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Discussion to Epistemic Uncertainty in Site Response as Derived from One-Dimensional Ground Response Analyses, Jonathan P. Stewart and Kioumars Afshari, DOI: 10.1061/(ASCE)GT.1943-5606.0002402.

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This paper is highly intriguing and deals with an important issue, the modelling uncertainty of 1D ground response analyses (GRAs). The discusser supports the author's position that the benefits of conducting site-specific GRAs are limited due to the uncertainties involved in the procedure, pertaining to both the physical model used in GRAs and the assumptions/simplifications underlying the analyses. However, the discusser is more pessimistic if we consider the difference between site response uncertainty of GRAs using surface-downhole pairs and the uncertainty of ergodic models using only surface recordings (Fig. 10 of this article).

RESIDUAL ANALYSIS

Following the notation used by Rodriguez-Marek et al. (2011), for collocated surface-borehole recording pairs, the total ground-motion residual between observation and prediction at a surface station s during an earthquake e can be separated into the ground-motion residual at borehole (Δ_{es}^{B}) and surface-to-borehole amplification residual (ΔAmp_{es}):

$$\Delta_{es}^{S} = \Delta_{es}^{B} + \Delta Amp_{es} \tag{1}$$

Δ_{es}^{B} can be further portioned into different independent, zero-mean and log-normally distributed random variables: between-event term δB_e, site-to-site term $\delta S2S_s^{B}$, path-to-path term $\delta P2P_{sl}^{B}$, and the remaining unexplained residual term $\delta W_{0,esl}^{B}$ (Eq. 2). Likewise, ΔAmp_{es} can be separated into $\delta S2S_s^{Amp}$ and δAmp_{es} (Eq. 3):

$$\Delta_{es}^{B} = \delta B_e + \delta S2S_s^{B} + \delta P2P_{sl}^{B} + \delta W_{0,esl}^{B} \tag{2}$$

$$\Delta Amp_{es} = \delta S2S_s^{Amp} + \delta Amp_{es} \tag{3}$$

Submitting Eqs. 2 and 3 into Eq. 1, the following relation can be obtained:

$$\Delta_{es}^{S} = \delta B_e + \delta S2S_s^{B} + \delta P2P_{sl}^{B} + \delta W_{0,esl}^{B} + \delta S2S_s^{Amp} + \delta Amp_{es} \tag{4}$$

If only surface recordings are used to derive site-to-site terms, as is the case for Al Atik (2015) and Rodriguez-Marek et al. (2013), the systematic deviations, $\delta S2S_s^{B}$ and $\delta S2S_s^{Amp}$, will both be inevitably mapped into $\delta S2S_s$, namely

$$\delta S2S_s = \delta S2S_s^{B} + \delta S2S_s^{Amp} \tag{5}$$

All three variables in Eq. 5 are considered to follow normal distributions with standard deviations $\emptyset_{S2S}^{S}$, $\emptyset_{S2S}^{B}$ and $\emptyset_{S2S}^{Amp}$, respectively.

COMPARISON OF SITE RESPONSE UNCERTAINTIES

The authors compared the site response uncertainties from GRAs ($\emptyset_{S2S}^{G}$) and two ergodic models in Fig. 10 of this paper. The site response uncertainties for the two ergodic models (Al Atik, 2015; Rodriguez-Marek et al., 2013) are based on residual analyses of surface recordings only and thus correspond to $\emptyset_{S2S}^{S}$. $\emptyset_{S2S}^{S}$

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reflects the ability of ergodic site-response models in capturing the site terms due to both the shallow strata and the deeper portion, namely $\delta S2S_s$ $(= \delta S2S_s^B + \delta S2S_s^{Amp})$ in Eq. 5.

In contrast, site response uncertainty from GRAs, $\emptyset_{S2S}^G$ in Fig. 10, only represents the performance of GRAs in depicting the relatively shallow site response associated with the soil column between surface and downhole sensor, namely $\delta S2S_s^{Amp}$ in Eq. 5 and thus corresponds to $\emptyset_{S2S}^{Amp}$. Thus, the authors compared the performance of GRAs and ergodic models in modelling different contents, and it is not a fair comparison for the latter. One might argue that $\emptyset_{S2S}^B$is small and its contribution to $\emptyset_{S2S}^S$ is negligible. The ideal scenario to test this is to quantify all the three terms in Eq. 5 using California surface and downhole data. However, such results are not directly available. Hence the discusser collects results for KiK-net surface-downhole arrays to demonstrate the impact of $\emptyset_{S2S}^B$ on $\emptyset_{S2S}^S$, or the difference between $\emptyset_{S2S}^S$ on $\emptyset_{S2S}^{Amp}$.

