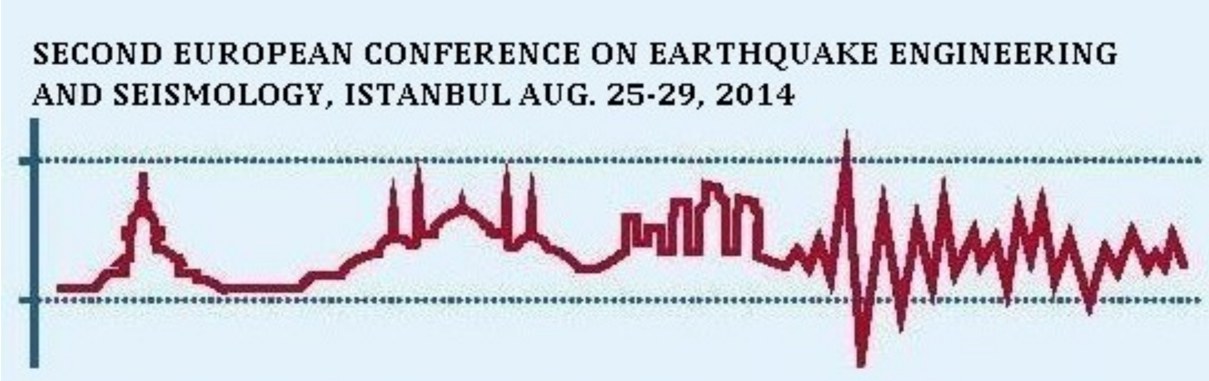

THE 2014 UPDATE OF THE SWISS NATIONAL SEISMIC HAZARD MODEL – KEY SCIENCE ISSUES

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The Swiss National Seismic Hazard Model is the authoritative resource used in building codes, risk analysis and decision making for public policies. Buildings, bridges, highways and other infrastructures built to meet the seismic design provisions are better suited to withstand strong ground shaking, thus not only saving lives but also leading to cost-effective designs. The Swiss Seismological Service is by law in charge to review the national seismic hazard model last issued in 2004 (Giardini et al. 2004; Wiemer et al. 2009) on a regular schedule and update with the best available science. The 2014 update is timed to include updated data, improved modelling techniques and results from two recently released probabilistic seismic hazard assessments (PSHA), i.e. the site-specific project PRP focusing on the hazard assessment of the four Swiss nuclear plants and the 2013 European Seismic Hazard Model (Giardini et al. 2013a; Woessner et al. 2014).

A seismic hazard model combines two essential ingredients: an earthquake source model and a ground motion model. The earthquake source model characterizes the earthquakes that might affect the site or area of interest and specifies their location, size and rate of occurrence. The ground motion model is concerned with the excited ground motions from these earthquakes, the wave propagation and possible site effects to the sites of interest. Both models need consider the uncertainty and variability in the processes in a probabilistic and statistically sound way. We address this with a logic-tree approach, the contemporary tool to represent in particular epistemic uncertainties in a seismic hazard assessment (Reiter 1990; Budnitz et al. 1997; Bommer and Scherbaum 2008). We address key scientific issues for the earthquake source model and the ground motion model in two working groups, one for the earthquake source and one for the ground motion model. Both teams revisited the assumptions of the 2004 model and revised model parts according to state-of-the art approaches.

For the revision of the hazard model, four earthquake datasets were available: the earthquake catalogues of Switzerland (ECOS-02 and ECOS-09; Fäh et al. 2003; Fäh, D. et al, 2011), the focal

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mechanism catalogue of the Swiss Seismological Service (per. Comm. N. Deichmann) and the SHARE European Earthquake Catalogue (SHEEC, Giardini et al. 2013b). The re-evaluation of the ground motion model was based on the new European Strong Ground Motion database and the data collected at the Swiss Seismological Service (Edwards et al. 2011, Edwards and Fae, 2013).

