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Seismic Hazard Assessment from Intensity Data

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Abstract

A new approach has been developed aiming at the probabilistic estimate of seismic hazard from the local seismic history. This is expressed in terms of seismic effects documented at the site during past earthquakes (macroseismic intensities). Thus, a specific statistical treatment is required to take into account the peculiar character of macroseismic data that are discrete, ordinal and range-limited. This procedure also allows the correct treatment of relevant uncertainty (ill-defined intensity values, catalogue completeness, etc.) in the frame of a coherent distribution-free statistical approach.

This methodology (hereafter "site" approach) has been implemented in a free computer program (SASHA: Site Approach to Seismic Hazard Assessment) and applied to the SHA of the Italian territory.
The program also implements a probabilistic procedure to "translate" hazard estimates in terms of intensity to other ground-shaking parameters (e.g. PGA): this "rescaling" procedure allows to compare the results of this approach with those of standard PSHA methodologies. This comparison is of great importance at the sites where a rich seismic history is available and it could provide a benchmark for different approaches.

Methodology

The assessment of seismic hazard (i.e. probability that in a future time span Δt the site considered will be shaken by at least one earthquake with local effects not lower than I_s) is performed in 3 steps (Albarello and Mucciarelli, 2002):

1. Building the Site Seismic History

The reconstruction of the effects produced by past earthquakes at a locality is characterized by uncertainty. This can be expressed through the exceedance probabilities $P_l(I_s)$, representing the degree of belief in the hypothesis that the l-th event has actually shaken the site with intensity = I_s (Magri et al., 1994). The values of $P_l(I_s)$ are defined over the whole range of the adopted macroseismic scale (e.g., I-XII for the MCS scale). In principle, these probabilities should be attributed after a critical analysis of documentary information available at the site about intensity data.
For earthquakes lacking direct information about local effects, probability $P_l(I_s)$ can be derived from the relevant epicentral data through the relation

$$P_l(I_s) = \sum_{I_e=1}^{12} g(I_e) S(I_s | I_e, D)$$

(g is the probability that epicentral intensity is I_e and S is the conditional probability that local seismic effects are $\geq I_s$, given an earthquake with epicentral intensity I_e and occurring at the distance D). Thus, the probability function P_l and the density g allow us to account for uncertainty on intensity at the site and at the epicentre respectively. The probability function S plays the role of the attenuation function expressed in probabilistic form (Albarello and D'Amico, 2005) and represents the uncertainty on the intensity deduced at the site, given epicentral intensity and source distance. This function has to be determined empirically and is presumably region-dependent.
The set of P_l probability functions, each corresponding to a different earthquake, represents the seismic history at the site, i.e. the local seismic catalogue.

2. Completeness of the Site Seismic History

Available information on past seismicity generally covers a time span much larger than that characterized by a satisfactory level of completeness. Usually, the longer this period, the more uncertain and unknown our knowledge about past seismic effects. On the other hand, longer catalogues are more representative of the seismogenic process. Therefore, both these aspects (completeness and representativeness) should be considered to evaluate the reliability of hazard estimates deduced from the site seismic history covering the specific time interval Δt_i.
In the site approach, the completeness of the local catalogue used for hazard computation is expressed in terms of a probability $L_i(C)$. This is assessed through a statistical methodology (Albarello et al., 2001) based on 3 assumptions: i) the seismogenic process is stationary, ii) the most recent part of the catalogue is complete, iii) the catalogue is statistically representative of the long-term stationary seismogenic process (representativeness).

3. Computing the Seismic Hazard

Starting from the local catalogue, for each time interval Δt_j of length equal to Δt (exposure time), the probability Q_j is assessed that at least one earthquake has shaken the site with intensity $\geq I_s$. If N_j is the total number of events that occurred during Δt_j, it results in

$$Q_j = Q(\Delta t, I_s | \Delta t_j) = 1 - \prod_{l=1}^{N_j} [1 - P_l(I_s)]$$

If the site catalogue covers a time span ΔT_i, a number K_i of distinct time intervals of lenght Δt_j can be individuated.
Seismic hazard H_i for intensity threshold I_s and exposure time Δt is computed as

$$H_i = H(\Delta t, I_s | \Delta T_i) = \sum_{j=1}^{K_i} s(\Delta t_j) Q(\Delta t, I_s | \Delta t_j)$$

