2018 and 2023 U.S. NATIONAL SEISMIC HAZARD MODELS

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Abstract

During 2017-2018, the National Seismic Hazard Model (NSHM) was updated by incorporating (1) new median ground motion models, new estimates of their epistemic uncertainties and aleatory variabilities, and new soil amplification factors for the central and eastern U.S.; (2) amplification of long-period ground motions in deep sedimentary basins in the Los Angeles, San Francisco, Seattle, and Salt Lake City areas; (3) an updated seismicity catalog, which includes new earthquakes that occurred between 2012 and 2017; and (4) improved computer code and implementation details. Results show significantly increased ground shaking in many (but not all) locations across the central and eastern U.S. and increased ground shaking in the four urban areas (listed above) that overlie deep sedimentary basins in the western U.S. During 2019-2023, the NSHM plans to consider additional updates for the 2023 NSHM including: 3D simulations in urban areas of Los Angeles and Seattle, additional soil amplification models for other urban areas (e.g., Reno, Las Vegas, and eastern and southern coastal plains of the U.S.), non-ergodic ground motion models that reconsider epistemic and aleatory uncertainty, topographic amplification, and new geological and geodetic models for faults. These maps will be considered by the Building Seismic Safety Council, American Society of Civil Engineers, and International Building Code committees for inclusion in upcoming building codes. Due to population growth, more people live and work in areas of moderate or high seismic hazard than ever before, leading to higher risk of undesirable consequences from future ground shaking.

Keywords: seismic hazard; seismic risk; earthquake ground shaking; earthquake ruptures

1. Introduction

The U.S. Geological Survey (USGS) National Seismic Hazard Model (NSHM) provides scientific models used to inform building codes, risk assessments, and other public policy across the United States. The model uses a catalog of historical earthquakes, geologic fault and tectonic information, geodetic strain-rate data, and strong motion records to develop probabilistic estimates of where future earthquakes will occur, how often they will occur, how big the earthquakes will be, and how strong the ground will shake.

The NSHM was updated in 2018 to account for new ground motion and catalog information [1]. This model updates the 2014 [2] and earlier NSHMs that incorporate important earthquake source forecasts and ground motion models (GMMs). The 2018 hazard model has been accepted into the 2020 NEHRP building code provisions for new and existing structures applied across the United States.

In this paper, we briefly summarize the changes in this update and also discuss improvements that are being considered for inclusion in the next update scheduled for 2023.

2. Changes introduced in the 2018 NSHM

In the 2018 NSHM update, we incorporated the following new information: (1) an updated seismicity catalog, (2) new NGA-East GMMs, aleatory uncertainties, and site amplification factors, and (3) new GMM information for earthquake ground shaking over sites located within deep sedimentary basins (with sediments generally deeper than 3 km).

2.1 Earthquake catalog

Figure 1 shows the declustered catalog for $M_w \geq 2.7$ in the central and eastern U.S. (CEUS), the declustered catalog $M_w \geq 4.0$ for the western U.S. (WUS), and the seismicity catalog for $M_w \geq 4.0$ between 2013 and 2018 (open black circles). Earthquakes with $M_w \geq 4.0$ occurred in almost half of the states during the past decade. Earthquake activity in Oklahoma and Kansas continues to be elevated compared to historical averages from earthquakes. These earthquakes are thought to be induced by wastewater disposal and petroleum reservoir enhancement processes. These induced earthquakes are removed, along with mining related events, to account for robust long-term forecasts.

