

DEVELOPMENT OF USGS NSHMS: DO SMALL CHANGES IN HAZARD IMPLY SMALL CHANGES IN RISK?

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Abstract: *One of the flagship products from the U.S. Geological Survey (USGS) is the National Seismic Hazard Model (NSHM). Since 1976, the NSHM has been periodically updated to reflect newly published earthquake science and provide probabilistic estimates of seismic hazard for the United States. During each update cycle, alternative models are deliberated, analyzed, and documented through logic trees and their corresponding logic tree branch weights. For example, the decision to modify a logic tree branch weight may be influenced by sensitivity analyses of the logic tree branches in their effects on the mean hazard. However, do small changes in traditional measures of hazard imply small changes in risk? In this study, we make use of two update cycles of the USGS NSHMs and a National Bridge Inventory (NBI) from the Federal Highway Administration (FHWA) to explore the preceding question. Specifically, we first identify geographic locations in the conterminous United States in which the change in hazard from one cycle to another is relatively small. Next, we model the seismic risk to highway bridges for these locations and for each update cycle, while simultaneously distinguishing low hazard environments from high hazard environments. These data enable quantitative analysis of how much changes in risk can be expected given small changes in hazard, investigating the importance of risk models in decision-making during development of the USGS NSHMs.*

1. Introduction

Since 1976, the U.S. Geological Survey (USGS) periodically updates the National Seismic Hazard Model (NSHM) to reflect newly published earthquake science (Algermissen and Perkins, 1976; Frankel et al., 2002, 1996; Petersen et al., 2020, 2015, 2008). During each NSHM update cycle, alternative models (e.g., seismic source characterization, ground motion models) are deliberated, analyzed, and documented through logic trees and their corresponding logic tree branch weights to account for epistemic uncertainty in hazard (Kulkarni et al., 1984). For a given location in the United States and a given intensity measure (IM) type (e.g., 1-sec spectral acceleration), a typical output of the NSHM is the mean hazard, which is derived from weighting hazard corresponding to different logic tree branches (Abrahamson and Bommer, 2005; McGuire et al., 2005).

Finalizing the logic tree is one of the key decisions when updating the NSHM. For example, a decision to modify the weight for a particular logic tree branch may be influenced by sensitivity analyses of the logic tree branches in their effects on the mean hazard. In this process, changes to the mean hazard that are 10% or more are usually considered as “significant” and, hence, require further investigation on the underlying reasons (Petersen et al., 2021). By contrast, changes to the mean hazard that are within 10% are usually considered lower priority.

The implicit assumption is that small changes in hazard would also result in small changes in risk. However, do small changes in traditional measures of hazard (e.g., changes to uniform-hazard ground motions within 10%) necessarily imply small changes in risk? This paper aims to explore this question.

2. Proposed approach

We propose to supplement analyses of changes in hazard across two NSHM update cycles with analyses of changes in risk. To this end, we focus on assessing seismic risk to highway bridges in addition to examining mean hazard for each NSHM update cycle. For a given highway bridge, we consider two metrics of risk: (1) annual probability of slight damage or worse, and (2) average annual loss (AAL) (e.g., Jaiswal et al., 2017).

More precisely, the annual frequency of exceeding a given damage state (DS), λ_{DS} , may be determined from the following (e.g., Baker et al., 2021):

$$\lambda_{DS} = \int_0^{\infty} \Pr(DS \geq ds \mid IM = im) |d\lambda_{IM}(im)| \quad (1)$$

where $\lambda_{IM}(im)$ denotes the soil-adjusted mean hazard curve (i.e., annual frequency of IM exceeding intensity level im that corresponds to a location-specific value of the time-averaged shear-wave velocity to a depth of 30 meters, V_{S30}), and $\Pr(DS \geq ds \mid IM = im)$ denotes the fragility curve for a given DS (i.e., probability of DS or worse for a given intensity level im). If the DS was defined as “slight damage,” λ_{DS} denotes the annual frequency of exceeding slight damage, which is equivalent to (i) the annual frequency of observing slight damage or worse, or (ii) the annual frequency of observing *some* damage to the bridge (Federal Emergency Management Agency (FEMA), 2022). Using a common Poisson assumption for converting frequencies to probabilities gives the first desired risk metric of interest (e.g., McGuire, 2004).

The second desired risk metric of interest may be determined from the following:

$$AAL = \int_0^{\infty} \mathbb{E}[L \mid IM = im] |d\lambda_{IM}(im)| \quad (2)$$

where $\mathbb{E}[L \mid IM = im]$ denotes the mean vulnerability curve (i.e., the expected loss for a given intensity level im). The mean vulnerability curve may be determined from the following (Equation 11-17 in FEMA, 2022):

$$\mathbb{E}[L \mid IM = im] = RC \sum_{i=2}^5 \mathbb{E}[DR \mid DS = ds_i] \times \Pr(DS = ds_i \mid IM = im) \quad (3)$$

where RC denotes the replacement cost of the highway bridge, $\mathbb{E}[DR \mid DS = ds_i]$ denotes the expected damage ratio (DR) for the i th DS, and $\Pr(DS = ds_i \mid IM = im)$ denotes the probability of observing the i th DS for a given intensity level im . The five DSs correspond, respectively, to (1) none, (2) slight, (3) moderate, (4) extensive, and (5) complete damage. Because zero loss is assumed for no damage, the summation in Equation 3 starts at $i=2$. The integrals in Equations 1 and 2 are evaluated for IM levels in which corresponding annual frequencies of exceedance are 10^{-5} or greater, because not all NSHM update cycles report hazard at exceedance frequencies less than 10^{-5} and because these levels might not contribute much to risk.