where dependence of H on the specific catalogue of length ΔT_i is made explicit and $s(\Delta t_j)=1/K_i$.
The above Eq. is then generalized to take into account the completeness of the local catalogue (assessed for each of the M possible time spans ΔT_i, included between the most recent and oldest extreme of the catalogue explored) and the unconditional seismic hazard results

$$H(\Delta t, I_s) = \sum_{i=1}^{M} L_i(C) H(\Delta t, I_s | \Delta T_i)$$

Values of H, computed for each intensity degree I_s represent the hazard curve at the site under study. A "reference intensity" (I_{ref}) can be derived from this curve, corresponding to the highest intensity with an exceedance probability $\geq P_{exc}$ (e.g., 10%) during Δt.
Likewise, a "reference PGA" (PGA_{ref}) value is derived from the hazard curve expressed in terms of intensity in the form

$$H(\Delta t, PGA) = \sum_{I_s=1}^{12} h(\Delta t, I_s) G(\log(PGA) | I_s)$$

$$h(\Delta t, I_s) = H(\Delta t, I_s) - H(\Delta t, I_s + 1)$$

where G represents the probability that the logarithm of peak ground acceleration at the site is $\geq$PGA, given that intensity is I_s.

The SASHA Program

The site approach has recently been implemented in the free computer program SASHA (D'Amico and Albarello, 2007; 2008).
The program allows a number of choices concerning the reconstruction of site seismic history (criteria for felt data selection, intensity attenuation with distance, etc.) and the hazard computation (exposure time, exceedance probability, etc.).
A conceptual flow chart of SASHA is shown in Figure 1.

The complete input consists of 3 files:
1) the list of sites where hazard is computed (sites database)
2) the set of available intensity observations (macroseismic database)
3) the catalogue with epicentral data of earthquakes potentially felt at the sites considered (epicentral catalogue)

SASHA has been developed in the framework of a research project devoted to PSHA in Italy (INGV-DPC Project S1: http://esse1.mi.ingv.it). Thus, region-dependent coefficients of the empirical relations implemented in the code are the ones most recently proposed for Italy (i.e. Pasolini et al., 2008 for the intensity attenuation with source distance; Faccioli and Cauzzi, 2006 to "convert" hazard estimates from intensity to PGA).

