Seismic hazard disaggregation in the Molise region, Italy: the case study of Campobasso

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ABSTRACT:
Large scale experimentations play a relevant role in the earthquake engineering research, similarly Structural Health Monitoring is able to give information of real structures. A few geotechnical structures are documented, because only data on seismic permanent deformations are available. The present paper deals with seismic hazard of the site of the Student House at University of Molise, where a geotechnical monitoring system has been designed and is currently under implementation. It is aimed at refining the seismic hazard characterization for identifying a set of relevant earthquakes for the theoretical analysis of the structure. Reference earthquakes expressed in terms of magnitude (M), distance (R) and ε, were therefore investigated. Uniform hazard spectra at different structural periods for a 475-year return period were disaggregated. Shapes of both the joint and marginal probability density functions were studied and the first two modes of M, R and ε were extracted and discussed.

Keywords: seismic hazard, disaggregation, geotechnical monitoring system

1. INTRODUCTION

Structural Health Monitoring (SHM) for civil structures represents an interesting option for structural engineers to gain knowledge about real response of the structural to service gravity and wind loads during time, so that opportunities are offered in the fields of construction management and maintenance. If structures in seismic areas are concerned, an additional advantage of such techniques exist. In fact, a real or near real-time tracking of the structural response and of evolution of damage can support methods and techniques to develop post-earthquake scenarios and support rescue operations.
SHM is based on in-situ, non-destructive measurements and analysis of structural characteristics and aims at defining location and severity of damage, and at the evaluation of its consequences on the residual life of the structure (Silkorski, 1999; Mufti, 2001). SHM is a very multidisciplinary field, where a number of different skills (seismology, electronic and civil engineering, computer science) and institutions can work together in order to increase performance and reliability of such systems, whose promising perspectives seem to be almost clearly stated. Information obtained from such systems could be useful for maintenance or structural safety evaluation of both existing and historical structures by using rapid evaluation of conditions of damaged structures after an earthquake, estimation of residual life of structures, repair and retrofitting of structures (Rainieri et al., 2008).

An example of integrated structural and geotechnical monitoring system has been designed and is currently under implementation by the Structural and Geotechnical Dynamic Laboratory at University of Molise (Fabbrocino et al., 2009), Fig. 1. Experimental activities are associated to numerical investigations both in the static and dynamic field (Rainieri et al., 2010). In this framework, the problem of the site-specific hazard in the area of the University of Molise in Campobasso, Italy, is tackled. In particular, the refinement of seismic hazard characterization is carried out in order to reference parameters for selecting dynamic input for theoretical analyses. In the present study, attention is focussed on disaggregation of seismic hazard at the Vazzieri site and on the selection of reference earthquakes expressed in terms of magnitude (M), distance (R) and ε. In particular, as proposed in Convertito et al., (2009) the uniform hazard spectrum at different structural periods for a 475-year return period were disaggregated. For each of the disaggregated variable the shapes of both the joint and marginal probability density functions were studied and the first two modes of M, R and ε were extracted and discussed. Results are provided and are intended as an interesting support for design of monitoring systems and retrofitting of existing constructions (Iervolino et al., 2010).

Figure 1. The Student House in Campobasso, Vazzieri - University of Molise. The monitored flexible retaining wall and sensor location (Rainieri et al., 2010).

2. METHODOLOGY

In this section a methodology to investigate the design earthquakes, expressed in terms of representative magnitude (M), distance (R) and ε is presented and applied for a wide region of the Appenninic region, Italy (Fig. 2). The result of probabilistic seismic hazard analysis (PSHA), for a specified site, is a hazard curve that represents the probability of exceedance of a ground-motion parameter *A* in a time interval of interest. The construction of the hazard curve requires the computation of the hazard integral (Cornell, 1968; Bazzurro and Cornell, 1999) that provides the mean annual rate of exceedance of a given threshold value A_0 as in Eqn. 2.1,

$$\sum_{i=1}^{N} E_i(A > A_0) = \sum_{i=1}^{N} \alpha_i \left\{ \int_M \int_R \int_\varepsilon I\left[A > A_0 \middle| m, r, \varepsilon\right] f(m) f(r) f(\varepsilon) dm dr d\varepsilon \right\}_i \tag{2.1}$$

where I is an indicator function for *A*. The ε parameter represents the residual variability of the *A* with respect to the selected ground motion prediction equation (GMPE). This indicator function is equal to 1 if *A* is larger than A_0 and 0 otherwise. The probability density functions (PDFs) of magnitude *M*, *f(m)*, distance *R*, *f(r)* and ε, *f(ε)* depend, respectively, upon the adopted earthquake recurrence model (e.g., Gutenberg and Richter, 1944), upon source geometry and the selected GMPE. Finally, α_i for each zone, is the mean annual rate of occurrence of earthquakes with magnitude greater than some specified lower bound (M 4.3 in this study).