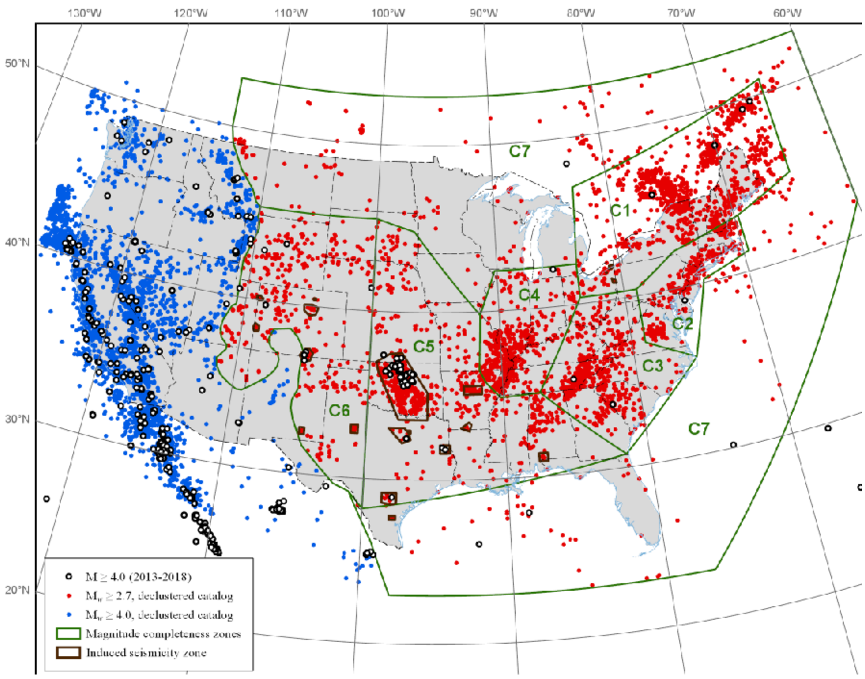

Fig. 1 – Map showing seismicity catalog from 1568 to 2017, magnitude completeness zones (e.g., C1, C2, etc.), and induced seismicity zones [1].

To account for earthquake rates, the NSHMs consider a gridded seismicity model that accounts for smoothed earthquakes across a grid and then assumes a Gutenberg Richter b-value (slope of the distribution) and a maximum magnitude truncation to calculate the rates of earthquakes for each magnitude at each grid cell. This process also uses completeness zones that indicate the completeness magnitudes used for counting earthquakes. Slight changes were made to the completeness zones in the CEUS due to modifications of the completeness zone boundaries C3 and C4 (shown in Figure 1). We smooth the seismicity using Gaussian fixed and adaptive smoothed techniques [1]. We did not modify the earthquake catalog in California since it would require an update of the UCERF3 grand inversion which is beyond the scope of this analysis.

2.2 NGA-East, aleatory variability, and amplification factors for the CEUS

During the past decade, the Pacific Earthquake Engineering Research Center (PEER) NGA-East Project developed new GMMs for the CEUS that applied a new uniformly processed database of strong motion records and additional earthquake ground shaking simulations [3]. Figure 2 shows a comparison of the models applied in 2014 and those applied in the new NGA-East models. For the update of the 2018 NSHMs, we applied a weighted combination of updated NGA-East seed models and NGA-East final models to account for a large range of epistemic uncertainty. The median ground motions are similar in 2018 to those we applied in 2014 for periods greater than 0.2s spectral acceleration but differ at shorter periods.

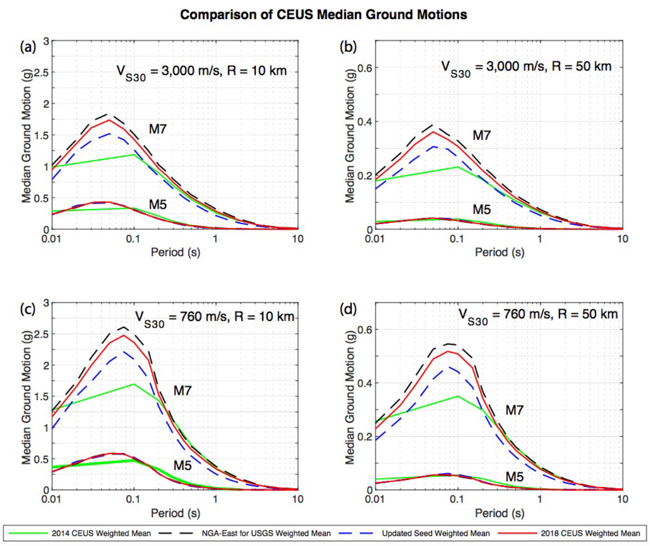

Fig. 2 – Comparison of the 2014 and 2018 NGA-East updated seed and final models, and the 2018 weighted models [1].

In addition to the introduction of new NGA-East models, the 2018 NSHM considers updated aleatory variability (sigma) models to account for the random, natural variability in the ground motions. Figure 3 shows a comparison of the 2014 CEUS, 2014 WUS, and 2018 CEUS aleatory variability. The variability is a function of V_{S30} (time-average seismic shear wave velocity in the upper 30 m of the crust). In general, the 2018 models are higher for M_w5 and M_w7 and for a wide range of V_{S30} values than the 2014 model. The models are more similar for spectral periods greater than about 1s.

