

ENGINEERING ADVANCES FOR DETERMINISTIC AND PROBABILISTIC, LINEAR AND NONLINEAR SEISMIC SOIL- STRUCTURE INTERACTION (SSI) ANALYSES

ACS SASSI Technical Newsletter No. 1/ March 2026

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ACS SASSI NQA V4 Software for Seismic SSI Analysis

The ACS SASSI NQA V4 software developed by GP Technologies (GP Technologies, 2025) is a specialized seismic SSI analysis software focused on safety-related facility designs. The ACS SASSI NQA V4 software provides a best-practice engineering analysis tool for performing the seismic SSI analysis of complex embedded, deeply embedded or buried structures. ACS SASSI NQA has been developed in compliance with the up-to-date US and international standards and regulatory requirements for safety-related structures. Based on the ASCE 4-16 and ASCE 43-19 requirements, ACS SASSI NQA V4 offers a perfect engineering balance between numerical sophistication and engineering practice for obtaining affordable and safe seismic designs of nuclear facility structures.

The ACS SASSI software is in a continued rapid development. Current ACS SASSI V4 includes a unique set of seismic SSI analysis capabilities, not existing in any other specialized SSI codes. Such capabilities include extending the standard SASSI Flexible Volume substructuring approach to nonlinear soil and structure behavior, fluid-structure-soil interaction (FSSI), and probabilistic seismic risk assessment (SRA) and SSI analysis, including refined models for inclined seismic wave propagation, or incoherent seismic wavefield simulation via advanced Monte-Carlo stochastic field algorithms (Ghiocel, 2004, 2022b).

Recent versions of ACS SASSI are also equipped with linearized fluid type elements, either of Lagrange type or Eulerian type, nonlinear spring elements to model 2D-space nonlinear hysteretic lead rubber bearing (LRB) or friction pendulum (FP) isolators, and Maxwell-chain model element (with combined springs and dashpots) for 3D-space frequency-dependent viscous-dampers including the GERB BCS devices (GERB, 2026). More recently, ACS SASSI included automatic section-cut and building back-bone curve generation capabilities for reinforced concrete (RC) and steel-plate composite concrete (SC) walls for nonlinear structural modeling, and a powerful ACS SASSI-Ansys® software integration capability that permits use of the Ansys Mechanical software (ANSYS, 2025) modeling capabilities.

ACS SASSI NQA includes uniquely efficient and accurate algorithms for seismic SSI or FSSI analysis of deeply embedded SMR structures, including the extremely fast SSI solution using the FVROM-INT approach (described hereafter) for both coherent and incoherent input motions. For deeply embedded

structures subjected to incoherent waves, ACS SASSI can include the variation of coherence function with depth per the NRC SRP 3.7.2 requirements for the SMR applications (Ghiocel and Todorovski, 2024, 2025). ACS SASSI can be also used for computing site-specific coherence functions using 2V-2D stochastic field models for shear wave and damping soil profile modeling (Ghiocel et al., 2017)

The many added specialized SSI capabilities make ACS SASSI the most complete practical engineering computational tool for seismic SSI analysis of safety-related structures. ACS SASSI NQA V4 is currently applied to a series of small modular reactor (SMR) projects, including deeply embedded based-isolated SMR structure designs (Ghiocel et al., 2025) or water-floating SMR designs (Sato et al., 2025a).

The coming 2026 ACS SASSI versions will include seismic hazard analysis capabilities to compute site-specific Design Response Spectra (DRS) per the ASCE 43-19 and NUREG/CR 6827 requirements, based on integrating probabilistic seismic hazard analysis (PSHA) and probabilistic site response analysis (PSRA) calculations. Later this year, a new fast GPU-CPU hybrid solver will be available in ACS SASSI, which will significantly speed-up complex dense matrix operations for SSI analysis of deeply embedded structures.

ACS SASSI NQA V4 Modular Configuration Toolboxes

The ACS SASSI software is specifically designed for practical solutions based on engineering best-practices in compliance with the ASCE 4-16 and ASCE 43-19 recommendations and current USNRC requirements. In addition to the main software, the ACS SASSI NQA V4 software includes several optional advanced SSI analysis options as illustrated in Figure 1.

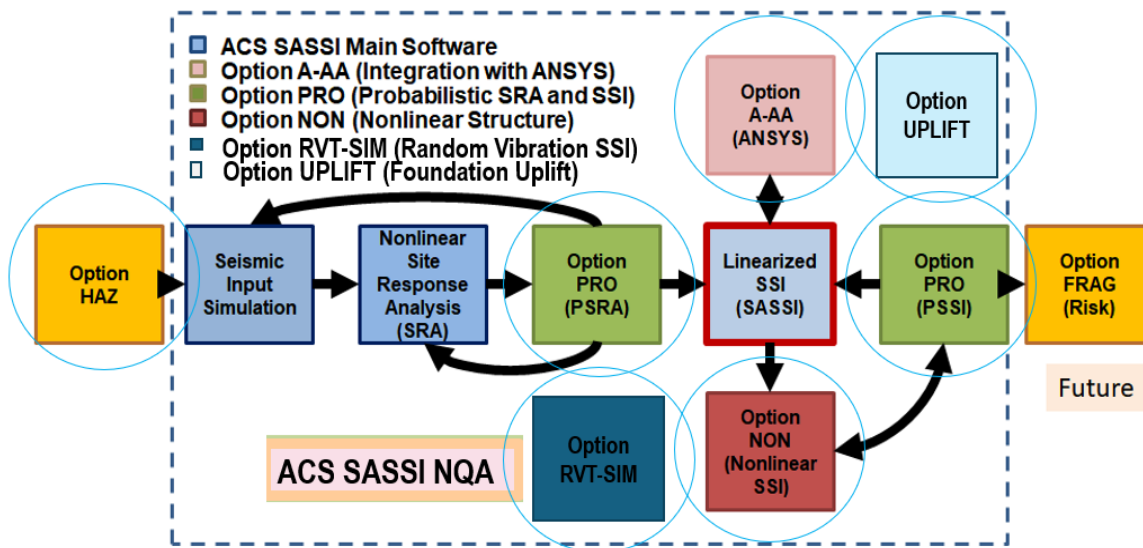


Figure 1. ACS SASSI NQA V4 Software Toolboxes Including Advanced Options

These advanced options include Option A-AA (ACS SASSI integration with the Ansys Mechanical software), Option PRO (probabilistic site response and SSI per ASCE 4-16 Sections 2 and 5), Option NON (nonlinear concrete shearwall structure analysis per ASCE 4-16/ACI 318-19, CSAN289.3-20 and JEAC 4601-15/JEAC 4618-09, and nonlinear FP or LRB isolators per ASCE 4-16), Option UPLIFT (including base

uplift per JEAC 4601), *Option HAZ* (seismic hazard calculations for computing DRS per ASCE 43-19), and *Option RVT-SIM* (SSI analysis based on random vibration theory combined with stochastic simulation).

