2014 Update of the United States National Seismic Hazard Maps

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SUMMARY:
The U.S. National Seismic Hazard Maps are revised every six years, corresponding with the update cycle of the International Building Code. These maps cover the conterminous U.S. and will be updated in 2014 using the best-available science that is obtained from colleagues at regional and topical workshops, which are convened in 2012-2013. Maps for Alaska and Hawaii will be updated shortly following this update. Alternative seismic hazard models discussed at the workshops will be implemented in a logic tree framework and will be used to develop the seismic hazard maps and associated products. In this paper we describe the plan to update the hazard maps, the issues raised in workshops up to March 2012, and topics that will be discussed at future workshops. An advisory panel will guide the development of the hazard maps and ensure that the maps are acceptable to a broad segment of the science and engineering communities. These updated maps will then be considered by end-users for inclusion in building codes, risk models, and public policy documents.

Keywords: Seismic hazard, Building code, Strong ground motion, Seismic design

1. NATIONAL SEISMIC HAZARD MAP UPDATE PROCESS

The U.S. Geological Survey (USGS) is responsible for the development of U.S. National Seismic Hazard Maps as part of the National Earthquake Hazards Reduction Program mandate to mitigate seismic risk across the U.S. These maps are updated every six years to sequency with the update cycle of the building code. To improve the seismic hazard maps, we convene a nationwide series of regional and topical workshops where we gather and assess new science information and we review published source and ground motion data and models. During 2012-2013, the National Seismic Hazard Mapping Project and participants from related organizations will update the hazard maps and publish revised maps in 2014 (Petersen et al., 2008).

Figure 1 shows the timeline for the update, including the regional workshops, interactions with the advisory panel, a three-month period for public comment, and building code products. We will hold seven workshops, including four regional workshops for the Central and Eastern U.S. (CEUS), Pacific NW (PACNW or PacNW), Intermountain West (IMW or Inter Mtn West), and California and three topical workshops on ground motions, geodetic models, and user-needs. Regional and topical workshops are designed to discuss new science information that may be incorporated into the updated maps, are open to the public, and typically involve 75 to 150 participants. We will also assemble an advisory panel of internal and external experts that will provide guidance for the update process. The final maps are based on work and ideas of many scientists and engineers from the National Seismic Hazard Mapping Project, advisory panel, and hundreds of scientists and engineers that provide comments in written form or at the workshops. It is important to consider the best available science for these maps that are used in developing building design provisions such as the National Earthquake Hazards Reduction Program (NEHRP), American Society of Civil Engineers (ASCE-7), and the International Building Codes (IBC, 2012). This paper presents some of the important seismic hazard issues discussed (or to be discussed) at the regional and topical workshops and is intended to stimulate further discussion. In addition, an initiative is being carried out during this update cycle to capture the uncertainty in the mean hazard curves at sites across the U.S.

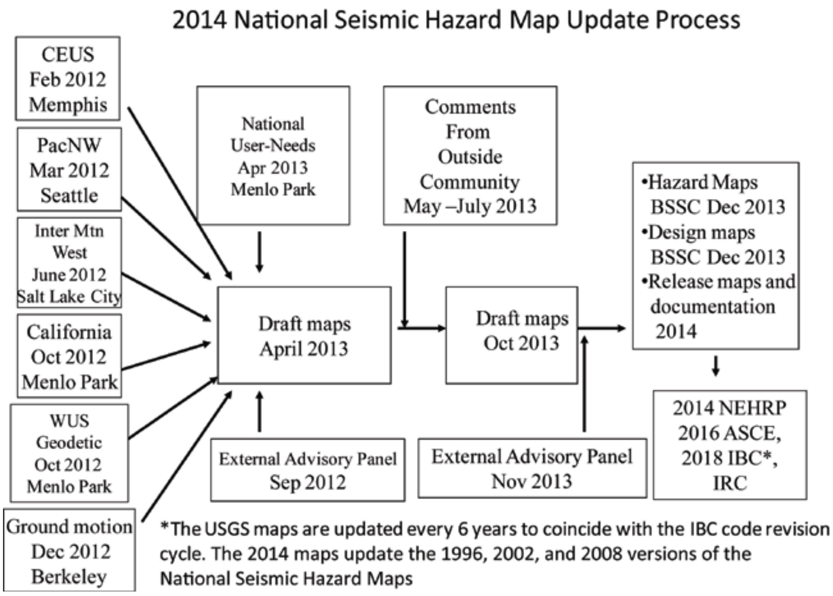

Figure 1. Diagram showing the process used to develop the 2014 National Seismic Hazard Maps and the dates of building codes that could apply these maps.

