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PROBABILISTIC SEISMIC HAZARD ESTIMATES FROM LOCAL SEISMIC HISTORY: A TOOL FOR RISK ASSESSMENT IN URBAN AREAS

Dario ALBARELLO[1] , Vera D'AMICO[2], Renata ROTONDI[3], Elisa VARINI[4] and Gaetano ZONNO[5]

Using macroseismic intensity to parameterize earthquakes effects allows a direct link of hazard assessment with risk estimates in urban areas. This is particularly true in most of European countries where long lasting documentary history is available about the effects of past earthquakes. The computational code SASHA (Site Approach to Seismic Hazard Assessment), was developed to allow a coherent probabilistic analysis of intensity data locally available (site seismic histories) to provide hazard estimates in terms of intensity by taking into account the specific nature of intensity (ordinal, discrete, finite in range, site-dependent) and relevant uncertainty (completeness, ill-definition of the oldest earthquakes, etc.). Thus, it resulted of specific interest in the frame of the EU research project UPStratMAFA "**U**rban Disaster **P**revention **Strat**egies Using **MA**croseismic Fields and **FA**ult Sources" *(Grant Agreement n. 230301/2011/613486/SUB/A5)*. In order to extend the application of this approach to sites and countries where local seismic histories are relatively poor, a new implementation of the code was provided, allowing to include in the hazard assessment information coming from different branches (historical studies, seismological instrumental information and numerical simulations). In particular, macroseismic information related to the seismic history locally documented, that represents the bulk of the considered information, can be integrated with "virtual" intensities deduced from epicentral data (via earthquake-specific probabilistic attenuation relationships) and "simulated" intensities deduced via physically constrained stochastic simulations from data on seismogenic faults activated during past earthquakes. This allows a more complete reconstruction of local seismic history and also reducing uncertainty affecting macroseismic data relative to older earthquakes. Some applications of the new SASHA code in different European countries will be described.

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Probabilistic seismic hazard estimates from local seismic history: a tool for risk assessment in urban areas

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Abstract

Using macroseismic intensity to parameterize earthquakes effects allows a direct link of hazard assessment with risk estimates in urban areas. This is particularly true in most of European countries where long lasting documentary history is available about the effects of past earthquakes.

The computational code **SASHA (Site Approach to Seismic Hazard Assessment)** was developed to allow a coherent probabilistic analysis of intensity data locally available (site seismic histories) to provide hazard estimates in terms of intensity by taking into account the specific nature of intensity (ordinal, discrete, finite in range, site-dependent) and relevant uncertainty (completeness, ill-definition of the oldest earthquakes, etc.). Thus, it resulted of specific interest in the frame of the **EU research project UPStratMAFA** "Urban Disaster Prevention Strategies Using MAcroseismic Fields and Fault Sources" (Grant Agreement n. 230301/2011/613486/SUB/A5).

In order to extend the application of this approach to sites and countries where local seismic histories are relatively poor, a new implementation of the code was provided, allowing to include in the hazard assessment information coming from different branches (historical studies, seismological instrumental information and numerical simulations). In particular, macroseismic information related to the seismic history locally documented, that represents the bulk of the considered information, can be integrated with "virtual" intensities deduced from epicentral data (via earthquake-specific probabilistic attenuation relationships) and "simulated" intensities deduced via physically constrained stochastic simulations from data on seismogenic faults activated during past earthquakes. This allows a more complete reconstruction of local seismic history and also reducing uncertainty affecting macroseismic data relative to older earthquakes. Some applications of the new SASHA code in different European countries will be described.

Site Approach to Seismic Hazard Assessment: the SASHA code

SASHA is a computer program (D'Amico and Albarello, 2008) to assess **seismic hazard in terms of macroseismic intensity** by following a probabilistic procedure (Albarello and Mucciarelli, 2002) developed to handle macroseismic data, which basically relies on **local information about the effects of past earthquakes** documented at the site, with a minor role of seismic source data. This approach allows the full exploitation of the large amount of macroseismic information available at the site in the frame of a formally coherent and complete treatment of intensity data, that takes into account the relevant uncertainty and inherently bounded, ordinal and discrete character of the intensities. As in the standard Cornell-McGuire approach, the seismogenic process is assumed to be stationary, but no reference model of possible seismogenic sources is required.

Seismic hazard is assessed in 2 steps (**Fig. 1**):

Step 1. Local seismic history (i.e., time series of macroseismic intensities) is built up by combining seismic effects observed at the site during past earthquakes and "virtual" intensities deduced from epicentral data or ground-motion simulations; each intensity evaluation is considered affected by a measurable uncertainty, which depends on the available information.

Step 2. Completeness and representativity of the site seismic history is evaluated, along with the relevant uncertainty (local completeness). The seismic recurrence at the site is parameterised for each intensity threshold I_s, using a fully distribution-free approach that does not require any pre-processing (e.g., aftershock removal, selection of mainshocks).