For engineering analyses purposes, it may be important to identify the most threatening earthquakes for the site of interest, while PSHA, for its integral nature, combines the contribution to the hazard from all *N* considered sources. However, the disaggregation procedure allows the decomposition of each point on the hazard curve, in terms of M, R and ε, from each selected source. Disaggregation in terms of ε may be useful to choose records for nonlinear dynamic analysis having the correct spectral shape at a period relevant for the dynamic behavior of the structure (Convertito et al., 2009). From an analytical point of view, the disaggregation's result is the joint PDF in Eqn. 2.2,

$$f(m, r, \varepsilon | A > A_0) = \frac{\sum_{i=1}^{N} \alpha_i \{ I[A > A_o | m, r, \varepsilon] f(m) f(r) f(\varepsilon) \}_i}{\sum_{i=1}^{N} E_i(A > A_0)} \tag{2.2}$$

which is the distribution of magnitude, distance, and ε conditional on the exceedance of the hazard level being disaggregated. In other words, given the exceedance of the A_0 ground-motion value, disaggregation provides how likely it is caused by each specific M, R, ε set (McGuire, 1995).

From the PDF in Eqn. 2.2 marginal PDFs may be obtained. They are univariate distributions of the disaggregation variables. The marginal PDF of a variable is obtained from the joint PDF saturating the other variables, that is, adding up all their contributions (Benjamin and Cornell, 1970). This gives the contribution to hazard of each variable alone. Marginal PDFs for M, R, and ε may be computed with Eqn. 2.3, 2.4 and 2.5,

$$f(m | A > A_0) = \int_R \int_\varepsilon f(m, r, \varepsilon | A > A_o) dr d\varepsilon \tag{2.3}$$

$$f(r | A > A_0) = \int_M \int_\varepsilon f(m, r, \varepsilon | A > A_o) dm d\varepsilon \tag{2.4}$$

$$f(\varepsilon | A > A_0) = \int_R \int_M f(m, r, \varepsilon | A > A_o) dr dm \tag{2.5}$$

In the case one wants or is allowed by the seismic code to use disaggregation of seismic hazard to identify the design earthquakes for the site of interest, semi arbitrary approaches based on these PDFs are usually adopted. For example, representative values of the distributions (e.g., median, modal, or the mean values of M, R, and ε) may be considered if a single design earthquake is sought.

The first step in the analyses of the present study consisted of the computation of the hazard curve and the uniform hazard spectra for the target site shown in Figure 1 (red square), in terms of peak ground acceleration (PGA) and spectral acceleration Sa(T), for T 0.3sec and T 0.75 sec. The spectral ordinates used in this study are close to the fundamental periods of bulkhead (T= 0.3 sec) and to one of fundamental period of the student house (T= 0.75 sec) for which the seismic design is carried out.

3. PROBABILISTIC SEISMIC HAZARD FOR CAMPOBASSO

The seismicity of central and southern Apennines (Italy), is often characterized by multiple sequences, with at least two main earthquakes of similar magnitude (Vallèe and Di Luccio, 2005). With a time interval between events varying from a few tenths of seconds to several months, such a behavior was observed for Irpinia (1980/11/23), Abruzzo (1984), Potenza (Basilicata, 1990–1991) and Umbria-Marche (1997) earthquakes. Similarly, the 2002 Molise sequence was characterized by compound earthquakes (2002/10/31 and 2002/01/11). The first shock (blue star in Figure 2, Mw 5.7, latitude: 41.72°N, longitude: 14.89°E) occurred in the vicinity of the village of San Giuliano di Puglia (green triangle in Figure 2), which caused the death of 29 people, most of them in the collapse of a primary school. The second shock (black star in Figure 2, Mw 5.7, latitude: 41.74°N, longitude: 14.84°E) occurred a few kilometers west ward from the first one, without making strong damages. Taking in account the position of the target site, that is close to the border between the zone 924 and 927 (Fig. 2), and the structure investigated in the present study, a site specific hazard analysis may be of main concern.