The 2014 update will be based on the 2008 version of the National Seismic Hazard Maps. Information used in producing these 2008 maps is available at the USGS National Seismic Hazard Mapping Project website: http://earthquake.usgs.gov/hazmaps/. This site includes a fault database, fault models, earthquake catalogues, gridded seismicity rates, computer codes, input files, documentation, workshop presentations, sensitivity studies, hazard maps, hazard curves, building code design values, and interactive web tools for displaying the hazard information.

2. CENTRAL AND EASTERN U.S. (CEUS) WORKSHOP

The CEUS earthquake source workshop was held February 22-23, 2012 in Memphis, TN. Major topics at this workshop were on the New Madrid Seismic Zone, a recently developed seismic source model for nuclear facilities (2012 CEUS-SSC model, http://www.ceus-ssc.com), the maximum earthquake magnitude considered in the hazard model, a newly compiled moment-magnitude earthquake catalogue, and potential revisions to other earthquake sources and zones. Prior to this workshop the USGS held meetings to specifically discuss geodetic models for the New Madrid Seismic Zone and the data required to improve the source characterization.

The New Madrid Seismic Zone is perhaps the most important source in the CEUS. The New Madrid region experienced a sequence of at least three large (M~7.5) earthquakes in 1811-1812. Paleo-liquefaction evidence indicates that 2-3 sequences of similar sizes earthquakes have occurred within this zone in the past few thousand years, with average return period of 500 years. These historic earthquakes and geologic data indicate a significant potential for large earthquakes rupturing across this zone. However, recent GPS studies and interpretations of intensity data have called into question the rate and size of future New Madrid earthquakes. Presentations at the workshop showed differing perspectives, and the workshop participants agreed that along with the geologic-based models, we need to include an additional model with a low weight in the logic tree for a very low recurrence rate for New Madrid earthquakes (based on recent GPS interpretations and faulting considerations). Additionally, participants also indicated that earthquake ruptures should be spread more evenly across the entire fault zone (rather than primarily over the central fault) and that a broader magnitude range should be considered for future New Madrid earthquakes. Alternative models will be evaluated in light of the geologic and intensity data and will be included in the logic tree used to update the maps. Participants also discussed the continued use of a logic-tree branch with all three segment rupturing together on the New Madrid Seismic Zone faults, and we may down-weight this branch compared to the clustered-event branch.

In addition to the New Madrid Seismic Zone, several other potential revisions are being considered for the fault model; these revisions are mostly based on the 2012 CEUS-SSC model for nuclear facilities. Alternative models were proposed for the Charleston SC area, the Meers OK, and Cheraw CO faults, and new models for the Commerce Geophysical Lineament and Wabash zone in southern Illinois. We will consider revising our model where alternative models suggest different levels of hazard than in the 2008 model. Some of these modifications can be important in the hazard analysis. For example, relatively important consequences result from dropping the branch assigned for Gutenberg-Richter magnitude-frequency distribution for some large repeating sources, such as Cheraw CO fault, as suggested by the 2012 CEUS-SSC model.

Other than the geologically identified earthquake sources in the CEUS, most other sources are based on historic seismicity patterns of M 3-5 earthquakes and global analogs of stable continental region earthquakes. A new moment-magnitude based catalogue was released as part of the CEUS-SSC report and this new data are being considered as the basis for the new maps. Smoothing parameters applied to the new catalogue are used to estimate earthquake rates. Sensitivity studies presented in the workshop compared fixed-width and adaptive-weighting smoothing parameters, as well as variations in magnitude-frequency distributions. Many of these models have merit and will likely be considered in the logic tree framework. A global analysis of large earthquakes provides analogs for estimating earthquake maximum magnitudes in the CEUS. Recent catalogues and Bayesian assessments of magnitude consider a broader range of magnitudes for both the craton and extended margin terrains. For example, the magnitudes considered in the new analyses span a range from the mid M 6's to the low M 8's, which is a range slightly larger than those considered in the 2008 model. We will consider additional research to constrain the range of earthquake magnitudes in this updated model. Additional seismicity-based source zones that have been proposed across the CEUS will also be considered in this update.