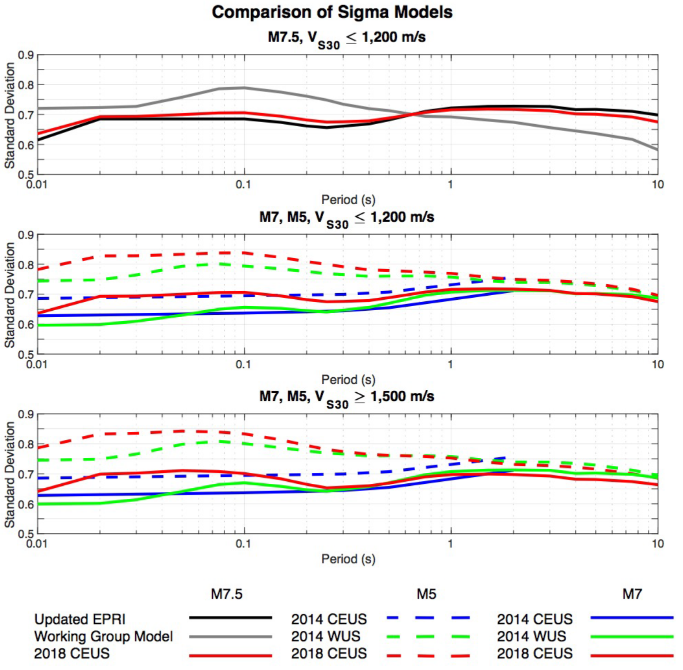

Fig. 3 – Comparison of the 2014 WUS and CEUS and 2018 CEUS aleatory variability (sigma) [1].

In past versions of the NSHMs, we did not have amplification factors for CEUS ground motions that we could apply directly in the hazard calculations. However, a working group was established in 2018 to provide these factors, allowing for country-wide mapping of various V_{S30} and periods [4, 5]. Figure 4 shows a comparison of the CEUS and WUS ground motions as a function of V_{S30}, period, distance, and M_w.

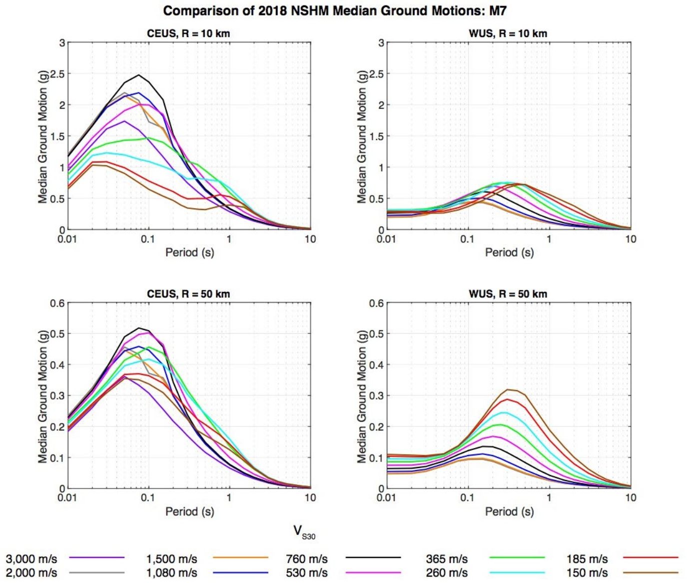

Fig. 4 – Comparison of the CEUS and WUS V_{S30} ground motions as a function of period, distance, and M_w [1].

The first-order comparison shows that for shorter periods, the WUS and CEUS ground motions differ significantly. The peak at 0.1s period in the CEUS is much higher than that observed in WUS shaking records. This peak is caused by the high impedance contrast between CEUS rocks with shallow soils overlying hard rock site conditions [4]. A gradient model is also considered for sites with more gradual impedance contrasts.

2.3 Basin amplification factors for the WUS

The 2018 NSHM considers 22 periods and 8 site classes, more than any previous version of the NSHM. This consideration of more periods demands careful attention to the long period site amplification of deep soils. The NGA-West2 GMMs considered $Z_{1.0}$ and $Z_{2.5}$ terms which define the depth to the 1.0 km/s and 2.5 km/s velocity horizons. These parameters were not considered in previous versions of the NSHM because uniform basin depth information was lacking. However, for the 2018 update, we consider depths of sediments in calculating the basin depth terms for urban regions of Los Angeles, the San Francisco Bay Area, Seattle, Washington, and the Wasatch area near Salt Lake City, Utah (Figure 5). We consider amplification for periods greater than 1.0s. Special considerations were made for amplifying subduction zone ground shaking within sedimentary basins [1].

