ACS SASSI NQA V4 Advances for Seismic SSI Analysis Based on the Newest US Engineering Practice Recommendations and Trends

Date: March 26, 2019

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ABSTRACT

The ACS SASSI software is a software in a continuous fast development. ACS SASSI V4 includes a totally new set SSI analysis capabilities that extends the “standard” linearized SASSI methodology for including soil and structure nonlinear hysteretic behavior, and the random variation aspects for site response and soil structure interaction (SSI) analysis. The advanced seismic SSI capabilities make ACS SASSI to be the most complete SSI analysis tool for the nuclear or safety-related structure projects.

The 1-day ACS SASSI workshop lecture will present key state-of-the-art advanced SSI analysis capabilities for seismic structural design and probabilistic safety evaluation of the NPP structures. These advanced capabilities address more recent US practice recommendations as reflected in the recent ASCE 4-16 standard, and the new trends as included in the soon-coming ASCE 43-19 and ASCE 4-21 standards. A special attention has been given to the new specific US practice recommendations for the deeply embedded structures (DES) applicable to the new designs of the advanced small modular reactors (SMR). The presentation reviews both the new computational capabilities and new features of the ACS SASSI NQA V4 main software modules, including new user interface features, improvements of the optional capabilities, such as A-AA, NON and PRO, and a brief description of the new option 2DSOIL.

The ACS SASSI workshop presentation agenda is as follows:

1. New Release ACS SASSI NQA V4 Main Software Capabilities and Features
2. Trends in the US Practice for Evaluating Seismic SSI Effects for New SMR Designs
3. Seismic Motion Incoherency Modeling and Effects on Structural SSI Responses
4. Implementation of SSI Analysis Considering Nonlinear Structure (Option NON)
5. Implementation of SSI Analysis Considering Probabilistic Site and SSI Responses (Option PRO)
6. Implementation of Interface between ANSYS and ACS SASSI (Option A/AA)
7. Implementation of SSI Analysis Considering 2D Soil Layering Models

1. New Release ACS SASSI NQA V4 Main Software Capabilities and Features

The new ACS SASSI NQA V4 (IKTR0) software will be available in April 2019. The computational speed of the SSI analysis is about 2-3 times faster than the latest ACS SASSI NQA V3 (IKTR10) software. Depending on the SSI problem size and the MS Windows workstation available resources, the SSI analysis runtime speed of the new 2019 version can go up to 5 times faster than the current 2018 version.

The 650k node limit of the ACS SASSI V3 IKTR10_650k is relaxed in the new version. The SSI model size can be unlimited, basically, being limited by the computer memory resources.

The new software license could be run by remote access through internal networks for *single* workstation or *multiple* workstations depending on the license type. Details and examples will be provided.

New features include a new finite element type in HOUSE module, and additional fast-post processing options for MOTION, RELDISP and STRESS modules.

The ACS SASSI V4 adds a specialized base-isolation type element. The new element is called HVD (high viscosity damper) and is required to model the frequency-dependent BCS (Base Control System) isolators. As indicated by some recent large-scale experimental tests and publications, the BCS isolators (developed by German GERB company) apparently could ensure a 3D base-isolation efficiency for large RB complex buildings in both horizontal and vertical directions. It should be noted that the current ACS SASSI Option NON capability is limited to modeling of the hysteretic base-isolators, such LRB (Lead Rubber Bearing) or FP (Friction Pendulum) isolators, which act efficiently only in the horizontal directions.

New improvements on the fast post-processing using compressed binary databases for MOTION, RELDISP and STRESS modules will be described in detail.

2. Trends in US Practice for Evaluating Seismic SSI Effects for New SMR Designs

The current trends as reflected in the newly revised or soon-coming ASCE nuclear seismic standards and in USNRC requirements for SMRs. The presentation will discuss key SSI modeling aspects, including the excavated mesh sizing, the adjacent soil hysteretic behavior, seismic wave composition incorporating obliquely propagating components for both uniform and nonuniform layered soil deposits are investigated through a series of examples. The wave traveling effects produced by the higher-order Rayleigh waves in the highly nonuniform soil deposits on SMRs are also discussed. The seismic SSI effects due to inclined soil layers vs. horizontal soil layers are summarized based on three SMR case studies. The V/H ratio approach versus 1D P-wave propagation approach is clarified. Effects of the motion incoherency on the soil seismic pressures and the in-structure response spectra (ISRS) in SMRs are exemplified. Finally, the effects of soft backfill vibration, the ground water effects and the foundation-soil separation are shown.

Other critical SSI modeling aspects which are not included in the mentioned case studies, but need engineering attention, will be also discussed.

3. Seismic Motion Incoherency Modeling and Effects on Structural SSI Responses

The key theoretical aspects and the implementation aspects related to the motion incoherency modeling and simulation and performing incoherent SSI analysis are described. Several comparative coherent-incoherent ACS SASSI SSI and SSSI case studies will be presented. Different SSI responses, such as soil pressures, ISRS, structural forces are discussed.

A practical simulation procedure for simulating “site specific” coherence functions vs. “generic” (Abrahamson) coherence function will be discussed.

4. Implementation of SSI Analysis Considering Nonlinear Structure (Option NON)

The key theoretical aspects and the implementation aspects related to Option NON will be discussed in detail. The presentation will provide details on the nonlinear modeling of the low-rise concrete structures, including the evaluation of the shear wall capacities and the automatic development of the back-bone curves for concrete (partition or panel) walls.