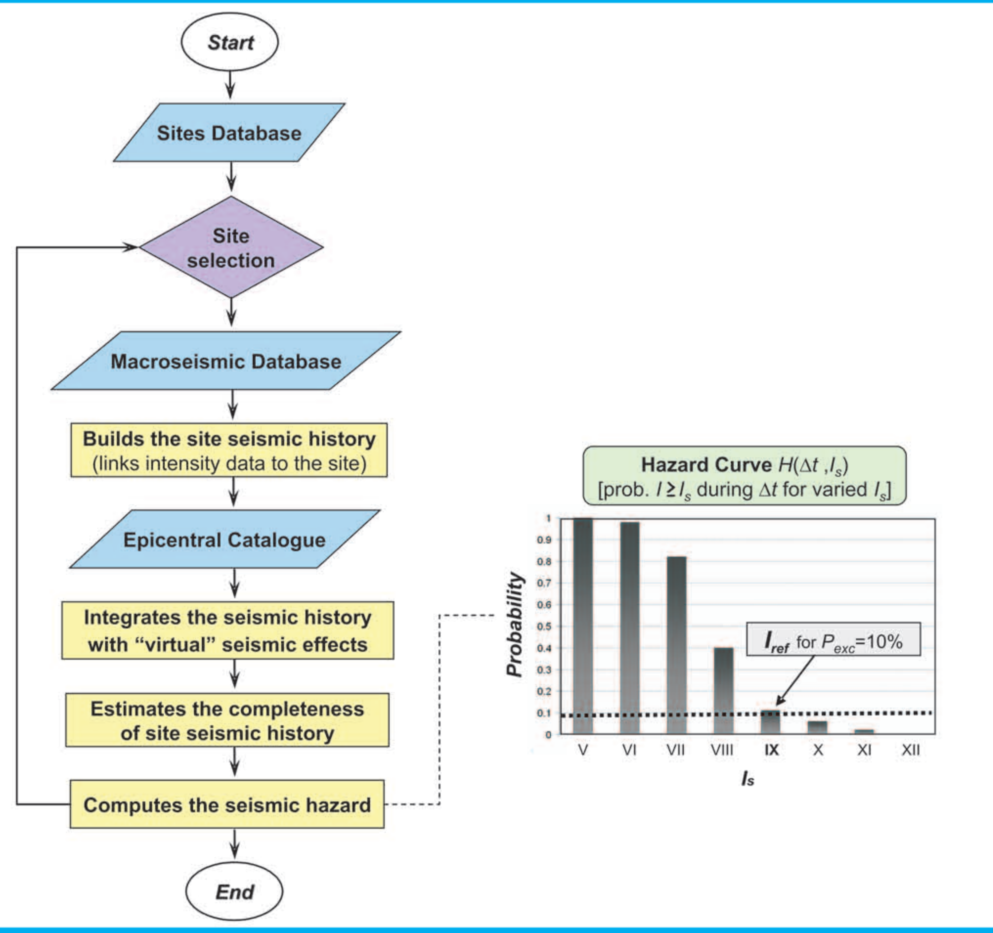

Figure 1
Flow chart of the SASHA program

Application to PSHA in Italy

Figure 2 shows the PSH estimates (I_{ref}= highest intensites with exceedance probability $\geq$ 10% in 50 years) derived by using the site approach in Italy. Computation was performed at the 8101 italian municipalities.