3. Case study

To illustrate changes in mean hazard, we consider two NSHM update cycles: (1) the 2014 NSHM (Petersen et al., 2015; Shumway, 2019), and (2) the 2018 NSHM (Petersen et al., 2020; Shumway et al., 2021). Because the former does not provide hazard for different values of V_{S30} , we use the approach by Jaiswal et al. (2020), which is based on the work of Stewart and Seyhan (2013), to account for local soil conditions in the hazard when calculating risk. Specifically, we convert the mean hazard curves from NSHM for a V_{S30} of 760 m/sec into soil-adjusted hazard curves $\lambda_{IM}(im)$, before applying Equations 1 and 2.

We consider the set of highway bridges that were studied by Jaiswal et al. (2020). Specifically, the National Bridge Inventory (NBI) from the Federal Highway Administration (FHWA) was used to derive an engineering exposure model, yielding estimates of replacement costs and Hazus highway bridge classes for each bridge (FEMA, 2022). To facilitate comparison between the two NSHM update cycles, we consider the subset of bridges within the conterminous United States (CONUS), which consists of roughly 610,000 bridges with a corresponding total replacement cost of roughly 1.55 trillion dollars.

To focus on illustrating key ideas with risk, we use “standard” fragility curves for each highway bridge (i.e., Table 7-6 in FEMA, 2022), which differs from the risk results presented in Jaiswal et al. (2020). For each DS, we assume a uniform distribution of DRs using the range of DRs from Table 11-11 in FEMA (2022) to determine $\mathbb{E}[DR \mid DS = ds_i]$ in Equation 3. In this study, the same exposure, fragility, and consequence models are used

for assessing risk in each of the two NSHM update cycles, and hence, if the entire (mean) hazard curves are identical between the two cycles, the resulting risks are theoretically the same. However, in practical risk assessments, exposure, fragility, and consequence models evolve with time, and hence, unchanged hazard may still yield changes to risk.

4. Changes in hazard versus changes in risk

To understand where changes in hazard across the NSHM update cycles are relatively small, we first compute uniform hazard ground motions (UHGMs) at each highway bridge location. For a given update cycle, the UHGM at a given bridge is defined as the 1-sec spectral acceleration that corresponds to a 2% probability of exceedance in 50 years (i.e., return period of about 2,475 years) and a V_{S30} of 760 m/sec. The spectral period of 1 second was chosen because highway bridge fragility curves are typically based on this spectral period (FEMA, 2022). The return period of 2,475 years and the V_{S30} of 760 m/sec were chosen because they are traditional measures of hazard in all USGS NSHM update cycles (Petersen et al., 2015); note that although 2,475 years has been used for design of major critical water crossings (e.g., New York City), shorter return periods are often used for design of less critical bridges (Marsh et al., 2014). At a given bridge location, the ratio between the UHGM from the 2018 NSHM and the UHGM from the 2014 NSHM measures the change in mean hazard.

Figure 1 illustrates ratios of UHGMs at all highway bridge locations in the CONUS. Small changes in hazard (i.e., ratios between 0.9 and 1.1) are colored as white, significant increases in hazard (i.e., ratios greater than or equal to 1.1) are colored as orange, and significant decreases in hazard (i.e., ratios less than or equal to 0.9) are colored as blue. During development of the 2018 NSHM, the orange and blue regions would be considered higher priority than the white regions for further investigation and understanding of the causes of changes between the two update cycles. For example, increases in hazard in the central and eastern United States were found to be mainly driven by changes in ground motion models (Petersen et al., 2021).

