Improving Our Understanding of 1D Site Response Model Behavior: Physical Insights for Statistical Deviations from 114 KiK-net Sites

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ABSTRACT:

Nonlinear soil behavior often exhibits a strong influence on surficial ground motions, and these effects have been incorporated into site response models in various ways. However, site response models are associated with large uncertainties and can on occasion poorly replicate observed ground motions. In this study, nonlinear site response model predictions for 5626 ground motions at 114 vertical seismometer arrays of Japan's Kiban-Kyoshin network (KiK-net) are calculated using DEEPSOIL and compared to observed ground motions and predictions from linear and equivalent-linear analyses in SHAKE. Using this large database of one-dimensional (1D) site response model predictions, a variety of statistical analyses are performed to quantify the models' bias and precision, and these statistical analyses are paired with physical insights into site and ground-motion behavior.

As expected, there are deviations between the linear, equivalent-linear, and nonlinear site response models at large shear strains, particularly when using cumulative Arias intensity as a basis for comparison. Another less intuitive result is the fact that all models -- linear, equivalent-linear, and nonlinear -- tend to underpredict high-frequency ground motions in the aggregate. A number of physical hypotheses are tested at a subset of sites to help explain this persistent bias: for example, modifying the shear-wave velocity profile to include a depth-dependent gradient, randomizing the shear-wave velocity profile, increasing the small-strain shear modulus, and decreasing the small-strain damping ratio. Some of these alterations (particularly the usage of a depth-dependent shear-wave velocity gradient) have a significant impact on the model bias, even more so than changing the constitutive model for dynamic soil behavior. Using an unprecedented number of sites and ground motions, the results of this study provide some insights for improvements to 1D site response model predictions moving forward.