assumed building vulnerability in comparison with the one implicit in the MCS scale (Fig. 3). With respect to the assumed vulnerability, the latter one provides a higher intensity for slight damage and a lower intensity for high damage, reducing the amplification difference among areas.

5. Conclusions

A methodology to evaluate site effects from building type and damage data collected after an earthquake is presented. In order to take into account the variability in building type and damage and the spatial correlation of the ground motion, the seismic intensity experienced by any building is evaluated by properly averaging the building type and the building damage observed in a neighbourhood of the building. Site effects in terms of seismic intensity are then obtained comparing the felt intensity, I_i, with the reference intensity, I_{ref}. In order to quantify site effects in terms of strong motion parameters, such as EPA, PGA, etc., empirical conversion laws have been used.

In comparison with other approaches previously proposed by the same author, this one is simpler, faster and does not require any special computational effort. However, the building survey must be exhaustive, which means that damage and building typology data must be collected for all the buildings in the area of interest.

The model has been applied to the San Giuliano municipality, stricken by the 2002 Molise-Puglia moderate earthquake. After some sensitivity analyses, model results for a suitable choice of the parameters show the presence of several amplification areas. Despite the limitations inherent to the model and the building data inaccuracies, typical of quick post-earthquake inspections, average amplification values within the different areas are in good agreement both with aftershock recorded values and with results of numerical analyses on a 2D linear equivalent soil model.

In terms of macroseismic intensity, in the area of most severe effects, where the school collapsed, the felt macroseismic intensity has been approximately 2 degrees (MCS scale) larger than in the historical centre. Spatial cluster analysis on ground motion amplification provides a clear-cut boundary between the stiff soil in the historical centre and the soft soil in the new expansion area. Again, this boundary is in very good agreement with geological evidence.

REFERENCES

AA.VV.; 2003: *Microzonazione di San Giuliano di Puglia.* Rapporto della Commissione Tecnico-Scientifica per la Microzonazione di San Giuliano di Puglia istituita dal Capo Dipartimento della Protezione Civile, 39 pp.

Ambrosini S., Castenetto S., Cevolani F., Di Loreto E., Funiciello R., Liperi L. and Molin D.; 1986: *Risposta sismica dell'area urbana di Roma in occasione del terremoto del Fucino del 13 gennaio 1915. Risultati preliminari*. Mem. Soc. Geol. It., **35**, 445-452.

Angeletti P., Baratta A., Bernardini A., Cecotti C., Cherubini A., Colozza R., Decanini L., Diotallevi P., Di Pasquale G., Dolce M., Goretti A., Lucantoni A., Martinelli A., Molin D., Orsini G., Papa F., Petrini V., Riuscetti M. and Zuccaro G.; 2002: *Rapporto finale del gruppo di lavoro per l'aggiornamento dell'inventario e della vulnerabilità degli edifici residenziali e pubblici e per la stesura di un glossario*. Servizio Sismico Nazionale, DPC, 76 pp.

Baggio C., Bernardini A., Colozza R., Corazza L., Della Bella M., Di Pasquale G., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F. and Zuccaro G.; 2000: *Manuale per la compilazione della scheda di I livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sismica*. Servizio Sismico Nazionale e Gruppo Nazionale per la Difesa dai Terremoti, 112 pp.

Baranello S., Bernabini M., Dolce M., Pappone G., Rosskopt C., Sanò T., Cara P.L., De Nardis R., Di Pasquale G., Goretti A., Gorini A., Lembo P., Marcucci S., Marsan P., Martini G.M. and Naso G.; 2004: *Una metodologia per microzonazione sismica: il caso di San Giuliano di Puglia*. 11th National Conference on Seismic Engineering in Italy, Genoa, Servizi Grafici Editoriali, Padova, pp. 20.

Braga F., Dolce M. and Liberatore D.; 1982: *A statistical study on damaged buildings and an ensuing review of the MSK-76 scale*. In: 7 ECEE, Athens, pp. 65-84.

Brambati A., Faccioli E., Carulli G.B., Cucchi F., Onori R., Stefanini S. and Ulcigrai F.; 1980: *Studio di microzonazione sismica dell'area di Tarcento (Friuli)*. CLUET Trieste.

Capotorti F., Monachesi G., Mucciarelli M., Sanò T. and Trojani L.;1997: *Danneggiamento ed effetti di sito nel terremoto umbro-marchigiano di settembre-ottobre 1997*. Ingegneria Sismica, **14**(3), 12-21.