Fast Domain Reduction in Complex Frequency for Non-Classical Damping Dynamic SSI Systems

The standard SASSI substructuring is well-suited to handle the dynamic behavior of systems with non-classical or non-traditional damping, such as soil-structure interaction (SSI) systems, equipment-structure interaction (ESI) systems, fluid-structure interaction (FSI) systems, or some base-isolated (BI) systems. All these systems are *dynamically coupled systems with non-classical damping*, since the energy dissipation in parts of the systems, such as structure and soil, or equipment and structure, or fluid and structure, or base-isolators and superstructure, is significantly different. Numerical examples indicated that significant errors could affect SSI responses by neglecting non-classical damping effects (Der Kiureghian, 1981). Der Kiureghian's generalization of the complex frequency formulation is based on using complex mode decomposition for non-classical damping systems. The complex values for the mode shape coordinates lead to different phase angles for free vibration motions at system degrees of freedom. The coupling phase effects, included in imaginary parts of complex responses, are of essence for an accurate seismic solution for non-classical damping SSI systems.

The standard SASSI Flexible Volume (FV) substructuring (Lysmer et al., 1981) uses an ingenious substructuring approach which made the frequency-dependent soil impedance calculations fast and trivial. Specifically, in the standard SASSI FV substructuring, only the free-field soil impedances and the free-field motions are required for computing the seismic soil forces for embedded foundations. The soil impedance computation is extremely efficiently solved by employing "theoretically exact" axisymmetric consistent non-reflective boundaries. Basically, the SASSI FV substructuring, instead of performing the SSI analysis for the structure coupled with the surrounding unbounded soil deposit, the SSI analysis is performed for the structure coupled only with the excavated soil (internal soil, removed by embedment excavation). Using the FV substructuring formulation, the original wave propagation problem or *external source or wave propagation SSI* problem with the seismic force excitation defined at the far distant external boundaries of the SSI system, including at the bottom bedrock, is reduced to a much smaller *internal source SSI* problem with the force excitation defined inside the excavated soil system.

Figure 2 compares the Domain Reduction Method (DRM) used in practice in the time domain via direct integration in the complex frequency domain via SASSI FV substructuring. More recently, in ACS SASSI, in addition to the FV substructuring, a new additional domain reduction algorithm was implemented specifically for deeply embedded structures (Ghiocel, 2022). Basically, the excavated soil stiffness, including the free-field soil impedance and the soil stiffness loss due to excavation cavity, is further condensed, so that no excavated soil elements are left in the SSI model (circled model in Figure 2). This added domain reduction algorithm in complex frequency is called Flexible Volume Reduced-Order

Modeling (FVROM). Also, the overall SSI solution parallelization is perfectly scalable with respect to each frequency separate solution.

Figure 2 right-side text highlights the numerical efficiency of the FVROM approach which provides a fast SSI solution in frequency with an extremely quick SSI reanalysis capability. This fast SSI reanalysis capability is applicable when structure design is modified, or if nonlinear structure SSI analysis is performed using iterative linearized SSI analyses, importantly, in compliance with the ASCE 4-16 standard Section C3.3.2 and USNRC regulatory requirements (Ghiocel, 2022a, Ghiocel et al., 2022a, 2022b).

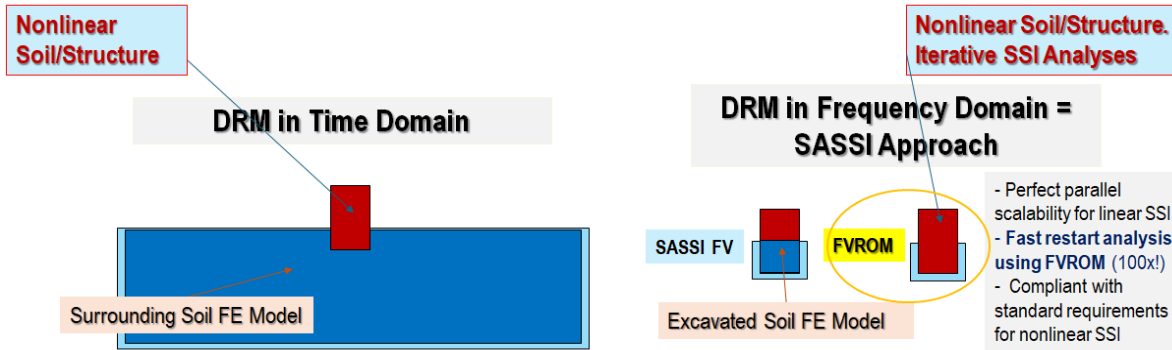


Figure 2. Comparative Soil Domain Reduction Methods in Time and Frequency Domains

Furthermore, since the soil impedance variation in frequency is much smoother than the SSI response variation, the excavated soil impedance condensation can be only executed for a small frequency set of “key or condensation frequencies”, and, then, be interpolated for the entire dense SSI frequency set without any loss in accuracy, as illustrated in Figure 3. The SSI solution accuracy can be easily checked by the user. The reduction of the SSI frequency set produces a significant reduction in runtime of SSI analysis. This extremely fast domain reduction algorithm including impedance interpolation is called Flexible Volume Reduced-Order Modeling with soil impedance INTERpolation (FVROM-INT) approach.

The FVROM or FVROM-INT approaches are extremely efficient for design reanalyses, including sensitivity studies, probabilistic structural analyses, or nonlinear iterative SSI analysis, by reducing the SSI solution runtime by up to hundreds of times in comparison of standard SASSI analysis.

