“Harmonization of Seismic Hazard Maps for the Western Balkan Countries”

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Recent Improvements of OHAZ Software

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OVERVIEW

- ✓ Accountting for unequal observational periods (completeness levels of the earthquake catalogs).
- ✓ Estimation of the reccurrence relationships (incremental and cumulative) in OHAZ.
- ✓ Calculation of the site-source distance, replacing the previous procedure with an accurate geodetic method.
- ✓ Extending the database of Predictive Ground-Motion Models (PGMM) with the following models:
  - Berge-Thierry et al. (2003).
  - Bindi et al. 2009 (update of the Sabetta-Pugliese 1996)
  - Akkar & Bommer 2007.
  - Boore & Atkinson 2008 (NGA, EERI 2008).

Accounting for data completeness

- Modeling of seismicity in a certain region, needs estimation of the parameters of magnitude-rate distribution (*a and b*-values, activity rate λ). This estimation is dependent on the correct identification of the magnitude of completeness, which represents the threshold, below which only a fraction of all events in a magnitude bin are detected.
- Completeness levels have to be estimated from the earthquake catalog, and parameters of magnitude-rate distribution are computed using a ML method (Weichert, 1980) that accounts for variable completeness.
- In OHAZ, seismicity rates are determined by counting earthquakes in each grid cell with user specified dimensions and adjusting for completeness, giving a maximum-likelihood estimate of the local rate:

$$N_a = N \frac{\sum_i \exp(-\beta m_i)}{\sum_i t_i \exp(-\beta m_i)}$$

N_a : annual event rate at or above minimum magnitude m_{min},
N: total number of events with $m \geq m_{min}$; m_i: magnitude classes;
t_i: observation period corresponding to magnitude class m_i.

Accounting for data completeness

- Magnitude observation periods have to be specified in the Command File (parameter - Completeness), or interactively in the OHAZ interface (page - Catalogue).

  Example:

  Completeness=4.5 1950,5.0 1905,5.5 1850,6.0 1600,6.5 1400,7.0 -500

Recurrence relationships

- An improved ML procedure to estimate the recurrence relationships is now implemented, including estimation of related uncertainties (Bollinger et al. (1993), Weichert (1980), Berril & Davis (1980)).
- OHAZ computes *a* and *b*-values, confidence intervals for both data and prediction, and return periods. Observed and maximum likelihood rate for magnitude $m \geq m_{min}$, and the relevant standard deviations are also computed.
- Both, incremental and cumulative recurrence relations are estimated. Data points and their confidence bounds are written to *pts.inc*, *pts.cum*, and *curve.cum* files.
- Magnitude observation periods have to be specified by the user. OHAZ calculates the time of observation and the number of events by magnitude classes ($m_i \pm \delta m$), using the earthquake catalog. The magnitude intervals should be equal.

Recurrence relationships

- The reccurrence relations can be estimated for entire area study and/or by seismotectonic zones which have to be specified in the seismotectonic file.
- An issue not yet finished: calculation of the normalized seismic activity rate (activity rate per unit of surface); a routine to calculate the surface of a polygonal zone is needed; to be written very soon.
- Example: see the file *bValMw.log*

Calculation of the site-source distance

- The approximate function

$$d_{rs}(\varphi_r, \lambda_r, \varphi_s, \lambda_s) = \sqrt{d\varphi^2 + d\lambda^2}$$

$$d\varphi = (\varphi_s - \varphi_r)\cdot 111.1, \quad d\lambda = (\lambda_s - \lambda_r) * \cos(\frac{\varphi_r + \varphi_s}{2})\cdot 111.1$$

that calculates the distance site-source, is replaced by an accurate geodetic procedure.

Predictive Ground-Motion Models

- OHAZ supports using of several European and world-wide predictive ground-motion models. The PGMM database is reorganized and extendend with the following models:
- Berge-Thierry *et al.* (2003).

  It is based on the updated European strong motion database (83%), and a few American records (17%) with $M_S \geq 6$. This model uses M_S as magnitude scale, and the hypocentral distance instead of the epicentral or fault distance (Sabetta & Pugliese 1996, Ambraseys et al. 1996). The dataset contains events from $4 \leq M_S \leq 7.9$, and from $4 \leq d_{hyp} \leq 330$km.
- Bindi *et al.* (2009).

  It is based on a revised Italian strong motion database (from 1972 to 2004), and is an update of the Sabetta-Pugliese 1996 PGM model. The authors confirm that the SP96 does not adequately fit the new strong-motion data, for its small standard deviation (which under-estimates the variability of the ground motion) and its non-zero bias.

Predictive Ground-Motion Models

- Akkar & Bommer 2007.

  It is based on the updated and re-processed strong motion databank from Europe and Middle East. The equations can be applied to predict the geometric mean displacement and pseudo-acceleration spectra for earthquakes with M_W between 5 and 7.6, and for distances up to 100 km. The equations also include style-of-faulting and site class as explanatory variables.

- Boore & Atkinson, NGA - EERI 2008.

  Model is based in an extensive strong-motion database compiled by the "PEER NGA" project. The relevant GMPEs predict the average horizontal-component ground motions (PGA, PGV, and 5-%-damped PSA at periods between 0.01s and 10s). The primary predictor variables are moment magnitude (M_W), closest horizontal distance to the surface projection of the fault plane (R_{JB}), and the time-averaged shear-wave velocity from the surface to 30 m (V_{S30}).

Predictive Ground-Motion Models

- The Boore & Atkinson equations are applicable for $M_W=5\text{-}8$, $R_{JB}<200$ *km,* and $V_{S30}=180\text{-}1300$ m/s. It is considered appropriate to be used in the European region (Bommer *et al.*, 2007).

To be implemented:

- Campbell & Bozorgnia, NGA - EERI 2008.

This model is developed as part of the PEER NGA project, to be used for estimating free-field ground-motions from shallow earthquake mainshocks in active tectonic regimes. It is valid for magnitudes ranging from 4.0 up to 7.5-8.5 (depending on fault mechanism) and distances ranging from 0-200 km. The model explicitly includes the effects of magnitude saturation, magnitude-dependent attenuation, style of faulting, rupture depth, hanging-wall geometry, linear and nonlinear site response, 3-D basin response, and inter-event and intra-event variability.

Site Response Calculation

Site response calculation is generalized, including not only the discrete model, but also continuous models which use the V_{S30} as predictor.

- In the previous version of OHAZ, only the discrete model was supported:

$$F_S(S) = b_{SA}SA + b_{SB}SB + b_{SC}SC + b_{SD}SD$$

SA, SB, *SC* and *SD* are dummy variables used to denote A (rock), B (stiff), C (soft), and D (very soft) soil category. User has to specify the regression coefficients for site categories.

- Two other site response models, which use the V_{S30} are now supported:
  - Linear soil amplification (Boore et al. 1997).

$$f_S(V_{S30}) = b_{lin}\ln(V_{S30}/V_{ref})$$

  - Nonlinear site response model (Boore & Atkinson, NGA 2008).

$$F_S(S) = F_{lin} + F_{NL}$$

- For the details see the *PGMM_OHAZ.doc*.

Planned improvements

- 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.
- Therefore, combining hazard curves in the framework of a logic-tree approach, need to be developed in the near future.
- Some improvements concerning the dynamic memory allocation, etc., are also necessary.
- Improving code to run faster, for large areas and dense grid (0.05 x 0.05°).

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Thank You !