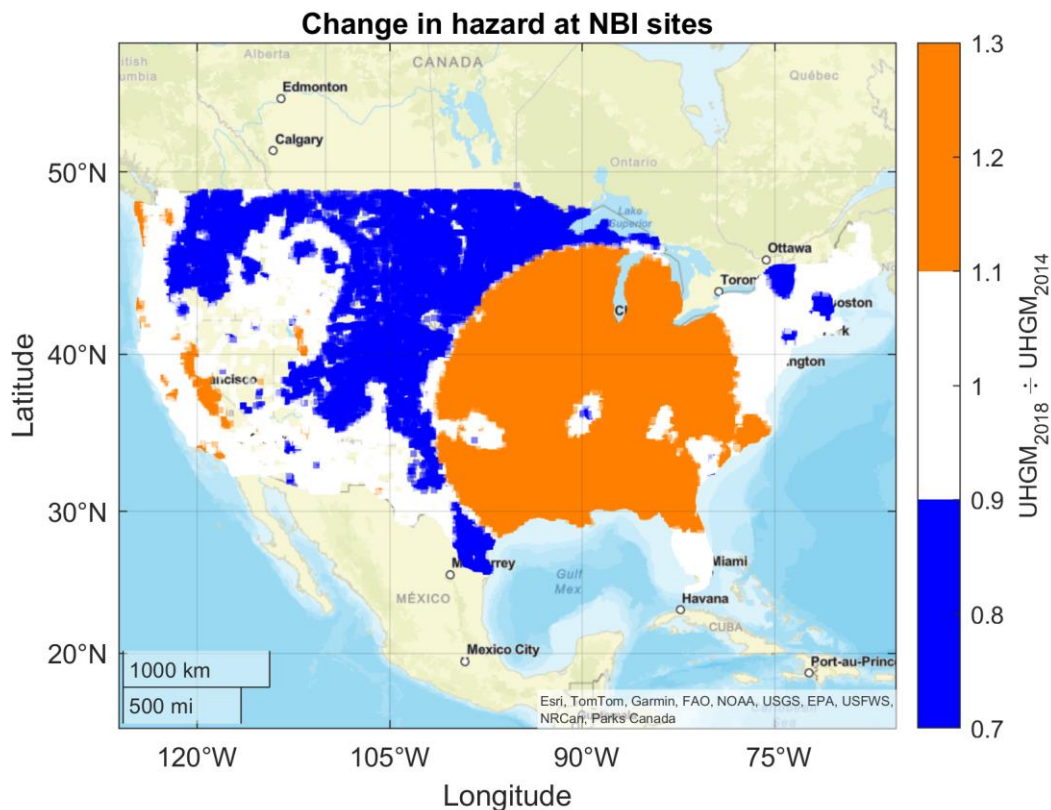


Figure 1. Ratio between uniform-hazard ground motion (UHGM) from 2018 NSHM and UHGM from 2014 NSHM at locations of highway bridges in the National Bridge Inventory (NBI); UHGM defined as 1-sec spectral acceleration for 2% probability of exceedance in 50 years and $V_{S30}=760$ m/sec.

If small changes in hazard also necessarily imply small changes in risk, the white regions from Figure 1 would also correspond to small ratios of risk between the two NSHM update cycles. Figure 2 demonstrates this is not the case for this traditional measure of hazard. Specifically, Figure 2 illustrates ratios of risk at only highway bridge locations that correspond to small changes in hazard. At such locations, we computed the annual probability of exceeding slight damage for both update cycles. We then measured the change in risk via the ratio between risk from 2018 NSHM and risk from 2014 NSHM. Because ratios exceeding 10% can be considered “actionable,” those that are within 10% are considered herein as small and colored white (Field et al., 2020). Therefore, Figure 2 demonstrates that small changes in hazard do *not* necessarily imply small changes in risk because not all of the locations are colored white. Although 47% of the bridges corresponding to small changes in hazard also resulted in small changes in risk, 20% of the bridges resulted in significant increases in risk (i.e., ratios of risk exceeding 1.1 as depicted in orange in Figure 2), and 33% of the bridges resulted in significant decreases in risk (i.e., ratios of risk less than 0.9 as depicted in blue in Figure 2).

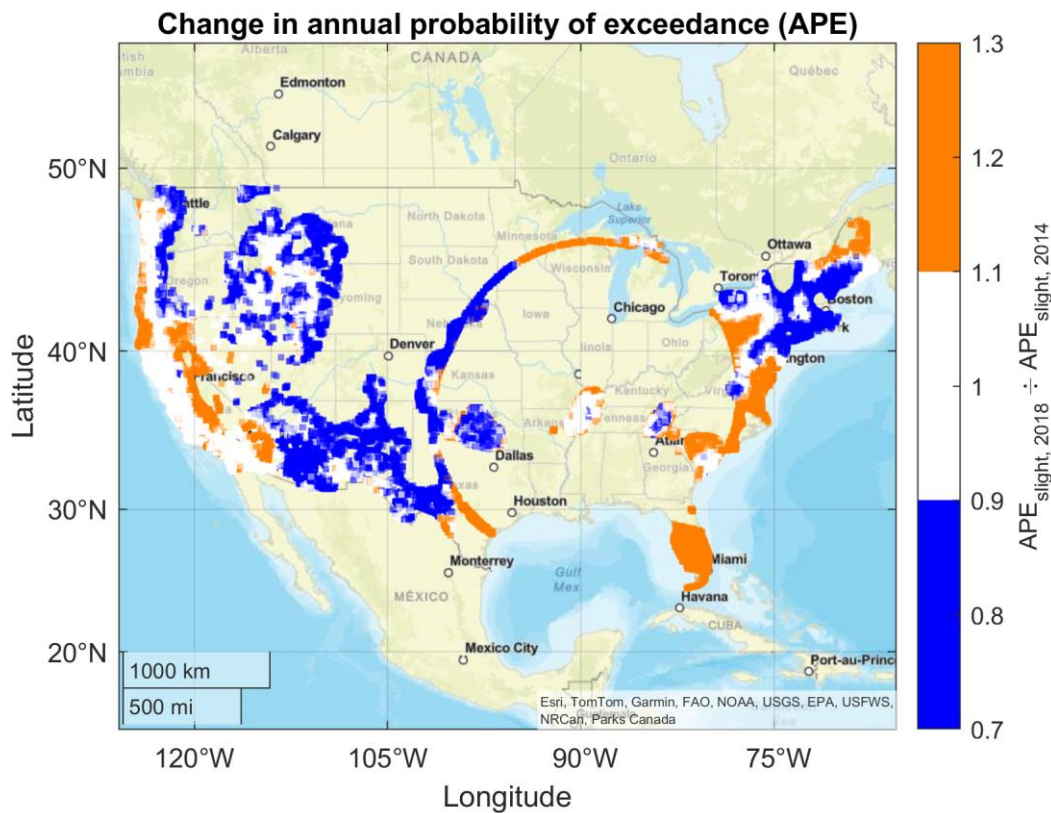


Figure 2. Ratio between annual probability of exceeding (APE) slight damage from 2018 NSHM and annual probability of exceeding slight damage from 2014 NSHM at highway bridges in which changes to uniform-hazard ground motion (UHGMs) across NSHM update cycles are within 10%.