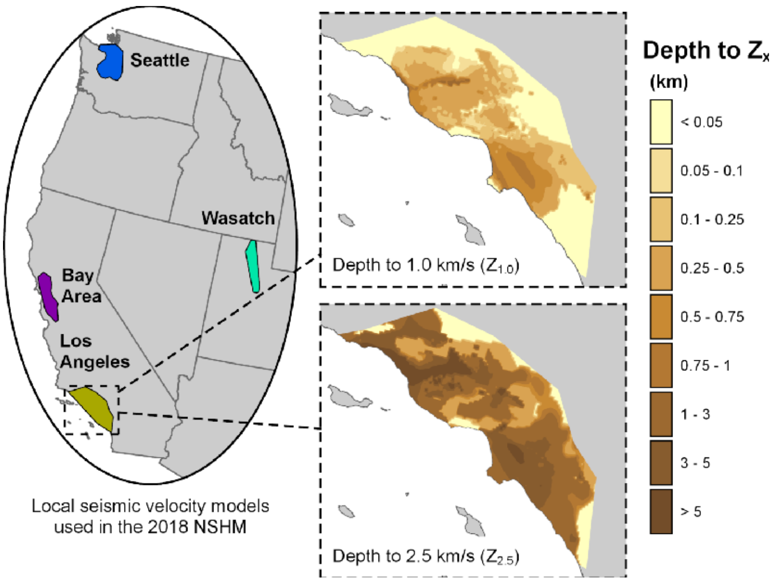

Fig. 5 – Locations where the depth of sediments were considered in 2018 NSHMs. For the Los Angeles area, detailed $Z_{1.0}$ and $Z_{2.5}$ depths are from the Southern California Earthquake Center model [6]

Figure 5 shows depths of $Z_{1.0}$ and $Z_{2.5}$ for southern California. For the 2018 NSHM update, we only included positive amplifications for the deepest sites and did not consider deamplification at shallow sites. This addition should be reconsidered in future versions of the NSHM maps as the data is reassessed and uncertainties are considered more fully.

Figure 6 shows changes in ground motions that are typically greater by about 40% at many sites in Seattle and Los Angeles and about 10-25% greater at sites in the San Francisco Bay Area and Salt Lake City area compared to the earlier models.

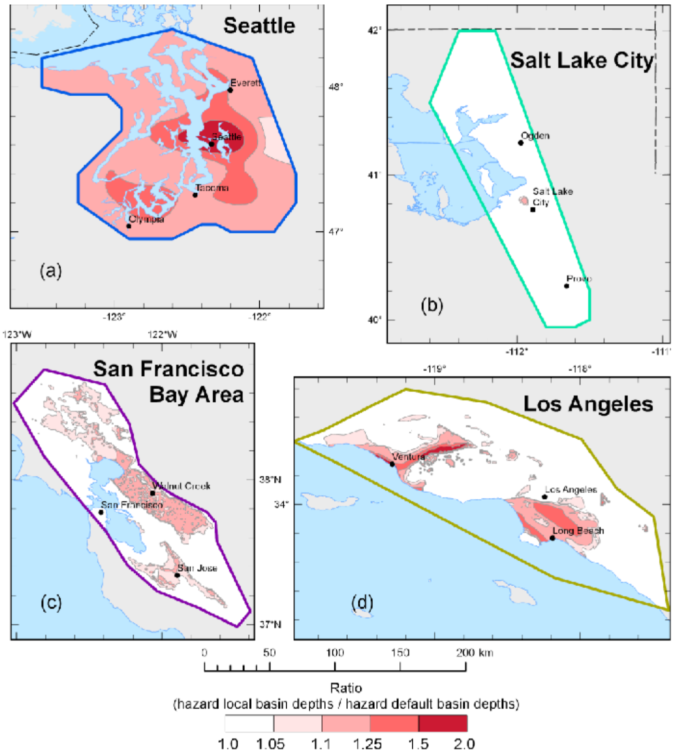

Fig. 6 – Ratio of hazard changes in the WUS urban areas that consider basin depths compared to those that do not [1].

