Getting better insights in the influence of uncertainties in seismic risk. Application to L'Aquila earthquake (2009).

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1. Objective:

Over recent years, numbers of tools for seismic risk analysis have been developed to evaluate casualties and losses induced by earthquakes. A recent overview of available models can be found in (Molina et al. 2010). These predictions software require a large number of quantitative parameters (parametric uncertainty) but also model structures (model uncertainty). The choice of the appropriate model and the determination of exact values of these parameters remain very difficult. Therefore, sensitivity analysis and uncertainty quantification have to be performed for these kinds of studies. In this context, the aim of this article is to present a methodology for getting better insight in the role played by the different uncertainty sources (parametric and model) based on a variance-based global sensitivity analysis. Contrary to Rohmer et al. (2014), we used a less greedy estimation algorithm (Benaïchouche & Rohmer 2016), which both allows providing global sensitivity measures, but also information on local sensitivity. The application case is the risk analysis performed for Aquila (Italy, 2009) earthquake.

2. Model simulation and sensitivity analysis methods:

The seismic damage assessment models evaluate earthquake-related risk, casualties, and losses through the convolution of two independent modules: seismic aggression and vulnerability. For seismic aggression estimation three steps are required: (1) Regional hazard estimation by calculating the ground shaking (Peak Ground Acceleration on bedrock PGA) induced an earthquake defined by its epicenter position (XY), depth (Z), magnitude (Mw) using ground motion prediction equations (GMPE) associated to a statistical parameter (Sigma). (2) PGA at local scale, which accounts for lithological effects via an amplification factor (LITH). (3) The PGA value is converted in macro-seismic intensity using conversion laws (GMICE). The obtained intensity is then convoluted with vulnerability module for damage estimation. In this work, we focus on the sensitivity analysis related to the estimated intensity output. All our simulations were performed with Armagedom software (Sedan et al, 2013).

To assess the sensitivity analysis of the intensity output we developed a new technique for Sobol' indices estimation, where the variance of the conditional expectation $V\left[E[(Y|x_i)]\right]$ is calculated from the expectation of the local conditional variance $E\left[V[(Y|x_i)]\right]$ by partitioning the input parameters space into clusters. This algorithm (ELVR) is presented in details in (Benaichouche & Rohmer, 2016). This method allows the estimation of the first order and second order Sobol' indices and its relationships with the inputs parameters (respectively: model) variation range width (respectively: model choice). Here, the obtained results with the developed technique will be presented and compared with those obtained with Saltelli's algorithm (Saltelli, 2002) for the first order Sobol' indices estimation.

3. L'Aquila earthquake and sources of parameter uncertainty:

L'Aquila is a moderate-sized city (∼73,000 inhabitants) located in Central Italy (Fig.1), 90km in the south-west of Roma. On 6 April 2009, a 6.3 earthquake magnitude hit the region causing severe damages: 308 people have died, 20% of the housing was heavily damaged and more than 40,000 people were left homeless (Tertuliani, 2010). The impact on religious and monumental heritage was also disastrous. The estimated intensity in the L'Aquila center is around 8.5 (EMS scale). In this context, our objective is the evaluation of uncertainties propagation (parameter and model) related to the average estimated intensity in the L'Aquila. The uncertainties sources for this application are summarized in table 1. The estimated values were obtained from Douglas et al. 2015. More details are provided in Douglas et al. (2015) and references therein.

4. Results and Conclusions:

The quantity of interest is the intensity (average over the whole area of the L'Aquila Historical city) for the Sobol' indices estimation with 7 random inputs (Table.1). Samples were generated using Sobol' quasi-random sequences technique. The performed simulations give an average intensity of 7.5 and a total variance of 1 (Fig.1 show the results of an arbitrary simulation). The results are given in Fig. 2 (left). Fig.2 (left) shows that the developed method requires a fewer number of model evaluations (1K simulations) to obtain an excellent convergence compared to those obtained with Saltelli algorithm (200K simulations).

Analysis of results of the first order effects (Fig.2-left) shows that the model is additive (sum of seven main effects is 95.6%). This means that all input parameters have a negligible interaction effects between them. This result is confirmed in Fig.2 (middle), which shows that all second order Sobol' indices effects are less than 4% (10K model evaluations). Therefore, the analysis can be restricted to the first order effects. We observe (Fig.2 - left) that the most influential input corresponds to the choice of the GMICE model with a main effect of 58% followed by the GMPE model with a main effect of 14%. Uncertainties on Magnitude (Mw) and Sigma represent a main effect of 8%. Finally, the position, depth and lithological site effects (denoted XY, Z and LITH) have a little influence (less than 3%). These results show that the appropriate choice of GMICE and GMPE models should be prioritized in future investigations.

A local analysis of the first order effects of the GMICE model shows (Fig.2 - right) that the GMICE equations {1,2,3} have respectively an influence of {22%,73%,80%}. This means that if additional information were available and the GMICE is fixed to {3}, the total variance on the average intensity could be reduced up to 80%. On the other hand, if it was fixed to {1} a reduction of 22% could be expected. The average reduction on total variance is given by the mean of these three values (58.3%) which correspond to first order Sobol' index obtained in Fig.2 (left).

