Quantifying Near–Surface Attenuation via Site–Specific Kappa (κ_0) to Improve High–Frequency Ground Motion Characterization in Central and Eastern United States

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Abstract

Site-specific probabilistic seismic hazard analysis requires the availability of strong ground motions at the site of interest, which are not often available in stable tectonic regions such as Central & Eastern US (CEUS). Due to the scarcity of ground motions in CEUS, nuclear power plants located in the region are designed based on ground motions from seismically active regions such as Western US. Ground motion characterization studies conducted in CEUS show an increased energy content in the high-frequency range, which leads to the observed ground motion response spectrum exceeding the design spectrum at higher frequencies. To properly assess the safety of nuclear power plants to seismic hazards, it is important to characterize high–frequency ground motions in the region. Various methods to simulate ground motions use the site–specific high-frequency spectral decay parameter kappa (κ_0) to characterize the high–frequency energy dissipation in ground motions. The most commonly used method to evaluate κ_0 is the acceleration spectrum method (κ_{0_AS}), which requires the availability of recorded strong ground motions. In this study, we explore an alternative method to compute κ_0 based on the subsurface characterization of the site of interest and the response of soils to a cyclic excitation at a reference depth (known as the transfer function method, κ_{0_TF}). Our findings at four sites from the Japanese database KiK–net, indicate that both methods provide reasonably similar estimations of near-surface attenuation when prescribing the same frequency bands during the calculation of κ_0. Empirical values of κ_{0_TF} (from recorded ground motions in our database), and theoretical estimates of κ_{0_TF} are also compared to assess the appropriateness of simplified approaches to obtain κ_{0_TF} in CEUS. One-dimensional linear-elastic site response analysis are used, while multiple proxies for stiffness and material damping ratio of the soils are explored. Probability density functions (PDFs) of κ_{0_TF} corresponding to the empirical and theoretical approaches agree reasonably well if uncertainty in the damping ratio used in theoretical formulations is accounted for. Finally, we propose a closed–form equation to estimate κ_{0_TF} (for a single layer profile) that does not require conducting site response analysis. The V_s proxies considered for the single layer approximation are V_{s30} and V_{s_mean}. Monte Carlo simulations are then conducted by assuming uncertainty in V_s and damping ratio. The PDFs of κ_{0_TF} estimates from the closed–form equation are found to be in good agreement with the PDFs of empirical and theoretical κ_{0_TF}. Further research is required to determine V_s and damping proxies (and their associated uncertainties) to use the closed–form equation when empirical data are not available. Appropriate probabilistic estimates of κ_{0_TF} in CEUS pave the way to obtain a suite of high–frequency ground motions, which may further be used in the seismic design of nuclear power plants, from improved characterizations of the design spectrum to creating fragility curves for safety–related electrical equipment such as relays.

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