Cara F., Rovelli A., Di Giulio G., Marra F., Braun T., Cultrera G., Azzara R. and Boschi E.; 2005: *The role of site effects on the intensity anomaly of San Giuliano di Puglia inferred from aftershocks of the molise, central southern Italy, sequence, November 2002*. Bulletin Seism. Soc. Am., **95**, 1457-1468.

Casciello M., Cesarano M., Naso G., Pappone G. and Rosskopf C.; 2003: *Il terremoto del 2002 in Molise e Puglia: i dati geologici e geomorfologici dell'area di S. Giuliano di Puglia.* Ingegneria Sismica, **21**(3), 32-37.

CNR–PFG; 1980: *Bozza di istruzione per la scheda di rilevamento danni*, Stato Maggiore Difesa, Roma, 12 pp.

Decanini L.D., Mollaioli F. and Oliveto G.; 2002: *Structural and seismological implications of the 1997 seismic sequence in Umbria and Marche, Italy*. In: Oliveto G. (ed) Innovative Approaches to Earthquake Engineering, WIT press, pp. 229-323.

Di Pasquale G. and Goretti A.; 2001: *Vulnerabilità funzionale ed economica negli edifici residenziali colpiti da recenti Eventi Sismici Nazionali*. In: X National Conference on Seismic Engineering in Italy, Potenza-Matera, 9-13 September.

Dolce M., Goretti A. and Masi A.; 1999: *Analisi dei danni causati al patrimonio edilizio dal sisma del Pollino del settembre 1998.* Ingegneria Sismica, **16**(3), 5-15.

Foster B. and Kodama S.; 2004: *Emergency management, recovery and reconstruction following the 2002 Molise, Italy, earthquake*. Earthquake Spectra, **20**, 323-338.

Galli P. and Molin D.; 2004: *Macroseismic survey of the 2002 Molise, Italy, earthquake and historical seismicity of S. Giuliano di Puglia*. Earthquake Spectra, **20**, 39-52.

Goretti A.; 2004: *Effetti di sito a San Giuliano a partire dai dati tipologici e di danno rilevati in emergenza sismica.* In: XI National Conference on Seismic Engineering in Italy, Genoa, 25-29 January.

Goretti A.; 2005: *Effetti di sito a Laino Borgo dai dati tipologici e di danno degli edifici rilevati dopo il sisma del 1998.* In: Di Pasquale G., Antonico L., Gullà G. and Sanò T. (eds), Microzonazione speditivi dei quattro comuni della Regione Calabria colpiti dagli eventi sismici del 9 settembre 1998. Fratelli Guido Arti Grafiche srl, Cosenza, pp. 99-109.

Goretti A. and De Sortis A.; 2003: *Il danneggiamento dovuto al sisma etneo del 29 ottobre 2002.* Ingegneria Sismica, **20**(1), 5-20.

Goretti A and Dolce M.; 2004a: *Site effects in Fabriano from post-earthquake typological and damage data collection*. Boll. Geof. Teor. Appl., **45**, 321-334.

Goretti A. and Dolce M.; 2004b: *Post-earthquake site effect evaluation from damage and building type data: an overview of italian recent applications.* In: XIII World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, Paper No. 263

Grunthal G.; 1998: *European Macroseismic Scale*. Chaiers du Centre Europèen de Gèodynamique et de Sèismologie, Vol 15, Conseil d'Europe, Luxembourg, 99 pp.

Gullà G. and Sdao F. (eds); 2001: *Dissesti prodotti o aggravati dal sisma del 9 settembre 1998 nei territori del confine calabro-lucano*. CNR-GNDCI, Pubblicazione N. 2121.

Margottini C., Molin D., Narcisi B. and Serva L.; 1987: *Intensity vs. acceleration: italian data*. In: Proceedings Workshop on Historical Seismicity of Central-eastern Mediterranean Region, Rome, pp. 213-226.

Medvedev S.V.; 1977: *Seismic Intensity Scale MSK 76*. Geophys. Pol. Acad. Sc. Inst. Publ., A-6 8117, Warsaw, 95-102.

Petrini V. and Guagenti E.; 1989: *Il caso delle vecchie costruzioni: verso una nuova legge danni intensità*. In: Proc. 4th National Conference on Seismic Engineering in Italy, Milan, pp. 145-153.

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