Probabilistic Soil-Structure Interaction (SSI) Analysis Per New ASCE 4 Standard; A Significant Improvement for Seismic Design-Basis Analysis and Fragility Calculations

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Over the last decade, the probabilistic site response and SSI analysis received an increasing attention in the US nuclear engineering practice. Probabilistic analysis is recommended for performing accurate probabilistic site response analyses (PSRA) and probabilistic SSI analyses (PSSIA) in accordance with the in accordance with the new ASCE 4-16 (Sections 2 and 5).

The paper investigates key probabilistic modeling aspects of PSRA and PSSIA. Illustrative case studies of using PSRA and PSSIA for the seismic design-basis analysis and the PRA fragility calculations are presented. The ACS SASSI PRO software uses probabilistic simulation based on the Latin Hypercube Sampling (LHS) per the new ASCE 4 standard recommendations. Probabilistic modelling include random variations due to, i) response spectral shape model for the seismic input, ii) low-strain soil shear wave velocity Vs and hysteretic damping D profiles for each soil layer, iii) soil layer shear modulus G and hysteretic damping D as random functions of soil shear strain, and iv) equivalent-linear or effective stiffness and structural damping for each group of structural elements and materials depending on stress levels in different parts of structure

For design-basis application, we show comparative probabilistic-deterministic studies for two generic RB complexes with different foundation sizes and a deeply embedded SMR, with the intention of confirming the ASCE 4 standard safety goal to achieve a 80% non-exceedance probability (NEP) level for the deterministic SSI analysis. The focus is on the computed ISRS.

For fragility applications, the a probabilistic nonlinear SSI analysis of a low-rise reinforced concrete shearwall building was performed using the combined ACS SASSI Options PRO and NON capabilities. The Cheng-Mertz shear hysteretic model was used to idealize the wall in-plane shear behavior. Both rock and soil sites are considered. For computing fragilities multiple point risk estimations were considered, for seismic hazard annual probabilities of 1e-4, 1e-5 and 1e-6. Probabilistic SSI responses in terms of ISRS, maximum accelerations and relative displacements, structural forces are computed and compared for different. Probabilistic ductility factors and inelastic absorption factors are computed and compared with the ASCE 43-05 recommendations. Probabilistic SSI analyses are performed with and without including the effect of epistemic uncertainties, in order to evaluate the effects of these uncertainties on the structural fragility curves and risk estimates. We also compared the fragility results obtained using the new ASCE 4 recommendations for probabilistic SSI and compare with the current EPRI guidance for "probabilistic" SSI analysis based on 5 deterministic SSI analysis (coming from 9 combinations of the LB, BE, UB soil profile with the LB, BE, UB structural stiffness minus the 4 low probability combinations LB-LB, UB-UB, UB-LB and LB-UB) with 5 spectrum compatible acceleration time-history inputs for each deterministic run case.

Conclusions provide valuable insights on the accuracy limitations of the current deterministic–based SSI approaches and the newer, more refined probabilistic simulation-based SSI approaches.