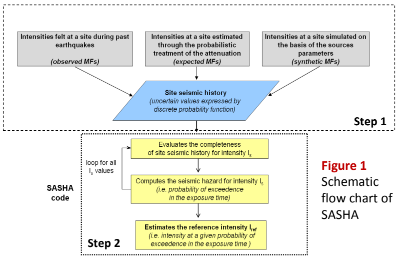


Figure 1 Schematic flow chart of SASHA

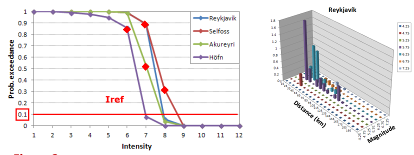


Figure 2 Example of hazard curves (left) at some test sites (red diamonds: highest intensity values (I_{ref}) with exceedence probability ≥10% in 50 years) and hazard deaggregation plot (right)

SASHA outcomes are (**Fig. 2**):

- **hazard curve** (i.e., probability, for each threshold I_s, that at least one earthquake with intensity $\geq I_s$ will occur at the site during the exposure time)
- **reference intensity I_{ref}**, which is determined from the hazard curve as a function of the probability threshold considered (e.g., 0.1)
- **deaggregation analysis** (i.e., magnitude/distance pairs more representative for the reference ground motion; identification of past earthquakes most important for the local hazard).

Probabilistic attenuation: the beta-binomial model

The major changes to SASHA performed for this project concern the reconstruction of the site seismic history: documented intensity data are integrated with **"virtual" intensities** estimated by a probabilistic attenuation model or by numerical simulations. In particular, the following attenuation model developed for the project was implemented.

The probability distribution of the intensity at a site, conditioned on the epicentral intensity I_0 and the epicentral distance d, is estimated by a **beta-binomial model**, both under the assumption of isotropic and anisotropic decay (**Fig. 3**). The estimation process is carried out according to the Bayesian paradigm, exploiting learning sets of macroseismic fields to assign the prior distributions of the model parameters.

The definition of suitable **learning sets** is a key point for an extensive use of the model. Zonno et al. (2009) suggest to apply a clustering procedure to the Italian historical earthquake database for deriving classes of macroseismic fields internally homogeneous from the attenuation point of view, but each with a different trend (Rotondi et al., 2013).

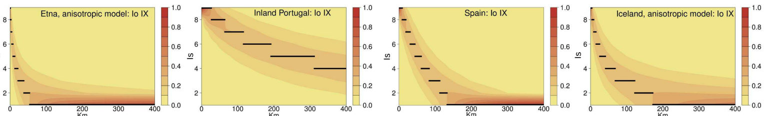
Under the isotropic assumption of intensity decay $\Delta I = I_0 - I_s$, we assume that, conditioned on the epicentral intensity I_0, the intensity I_s at any site at distance d from the epicentre has the same binomial distribution

$$\Pr\left(I_s = i \mid I_0 = i_0, p(d)\right) = \binom{i_0}{i} p(d)^i \left[1 - p(d)\right]^{i_0 - i} \quad \text{with} \quad p(d) = \left(\frac{\gamma_1}{\gamma_1 + d}\right)^{\gamma_2}$$

where γ_1 and γ_2 are obtained by smoothing the Bayesian estimates of the binomial parameter p given for a set of fixed distances.

As for the anisotropic assumption, we considered the hypothesis of elliptic isoseismal lines. The key idea is to apply the model as in the isotropic case to the plane transformed so that ellipses with the major axis along the fault rupture become circles with centre in the middle point of the rupture (Azzaro et al., 2013).

Figure 3 Examples of probability distributions of the intensity I_s given the epicentral intensity I_0=IX, for the test areas. In black the most probable I_s at any epicentral distance



Application in test areas

Seismic hazard was computed in the 4 test areas of the project (**Fig. 4**):

a) **Mt. Etna region, Southern Italy**
b) **Portugal**
c) **Alicante-Murcia region, Southeast Spain**
d) **Iceland**

In areas a) and c), site seismic histories were built up integrating observed intensity data with "virtual" intensities derived from the attenuation model; in area b), also "simulated" intensities were considered; in area d), only intensities deduced via the attenuation model were used.

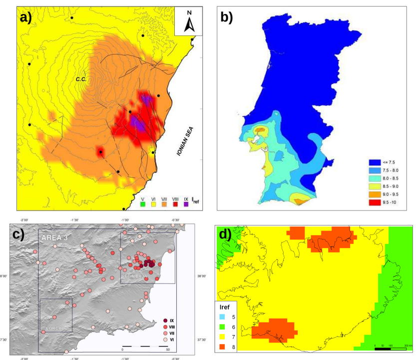


Figure 4 Examples of seismic hazard estimates in the test areas: highest intensity values (I_{ref}) with exceedence probability ≥10% in 50 years

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