We prepared in total four source models that describe the earthquake activity using different assumption. The SEIS-model of the 2004 hazard assessment (Wiemer et al. 2009) based on ECOS-02 catalogue and the SHARE model (Giardini et al. 2013b; Giardini et al. 2014) based on the SHEEC catalogue are considered for epistemic uncertainties in the magnitude determination of earthquakes, i.e. both are based on different catalogues providing alternative moment magnitudes for each event, as well as for harmonization purposes by embedding the European reference model.

The three new areal zonation models are based on the ECOS-09 catalogue. One of them uses the SEIS-model zonation of the 2004 hazard model, termed SEIS14, and assumes a homogeneous distribution of earthquake activity within each zone; however, the activity rate parameters are determined in each zone and with a new method. The SEIS14 model is primarily oriented at the seismicity distribution. We introduced a new concept for the source model zonation that follows only the largest tectonic features leading to five zones. These major tectonic features are the Po plain, Alpine Belt, the Alpine Foreland, the RhineGraben and the seismicity on the Swabian Alb following the neotectonic definition of the Hohenzollern Graben. We used this zonation model in two ways: Firstly, we used the traditional way in that we assume homogeneous distribution of rates based on the zone-specific activity rates only considering events above magnitude M_W=5. Secondly, we distribute the activity rates in these five zones heterogeneously with the rates determined using the completeness-time-history of the catalogue down to M_W=2.5. The heterogeneity is determined with an adaptive-kernel smoothing approach (Hiemer et al. 2014) and the kernel sizes are optimized by pseudo-prospective testing procedures. For all new source models we estimates the activity rates within each zone using a Bayesian penalized maximum likelihood approach (Johnston et al. 1994) quantifying the uncertainty of the rate estimates including magnitudes down to M_W=2.5.
In a last step, we combine all five source models to an ensemble earthquake source model with an innovative weighting scheme. The philosophy here is that clustering of seismicity is more prominently considered for the smaller magnitude events while larger events are more homogeneously distributed in space. Thus the weight of single models change depending on the magnitude with the largest weight given to the SEIS-zonation models.

We separately determined the depth distribution, style of faulting and preferred rupture orientation, i.e. strike and dip, and devised the same parameterization to all new source models. The latter is determined from inverting for the stress tensor from the focal mechanisms to define the principal stress axis and then use this information to find the optimal rupture orientations. We, however, leave always some probabilities to other orientations and do not exclude unlikely faulting styles and orientations. We also introduced a depth dependent b-value (Spada et al. 2013) as we have evidence for differences in the shallow crust (d<5km) and the deeper crust (d≥5km), a feature that is also seen in the stochastic ground motion models.

The ground motion model combines models from two principal approaches. Considering the Swiss territory as active shallow crust, we use the empirical ground motion prediction equations as in SHARE that are based on the analysis of global datasets and recalibrated to the reference rock velocity of vs30=1100m/s for Switzerland. In addition, we use the stochastic ground motion model for Switzerland (Edwards and Fah 2013) that is constrained by ground motions observed from small local and regional earthquakes in addition to macro-seismic intensities observed from large damaging events in Switzerland. Epistemic uncertainties in the latter model are accounted for by using different stress drop values for the earthquake source (10-100bar) facilitating also the use of different stress drop sets for shallow and deep earthquakes which is consistent with the idea of a depth dependent b-value.

We calculated a full set of products including hazard curves, uniform hazard spectra, and hazard maps for return periods between 100 and 10'000 years and frequencies from 0.5-50Hz with the GEM-OpenQuake engine, starting the hazard integration at a moment magnitude of M_W=4.0, supplying relevant information to the Swiss earthquake engineering community for all built environment and critical infrastructures such as dams. Our results are also consistent with the hazard estimates at the sites of the nuclear power plants in Switzerland.

We present the model philosophy, assumption components, and uncertainties. We discuss the innovative model components and how we attempt to harmonize the hazard values with respect to the 2013 European Hazard Model.

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