Fast Nonlinear Seismic SSI Analysis for Low-Rise Concrete Shearwall Buildings for Design-Basis and Beyond Design Applications

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The paper presents a fast nonlinear SSI approach based on a hybrid time-complex frequency approach. The hybrid approach uses an iterative equivalent-linearization procedure for solving the SSI global solution in complex frequency, combined with a nonlinear analysis in time-domain procedure applied to include locally the true hysteretic behavior of degrading structural components. The nonlinear SSI analysis based on the hybrid approach is only 2-3 slower than a linear SSI analysis, but by at least hundreds of times faster and robust than a true nonlinear SSI analysis based on time integration approach using a general purpose FEA code.

To perform the seismic nonlinear SSI analysis the following steps were applied via the ACS SASSI Option NON software: 1) For the initial iteration, perform a linear SSI analysis using the (uncracked) elastic properties; 2) Compute the local hysteretic behavior for each structural wall/pier in time domain; 3) Calibrate the local equivalent-linear hysteretic models in frequency domain for each nonlinear structural wall/pier; 4) Perform a new SSI analysis iteration using a fast reanalysis (restart analysis) in the complex frequency domain using the linearized hysteretic models computed in step 3) for all selected nonlinear wall/piers; 4) Check convergence of the nonlinear SSI response after new SSI iteration, and stop or go back to Step 2 if the convergence was not achieved.

Firstly, a validation study is presented for a low-rise reinforced concrete shearwall structure. Comparative nonlinear fixed-base seismic analysis were carried out using the fast hybrid approach vs. a true nonlinear time-domain integration approach using PERFORM3D. The comparison were made for

i) Design level earthquake of 0.30g for correctly including the concrete cracking in structures as a function of stress levels, in accordance to the new ASCE 4-16 standard (Sections 3.2.2 and 3.3.2) and the most recent USNRC SRP requirements, and

ii) Beyond design level earthquake of 0.60g for correctly including the post-cracking reinforced concrete behavior, in accordance with the ASCE 43-05 recommendations for the inelastic absorption factor values to be used in structural fragility analyses.

The fast nonlinear SSI analyses were performed for both hard rock and soft soil sites. Nonlinear SSI responses are compared in terms of displacements, accelerations, ISRS and structural forces.

For design level, the paper compares the effective stiffness and damping properties in the cracked concrete structure computed using the fast nonlinear SSI analysis and the simplified two-step approach for the concrete cracking as recommended in the new ASCE 4-16 standard in Section 3.

For beyond design level, nonlinear SSI analysis was performed for annual seismic hazard occurrence probabilities of 1.e-4, 1.e5 and 1.e6. Comparisons between the computed inelastic absorption reduction factors, displacements, structural forces and ISRS for different seismic input amplitude levels for both soil and rock sites are included.