3. PACIFIC NORTHWEST (PACNW) WORKSHOP

The PACNW workshop was held March 21-22, 2012 in Seattle, WA. Two workshops were held during November, 2010 and December, 2011 in Corvallis and Eugene, OR to prepare for the 2012 PACNW workshop. The topic discussed included: (1) correlation of turbidites on the Pacific abyssal plain with on-land tsunami data (Frankel, 2011) and (2) the seismogenic width of the Cascadia subduction zone. In addition to these workshops, a working group on active faults in the PACNW also met to discuss new fault parameter updates to the maps. Discussion topics at the 2012 PACNW workshop included: estimating seismogenic extent (sizes) of ruptures on the Cascadia subduction zone, assessing magnitudes and rates of Cascadia earthquakes and related deep earthquakes; modelling of crustal fault sources from LIDAR imagery analysis and trenching studies; and applying new ground motion prediction equations for interface and intraslab earthquakes (see http://earthquake.cr.usgs.gov/hazards/about/workshops/pacNW_workshop.php).

How to model future earthquakes on the Cascadia subduction zone is one of the critical issues for this 2014 update. The 10,000 year-long turbidite record from Goldfinger and others (2012) indicates that the zone may rupture in large M 9.0 earthquakes but may also rupture in a sequence of M 8 ruptures. A key result of this workshop was that the participants accepted the concept of additional M8 earthquakes rupturing only the southern portion of the Cascadia Subduction Zone. Evidence for these earthquakes is manifested in the deep sea turbidite and lake deposits in southwestern Oregon. The workshop participants also heard evidence of M8 earthquakes that only rupture the northern portion of the Cascadia Subduction Zone, but these are not as well documented as the events to the south. Participants came to a consensus that the next maps should use a mean recurrence rate of 0.001 per year for M8 earthquakes that only rupture the southern part of the Cascadia Subduction Zone. Workshop participants agreed that including a deep seismicity zone along coastal WA and OR is important because these earthquakes are an important contributor to the seismic hazard.

New LiDAR data in the region gives geologists the opportunity to identify previously unrecognized faults that have not previously been recognized. These faults are scattered across Washington and Oregon and earthquake ruptures on these structures could generate strong ground shaking across populated regions. The slip rate is not known for many of these faults so it is difficult to determine earthquake rates for the hazard analysis. Workshop participants agreed that these features should be discussed in the documentation of the maps so that users are aware of this additional source of hazard, even if they are not explicitly included in the hazard analysis.

We also discussed subduction interface and intraslab ground motion models at the PACNW workshop. The new recently released BC-Hydro model (Abrahamson, 2012) shows faster fall-off in shaking with distance from large earthquakes than the current models. We will likely include this new ground motion model in the ground motion logic tree for Cascadia and deep earthquakes.

4. INTERMOUNTAIN WEST (IMW) WORKSHOP

The IMW workshop will be held June 13-14, 2012 in Salt Lake City, UT. To prepare for this workshop the National Seismic Hazard Mapping Project identified eight regional seismic hazard issues to the Western States Public Policy Council which were discussed at the second Basin and Range Province Earthquake Working Group, BRPEWG, held November 14-16, 2011 in Salt Lake City. At that meeting we debated the following topics: (1) How should magnitude-frequency relations be modelled for a single fault?; (2) How should historic seismicity be smoothed to provide rates consistent with precarious rock data?; (3) How close does the model rate of earthquakes need to match the historic rate of earthquakes?; (4) What are the sources of uncertainty in earthquake magnitudes?, (5) How should we estimate magnitudes for future normal-faulting earthquakes?, (6) How should antithetic fault pairs be modelled?; (7), What uncertainties should we assign to slip rates of normal faults?; and (8) What dip should we assume for normal fault earthquakes? In addition, a working group on Utah earthquake probabilities was convened to estimate probabilities of earthquakes across most of Utah. These issues will all be debated at the IMW Workshop. In addition, the Working Group on Utah Earthquake Probability will assess single and multi-segment ruptures and their corresponding probabilities for the Wasatch Fault in Utah. We will also discuss this new model along with a logic tree treatment of the maximum magnitude of the gridded seismicity sources across the IMW that was not considered in previous models.

