Title
Site-to-Site Standard Deviation Model for Central and Eastern North America

Authors
Stewart, Jonathan
Parker, Grace A
Al Atik, Linda
et al.

Publication Date
2018-07-13

Memorandum

Date: July 13, 2018

To: The USGS National Seismic Hazard Mapping Project

From: Jonathan P. Stewart, Grace A. Parker, Linda Al Atik, Gail M. Atkinson, Christine Goulet

RE: Modified ϕ_{S2S} model for CENA

During the March 7, 2018 USGS workshop on the national seismic hazard maps, there was discussion of what aleatory variability model should be used with the NGA-East site factors provided in Stewart et al. (2017). The writers of this memo were asked by Mark Petersen to examine this issue in an email sent on 3/16/2018. After several web meetings and related work, we provided a model in a Power Point file that was sent to USGS on April 24, 2018. That model provided values of site-to-site variability (ϕ_{S2S}), which is a component of within-event variability (ϕ), which in turn is a component of overall variability (σ) used in hazard calculations. All uncertainty components other than ϕ_{S2S} were unchanged from earlier recommendations provided in a PEER report by Goulet et al. (2017).

The model for ϕ_{S2S} that was originally provided is given by:

$$\phi_{S2S} = \phi_{S2S}(\mathbf{M} < \mathbf{M}_1) + \begin{cases} 0 & \mathbf{M} < \mathbf{M}_1 \\ \frac{\Delta\phi_{S2S}}{\Delta\mathbf{M}}(\mathbf{M} - \mathbf{M}_1) & \mathbf{M}_1 < \mathbf{M} < \mathbf{M}_1 + \Delta\mathbf{M} \\ \Delta\phi_{S2S} & \mathbf{M} > \mathbf{M}_1 + \Delta\mathbf{M} \end{cases} \quad (1)$$

where ϕ_{S2S} ($\mathbf{M} < \mathbf{M_1}$) is a V_{S30}-dependent model for small magnitudes and $\Delta\phi_{S2S}$, $\mathbf{\Delta M}$, and $\mathbf{M_1}$ are parameters that are required to express magnitude-dependence. The ϕ_{S2S} ($\mathbf{M} < \mathbf{M_1}$) term was given by:

$$\phi_{S2S}(\mathbf{M} < \mathbf{M}_1) = \begin{cases} \phi_{S2S,1} & V_{S30} < V_{\phi 1} \\ \phi_{S2S,1} - \frac{(\phi_{S2S,1} - \phi_{S2S,2})}{V_{\phi 2} - V_{\phi 1}}(V_{S30} - V_{\phi 1}) & V_{\phi 1} < V_{S30} < V_{\phi 2} \\ \phi_{S2S,2} & V_{S30} > V_{\phi 2} \end{cases} \quad (2)$$

where $\phi_{S2S,1}$, $\phi_{S2S,2}$, $V_{\phi 1}$, and $V_{\phi 2}$ are parameters required to express V_{S30}-dependence.

USGS staff, including Art Frankel, Mark Peterson, Peter Powers, Allison Shumway, and Sanaz Rezaeian, expressed concerns regarding several aspects of the ϕ_{S2S} model as given in Eqs. (1) and (2). One concern was that the total ϕ for CENA at long periods was lower than in the western US, which is caused by empirical ϕ_{S2S} values derived from NGA-East data being lower than those from the western US for comparable magnitudes (Goulet et al. 2017, Figure 5.5). The second concern was that the magnitude-dependence of total ϕ for CENA is too large, which caused total σ at large magnitudes to be too small for short oscillator periods.

We found these concerns to be persuasive and have reconsidered both aspects of the original model. We begin with the second issue, concerning magnitude-dependence. The original ϕ_{S2S} model adopted $\Delta\phi_{S2S}$ values derived from western US data using the NGA-West2 GMMs. Those values were negative at short periods and positive at long periods, with the transition occurring at about 1.0 sec oscillator period. When combined with the magnitude-dependent ϕ_{ss} models in Goulet et al. (2017), the overall magnitude dependence of ϕ is excessive.