Redefining the metric of risk as AAL instead of annual probability of exceeding slight damage results in a similar but not identical conclusion. Specifically, Figure 3 illustrates ratios of AAL at only highway bridge locations that correspond to small changes in hazard. In this case, 41% of the bridges corresponding to small changes in hazard resulted in small changes in risk (white), 22% of the bridges resulted in significant increases in risk (orange), and 37% of the bridges resulted in significant decreases in risk (blue). Therefore, Figure 3 also demonstrates that small changes in hazard do *not* necessarily imply small changes in risk because, again, not all of the locations yield changes in risk that are within 10%.

Because small changes in hazard do not necessarily imply small changes in risk, risk modeling would better inform decisions during development of NSHMs. For example, one of the debated decisions in the 2023 NSHM was about weighting the logic tree branch corresponding to “Classic” fault segmentation (Field et al., 2023). Although the weight was originally expected to increase at the start of the 2023 NSHM, it was ultimately decreased. One of the reasons for ultimately down-weighting the “Classic” segmentation branch is that the exact branch weights were not highly influential with respect to the mean hazard. If the weights were also not

highly influential with respect to bridge risk, one can be more confident in the decision to down-weight; by contrast, if the weights were highly influential with respect to bridge risk, more deliberations may be needed to justify going against the original expectation at the start of the NSHM update cycle. Consequently, decisions in NSHM development would be better informed if risk metrics were also examined in addition to hazard metrics.

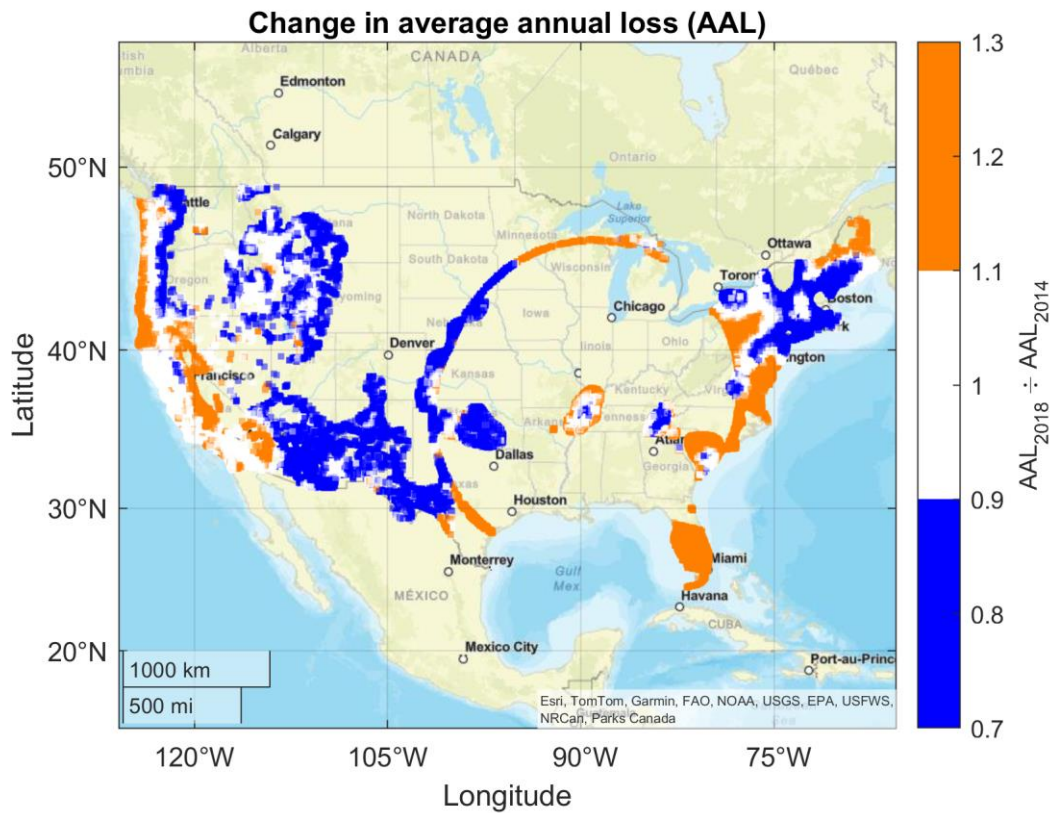


Figure 3. Ratio between average annual loss (AAL) from 2018 NSHM and AAL from 2014 NSHM at highway bridges in which changes to uniform-hazard ground motion (UHGMs) across NSHM update cycles are within 10%.

Small changes in hazard do not necessarily imply small changes in risk because assessing risk requires additional considerations beyond traditional measures of hazard. For example, assessing risk requires the complete hazard curve (Equations 1 and 2), whereas the UHGM focuses upon one return period (e.g., 2,475 years). Similarly, the risk must account for local soil conditions, whereas the UHGM focuses on a fixed value of V_{S30} (e.g., 760 m/sec). Besides these, assessing risk requires fragility and vulnerability models that are appropriate for a given asset type (e.g., highway bridge), whereas the UHGM is independent of asset types.