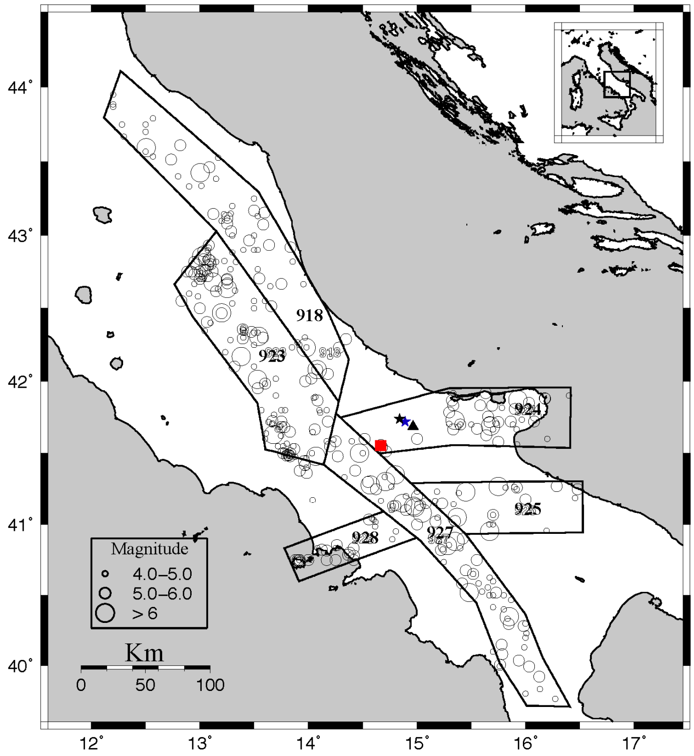

Figure 2. Seismic source zones configuration used to compute the hazard. Location of the target site used in the analysis is identified by red square. Circles, whose width is proportional to magnitude, represent the location of the earthquakes (M>4.0) retrieved from the CPTI04 catalog (Gruppo di lavoro Catalogo Parametrico dei Terremoti Italiani [CPTI], 2004). Stars represent Molise earthquakes sequence: 2002-10-31 Mw 5.7 (Blue) and 2002-11-01 Mw 5.7 (Black). Black triangle represents San Giuliano di Puglia village.

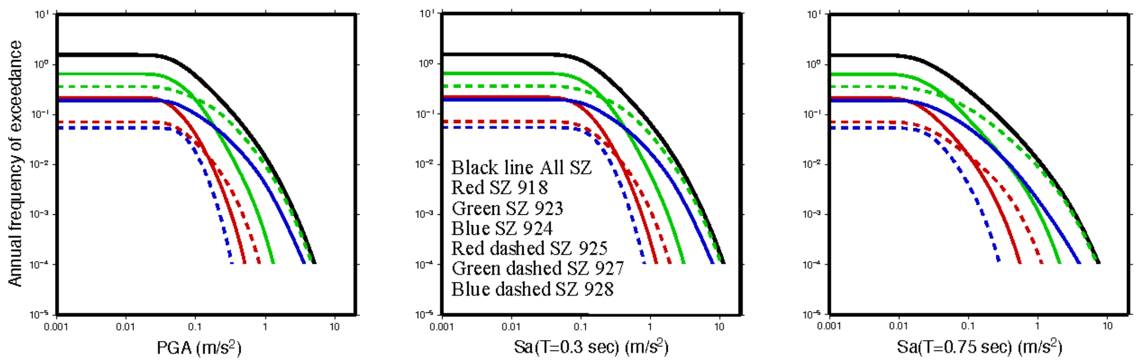

Figure 3. Hazard curve for target site for PGA (left), Sa(T= 0.3 sec) (center) and Sa(T= 0.75 sec) (right). Lines represent the hazard curve computed considering the contribution of all seismogenic zones (black), SZ 918 (red), SZ 923 (green), SZ 924 (blue), SZ 925 (red dashed), SZ 927 (green dashed), SZ 928 (blue dashed).