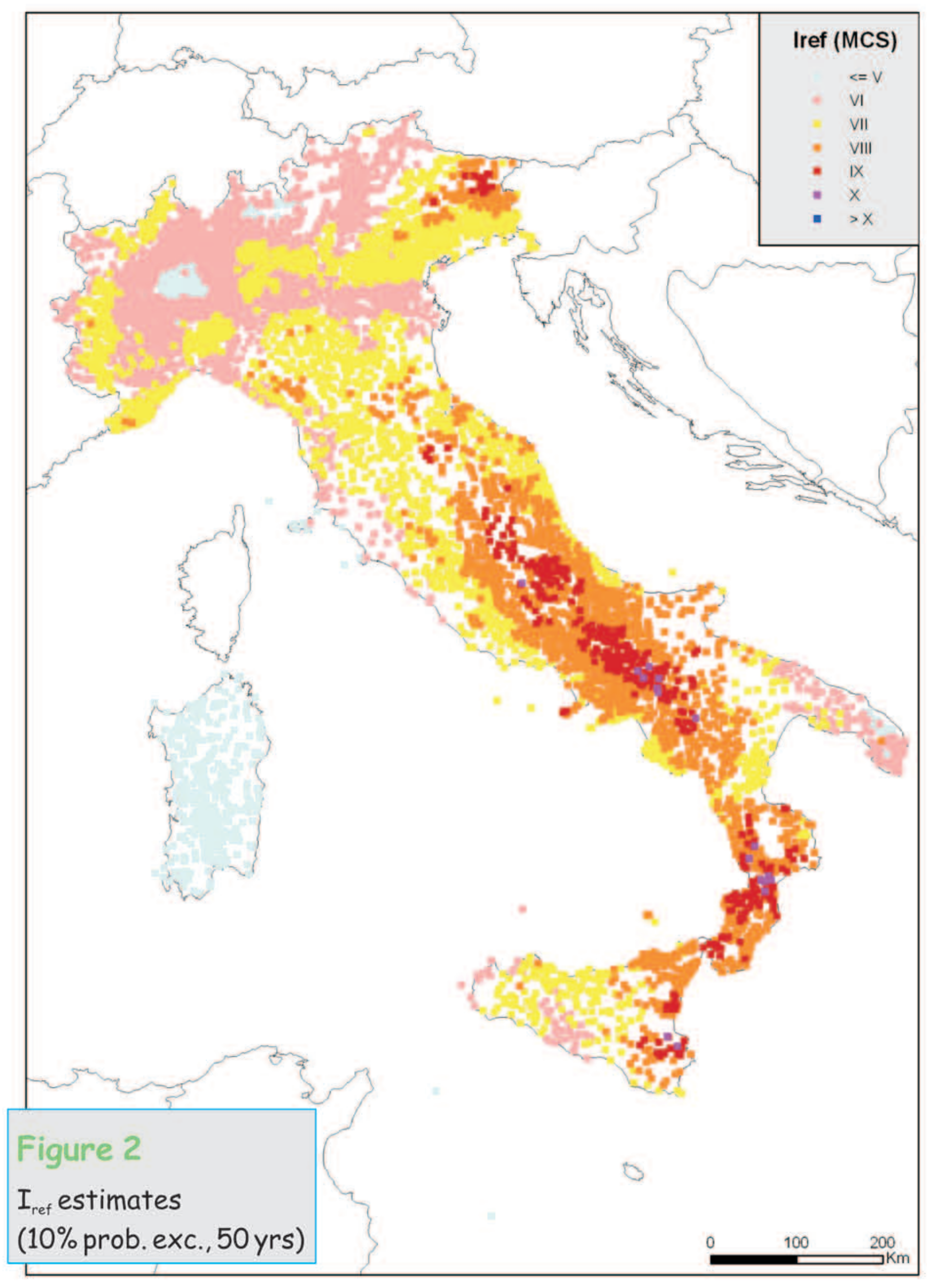

Figure 2
I_{ref} estimates
(10% prob. exc., 50 yrs)

The seismic history of each locality was built from intensity data provided by the DBMI04 database (Stucchi et al., 2007), listing about 58,000 macroseismic observations since 217 B.C. For earthquakes lacking local felt data, virtual seismic effects were deduced from relevant epicentral data (CPTI Working

The pattern of I_{ref} values is consistent with Figure 3 (maximum intensities documented during the past in Italy), since more hazardous areas correspond to those characterized by stronger past seismicity.

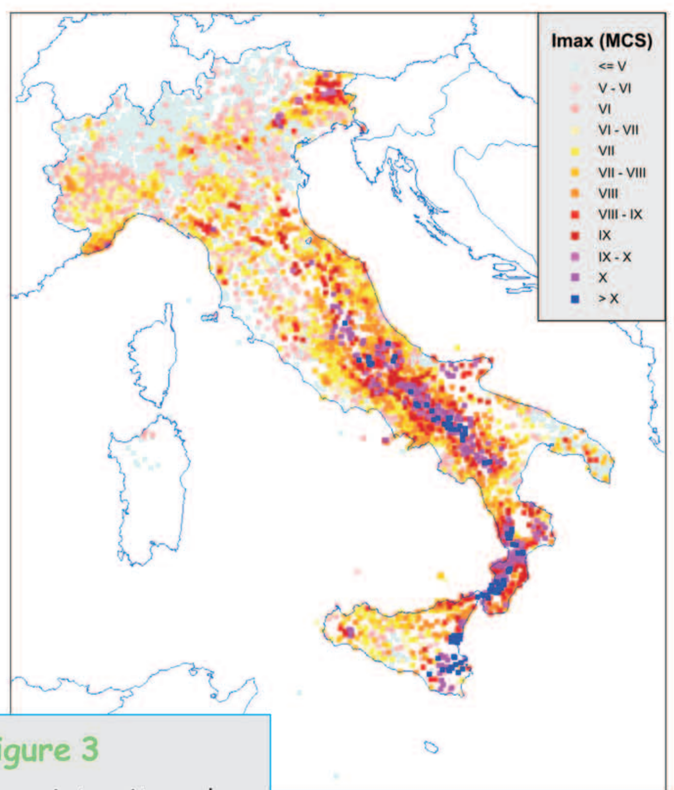

Figure 3
Max. intensity values observed at each site

In low-hazard zones (see e.g., northern Italy in Figure 2), poor seismic histories are available (Figure 4) and thus the relevant hazard values more strongly depend on the attenuation relations rather than on the few felt data at disposal.