To better understand the preceding considerations, Figure 4b shows the mean hazard curves for SA(1.0) from the two update cycles for the Sunshine Skyway bridge in Florida. Based on Figure 4b, the UHGM for 2% probability of exceedance in 50 years is equal to 0.0253g from 2018 NSHM and equal to 0.0242g from 2014 NSHM; therefore, the change in mean hazard is relatively small as the ratio between the two UHGMs is within 10% ($0.0253 \div 0.0242 = 1.0455$). However, the full hazard curves from the two cycles are noticeably dissimilar (e.g., for very long return periods at this location, hazard from 2018 NSHM exceeds hazard from 2014 NSHM). This discrepancy between hazard curves can be magnified after accounting for soil conditions and further propagates to changes in risk metrics that require integration of hazard (e.g., Equations 1 and 2). Therefore, although changes in UHGMs between cycles might be small (e.g., 4.55% increase in Figure 4b), the resulting changes in risk could be large (e.g., the AAL for Sunshine Skyway bridge increased by 65.6%); however, the differences between hazard and risk changes would depend on the return period chosen for defining the UHGM (e.g., 1,000 versus 2,475 versus 10,000 years).

As a second example, Figure 4a shows the hazard curves for SA(1.0) from the two update cycles for the Drift Creek Covered bridge in Oregon. Based on Figure 4a, the UHGM for 2% probability of exceedance in 50 years is equal to 0.598g from 2018 NSHM and equal to 0.562g from 2014 NSHM; therefore, the change in mean hazard is again relatively small as the ratio between the two UHGMs is within 10% ($0.598 \div 0.562 = 1.0641$). However, Figure 4c shows that the fragilities (i.e., conditional probability of exceeding slight damage) corresponding to the two UHGMs are, respectively, 0.313 and 0.278; therefore, the change in fragility exceeds 10% ($0.313 \div 0.278 = 1.126$). The two bridge examples shown in Figure 4 are not exhaustive and readers can perform their own seismic risk assessments of highway bridges using an open-source interactive tool that was recently published in support of the 2023 NSHM (Kwong and Jaiswal, 2023a, 2023b).

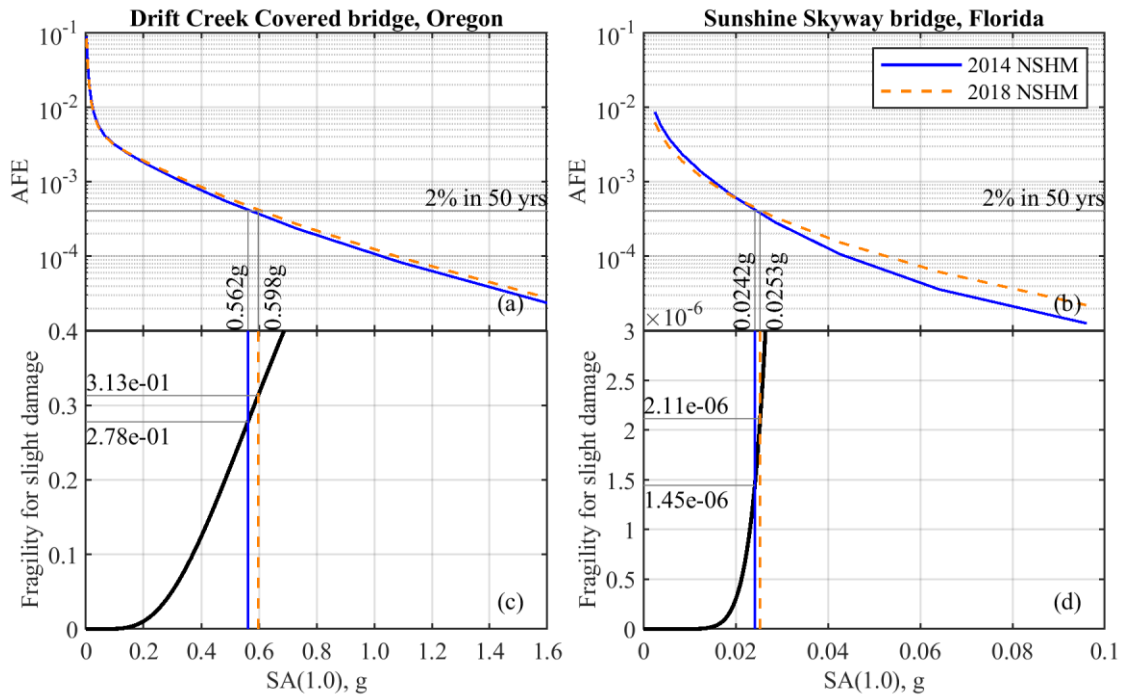


Figure 4. Examples of small changes in hazard but non-small changes in risk: (a) hazard curves at Drift Creek Covered bridge in Oregon (45, -123.86) for $V_{S30}=760$ m/sec, (b) hazard curves at Sunshine Skyway bridge in Florida (27.59, -82.63) for $V_{S30}=760$ m/sec, (c) standard fragility curve for slight damage for Drift Creek Covered bridge in Oregon (HWB3), and (d) standard fragility curve for slight damage for Sunshine Skyway bridge in Florida (HWB1). AFE: annual frequency of exceedance. SA: spectral acceleration.