The selected seismogenic zones have been retrieved from the Italian zonation (ZS9) also adopted by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) (Meletti et al., 2008).The activity rates, *b*-values, and minimum and maximum magnitudes for each zone are listed in Table 1. Figure 2 shows the location of the main earthquakes, both historical and recent, having magnitude larger than M 4.0, contained in the CPTI04 catalog (see the Data and Resources section).The activity rates and the values selected for the analyses performed in this work are based on the study proposed by Barani et al. (2009).

Table 1. Parameters of the Selected Seismogenic Zones Shown in Figure 2.

Zone	α (events/yr)	*b*	Mmin	Mmax
918	0.217	-0.840	4.3	6.4
923	0.645	-0.802	4.3	7.3
924	0.192	-0.945	4.3	7.0
925	0.071	-0.508	4.3	7.0
927	0.362	-0.557	4.3	7.3
928	0.054	-1.056	4.3	5.8

The selected GMPE considered is that of Sabetta and Pugliese (1996), which was derived from Italian strong-motion data. The hazard curves have been computed for PGA, Sa(T= 0.3 sec) and Sa(T= 0.75 sec) for the return period TR = 475 yr. To this aim, the numerical computation of equation (2.1) was carried out using relatively small increments: 0.5 km for distance, 0.05 for magnitude, and 0.2 for ε. These steps reduce the problems of numerical interpolation commonly used to produce the hazard maps and, from a disaggregation point of view, allow to limit the issues related to the appropriate selection of the bins used to collect the contributions of the hazard variables. In fact, the identification of the modes of the PDFs may depend on the size of the M, R, and ε bins used for disaggregation (Bazzurro and Cornell, 1999). To better understand the results for the target site, the hazard was computed considering the contribution of all seismogenic zone (SZ) and each one separately.

The site-specific analysis will be used to show how the hazard at the target site can be affected by the parameterization of the selected seismogenic sources. The UHSs obtained in this study are compared to that provided by INGV for the site of interest. Notice that, the comparison is only qualitative because INGV used a more sophisticated approach, based on logic tree accounting for several GMPEs, a larger number of seismic zones and parameters that refer to the earthquake catalogue corrected for both statistical and historical completeness.

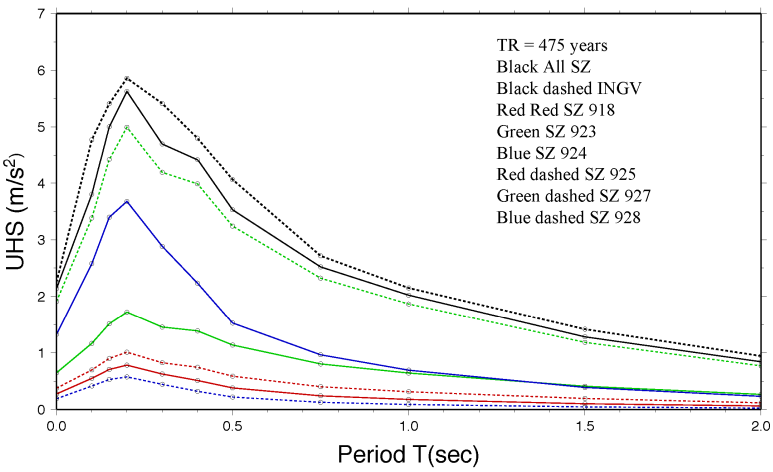

Figure 4. Uniform hazard spectra in m/s^2 for the target site and 475 yr return period. Lines represent the uniform hazard spectra computed considering the contribution of all seismogenic zones (black), SZ 918 (red), SZ 923 (green), SZ 924 (blue), SZ 925 (red dashed), SZ 927 (green dashed), SZ 928 (blue dashed). The black dashed line represents the INGV uniform hazard spectrum.