To correct for this, we now target the magnitude dependence of the total ϕ model given in Table 5.5 of Goulet et al. (2017). It is important to note here that we do not target the ϕ values in that table, just their magnitude dependence (difference between the values for **M** 5 and **M** 7). To develop these new $\Delta\phi_{S2S}$ values, we computed the change in $\phi_{S2S,1}$ (which are empirically constrained from CENA data) that would be required for large **M** to match the change in ϕ values between **M** 5 and 7. These computations used the **M**-dependent global ϕ_{ss} model given in Table 5.2 of Goulet et al. (2017) (i.e., in that table, the **M**-dependence was taken as by *b* minus *a* for the central branch). We found that the **M**-dependent global ϕ_{ss} model provides levels of **M**-dependence in total ϕ that nearly match the target from Table 5.5 of Goulet et al. (2017). The additional magnitude-dependence of $\Delta\phi_{S2S}$ that would be required for a perfect match range from -0.019 to +0.067. The absolute values for many periods (including PGA and PGV) are below 0.01. Accordingly, our judgment is that the **M**-dependent ϕ_{ss} model is sufficient to capture the **M**-dependence of total ϕ model.

As a result of this simplification, the ϕ_{S2S} model can now be expressed as:

$$\phi_{S2S} = \begin{cases} \phi_{S2S,1} & V_{S30} < V_{\phi 1} \\ \phi_{S2S,1} - \frac{(\phi_{S2S,1} - \phi_{S2S,2})}{V_{\phi 2} - V_{\phi 1}} \left(V_{S30} - V_{\phi 1}\right) & V_{\phi 1} < V_{S30} < V_{\phi 2} \\ \phi_{S2S,2} & V_{S30} > V_{\phi 2} \end{cases} \quad (3)$$

To address the first issue, we have modified the coefficients for $\phi_{S2S,1}$ to match values from western US sites for oscillator periods of 0.3 and greater using data over the full magnitude range from that data set. No changes were made to $\phi_{S2S,2}$, $V_{\phi 1}$, or $V_{\phi 2}$. Figure 1 plots the current values of $\phi_{S2S,1}$ along with the previous values. Values of $\phi_{S2S,2}$ are also shown for completeness.

Figure 2 plots the period-dependence of ϕ for magnitudes of 5 and 7 as given in Table 5.5 of Goulet et al. (2017) and from the present model. For the present model, ϕ_{ss} is taken from Table 5.2 of Goulet et al. (2017) (global model, central branch). The principle change is that the present model has higher ϕ values for short periods ($\leq \sim 1.5$ sec). This increase in ϕ is what was discussed during the March 7 2018 USGS workshop as being needed to account for the impact of site effects. Values of ϕ are smaller at long periods. Coefficients for the revised model are given in a spreadsheet.

Figures 3 and 4 show comparisons of total aleatory σ for magnitudes 5 and 7 as given in the present recommendations, the model provided in Table 5.5 of Goulet et al. (2017), and the 2013 EPRI model. The results labelled as 'present recommendations' in Figures 3 and 4 use **M**-dependent τ from Table 5.5 of Goulet et al. (2017), **M**-dependent ϕ_{ss} from Table 5.2 of Goulet et

al. (2017) (global model, central branch), and take $\phi_{S2S} = \phi_{S2S,1}$ as provided here. The higher standard deviation at short periods is caused by the increase in ϕ_{S2S}. We recognize that there are modest decreases at periods longer than about 0.7-1.5 sec, which are due to differences in ϕ as observed in Figure 2; we consider the values provided here to be more credible.

