NATO Science for Peace and Security Programme

CLOSING CONFERENCE
OF THE NATO SfP 983054 (BSHAP) PROJECT
"Harmonization of Seismic Hazard Maps for the Western Balkan Countries"

May 12-13, 2011
Zagreb, Croatia

Seismic Hazard Assessment using Spatially Smoothed Seismicity Approach and OHAZ Software

Neki Kuka

Institute of Geosciences
Polytechnic University of Tirana

Mathematical Background

- Mathematical background is the total probability theorem (Cornell (1968, 1971), Merz & Cornell (1973):

$$P(U>u)=\int_R\int_{m_0}^{m_{max}}P(U>u)|m,R)\cdot f_M(m)\cdot f_R(R)\cdot dm\cdot dR$$

P(U>u|m,R): probability that ground motion level *u* will be exceeded, given an earthq. of mag. *m* on a source at distance *R* from the site;
$f_M(m)$: probability distribution of magnitude,
$f_R(R)$: probability distribution of site-source distance;
m_0, m_{max}: lower and upper bound of magnitude, $m_0<m<m_{max}$.

- Summation over all seismic sources gives the anual rate of ground motion exceedance:

$$\mu_u=\sum_{i=1}^{n}\mu_i(u)=\sum_{i=1}^{n}\lambda_i(m_0)\int_R\int_{m_0}^{m_{max}}P(U>u)|m,R)\cdot f_M(m)_i\cdot f_R(R)_i\cdot dm\cdot dR$$

$\lambda_i(m_0)$: the annual rate of occurrence of earthquakes of magnitude greater than m_0.

Mathematical Background

- Except probability distribution of the magnitude and site-to-source distance, implementation of the PSHA also requires:
  - A model to describe reliably the seismic activity rate in the region.
  - A model to characterize the process that generates the ground motion.
- Different approaches proposed, are distinguished on the way they model seismicity within an area: assuming the earthquake rate of occurrence is uniform throughout (source zone approach), or considering it as spatial variable (gridded seismicity: spatially smoothed, kernel methodology).
- Intensive efforts are made last years to derive new predictive ground motion models (PGMM) using a much more larger database (Europe-Middle East, USA (NGA project), Japan).

General methodology

- Generally, four different classes of earthquake source models are used (NSHM, USGS, 2008):
  1) Smoothed gridded seismicity,
  2) Uniform background source zones,
  3) Geodetically derived source zones,
  4) Faults.
- The first two models are based on the earthquake catalog and characterize the hazard from earthquakes between M5 and M6.5-7.0.
- The geodetically derived source zones are used to assess the hazard between M6.5 and the largest potential earthquake in a region.
- Faults mostly contribute to the hazard for earthquakes stronger than M6.5.

Seismicity-Derived Hazard Component

- Random seismicity-derived sources account for two types of earthq.:

  1) those that occur off known faults, and

  2) moderate-size earthquakes that are not modeled on faults.

  The gridded-seismicity models are based on historical earthquakes and account for the observation that stronger earthquakes occur at near clusters of previous smaller earthquakes.

- Uniform background zones account for the possibility of future random seismicity in areas without historical seismicity and establish a floor to the seismic –hazard calculations.

- Special zones allow for local variability in seismicity characteristics within a zone (change in *b*-value, changes in M_{max}, depth, etc.).

- These models are combined together to account for the suite of potential earthquakes that can affect a site.

Practical implementation

- Application of PSHA requires a homogenous catalog of historical earthquakes, a description of possible faults and earthquake sources, the parameters describing seismicity for those faults and earthquake sources, and appropriate PGM models in region.

- Seismicity models require a declustered earthquake catalog of independent events for calculation of Poissonian (time-independent) earthquake rates.

- Completeness levels have to be estimated from the catalog, and parameters of magnitude-rate distribution (*b*-values and annual seismic activity rate) are computed using a MLE method that accounts for variable completeness. The uncertainty in the magnitudes must be taken into account.