How much change in risk can be expected from a given change in hazard? For the Drift Creek Covered bridge in Oregon, a 6.41% increase in UHGM (Figure 4a) resulted in a 12.6% increase in fragility (Figure 4c), and for the Sunshine Skyway bridge in Florida, a 4.55% increase in UHGM (Figure 4b) resulted in a 45.5% increase in fragility (Figure 4d). Although the increase in fragility for the Sunshine Skyway bridge may be relatively large, the absolute values of the fragility are relatively small. Therefore, we can focus our attention on the subset of bridges in which the absolute values of fragility are non-negligible (e.g., the fragility exceeds 0.1% probability).

Computing the ratios of UHGMs and ratios of fragility for all highway bridges in which the fragility is non-negligible leads to the results shown in Figure 5. Specifically, Figure 5a compares ratios of fragility against ratios of UHGMs for such bridges in a low hazard environment, whereas Figure 5b compares such ratios for bridges in a high hazard environment. With the UHGM defined as 1-sec spectral acceleration at 2% in 50 years and a V_{S30} of 760 m/sec, we define “low hazard” as locations in which the UHGM is 0.05g or less and “high hazard” as locations in which the UHGM is 0.5g or more. These two thresholds roughly correspond, respectively, to modified Mercalli intensity (MMI) values of V and VIII (Jaiswal et al., 2015).

In both hazard environments, the relation between changes in fragility and changes in UHGM is nonlinear. Put differently, changes in UGHMs do not necessarily imply comparable levels of changes in fragility because not all ratios fall along the diagonal line. For example, Figure 5a shows that in a low hazard environment, an increase in UHGM of about 23% could result in an increase in fragility of about 200%, and a decrease in UHGM

of about 20% could result in a decrease in fragility of about 70%. Similarly, Figure 5b shows that in a high hazard environment, an increase in UHGM of about 40% could result in an increase in fragility of about 100%, and a decrease in UHGM of about 12% could result in a decrease in fragility of about 22%. The nonlinear relation is stronger for low hazard environment than high hazard environment. Because epistemic uncertainties in hazard could be larger for low hazard environments than for high hazard environments, this difference in nonlinear relation indicates more careful consideration is warranted about implications from changes in hazard for geographic regions of low hazard, even when such changes in hazard may seem to be small.

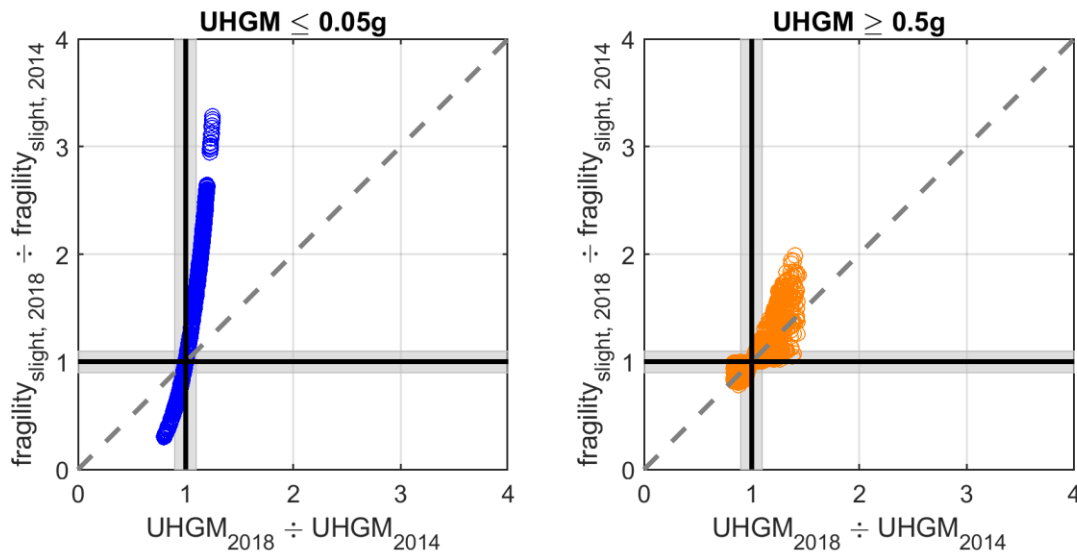


Figure 5. Ratios between fragility from 2018 NSHM and fragility from 2014 NSHM versus ratios between hazard from 2018 NSHM and hazard from 2014 NSHM: (a) low hazard, and (b) high hazard locations; to avoid division by unreasonably small numbers, ratios are only shown for bridges in which fragility exceeds 0.1%. Light grey shaded regions indicate ratios within 10%. UHGM: uniform-hazard ground motion.

Figure 6 demonstrates that the relations described in the preceding for fragility remain valid when we focus on AAL instead of fragilities. For example, the relation between changes in risk and changes in UHGM is again nonlinear for both low and high hazard environments. Considering AAL as the risk metric, Figure 6 shows that in a low hazard environment, an increase in UHGM of about 19% could result in an increase in risk of about 369% and a decrease in UHGM of about 20% could result in a decrease in risk of about 88%. Similarly, Figure 6b shows that in a high hazard environment, an increase in UHGM of about 40% could result in an increase in risk of about 92% and a decrease in UHGM of about 10% could result in a decrease in risk of about 16%. As before, the disconnect between hazard and risk is stronger for low hazard environment than high hazard environment.

Collectively, the results from Figure 2 through Figure 6 demonstrate that small changes in hazard may still potentially lead to significant changes in risk. Therefore, risk modeling may play an important role for making decisions during development of NSHMs; however, the corresponding challenge lies in deciding a necessary and sufficient set of risk metrics (Field, 2022). At a minimum, understanding of the hazard return periods that drive different risk metrics seems important.