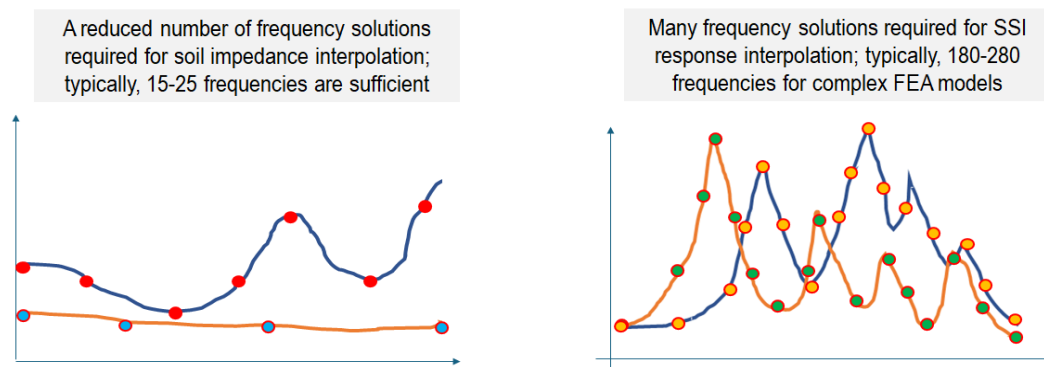


Figure 3. Frequency Interpolation for Smooth Soil Impedance (left) vs. Unsmooth SSI Responses (right)

The FVROM and FVROM-INT algorithms have been successfully applied to several deeply embedded SMR projects in US and Japan. During these projects, it was shown that FVROM-INT can reduce the seismic SSI solution runtime between 30 to 100 times depending on the soil layering nonuniformity, i.e. uniform variations vs. abrupt variations with depth, which largely affects the soil impedance variation smoothness in frequency space (Ghiocel et. al, 2024, Hashemi et al., 2024).

Deeply embedded structure projects for SSI models, as shown in Figure 4 for a SMR SSSI model (Hashemi et al., 2024) and Figure 5 (Ghiocel et al., 2024) for a large-diameter tank FSSI model on piles, benefited using the FVROM-INT approach by largely compressing schedules and reducing analysis costs.

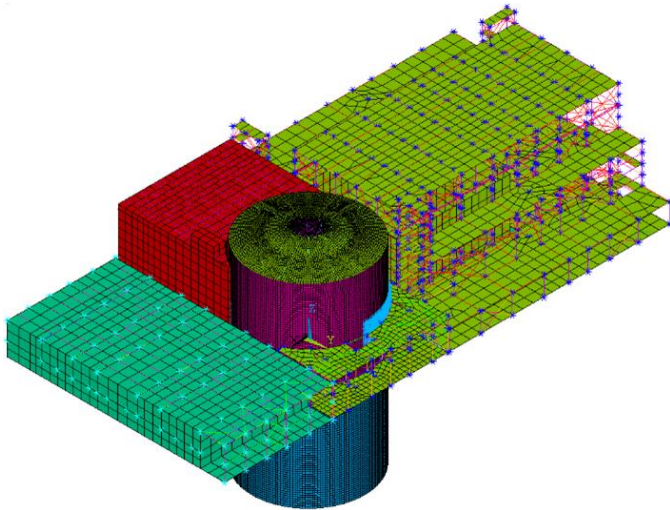


Figure 4. Deeply Embedded SMR SSSI Model

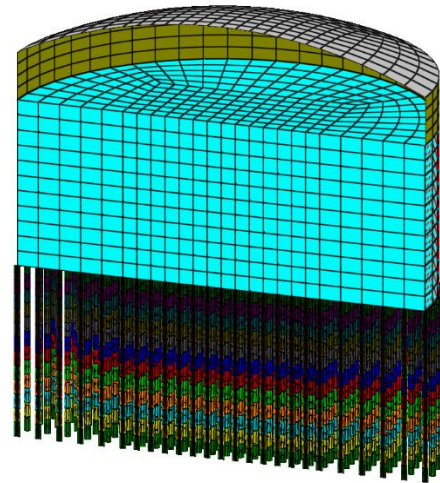


Figure 5. Large-Diameter Tank FSSI Model on Piles

Iterative Hybrid Approach for Modeling of Nonlinear Behavior of Structure and Surrounding Soil, Hysteretic Base-Isolators, and Wall-Soil Interfaces

ACS SASSI includes a highly efficient nonlinear structure SSI hybrid approach based on performing a fast iterative equivalent-linear SSI analysis in complex frequency domain coupled iteratively with a nonlinear hysteretic quasistatic time domain analysis.

From a pure mathematical modeling point of view, the nonlinear direct-integration approach in time domain appears superior to the iterative equivalent-linear hybrid approach in the time-frequency domains. However, the time-integration approach has serious modeling difficulties for accurately modeling of non-classical damping SSI systems for which the damping matrix is a full dense matrix. Using the variable Rayleigh damping might not provide an accurate SSI solution due to inherent filtering of the low and high frequency structural vibration modes. Also, numerical damping effects for time-domain integration approaches are quite challenging for analysts. From a practical design point of view, the nonlinear time-domain integration approaches appear less attractive since they result in significantly costlier analysis. The practical advantages of using iterative linearized SSI analyses are large, since they

are much faster and more robust resulting in both much cheaper and safer analyses. In addition, iterative linearized SSI analyses provide large benefits by making design sensitivity investigations, including design reanalyses, extremely efficient, simple to check and requiring only very limited computed resources.

The ACS SASSI iterative hybrid approach offers practical design solutions based on engineering best-practices in accordance with ASCE 4-16 and ASCE 43-19 recommendations and USNRC requirements.

The iterative hybrid approach includes two coupled analysis steps at each iteration:

Step 1: Perform an *equivalent-linear SSI analysis* in complex frequency via the SASSI approach to compute the structural boundary displacements for each nonlinear component

Step 2: Perform a *nonlinear time-domain quasistatic hysteretic analysis* for each nonlinear component loaded at its boundaries with the SSI displacements from Step 1, to compute the nonlinear hysteretic responses based on component back-bone curves (BBC) and user-selected hysteretic model types from the available software library (including eight types).