3. New hazard models and comparisons with 2014 NSHM

In Figure 7, a total mean hazard map for 2% probability of exceedance in 50 years at a 0.2s spectral acceleration (SA) for V_{S30}=760 m/s is shown. The maps for other periods and site classes are now considered for the first time in U.S. building code procedures.

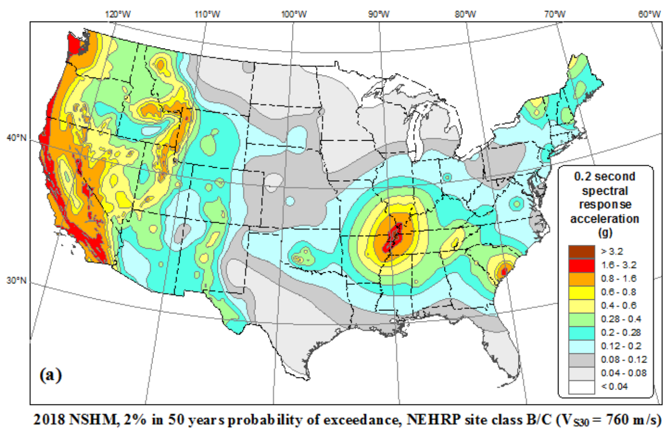

Fig. 7 – 2018 hazard map for 2% probability of exceedance in 50 years, 0.2s SA, V_{S30}=760 m/s [1].

Figure 8 shows difference and ratio maps of the 2018 NHSM 0.2s SA map (Figure 7) versus the 2014 NSHM map. The largest changes at 0.2s are near the New Madrid seismic zone where the NGA-East and updated aleatory variability have increased the seismic hazard. Hazard is lower at many sites in the WUS due to changes in magnitudes introduced in the earthquake catalog. The 2018 maps, hazard curves, and comparisons with 2014 NSHM can be found at the USGS ScienceBase Catalog [7].

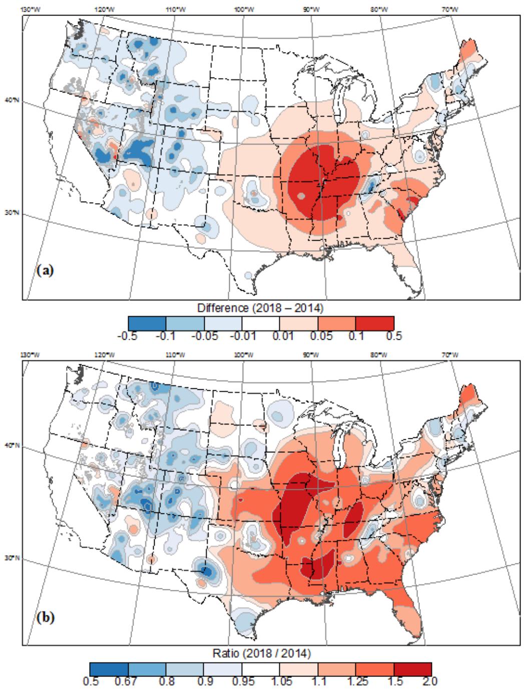

Fig. 8 – Comparisons of difference and ratio between the 2018 and 2014 NSHMs [1].

4. New hazard changes being considered for 2023 update

The focus of the 2023 NSHM will be to update the WUS source model (e.g., new faults) and subduction-zone GMMs (i.e., NGA-Subduction). Additional updates may include GMMs derived from physics-based 3D simulations [e.g., 8], non-ergodic ground motion models [e.g., 9], additional basin-effect models for urban areas in the WUS [e.g., 10], topographic amplification, improved Atlantic and Gulf Coast site-effect models [e.g., 11], the Uniform California Earthquake Rupture Forecast (UCERF) with updated catalogs and other logic tree modifications and updated geologic and geodetic models in other areas [e.g., 12], and an improved treatment of the WUS-CEUS attenuation boundary.

5. Conclusions

The USGS produced the 2018 NSHM for use in a variety of applications. Building codes, risk assessments, and policymakers apply these models in mitigating earthquake risk across the U.S., so it is critical that they have an appropriate level of development, maturity, and acceptance within the science and engineering communities. The 2018 NSHMs made the first attempts to improve ground shaking estimates in the CEUS and in urban regions of the WUS by better accounting for basin and site terms. Additional work is needed to refine these models, including additions of 3D earthquake simulations that enhance our ground motion shaking databases. We welcome all comments on suggested improvements to the models.

6. Acknowledgements

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7. References

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