Practical implementation

- To calculate the hazard from a particular source, usually a doubly-truncated exponential or G-R mag.-frequency distribution is used.

- Seismicity rate parameters (a- and b-values) are obtained from analysis of the catalog. For the gridded-seismicity models, the earthquake rates determined for cells are spatially smoothed using a two-dimensional Gaussian smoothing operator (Frankel, 1995) and/or an elliptic rupture-oriented function (Lapaine et al., 2002).

- The hazard is calculated for potential earthquakes at each grid cell. Earthquakes smaller than M6.0 might be characterized as point sources at the center of each cell, whereas earthquakes larger than M6 assume hypothetical finite vertical or dipping faults centered on the source grid. Lengths of the finite faults are determined using the relevant relations (Wells and Coppersmith) for faulting styles.

Estimating Seismicity rates

- In light of the recently well established spatial variability in *b*-values, the choice is between an overall constant *b*-value, as done usually in USA (NSHM project), and large variability of *b*-values in regional zonations, which are often simply statistical variations due to the small sample sizes.

- Source zone approach requires to assess the *b*-value for small areas, due to the hypothesis of uniform seismicity within a zone. This induces undue fluctuations of *b* particularly in zones of low seismicity.

- Smoothed seismicity models generally use constant b-values for relatively large areas;

Maximum magnitude

- It is the most difficult parameter to be assessed because the database to derive it is statistically very limited. M_{max}, should be relatively large, because big earthquakes may have very large return periods that sometimes exceeds 10000 years and probably are not evidenced in the historical or geological documents.
- The estimation of M_{max} to some extent should reflect the uncertainties that associate this parameter.
- M_{max} should not differ to much among the zones if there are not fundamental differences between tectonic regions that would justify a different behavior in regard to the expected maximum magnitude.
- M_{max} and the recurrence parameters should be calculated in global and for every seismotectonic zone.

Predictive Ground Motion Models

- GMPE-s relate the source characteristics of the earthquake and propagation path of the seismic waves to the ground motion at a site. The PGM is typically quantified in terms of a median value (a function of magnitude, distance, style of faulting, and other factors) and a probability density function.
- New PGME are proposed recently for our region (Cauzzi & Faccioli 2008, Bindi et al. 2009, Akkar and Bommer 2010).
- New attenuation relations are proposed in the framework of NGA project (USA). They represent significant advancements using a larger standard dataset of ground motions, and source and path parameters.
- The ground motion can be calculated for various PGME relations, and then results can be combined using a weighted logic tree analysis.

Uncertainty investigation

- PSHA considers only the inherent random uncertainties ("aleatory" uncertainties), integrating over randomness to calculate the seismic hazard curve; this is what is meant by "annual probability of exceedance".

- Due to inadequacy or lack of available data and incomplete understanding of earthquake and ground-motion generating processes, it is difficult to specify the various input models and their parameters without any uncertainty.

- The large uncertainties in seismic hazard are not a defect of method. They result from lack of knowledge about earthquake causes, characteristics, and ground motions. PSHA only reports the effects of these uncertainties, it does not create or expand them.

Uncertainty investigation

- Uncertainties in interpretations can be handled explicitly through multiple hypothesis, leading to uncertainties in seismic hazard.

- Usually, PSHA uses the logic-tree methodology to quantify the effect of these additional uncertainties, termed as "epistemic" uncertainties.

- To account for the effect of the epistemic uncertainties, the basis PSHA have to be performed for all the combinations of input leading to various end branches, and resulting hazard curves are assigned the corresponding weights. These can be used to define the mean or the median hazard curve, as well as the hazard curves with desired confidence intervals.

Software for PSHA

- Software to be used in the framework of BSHAP project has to provide the features presented in the above presentation. It is difficult to have all these features implemented in a single computer code.

- Various PSHA computer codes are in use (FRISK88M™, EZ-FRISK, Crisis 2007, OHAZ, etc.). NSHM project (USGS) has made public the source codes they use for the national seismic hazard maps of USA.