Without any doubt, a nonlinear SSI analysis combining the FVROM-INT approach with the iterative hybrid frequency-time approach is at least hundreds of times faster than a nonlinear time-domain direct integration SSI analysis. In addition, rapid access for reviewing the SSI system frequency domain transfer functions for the linearized SSI responses provides important information for engineering insights, so that analysts can understand in-depth the structure dynamic behavior, and eventually improve the final designs.

The above iterative hybrid SSI approach was successfully applied to capture nonlinear structure behavior (Ghiocel et al., 2022a, 2022b, Nitta et al., 2022, Sato et al., 2025b, Tsukada et al., 2025), but also the soil nonlinear hysteretic behavior in the vicinity of piles (Ghiocel and Bulut, 2022, Ghiocel et al., 2024), or capture the slipping effects for the SMR embedded wall-soil interfaces (Ghiocel, 2022, 2025) or base-isolated SMR superstructure sliding for the FP bearings (Ghiocel et al., 2025).

More details on the iterative hybrid approach applications are provided hereafter in Option NON section.

Brief Description of Advanced SSI Modeling Options

1) ACS SASSI-Ansys® Software Interfacing (Option A-AA)

The ACS SASSI-Ansys software interfacing capability or Option A-AA provides an advanced two-step seismic SSI approach capable of using detailed Ansys Mechanical software (ANSYS, 2025) finite element (FE) models for stress analysis, eventually including the local nonlinear material behavior and/or localized nonlinear geometric aspects within the structure or at the foundation-soil interface. The Option A-AA capability is efficiently handled by the ACS SASSI User Interface (UI). There are two ACS SASSI-Ansys software interfacing options, *Option A* or *Option Ansys*, and *Option AA* or *Option Advanced Ansys*.

Option A for Ansys Mechanical software (ANSYS, 2025) interfacing includes an automatic export of the Step 1 seismic SSI response as input boundary conditions for performing a Step 2 detailed nonlinear or linear SSI stress analysis in the Ansys Mechanical software using either quasi-static or dynamic refined models. Additionally, this functionality can be used to compute soil pressure on foundation walls and basemat, including soil separation effects.

The Option AA for the advanced Ansys Mechanical software (ANSYS, 2025) interfacing capability directly runs SSI analysis using Ansys Mechanical software FE models. The Option AA Ansys Mechanical software models can include advanced Ansys Mechanical software element types, such as pipes, fluid elements, layered shells, MPC elements, or modeling options as coupled nodes, constraint equations, or even super-element (MATRIX50).

Option AA directly uses the Ansys Mechanical software FE model structural stiffness (K), mass (M), and damping (C) matrices with no need for model conversion to ACS SASSI.

In addition to these Option AA capability, three additional AA-based SSI analysis options are available:

- 1) The *Option AA-SE* uses Ansys Mechanical software super-elements (MATRIX50) for SSI solution
- 2) The *Option AA-R* uses the Ansys Mechanical software model and solver for performing harmonic FSSI analysis for embedded models, including FLUID30 elements with the soil impedance exported from ACS SASSI. Alternatively, ACS SASSI model with ACOUSTIC elements can be used.
- 3) *Option AA-F* uses the ACS SASSI model and solver for the FSSI solution incorporating the Ansys Mechanical software FLUID80 element matrices using SASSI methodology. Alternatively, ACS SASSI model with FLUID elements can be used.

2) Probabilistic Modeling (Option PRO)

Option PRO for probabilistic site response analysis (PSRA) and probabilistic SSI analysis (PSSIA) using efficient Latin Hypercube Sampling (LHS) simulations. Probabilistic SSI modeling is illustrated in Figure 6 (Ghiocel, 2017). Option PRO is consistent with probabilistic site response and SSI analysis procedures described in the ASCE 4-16 and ASCE 43-19 standards and USNRC requirements for site-specific applications, including RG1.208 and NUREG/CR 6827 for the PSHA-PSRA integrated calculations.

The *low-strain soil profiles* for the shear wave velocity (V_s) and the hysteretic damping (D) are modeled as random soil profiles or mathematically by one-dimensional 1D-2V or 2D-2V stochastic fields with a given spatial correlation structure that is usually variable with depth, based on soil column field data. In addition, the *soil layer thicknesses* and *soil material curves*, the normalized shear modulus (G), and damping (D) curves, are modeled as functions of soil shear strain with smooth randomized variation curves for each soil layer, also varying with depth. A simplified Toro model for V_s profile is also included.

The effective/equivalent linear structural component (walls, floors) *stiffness (K)* and *damping (D)* random variations in the concrete structures or for base-isolators are modeled as two correlated random

variables which depend on the wall strain levels. Different parts of a reinforced concrete structure might have quite different stiffness and damping values depending on the local deformation levels.

The *seismic input* ground motion response spectrum shape can be considered either with a constant or a stochastically variable shape as shown in Figure 7 (ASCE 4-16 Section C5.5, Methods 1 and 2).