5. CALIFORNIA WORKSHOP

The California workshop will be held October 2012 in the San Francisco Bay area, CA. The Uniform California Earthquake Rupture Forecast (UCERF 3.0) model will be released during the summer of 2012 and will provide the foundation for updating the USGS maps. This model updates the UCERF 2.0 model (Field et al., 2009) which is a time-dependent hazard model that applies paleoseismic dates and slip rate data for developing a California state-wide deformation model. The new UCERF 3.0 model will consider temporal and spatial earthquake clustering and ruptures that include fault-to-fault jumps that link adjacent sections of faults. This new model permits larger multi-segment ruptures and results in fewer M 6.5-7.0 earthquakes compared to the UCERF 2.0 model, thereby reducing the discrepancy between model earthquake rates and observed rates determined from the earthquake catalogue. As part of the UCERF 3.0 process, workshops discussed alternative fault models, deformation models, earthquake-rate models, and probability models. An oversight group provides management and technical advice for this activity. The UCERF 3.0 model will be discussed at the California regional workshop to determine how the new models will be implemented in the 2014 maps.

6. GEODETIC WORKSHOP

The geodetic workshop will be held October, 2012 following the CA workshop in the San Francisco Bay area, CA. Satellite geodetic data (GPS) have been collected over the past several decades and most scientists participating in our workshops share the opinion that the National Seismic Hazard Map models should consider those data. In the past, geodetic-based models have not typically been used directly in seismic hazard analysis. However, we would like to incorporate the abundant geodetic data in simple models that are considered reasonable by the geodetic community.

The geodetic models consider slip rates with geologic constraints on the San Andreas Fault System, Cascadia Subduction Zone, Walker Lane, Wasatch Fault, and other regional faults, with the remaining strain rate budget being allocated to surrounding areas. Geodetic models constrain the regional loading rate but not how strain is released, so additional assumptions need to be made to estimate earthquake rates. Several parameters need to be defined including the magnitude-frequency distribution of earthquakes on the fault and the ratio of aseismic/seismic slip rates. Further, the strain rate data can provide constraints on the level of earthquake activity both on and off the mapped faults.

Some of the new geodetically-derived models indicate total moment rates that exceed the geologic moment rates. This discrepancy may be related to the uncertainty in the seismogenic depth of the fault or background earthquake sources, occurrence of aseismic slip that does not generate earthquakes, or occurrence of seismic slip on unknown faults. Another important issue for seismic hazard assessment involves the stationarity of slip rates through time (transient effect and clustering in deformation rates). This leads to the question of whether the activity of faults can turn off or on or can exhibit temporal clustering. These discrepancies and issues will be discussed at the Geodetic workshop.

7. GROUND MOTION PREDICTION EQUATION (GMPE) WORKSHOP

The GMPE workshop will be hosted by the Pacific Earthquake Engineering Research Center (PEER) during December, 2012 in Berkeley, CA to discuss published ground motion models for earthquakes within active crustal areas, stable continental regions, and subduction zones. This meeting will discuss the update of the 2008 ground motion models discussed and referenced in Petersen et al. (2008).

For active crustal areas, we will consider a new database of strong motion records that has been compiled under the NGA-West II project (the next generation attenuation GMPEs for shallow crustal earthquakes in active tectonic regions, which is an update to the NGA-West I models, Power et al., 2008). This database is 2.2 times larger than that used for NGA-West I and contains records from recent earthquakes in New Zealand, China, Italy, Mexico and Japan. Five new GMPEs are envisioned to be developed under the NGA-West II project. These GMPEs will be discussed during the workshop by the model developers. The focus will be on the implementation and effects of the new GMPEs in the National Seismic Hazard Maps. One of the most important issues is how to weight of each ground motion model in the seismic hazard analysis. This will be determined at the workshop and will involve comparisons to data and discussions of the differences between prediction equations. The NGA-West II project has established working groups focused on modelling of site effects, ground motion directionality, directivity effects, and aleatory and epistemic uncertainties in the models. The findings of each group and the sensitivity of the hazard will be discussed.