One of the reasons for the disconnect between changes in hazard and changes in risk lies with our typical focus on only one return period as opposed to multiple return periods when evaluating changes in hazard. For example, Figure 4b demonstrates that although the ground motions at the 2% in 50 years level (annual frequency of exceedance (AFE) of about 4.04×10^{-4}) differs by about 4.55%, the ground motions at the 0.5% in 50 years level (AFE of about 1.0×10^{-4}) differs by about 18.2% because the shape of the hazard curve changed between the two NSHM update cycles.

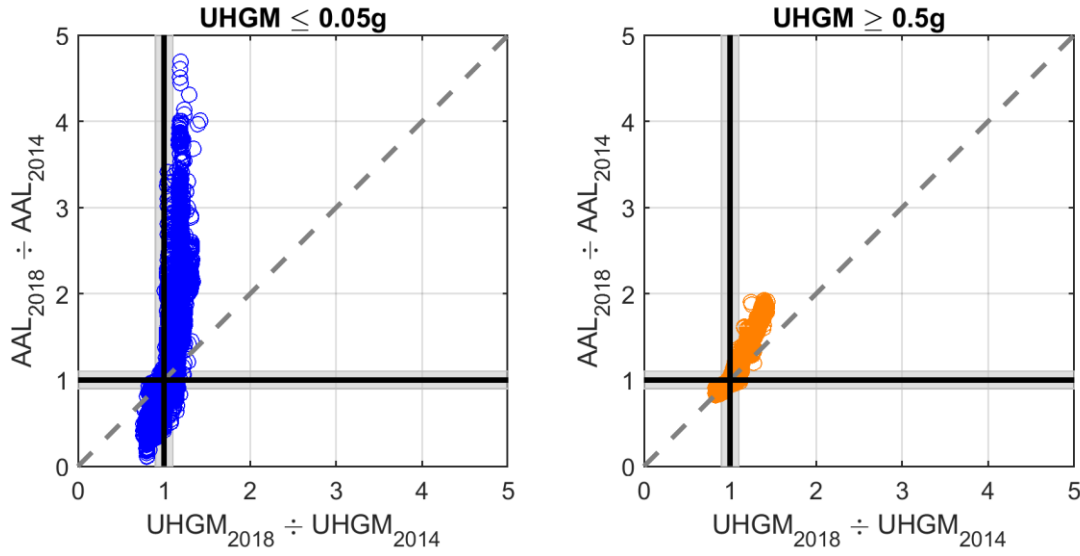


Figure 6. Ratios between AAL from 2018 NSHM and AAL from 2014 NSHM versus ratios between hazard from 2018 NSHM and hazard from 2014 NSHM: (a) low hazard, and (b) high hazard locations; to avoid division by unreasonably small numbers, ratios are only shown for bridges in which AAL exceeds \$10. Light grey shaded regions indicate ratios within 10%. UHGM: uniform-hazard ground motion. AAL: average annual loss.

Therefore, one approach towards improving the disconnect between changes in hazard and changes in risk is to evaluate changes in hazard for the complete curve instead of one return period. For example, suppose that we quantify the changes in hazard curve across the two update cycles using the following metric, which is a weighted geometric mean (across IM levels) of ratios between AFEs from the two cycles:

$$R_{\text{hazCrv}} = \prod_{i=1}^{n_{IML}} \left[\frac{\lambda_{IM,2018}(im_i)}{\lambda_{IM,2014}(im_i)} \right]^{w_i} \quad (4)$$

$$w_i = \frac{\lambda_{IM,2014}^{-1}(im_i)}{\sum_{j=1}^{n_{IML}} \lambda_{IM,2014}^{-1}(im_j)} \quad (5)$$

where n_{IML} denotes the number of IM levels used for calculating AFE, λ_{IM} . At each IM level, the ratio of $\lambda_{IM,2018}$ to $\lambda_{IM,2014}$ in Equation 4 measures the change in AFE across the two cycles. Taking the weighted geometric mean of such ratios, with weighting by return period via Equation 5, yields a single metric that captures changes in the hazard curve better than using changes in UHGMs. If R_{hazCrv} exceeds unity at a given location, then the hazard curve from the 2018 NSHM is, on average across IM levels, greater than the hazard curve from the 2014 NSHM.

Figure 7 shows values of R_{hazCrv} at only highway bridge locations that correspond to small changes in UHGMs (i.e., ratios of UHGMs from Figure 1 that are within 10%). The fact that not all locations are colored white confirms our hypothesis that small changes in UHGMs do not necessarily imply small changes in hazard curves. Comparing Figure 7 against Figure 2 and Figure 3 demonstrates that the disconnect between hazard and risk is improved when considering the full hazard curve at multiple return periods instead of UHGMs at a single return period. For example, increases in R_{hazCrv} that are significant (orange regions in Figure 7) correspond roughly to increases in risk that are also significant (orange regions in Figure 2 and Figure 3). Similarly, decreases in R_{hazCrv} that are significant (blue regions in Figure 7) correspond roughly to decreases in risk that are also significant (blue regions in Figure 2 and Figure 3).

However, some disconnect between hazard and risk remains. For example, although changes in R_{hazCrv} in California are relatively large (Figure 7), the change in AAL in the same region is relatively small (Figure 3). Therefore, despite improvements from considering UHGMs at a single return period to considering full hazard

curves at multiple return periods, risk modeling would still be useful for informing decision-making during development of USGS NSHMs. By including appropriate risk metrics during hazard model development, the effects from changes in hazard on changes in risk can be more directly quantified and any potential disruptions to range of end-users of NSHM can be understood sooner rather than later.