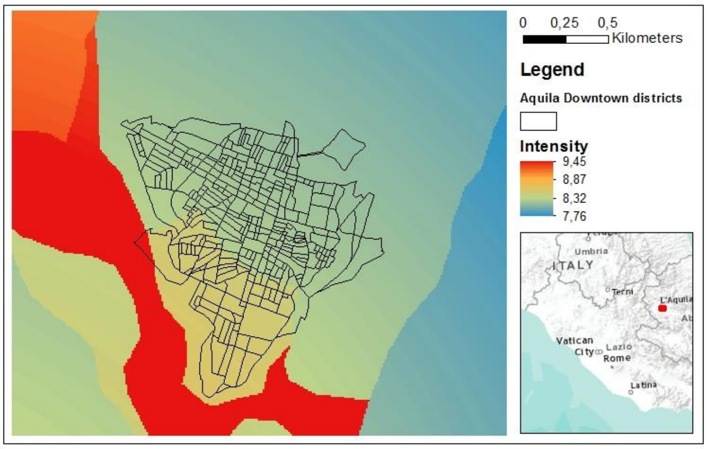

Fig.1. Estimated macro-seismic intensities (IEMS) in L'Aquila Downtown with Armagedom software (Sedan et al., 2013).

Uncertainty source	Representation
XY (Parameter)	Uniform distribution with ±5km
Z (Parameter)	Uniform distribution with ±5km
Mw (Parameter)	Uniform distribution between 5.5 et 6.5
Sigma (Parameter)	Uniform distribution between -0.5 et 0.5
GMPE (Model)	Discrete variable with variable uniformly taken from {1,2,3,4,5,6,7}
GMICE (Model)	Discrete variable with variable uniformly taken from {1,2,3}
LITH (Parameter)	Uniform distribution with 20% from estimated value

Table1. Source of uncertainty description and assumption for representing them in L'Aquila application (XY: Earthquake position, Z: Earthquake depth, Mw: Earthquake magnitude, Sigma: Statistical parameter for GMPE, GMPE: Selection of the GMPE, GMICE: Selection of the GMICE and LITH: Amplification factor of lithological effects).

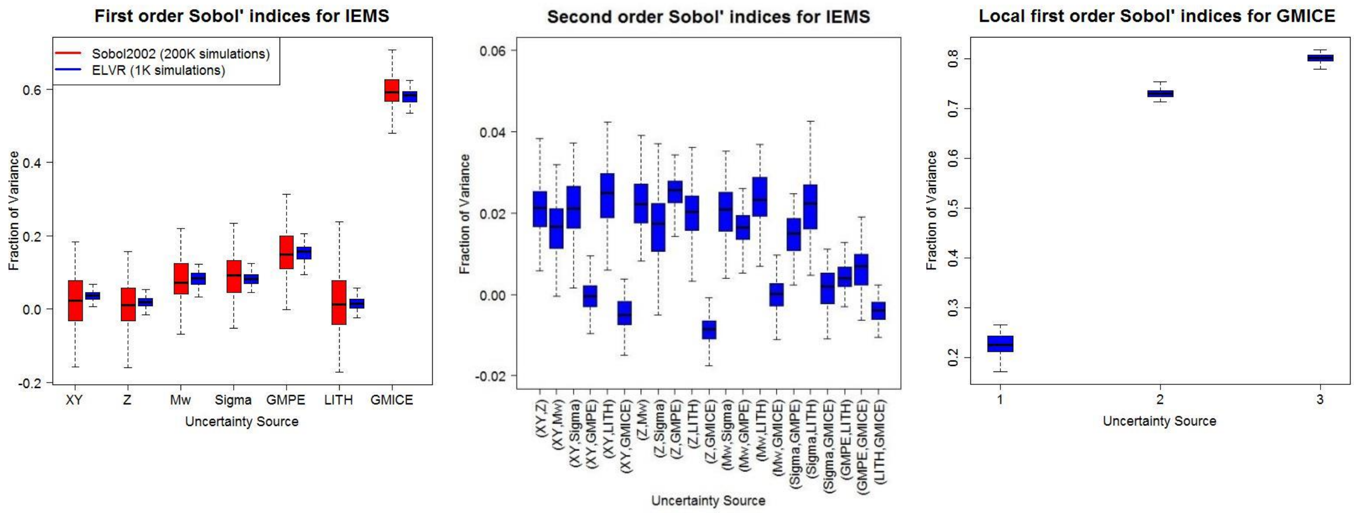

Fig. 2. Boxplot summarizing the influence on sensitivity results for the first order (left), second order (middle) Sobol' indices and the local first order Sobol indices for the GMICE (right) of intensity (IEMS) output. Bottom and top of the boxplot are the 25th and 75th percentile, the ban near the middle of the box is the median and the ends of the whiskers are the minimum and maximum. To obtain confidence intervals (as boxplots) for each estimated indices we perform a bootstrap with 100 replicates.

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