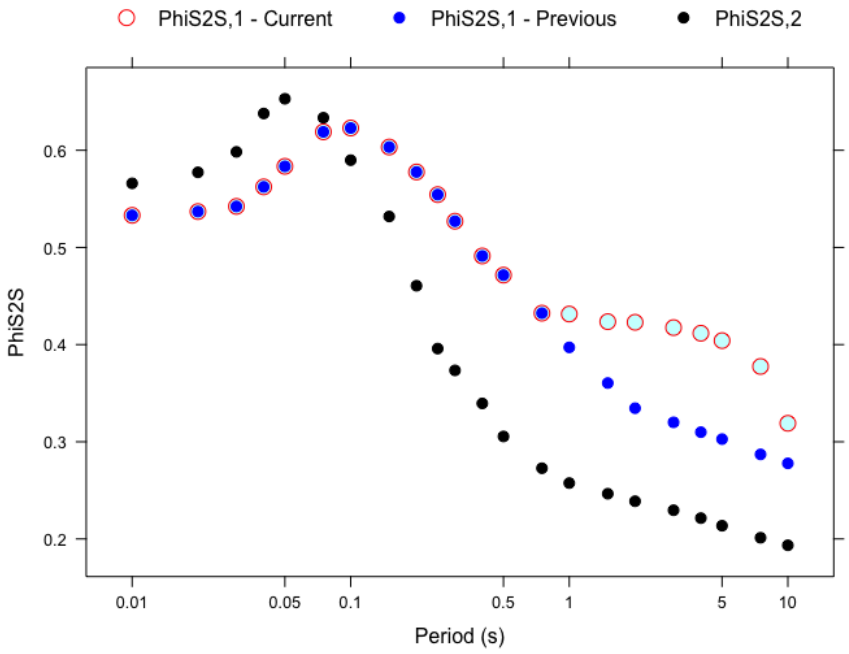

Figure 1. Site-to-site standard deviation values ($\phi_{S2S,1}$ and $\phi_{S2S,2}$) from current and previous models.

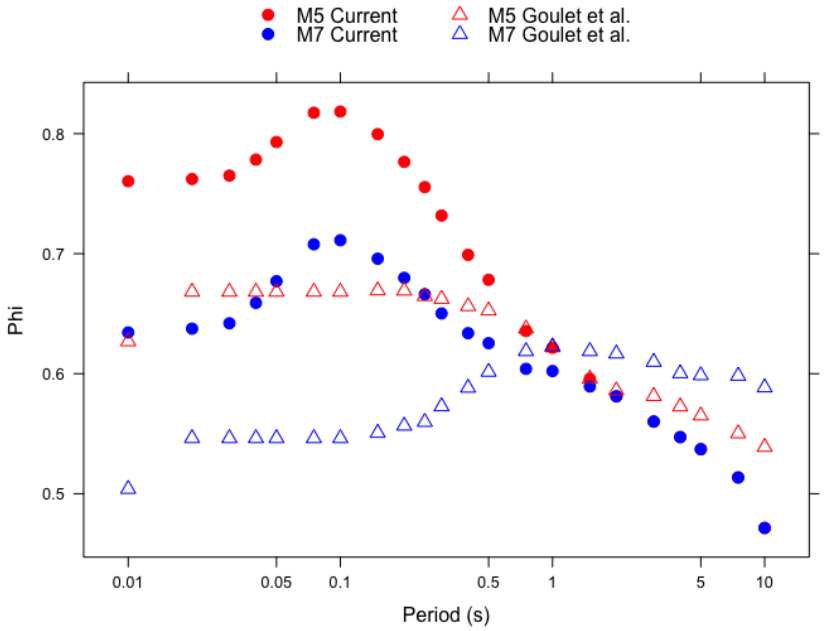

Figure 2. Comparison of total ϕ values for magnitudes of 5 and 7 from Goulet et al. (2017) and present recommendations.