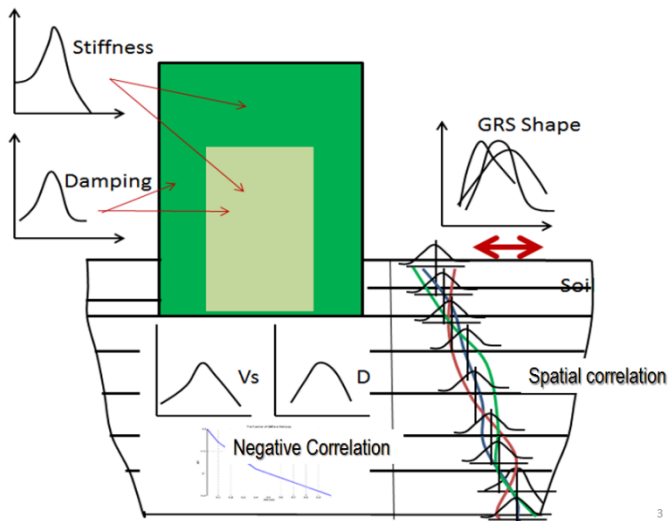


Figure 6. Probabilistic SSI Models

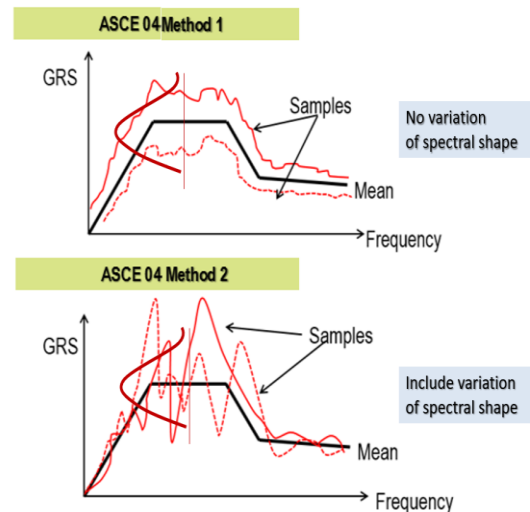


Figure 7. Probabilistic Seismic GRS Inputs

Option PRO should be combined with Option NON to “automatically” capture the reinforced concrete wall cracking and post-cracking behavior for severe earthquakes. The combination of Options PRO and NON analysis provides an accurate SSI analysis solution for capturing the probabilistic nonlinear structure behavior, which is different for each simulated randomized sample of seismic motion input and soil profile. Option PRO can also simulate uncertain variations in the structure wall capacities. The combination of Option PRO and Option NON is especially recommended for probabilistic seismic analyses for both design level (DBE) and beyond-design level (BDBE). For the BDBE seismic analyses, the nonlinear structure behavior becomes much more significant, and, therefore, combining Option PRO with Option NON becomes vital for obtaining meaningful fragility analysis results.

ACS SASSI Option PRO is also applicable to seismic SSI analysis of base-isolated structures per ASCE 4-16 Section 12 and ASCE 7-22 recommendations for evaluating 80th and 90th percentile responses for the DBE and BDBE levels.

Option PRO should be combined with Option HAZ for performing probabilistic SAF simulations and computing soil UHRs and seismic DRS per the ASCE 43-19 Section 2 and NUREG/CR 6827 requirements.

3) Nonlinear Structural Analysis (Option NON)

ACS SASSI Option NON delivers efficient and accurate calculations for nonlinear structural behavior for application including RC and SC walls, hysteretic base-isolation systems, and soil interface slipping. The ACS SASSI Option NON nonlinear SSI methodology is based on the highly efficient iterative hybrid

approach described earlier herein, which couples the equivalent-linear complex frequency SSI analysis with a fast nonlinear time-domain hysteretic analysis using structure reduced-order modelling, as visually illustrated in Figure 8. The structure reduced-order modelling uses macro-mechanics models for idealization of the RC or SC wall behavior (Ghiocel et al., 2022a, 2022b, Sato et al., 2025b). The iterative SSI approach which was implemented in ACS SASSI Option NON is fast converging in only few iterations.

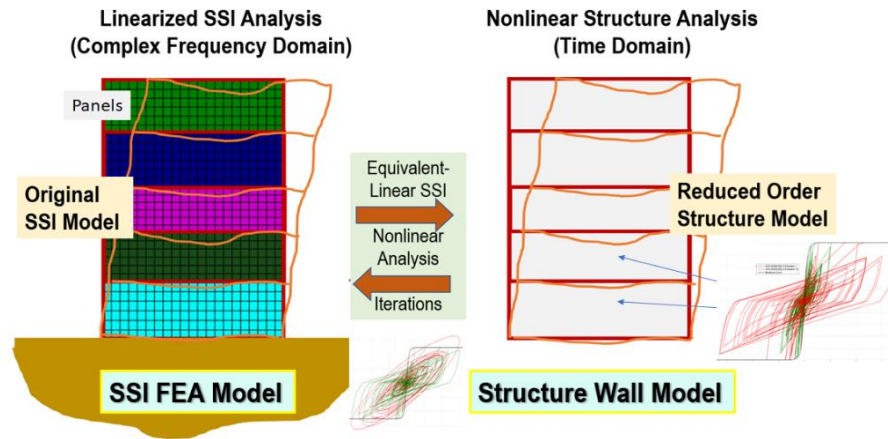


Figure 8. ACS SASSI NON Iterative Hybrid Frequency-Time Approach

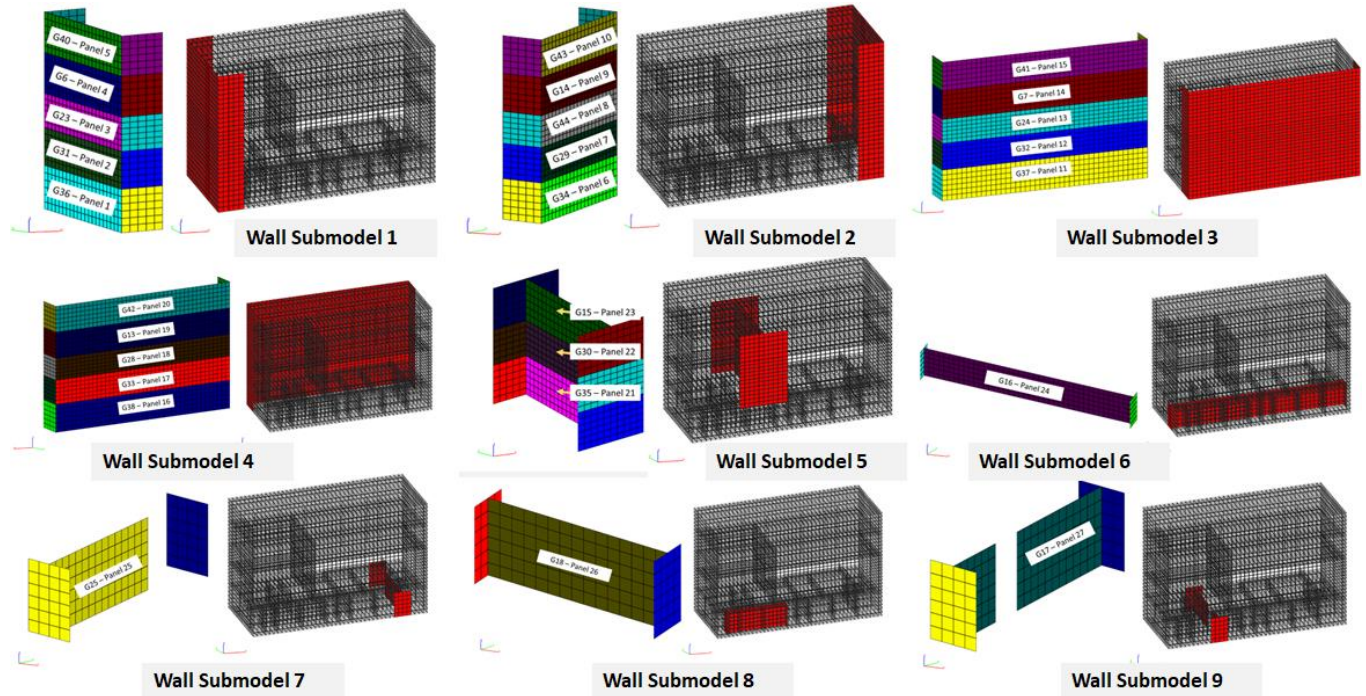


Figure 9. Splitting RC Shearwall Structure Model in Nonlinear Wall Submodels and Panels (per Floor)