Per recent US practice requirements, for the site-specific licensing applications, the structure concrete cracking has to be considered based on the computed seismic strain levels in different parts of the structure. Using Option NON, the concrete cracking can be considered efficiently and accurately based on the local stress levels, in accordance with the US practice requirements per the ASCE 4-16 standard for the low-rise shearwall buildings. Option NON is also useful for performing accurate beyond-design level probabilistic SSI analyses for seismic fragility calculations that are based on a set of randomly simulated seismic input motions with different spectral amplitudes. Both design-level and beyond design-level example will be presented. Option NON can be used for both deterministic or probabilistic nonlinear SSI analysis as shown by few examples. Further, Option NON can be used for modeling seismically base-isolated buildings and heavy equipment, or for modeling the foundation-soil friction interface. For foundation-soil separation effects that produce gaps between foundation and soil, Option NON needs to be coupled with Option A as shown by an example.

5. Implementation of SSI Analysis Considering Probabilistic Site and SSI Responses (Option PRO)

The key theoretical aspects and the implementation aspects related to Option PRO will be discussed in detail. Option PRO for Probabilistic Analysis is required for performing accurate probabilistic site response analyses (PSRA) and probabilistic SSI analyses (PSSIA) for the design-basis analysis in accordance with the recent ASCE 4-16 and soon-coming ASCE 43-19 standards, and the US NRC NUREG/CR 6728 and RG 1.208 requirements for computing the seismic inputs for SSI analysis. The ASCE 4-16 standard addresses both the probabilistic site response analysis (PSRA) and the probabilistic SSI analyses (PSSIA) in Sections 2 and 5.5, respectively. Probabilistic modelling should include at least the 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, iv) Equivalent stiffness and damping for concrete structural elements depending on the strain levels in different parts of the structure; Option PRO could be coupled with Option NON for automatic computations.

The presentation will illustrate the application of the new ASCE 4-16 standard recommendations for probabilistic SSI analysis *applicable to the design-basis level (DBE) applications*. Few case studies including a surface and a deeply embedded SMR-type structure are presented. Probabilistic and deterministic SSI analyses were comparatively performed for a surface and a deeply embedded SMR SSI model. The comparative SSI results include in-structure response spectra (ISRS) at different locations. The presentation will also illustrate the application of the new ASCE 4-16 standard recommendations for probabilistic SSI analysis *applicable to the beyond design-basis level (BDBE) applications*. Probabilistic SSI analyses for the beyond design-basis (BDBE) applications are typically performed for seismic input review levels that are much larger than the design-basis (DBE) seismic input, often by 2-3 times. For such much larger BDBE seismic inputs, the role of the nonlinear soil and structure behaviors become very important SSI modelling aspects for obtaining meaningful seismic margin results. Option PRO should be coupled with Option NON for the BDBE applications. Structural and equipment fragility results are compared for several assumptions for selecting the review levels: i) 3 review hazard levels for annual probabilities of 1.e-4, 1.e-5 and 1.e-6, b) 7 review hazard levels for annual probabilities of 3.e-4, 1.e-4, 3.e-5, 1.e-5, 3.e-6, 1.e-6 and 5.e-7, iii) 1 review hazard level for annual probability of 1.e-4, and iv) 1 review hazard level for annual probability of 1.e-5.

6. Implementation of Interface between ANSYS and ACS SASSI (Option A/AA)

The key theoretical and practical aspects related to the ANSYS interfacing options, Options A and AA will be presented. Option AA or Advanced ANSYS allow the analyst to perform SSI analysis using directly ANSYS structural FE models, with no need to convert these ANSYS structural FE models. The Option AA capability accepts ANSYS FE models that can also include curved pipe elements, fluid elements and even super-elements. Thus, Option AA provides much more refined FE modeling than using the ACS SASSI FE models.

Option A or ANSYS is very important analysis capability to include the SSI effects for stress analyses using refined ANSYS models, via an extremely efficient and accurate two-step SSI approach. The SSI effects in structure affects both the infrastructure deformation and the seismic forces in the structure. In the past, the infrastructure deformation effects were often neglected. The neglect of infrastructure deformation due to SSI effects is no longer acceptable in US and international practice for new reactor nuclear applications. For soft soil sites, the SSI effects produce foundation deformation that could highly amplify the bending moments and the structural forces in the slabs and adjacent walls. Using the ACS SASSI Option A for the detailed ANSYS SSI stress analysis can be efficiently and accurately performed, including both the effects of the foundation deformation and the dynamic seismic forces in the structure.

The Option AA implementation is detailed, and few of its application will be shown. The Option AA applications will show the use of i) ANSYS FLUID80 fluid elements for a deeply embedded pool structure under coherent and incoherent motions, and, ii) ANSYS MATRIX50 super-elements for a SSI analysis of a concrete shell structure. As explained in the presentation, the ANSYS MATRIX50 super-element can be used via Option AA, but also converted into a set ACS SASSI General Matrix elements.

The presentation will show a number of examples of the use of Options A and AA. An important example will be related to the computations of seismic soil pressures on the deeply embedded foundation walls, including the effects of adjacent soil hysteretic behavior and foundation-soil separation effects.

7. Implementation of SSI Analysis Considering 2D Soil Layering Models

Option 2DSOIL is a new SSI advanced capability that will be released by this Spring 2019. The presentation will describe this new advance capability. Few application examples will be shown.