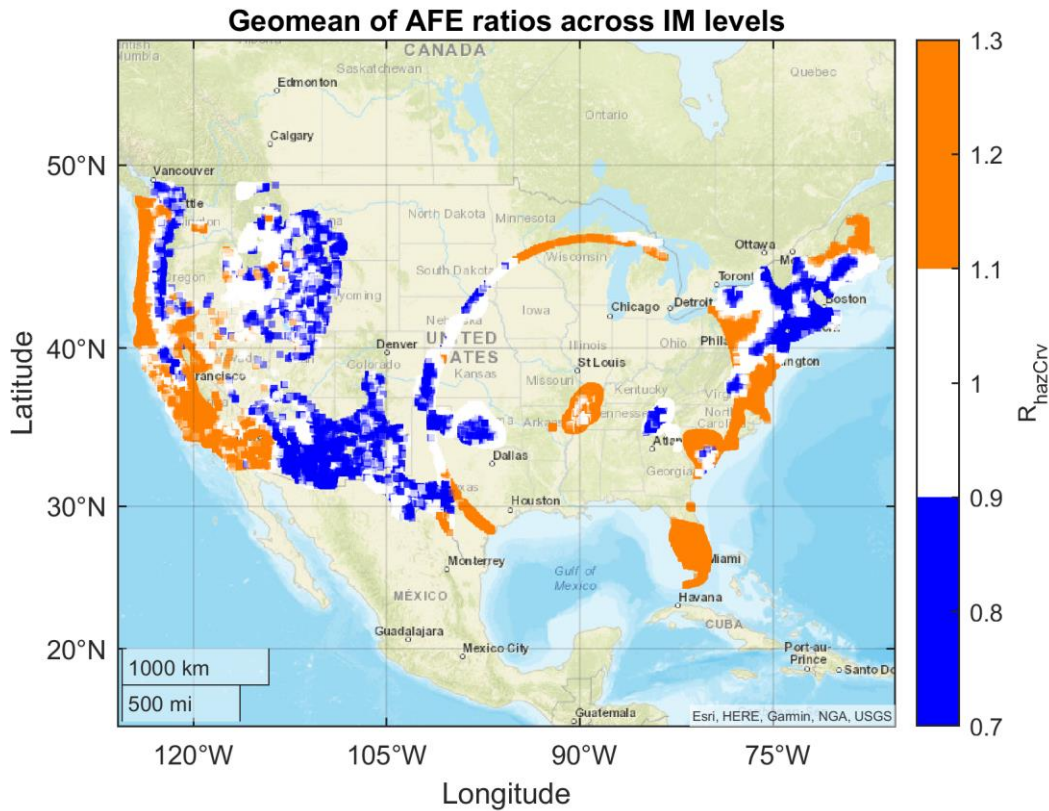


Figure 7. Geometric mean (across intensity measure, IM, levels) of ratios between annual frequencies of exceedance (AFE) from 2018 NSHM and AFEs from 2014 NSHM at highway bridges in which changes to UHGMs across NSHM update cycles are within 10%.

5. Limitations

While the key conclusions derived from this study are relatively insensitive to our choice of risk metric (Figure 2 versus Figure 3) and to our definition of “low” versus “high” hazard (Figure 5 and Figure 6), the conclusions are, strictly speaking, limited to the assumptions adopted herein. For example, the use of a distance cutoff of 1000 km in the seismic hazard calculations leads to the circular boundary around the New Madrid seismic zone in Figure 1 (Shumway et al., 2024). Also, the analyses in this paper can be repeated for other definitions (e.g., what constitutes “small” change in hazard or risk), other exposure and fragility models (e.g., improved estimates of fragility for the highway bridges), and other asset types (e.g., pipelines). Finally, it is impossible to clarify what constitutes a “small” or “large” change in hazard without carefully examining fractile hazard curves that quantify epistemic uncertainties in hazard (e.g., Hamburger et al., 2017; Kwong and Jaiswal, 2023b; Lee et al., 2018).

6. Conclusions

Although decisions during development of U.S. Geological Survey (USGS) National Seismic Hazard Models (NSHMs) are based on scientific deliberations, they can also be influenced by whether changes to the NSHM produce changes in mean hazard that are relatively significant. One implicit assumption here is that small changes in hazard would likely correspond to small changes in risk as well. To explore this assumption, we made use of two USGS NSHM update cycles and the National Bridge Inventory from the Federal Highway Administration. We found that small changes in hazard do not necessarily imply small changes in risk and that the disconnect is stronger for low hazard environments than for high hazard environments (when changes are

quantified with ratios). For example, an increase in average annual loss (AAL) of 200% (i.e., factor of three) can result from an increase in uniform-hazard ground motion (UHGM) of about 4%. Further, even a more significant increase in hazard also does not necessarily imply a commensurate increase in risk. For example, an increase in UHGM of about 40% could lead to an increase in AAL of about 90%. Although the disconnect between hazard and risk is improved when examining a weighted average of hazard at multiple return periods (rather than UHGMs at a single return period), some disconnect between hazard and risk remains. Therefore, giving risk models an increased role in decision making during development of USGS NSHMs would be beneficial.

7. Acknowledgments

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