Rodriguez-Marek et al. (2011) developed ground-motion models (GMMs) for surface and downhole stations, respectively and derived $\emptyset_{S2S}^S$, $\emptyset_{S2S}^B$ and $\emptyset_{S2S}^{Amp}$ (Fig. 1a) by residual analyses. Fig. 1a illustrates the obvious difference between $\emptyset_{S2S}^S$ and $\emptyset_{S2S}^{Amp}$ due to the existence of $\emptyset_{S2S}^B$ which varies between 0.22 and 0.35 in the examined period range. $\emptyset_{S2S}^S$ is higher than $\emptyset_{S2S}^{Amp}$ at relatively short spectral periods ($< \sim 0.7$ s) by as large as 0.1 (ln scales). Due to the negative correlation between the residual terms $\delta S2S_s^B$ and $\delta S2S_s^{Amp}$, the square root of $({\emptyset_{S2S}^B}^2 + {\emptyset_{S2S}^{Amp}}^2)$ is the upper-bound estimate of $\emptyset_{S2S}^S$. Furthermore, it is more straightforward to compare the spatial variabilities of site response without the use of any site proxies (Fig. 1b).

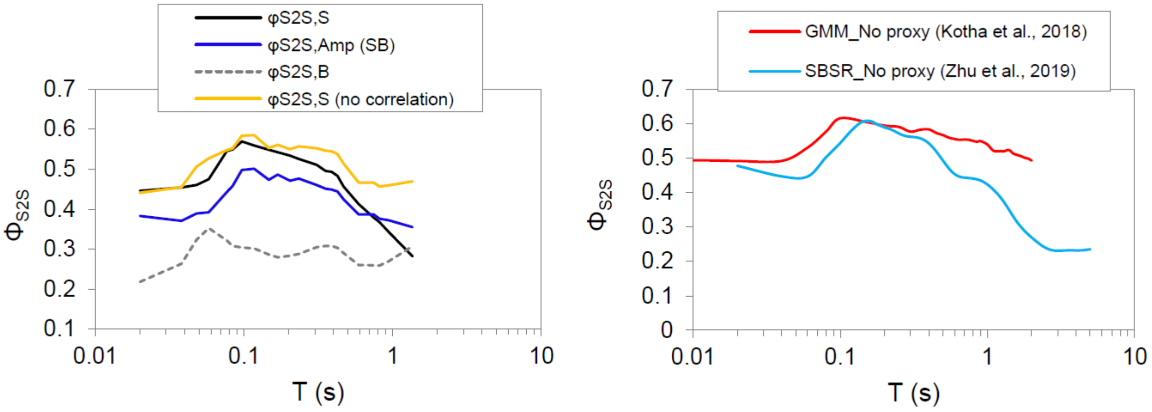

FIG. 1. Spatial variability of site response (in response spectrum domain) at KiK-net surface (S) and borehole (B) stations (in natural-log scales). (a) Site-to-site variabilities ($\emptyset_{S2S}^S$, $\emptyset_{S2S}^B$ and $\emptyset_{S2S}^{Amp}$) of site response after removing the site effects captured by site proxies (V_{S30} and H_{800}) (Rodriguez-Marek et al., 2011). The square root of the sum of ${\emptyset_{S2S}^B}^2$ and ${\emptyset_{S2S}^{Amp}}^2$ is also shown as a reference (assuming no correlation between residual terms $\delta S2S_s^B$ and $\delta S2S_s^{Amp}$). (b) Site-to-site variabilities of site response without the use of any site proxy (Kotha et al., 2018; Zhu et al., 2019).

Kotha et al. (2018) obtained site responses at 588 KiK-net stations within the GMM framework, and their site terms represent the complete site response at each site since no site proxy was included in their GMM.

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Zhu et al. (2019) derived site responses at 207 KiK-net stations using surface-to-borehole spectral ratio (SBSR) approach, and thus their results reflect only partial site response. Fig. 1b displays the standard deviations of median site responses across all sites in the respective datasets. $\emptyset_{S2S}$ for SBSR is smaller than that for GMM at nearly all periods, especially at longer periods. The difference at short period (< ~ 0.15 s) is because ignoring deeper structures tends to result in underestimated site response at not just long periods, but also at short periods, as demonstrated by Zhu et al. (2020) using the Garner Valley Downhole Array, and subsequently a lower standard deviation.

Fig. 10 of this paper actually compares the performance of ergodic site response models in capturing the complete site response with that of GRA in depicting the partial site response. Since the complete site response has a higher degree of variability than the partial site response, it is not a "level playing field". If the contribution of $\emptyset_{S2S}^{B}$ to $\emptyset_{S2S}^{S}$ is considered, the margin of benefit in conducting GRA over ergodic models would be even narrower than as shown in Fig. 10, if not none, in relatively short period range where GRA is expected to work. However, not considering $\emptyset_{S2S}^{B}$ does not undermine the conclusion of this paper on the limited benefits of site-specific GRAs. Finally, it is worth noting that site-to-site variability is highly region-dependent, and thus the amount of difference between $\emptyset_{S2S}^{S}$ and $\emptyset_{S2S}^{Amp}$ as displayed in Fig. 1 cannot be directly applied to sites in California.

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