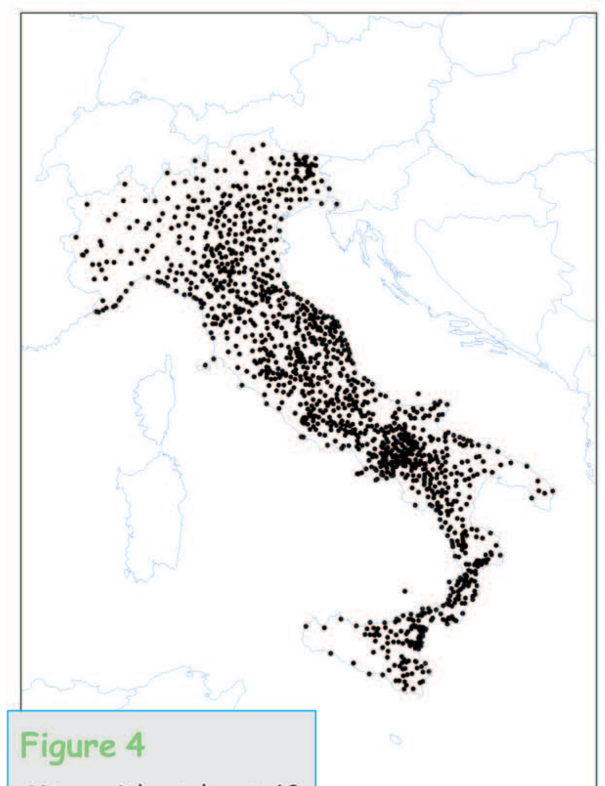

Figure 4
Sites with at least 10 macroseismic data

Figure 5 shows the PSH estimates expressed in terms of PGA (PGA_{ref}= highest PGA values with exceedance probability $\geq$10% in 50 years) derived through the probabilistic procedure developed to "translate" hazard estimates from intensity to PGA (see above).

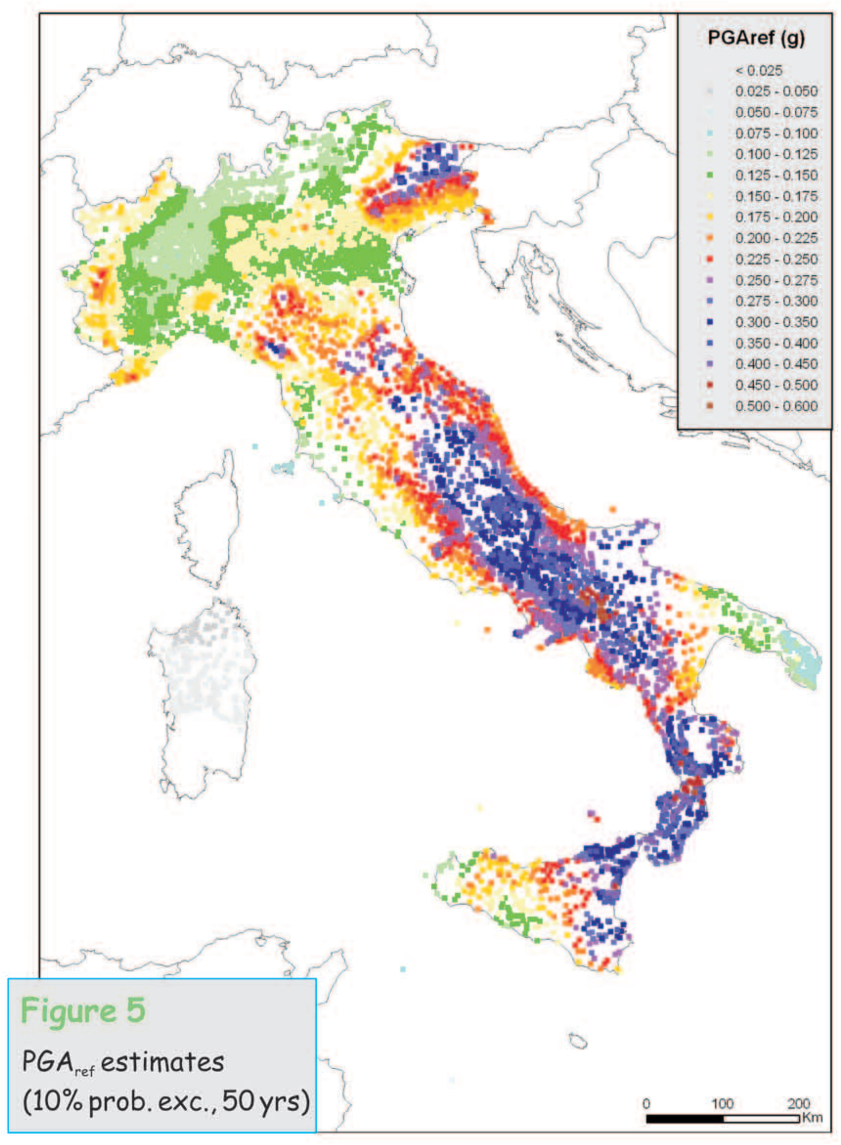

Figure 5
PGA_{ref} estimates
(10% prob. exc., 50 yrs)

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