- The main difference between these codes stands in the way they estimate the seismic activity rate:
  - ***Source zone approach***: the rate of occurrence is assumed uniform within the source zones; therefore every location within the area has equal probability that an event will occur. This hypothesis is often in open conflict with spatial distribution of the earthquake epicenters.

Software for PSHA

- ***Gridded (random) seismicity:*** Seismic activity rate is considered as spatial variable within the source zones; only the slope (*b-value*) of the G-R mag-frequency distribution is constant throughout the zone.

- In our opinion, the gridded seismicity approach provide an easy and much more realistic modeling of the seismicity, avoiding the strong requirement of the uniform seismicity.

- Starting from 1996 (1996, 2002-2003, and 2008-2009 editions) the national seismic hazard maps of the USA, are compiled using gridded seismicity, considering also the contribution of specific faults that might generate events with M_W greater than 6.5.

- Computer code OHAZ, used for hazard calculation in the BSHAP project, is based on the smoothed-gridded seismicity methodology.

OHAZ Software

- Seismicity rates are determined by counting earthquakes in each grid cell (user specified dimensions) and adjusting for completeness, giving a maximum-likelihood estimate of the local rate. The recurrence parameters are obtained from analysis of the earthquake catalog; the doubly truncated-exponential or the log-linear magnitude-frequency distribution is supported.
- *Smoothing procedure of the gridded rates*:
  - Two-dimensional spatial Gaussian smoothing accounts for earthquake epicenter location uncertainties.
  - Elliptical smoothing (Lapajne et al. 2003) enables the rupture-oriented smoothing, following orientation of the earthquake generation tectonic faults in the region. The fault type, strike and the weight of a certain faults for each seismotectonic zone are specified in a special seismotectonic file.

OHAZ Software

- Based on the smoothed seismicity rates, and applying appropriate PGM models, program calculates probabilistic hazard curves that depict the annual frequency of exceedance at given ground-motion levels. To obtain a probability from an annual frequency of exceedance, OHAZ applies the Poisson probability distribution.

- By interpolating the hazard curves at the annual frequency of exceedance specified by the user, the hazard maps are obtained, which represent the spatial variability of the ground motion parameter taken into consideration.

OHAZ Software

- OHAZ enables the selection from a range of European-Middle East (Ambraseys et al. 1996, Sabeta & Pugliese 1996, Berge-Thierry et al. 2003, Ambraseys et al. 2005, Bindi et al.2009, Akkar & Bommer 2010, etc.), and world-wide (Boore et al. 1997, Boore and Atkinson 2008, Cauzzi & Faccioli 2008, etc.) predictive ground-motion equations.

- Different alternatives may be considered about fundamental hypothesis on input parameters to account for and to propagate uncertainties in the model within a logic-tree framework.

- OHAZ is user-friendly Windows software. *It is a joint contribution of Environmental Agency of the Republic of Slovenia and the Institute of Geosciences of Albania to the BSHAP Project.*

BSHAP implementation

- Grid 10x10 km, area [12.5°-24.5°E, 38°-47.5°N].

  The seismicity rate (M_0=4.0) in every grid-cell was calculated. Then spatially smoothing using a 2-D Gaussian smoothing operator with correlation distance 20 km, and an elliptical smoothing oriented according to the main tectonic faults in the seismotectonic zones.
- Four PGME are used: Akkar & Bommer 2010 (weight=0.3), Bindi et al. 2009 (weight=0.2), Cauzzi & Faccioli 2008 (weight=0.3), Boore & Atkinson 2008 (weight=0.2).
- Hazard curves at the nodes of the grid covering Albania (13.5°-23.5°E, 39°-47.0°N); integration range - M_W: 5.0-M_{max} of the zone.
- Seismic hazard maps for PGA, etc.(10% PE in 10 years, and 10% PE in 50 years) are calculated.
- Mapping software: GMT (version 4.5.5).

Thank You !