For stable continental regions, a new database of ground motions is to be compiled under the NGA-East project. This database will include new recordings from recent earthquakes such as the 2011 central Virginia and 2008 Mt. Carmel earthquakes as well as new simulations in the central and eastern U.S. USGS plans to validate existing GMPEs by comparing the predictions against new data and analysing the residuals. This process could result in adjusting the weights assigned to each model, favouring those that best match the new empirical database. Also, we will consider two newly published ground motion models. Hazard comparisons of the 2008 model and the updated model constructed by implementing the new models and weights in the updated hazard maps will be discussed. NGA-East has working groups that consider: database development, earthquake strong motion simulations, path/source parameters, geotechnical parameters (site effects), and sigma (uncertainty assessment).

For subduction zones, we have new data from the 2012 Tohoku-Japan and 2010 Chile earthquakes and two new ground motion models developed by BC Hydro (Abrahamson, 2012). Generally, the BC Hydro models tend to fall off faster than the current ground motion models so this will cause a reduction in hazard at large distances from the subduction zone rupture. A new NGA-Subduction zone project has been initiated and will facilitate future updates of the map.

8. USER-NEEDS WORKSHOP

The discussions and decisions at the workshops described so far will contribute to the development of the 2014 U.S. seismic hazard model, which is used to generate the U.S. National Seismic Hazard Maps. The underlying hazard model, however, can provide a wealth of seismic hazard information in addition to the maps. The USGS provides this additional information, such as risk-targeted design maps and scenario ground motions in urban areas, for specific user groups, including structural engineers, urban planners, other Federal agencies, risk modelers, and insurers. In the course of updating the hazard models, the USGS will also update the hazard information it provides to end-users.

The User-Needs Workshop will be held during the Spring of 2013 in California to discuss current and potential products of the U.S. seismic hazard model. In particular, we hope to learn from the user community what existing products are most useful and why, as well as what products can be improved and how. We are also considering new products which might be of interest to end-users. For example, hazard maps could be produced for inelastic spectral displacement. Also, users will have ideas for beneficial products. In the short term, feedback from this workshop will help the USGS prioritize information derived from the 2014 update of the seismic hazard model. In the long term, however, different decisions can be made in the next update, based on the needs of the user community. For example, there may be wide interest in time-dependent models or intensity measures based on the maximum horizontal component as opposed to the geometric mean. The discussions of how existing products are used, and how potential products might be used, will help prioritize the development of future USGS seismic hazard products.

9. UNCERTAINTY IN THE MEAN HAZARD

The National Seismic Hazard Maps are derived from the mean hazard curve, which considers both the aleatory uncertainty and the epistemic variability of the seismic hazard model input parameters. Logic trees are typically used to characterize the epistemic variability, which is uncertainty attributable to incomplete knowledge about a phenomenon. Epistemic uncertainty is reflected in a range of variable models (e.g., a range characteristic magnitudes), multiple expert interpretations (e.g., different moment-area relationships), and statistical uncertainty (e.g., different b-values). The hazard calculations are performed following all the possible branches through the logic trees, each analysis producing a single hazard curve showing ground motion against annual frequency of exceedance and the mean hazard curve is obtained by combining all the hazard curves for all the branches based on the weights along all the component branches. The results from each of the possible branches help to define the uncertainty in the hazard. This can be used by end-users to assess the range of hazard values that are considered to be reasonable instead of simply depending on the mean estimate. This assessment can help end-users in understanding the consequences of outlier models and planning for less likely (but still important) alternatives.

10. CONCLUSIONS

The advisory panel to the National Seismic Hazard Maps (listed under Acknowledgements) will meet with the project members following the completion of the workshops and again after the public comment period and revisions to the public and workshop comments have been made. This panel has internal USGS and external scientific representatives from all the geographic regions and topical areas needed to create the maps. We plan to take the logic trees developed for this hazard analysis and make uncertainty maps that show the variation in hazard across the U.S. using a Monte Carlo approach. These updated maps and other products will be considered by the Building Seismic Safety Council (BSSC), risk modellers, and public policy officials. The National Seismic Hazard Mapping Project website (http://earthquake.usgs.gov/hazmaps/) hosts hazard information where end-users can obtain any of the background documentation and data, access the deaggregation and GIS tools, and acquire the final values used in the building codes. We welcome any discussion of these projects.

The goal of the 2014 update of the National Seismic Hazard Maps is to incorporate the best available science for public policy uses. These maps benefit from the expertise and advice of many scientists, engineers, and public policy officials and improvement of the input parameters will allow safer buildings to be built in a cost-effective manner.

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