In Figure 4 the UHSs corresponding to TR =475 yr calculated at 11 vibration periods for the target site are shown. In the same figure, the UHS retrieved from the INGV Web site is also shown. This UHS corresponds to the weighted mean of the UHSs at the four closest grid points to the target site, at which INGV computed PSHA. For the selected site, the disaggregation analysis was also compared to that of INGV, which through the same Web site (see the Data and Resources section), provides disaggregation of seismic hazard in terms of contribution of M and R bins, but only for PGA. In particular, Table 2 lists the range of variability of M and R for the four closest grid points to the target site. Concerning the ε variable, only the mean value obtained from disaggregation is provided by INGV. The comparison of disaggregated values in terms of modal and mean values for the target site, obtained from the joint PDFs, is given in Table 2. In particular, ($\overline{R}$, $\overline{M}$, $\overline{\varepsilon}$) refer to the mean values, and (R*, M*, ε*) refer to the modal values.

Figure 5 shows the results of disaggregation for the target site for PGA, Sa(T= 0.3 sec) and Sa(T= 0.75 sec), respectively, obtained in the present study in terms of both joint and marginal PDFs. Because the joint PDF in Eqn. 2.2 may be hardly represented in a figure, the three bivariate PDFs shown have been obtained by marginalizing on the third hazard variable not given in the plot. As an example, Eqn. 3.1,

$$f\left(m,r \middle| A > A_0\right) = \int_{\varepsilon} f\left(m,r,\varepsilon \middle| A > A_o\right) d\varepsilon \tag{3.1}$$

indicates how to obtain the joint PDF of M and R only from that of M, R and ε. In each figure, left, central and right panels give the contributions in percents to PGA, Sa(T= 0.3 sec) and Sa(T= 0.75 sec) hazards, respectively. The central part of each panel shows specific joint PDFs for two of the three hazard variables. On the external axes, the marginal PDFs obtained from the joint PDFs are also shown. The results of disaggregation analysis show that disaggregated PDFs feature a unimodal shape for all vibration periods for the return period of 475 yr. This may be due to the fact that only one seismogenic zone represents the most hazardous zone in terms of activity rate and maximum magnitude at all the selected vibration periods. However, the joint and marginal PDFs for different return period (e.g., 101 yr, not reported in this work) at the same target site feature a bimodal shape.

On the other hand, the results of the disaggregation allows to identify the zones 924 and 927 (Fig. 2) as responsible for the hazard levels at the site. The larger contribution of larger magnitude distant events observed in disaggregation for Sa(T= 0.3 sec) and Sa(T= 0.75 sec) with respect to that of PGA can be ascribed to their lower frequency content compared to lower magnitude nearby earthquakes affecting the spectral ordinates more at high frequencies. As a consequence, for the selected spectral ordinates and return period, only one design earthquake does exist. These results may have an important implication for this and other sites in the study region.

Table 2. Modal and mean values for the hazard variables for the target site and for PGA, Sa(T= 0.3 sec) and Sa (T= 0.75 sec)*

		R* (Km)	M*	ε*	$\overline{R}$ (km)	$\overline{M}$	$\overline{\varepsilon}$
Target site							
PGA	This study	9,25	6,2	0,400	13,92	6,5	0,533
	INGV	0-10	4.5-5.5	NA	9.87-11.50	5.7-5.9	0.861-1.040
T= 0.30 sec		10,75	6,4	0,400	14,82	6,4	0,720
T= 0.75 sec		21,75	7,0	0,400	20,61	6,8	0,602

The values have been retrieved from the joint PDFs. $\overline{R}$, $\overline{M}$ and $\overline{\varepsilon}$ refer to the mean values, and M, R*and ε*to the modal values.

