Comparative Study of Time-Domain versus Frequency-Domain Seismic Soil-Structure Interaction Analysis of Pressurized Water Reactor Containment Building

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The equivalent linear approach in frequency domain (ELFD) is the current state of practice for performing seismic soil-structure interaction (SSI) analysis of nuclear facilities. Although ELFD method would produce reliable results for small to medium intensity ground motions, its application to analyze structures under large seismic events is debatable. The latter is due to the fact that the equivalent linear and linear assumptions for modeling the soil and the structure respectively in addition to ignoring the nonlinearities at the soil-structure interface may result in non-physical responses when the soil-structure system components are pushed well beyond their yield. Nonlinear analysis in time domain (NLTD) on the other hand enables the explicit modeling of the soil nonlinear and hysteretic response, structural nonlinearities, damage and failure as well as separation and sliding at the soil-structure interfaces. Although the NLTD approach has been successfully employed in other industries, it has not yet been widely adopted in the nuclear industry.

In this study the seismic response of a typical Pressurized Water Reactor (PWR) nuclear containment building under a seismic event, scaled to various intensities, is analyzed using three different approaches: equivalent linear frequency domain (ELFD), equivalent linear time domain (ELTD), and nonlinear time domain (NLTD). The time domain response history analyses are performed in LS-DYNA using validated techniques developed and accepted for commercial applications. A novel treatment of damping is used for ELTD to achieve nearly frequency-independence and thus allow direct comparison with ELFD. The ELFD analysis is performed in SC-SASSI using the direct method of substructuring. SC-SASSI is an in-house version of SASSI program developed at SC Solutions, incorporating high-performance computing (HPC) capabilities.

It is shown that the obtained seismic responses, presented as in-structure response spectra (ISRS) at different locations within the containment building, are equivalent for both ELTD and ELFD analyses. The significant computational efficiency offered by ELTD approach in comparison to ELFD for large SSI model sizes would make it a viable alternative to ELFD. Soil material and interface nonlinearities are then introduced into the time domain model to perform the third analysis, NLTD. It is shown that the seismic response of the nonlinear system deviates from what is obtained via linear analyses. Linear analyses generally over-predict the response, but the observed differences are dependent on the frequency range of interest, the site soil and structural properties of the SSI system, as well as the characteristics of the ground motion under study. Finally, the NLTD analysis was repeated with nonlinear structural floor slabs to study the effect of concrete cracking on the vertical response of these floors. Linear structural models usually predict very large vertical floor accelerations, even when approximating the effects of cracking via stiffness and damping adjustments of the affected elements. Such vertical demands may be moderated if concrete cracking is considered in the NLTD analysis.