Figure 9 shows the split of RC shearwall structure 3DFEM into nonlinear wall submodels consisting of one panel per floor level (wall partitions modeled by macro-mechanics models). This split of the structure

model in a series nonlinear wall submodels is made highly efficient for users by using the ACS SASSI UI specialized commands for partitioning of the structure model in a number of nonlinear submodels.

The nonlinear structure SSI approach implementation for RC and SC walls, conceptually follows the Japanese standard structural modelling and seismic engineering practice. Specifically, the implementation is compliant with the nonlinear structure modelling for reinforced concrete (RC) and steel-composite (SC) structure requirements in the Japanese JEAC 4601-2015/4618-09 and AIJ RC 2018 standard, but also in the US and ASCE 4-16 and ACI 318-19/ACI 349-13/AISC N690-18 standards.

The RC or SC walls nonlinear modelling includes two constitutive components as shown in Figure 10:

1. Back-bone curves (BBC) for in-plane shear and in-plane bending deformation for each RC wall at each floor level per standard equations or available experimental tests (left plot, red line)
2. Hysteretic models (HM) for in-plane shear and in-plane bending cyclic deformation effects for each RC/SC wall panel at each floor level (left plots, blue loops).

Figure 11 shows the maximum point-oriented hysteretic models for shear and bending deformation required per JEAC 4601-15.

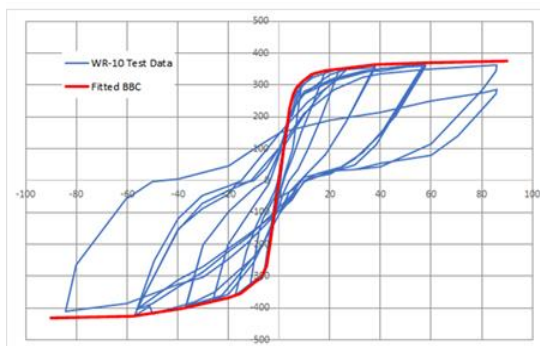


Figure 10. Experimental Hysteretic Response

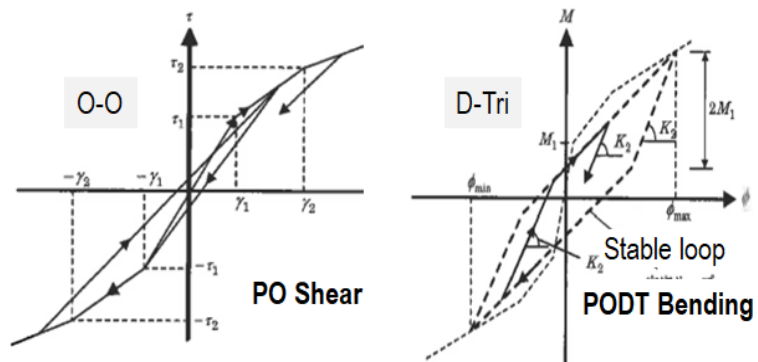


Figure 11. Max. Point-Oriented Models Per JEAC 4601-15

The BBC are determined for both hysteretic shear and bending in-plane deformation in the wall planes, either per standard recommendations including capacity equations, or per available experimental tests, as illustrated in Figure 12.

The ACS SASSI NON software hysteretic model library contains eight types of models:

1. Cheng-Mertz Shear or Bending (2)
2. Takeda
3. General Masing Rule
4. JEAC 4601 Maximum Point-Oriented Shear or Bending (2)
5. Hybrid Shear or Bending (2)

Figure 13 shows the linear and nonlinear ISRS computed for a BDBE input using ACS SASSI NON.

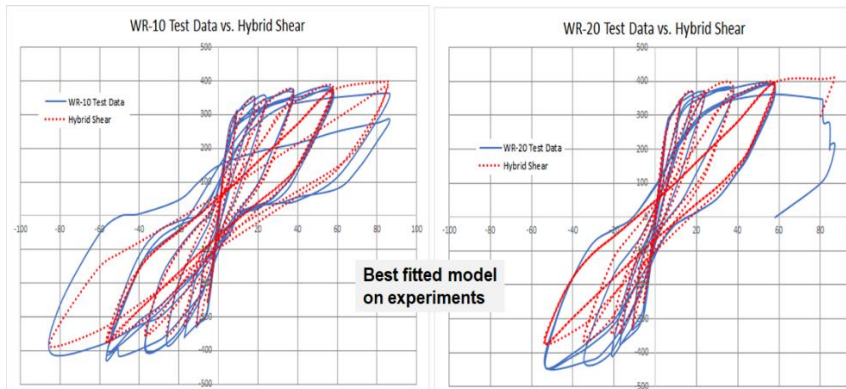


Figure 12. Best-Fitted Hybrid Models from Hysteretic Model Library

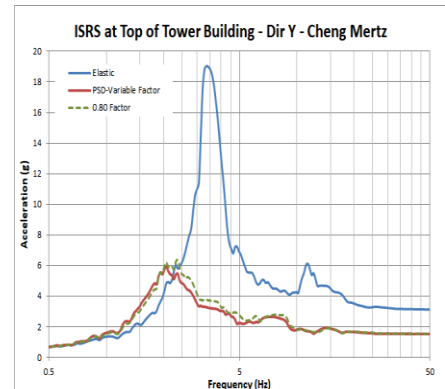


Figure 13. Linear vs. Nonlinear ISRS

Independent verification and validation studies against experimental testing (NUPEC data) and rigorous nonlinear time-domain analysis (based on IAEA KARISMA project) indicated that the iterative SSI equivalent-linearization procedure implemented in the ACS SASSI Option NON provides reasonable accuracy and very high numerical efficiency (Ichihara et al., 2022, Nitta et al., 2022a, Tsukada et al., 2025).