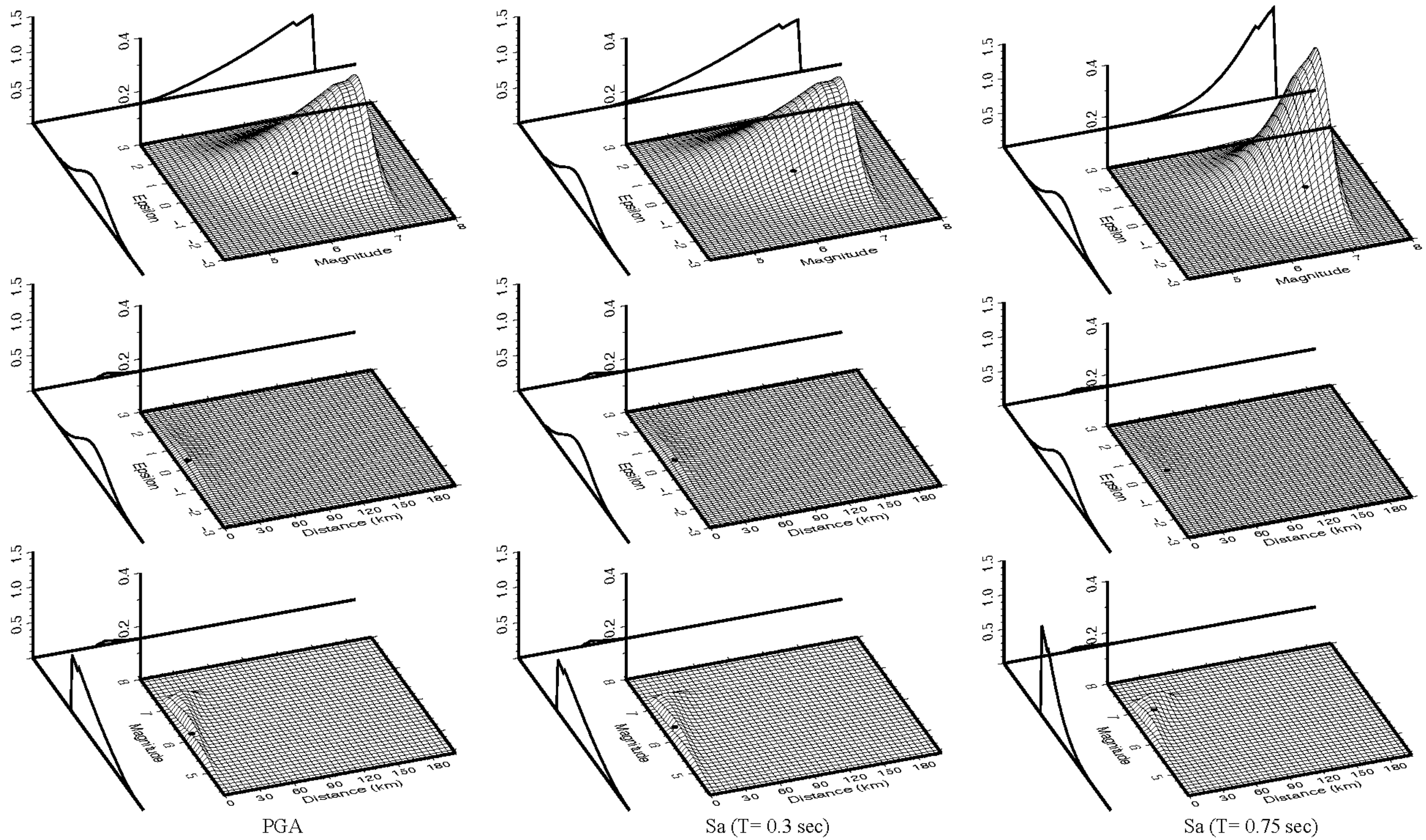

Figure 5. Disaggregation results expressed as contribution to 475 yr return period hazard for the target site. Left panels refer to PGA, central panels refer to Sa(T= 0.3 sec) and right panels refer to Sa(T = 0.75 sec). The central part of each panel shows the joint PDFs for the specific hazard variable pair. On the external axes the marginal PDFs obtained from the joint PDFs area also shown.

4. CONCLUSIONS

In the present paper, some results of an interdisciplinary study are reported. In particular, the work represents a contribution to the development of an integrated structural and geotechnical monitoring system on structures located in a medium to high seismic hazard area in Italy. A site specific probabilistic hazard assessment has been carried out in order to provide refined information on relevant earthquakes expressed in terms of magnitude (M), distance (R) and ε that can affect the structure of interest. The uniform hazard spectrum at different structural periods for a 475-year return period were disaggregated for the site of Vazzieri in Campobasso, Molise region, Italy. For each of the disaggregated variables the shapes of both the joint and marginal probability density functions were studied and the first two modes of M, R and ε have been evaluated and discussed. In particular, the analysis showed that for the site of interest and the selected return period a single design earthquake can be used for representing the hazard at the site.

DATA AND RESOURCES

Hazard data from INGV were retrieved via the Progetto S1 Web site: http://esse1-gis.mi.ingv.it/s1_en.php. The CPTI04 catalog can be accessed at http://emidius.mi.ingv.it/CPTI04.

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