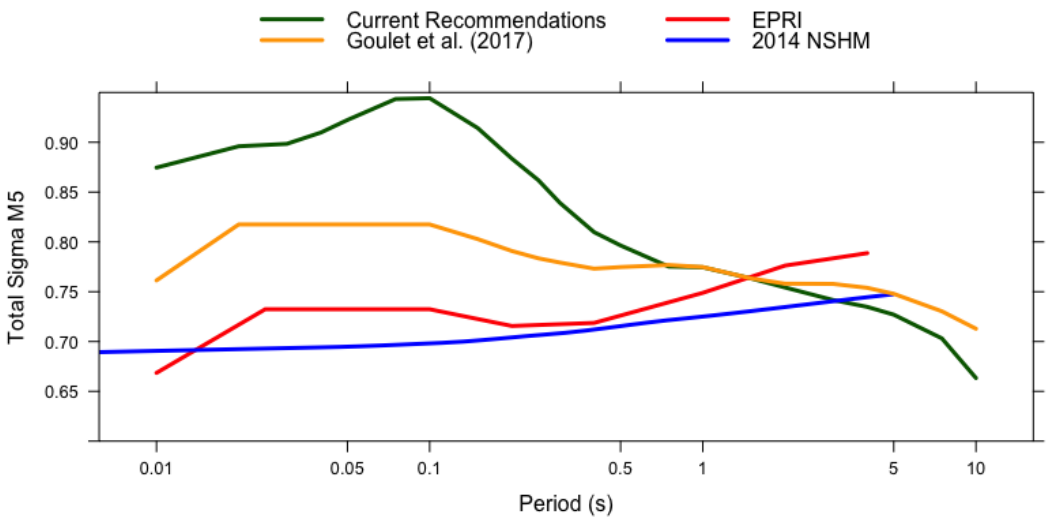

Figure 3. Comparison of σ models as a function of oscillator period from the present recommendations, Goulet et al. (2017), and EPRI (2013) for magnitude 5.

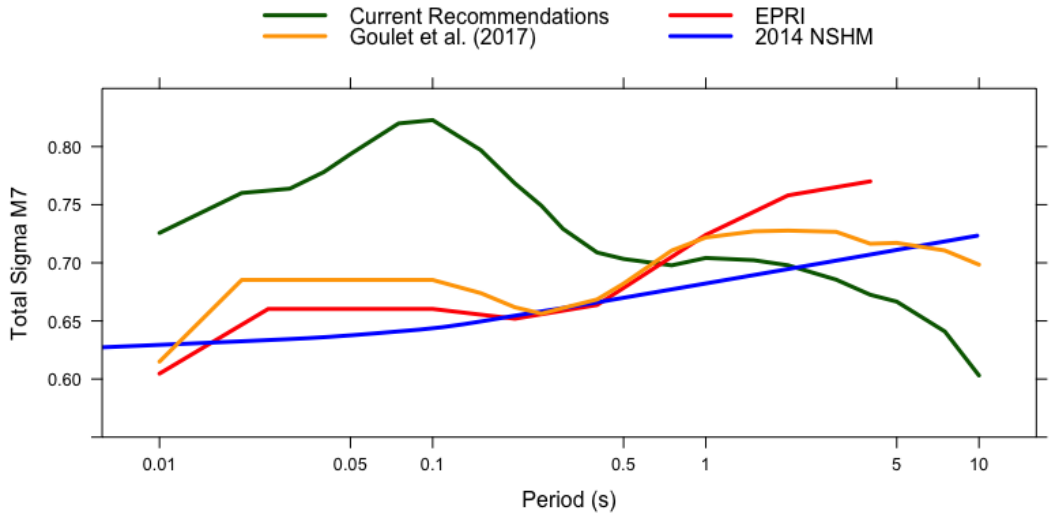

Figure 4. Comparison of σ models as a function of oscillator period from the present recommendations, Goulet et al. (2017), and EPRI (2013) for magnitude 7.