Option NON is applicable for DBE or DBE SSI analysis and can be used to model the hysteretic behavior of the seismic 2D-space base-isolators, such as LRB or FP isolators. Figures 14 and 15 show the application of ACS SASSI NON to a seismically base-isolated embedded SMR structure with Friction Pendulum (FP) isolators modelled by nonlinear shear springs at the upper baseslab level (Ghiocel et al., 2025).

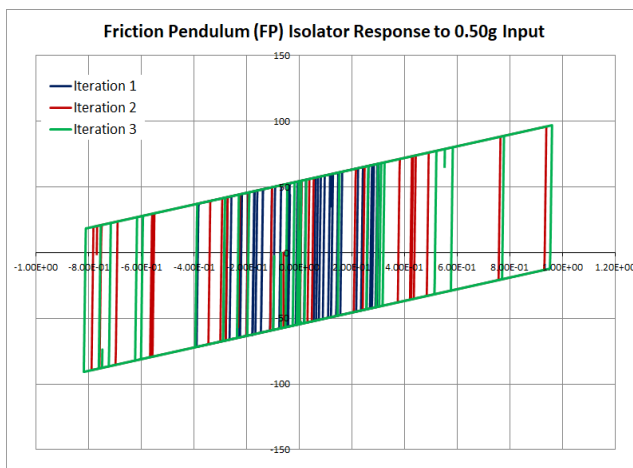


Figure 14. Iterative FP Isolator SSI Displacements

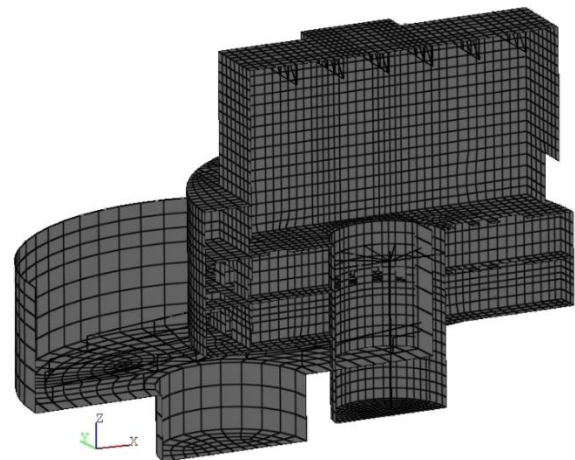


Figure 15. Embedded Base-Isolated SMR Sliding

4) Uplift Analysis Based on JEAC 4601-2015 Standard (Option UPLIFT)

Option UPLIFT is based on the Japanese JEAC 4601-2015 standard recommendations. It uses two nonlinear uplift approaches based on the severity of the foundation uplift:

- 1) A simplified nonlinear uplift approach based on a nonlinear static uplift analysis, applicable if the base surface contact ratio is in the 65%-75% range, and

2) A refined nonlinear uplift approach based on a nonlinear time-domain dynamic uplift analysis, applicable if the surface contact ratio is in the 50%-65% range.

For the contact ratios above 75%, the linear SSI analysis results are considered reasonably accurate. The JEAC 4601-2015 foundation uplift approaches were implemented in the ACS SASSI Option UPLIFT software by combining the equivalent-linearization of the overall structure SSI analysis in complex frequency domain with the nonlinear base uplift analysis in time-domain occurring at the foundation-soil interface per the JEAC 4601-2015 standard requirements.

Figures 16 and 17 show SSI analysis of a surface RB complex which uplifts, especially on transverse direction. When uplift occurs, the overall SSI system behaves more flexible and lower damped for the global rocking SSI mode motions (Nitta, 2022b).

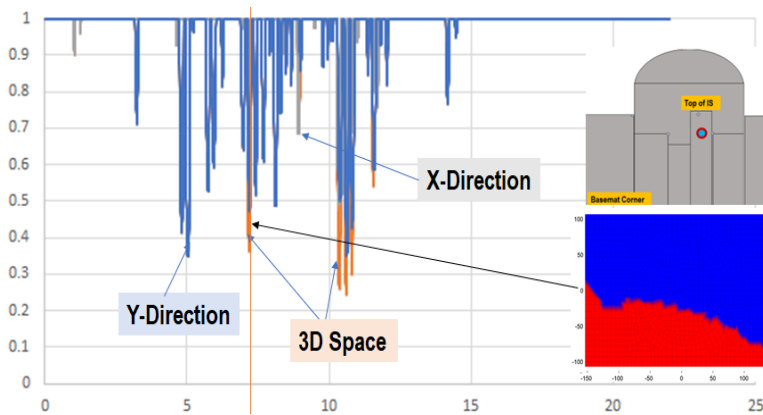


Figure 16. Basemat Contact Surface Ratio During Earthquake

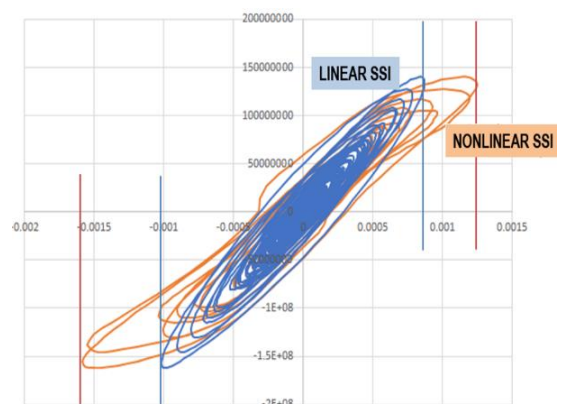


Figure 17. Basemat Moment-Rotation

5) Random Vibration Theory with Stochastic Simulation (Option RVT-SIM)

The RVT-SIM approach combines the Random Vibration Theory (RVT) in complex frequency domain with the stochastic simulation (SIM) in time domain to efficiently compute the maximum SSI responses. The RVT-SIM approach input is the ground response spectra (GRS). No input time histories are required in this approach. The RVT-SIM approach (Ghiocel and Grigoriu, 2013) uses the input GRS to compute the ground power spectral density (GPSD), then uses the stochastic simulation to compute the maximum SSI responses based on the in-structure response power spectral density (RPSD). The RVT-SIM flowchart is shown in Figure 18.

The RVT-SIM approach implements three analytical formulations to compute the mean maximum SSI responses: *MK-UK Approach* (Unruh and Kana, 1981), *AD Approach* (Davenport, 1964) and *AD-DK Approach* (Der Kiureghian, 1981). Comparative ISRS results using RVT-SIM are shown in Figure 19.

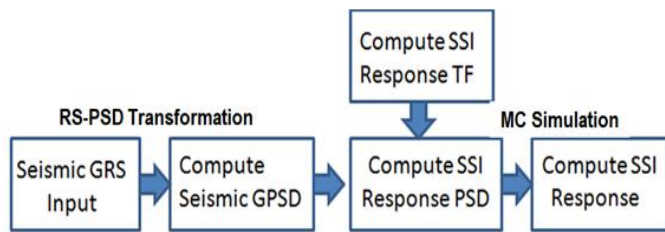


Figure 18. RVT-SIM Implementation Flowchart

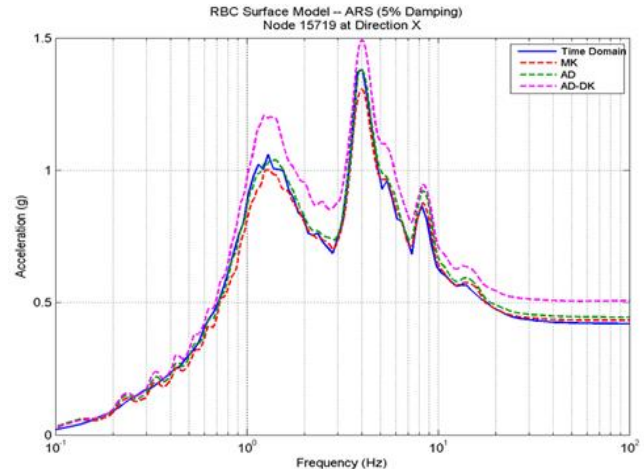


Figure 19. RVT-SIM ISRS vs. Time-Domain ISRS

6) Soil Seismic Hazard Analysis (Option HAZ)

ACS SASSI Option HAZ applies the ASCE 43-19 Chapter C2 methodology for developing site-specific seismic Design Response Spectra (DRS) by combining site-specific Probabilistic Seismic Hazard Analysis (PSHA) results with the Probabilistic Site Response Analysis (PSRA) results. Per NUREG/CR 6827, the DRS is determined based on the computed seismic soil hazard curves (HC) and the soil uniform hazard response spectra (UHRS) for different values of the mean annual probability of exceedances (MAPE), say from 10^{-2} to 10^{-6} , computed based on probabilistic seismic soil layering responses performed for disaggregated controlling earthquakes (DCE), as functions of magnitude M and fault distance R.

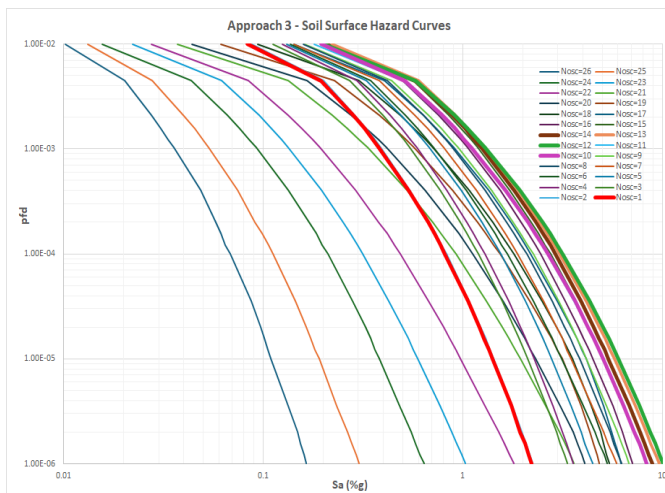


Figure 20. Surface Soil Hazard Curves (HC)

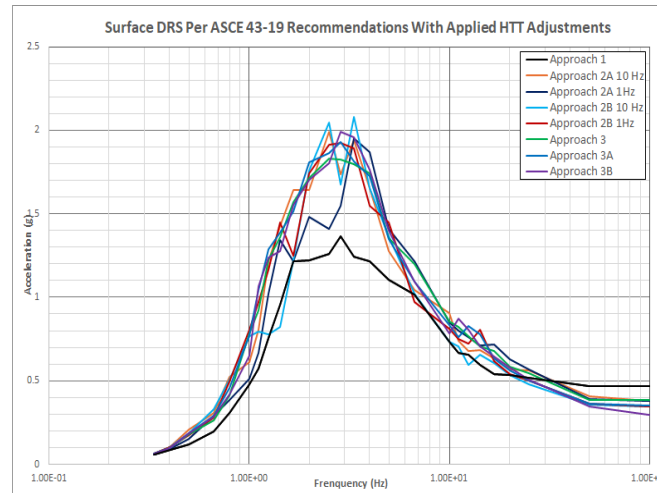


Figure 21. DRS Per ASCE 43-19 Approaches

The soil HC and UHRS can be computed at the soil ground surface and/or at any specified depth in the soil column below ground surface. Per ASCE 43-19 Chapter C.2 guidance, DRS is determined based on the computed UHRS for two levels of MAPE, H_D (seismic hazard exceedance probability, usually 10^{-4}) and

H_p (structure performance goal probability, usually 10^{-5}). Option HAZ implements all Approaches 1, 2A, 2B, 3A and 3B from ASCE 43-19 Section C.2, plus the more rigorous Approach 3 (including all bins for M and R), considered as the reference approach.

Figure 20 shows the soil HC computed for 26 frequencies from 0.33 Hz to 100 Hz for a selected site in a high seismic area. The computed surface DRS using the ASCE 43-19 Chapter C2 approaches, Approaches 1, 2A, 2B, 3A, 3B, and, also Approach 3 as reference approach are plotted in Figure 21.

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