Department of Energy
Washington, DC 20585

August 21, 2015

The Honorable Joyce L. Connery
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue NW, Suite 700
Washington, DC 20004

Dear Madam Chair:

On April 8, 2011, the Defense Nuclear Facilities Safety Board Chairman sent the Department of Energy (DOE) Deputy Secretary a letter discussing technical and software quality assurance concerns with the computer program, System for Analysis of Soil-Structure Interaction (SASSI). SASSI is widely used within DOE, and across the nuclear industry, to analyze the effect of seismic ground motions on structures, and its outputs can play a key role in the seismic design of facilities. The Deputy Secretary replied on July 29, 2011, listing a number of actions the Department would take to address the concerns. The cornerstone action was to complete a set of validation and verification (V&V) problems for SASSI that would confirm that SASSI meets its intended functions, and it does not perform any unintended functions, for the types of design situations faced by DOE projects.

DOE initiated the SASSI V&V project in 2011. To complete the test problems, we commissioned experts highly experienced in applying SASSI at DOE and other nuclear facilities. We established a panel of three peer reviewers and a project technical integrator, all with international reputations in soil-structure interaction analysis, to provide rigorous peer review and to ensure the development of the required range of test problems and input parameters necessary to demonstrate the accuracy of the SSI solution. Three technical meetings of project participants and other stakeholders were held to review progress and receive feedback. Your staff actively participated in all of these meetings, and they also provided helpful, timely reviews of test problems as they evolved.

I am pleased to report that the SASSI V&V problem set is now complete. The problems are documented in twelve engineering calculations on the enclosed DVD. Draft copies of these calculations were provided to your staff earlier this year. Distribution of the calculations and associated files to the broader technical community is through a dedicated website accessible from the DOE Chief of Nuclear Safety website at this address:

http://www.energy.gov/em/system-analysis-soil-structure-interaction-sassi-verification-validation-vv-problem-set.

I have also notified all Office of Environmental Management site offices responsible for nuclear facilities of the project completion. My memorandum, a copy of which is enclosed, summarizes the SASSI V&V project, provides high-level guidance for using SASSI at DOE facilities, and reiterates software quality assurance requirements. I also provided this information to the Chief of Defense Nuclear Safety for communication to the relevant National Nuclear Security Administration site offices. With the completion of the SASSI V&V project and my communication to the DOE site offices, DOE has addressed all of the concerns outlined in the April 8, 2011 letter.

If you have any questions about this information or the SASSI V&V project, please contact me at (202) 586-0799.

Sincerely,

Richard H. Lagdon, Jr.
Chief of Nuclear Safety
Office of the Under Secretary for Management
and Performance

Enclosure(s)

cc:
David Klaus, S-3
Monica Regalbuto, EM-1
Mark Whitney, EM-1
Joseph Olencz, AU-1.1
Mark Do, AU-1.1
Debra Rosano, AU-33
James McConnell, NA-50
Don Nichols, NA-51
James Hutton, EM-40
Robert Murray, EM-43
Stephen McDuffie, CNS
Debra Sparkman, CNS
Brent Gutierrez, SRS

Department of Energy
Washington, DC 20585

August 20, 2015

MEMORANDUM FOR DISTRIBUTION

FROM: RICHARD H. LAGDON, JR.
CHIEF OF NUCLEAR SAFETY
OFFICE OF ENVIRONMENTAL MANAGEMENT

SUBJECT: Guidance on the use of the System for Analysis of Soil-Structure Interaction (SASSI)

SASSI is a computer code for performing finite element analyses of soil structure interaction (SSI) during seismic ground motions. It is widely used across the U.S. Department of Energy (DOE) complex and the commercial nuclear industry. SASSI was originally developed in 1981 by the University of California, Berkeley (UCB) (Reference 1, 2). In 2010, analysts discovered that under certain conditions, especially when using SASSI's subtraction method (SM), SASSI can produce spurious results (Reference 3). The Defense Nuclear Facilities Safety Board (DNFSB) expressed concerns with DOE's use of SASSI in an April 8, 2011 letter (Reference 4), and in a July 29, 2011 response (Reference 5), DOE agreed to take certain actions to address the concerns. These actions included developing test problems for SASSI verification and validation (V&V), as well as providing additional SASSI user guidance over both the short and long term. The short term guidance was an SSI report focused on the SM, provided to Office of Environmental Management (EM) sites on August 4, 2011 (Reference 6). DOE initiated the SASSI V&V project in late 2011, which commissioned several renowned SSI experts to develop and peer review the V&V test problems. The project completed earlier in 2015. The V&V test problems are available through the EM Chief of Nuclear Safety website at http://www.energy.gov/em/system-analysis-soil-structure-interaction-sassi-verification-validation-vv-problem-set. This memorandum completes the guidance to SASSI users in the DOE complex.

In the years following SASSI's development, and continuing today, UCB modified the SASSI code to add new features, such as the SM, and correct defects. Over the past thirty-plus years, through procurements and other acquisition methods, the UCB SASSI source code has been distributed through professional agreements and purchase orders to individuals and companies across the United States. Once they obtained the source code, individuals and companies have been able to customize the UCB SASSI computer program to fit their specific needs. The SASSI code consists of a set of modules that interact with each other to provide the solution to the SSI problem. Most customization has retained the original UCB module structure. While some individuals and companies have changed the UCB SASSI name to reflect the new software product, some have simply left the software name as SASSI. Most in the SSI community still refer to all variations as "SASSI." This can cause confusion as to what specific variation is being referenced.

The guidance below applies to all variations of SASSI. The guidance is divided into sections focusing on: 1) structuring SSI problems for SASSI and use of the SM, and 2) software quality assurance (SQA) requirements that apply when using SASSI.

Soil Structure Interaction Methodology

Since SASSI has become the *de facto* industry application used in the analysis of most SSI problems, having and maintaining confidence in the accuracy and applicability of its solution algorithms is essential. The many variations of SASSI differ primarily in modeling size capability and execution speed, but are based on the same flexible volume concept in the original formulation developed at UCB. The user community must be aware of the required run parameters (e.g., finite element meshing requirements, solution parameters) and the need to validate computed results for each problem investigated to ensure that the results are valid and appropriate for use in designing a particular facility.

As described in the correspondence from W. S. Tseng (Reference 7), SASSI uses a method of substructure deletion known as the flexible volume method, also called the "direct method," in which every node within and on the volume of the excavated soil volume is treated as an "interaction node" coupling the free-field soil system and the excavated soil volume. In the late 1990s the SM was developed (Reference 8), a simplified method of sub-structuring in which only the nodes lying on the outer perimeter boundary of the excavated soil volume are treated as interaction nodes. Since only the boundary nodes of the excavated soil volume are interaction nodes, the number of interaction nodes for the SM is substantially reduced compared to the direct method, thereby significantly reducing computation times. The reduction becomes very significant as the soil excavation volume becomes larger and the number of finite elements in the SASSI model increases.

The direct method requires every node in the excavated soil volume to be an interaction node. Therefore, under free-field ground motion excitations, the excavated soil volume moves compatibly with the free-field soil system, and with the local deformation from the structural loading at every interaction node within and on the boundary of the excavated soil volume. As a result, the direct method could achieve a reasonable simulation, for engineering purposes, to the coupled soil-structure system, even though finite element formulations are used as approximations to the actual flexibility of the excavated zone. As with other finite element methods to analyze wave propagation problems, a finer mesh and layering leads to a better approximation of the wave problem. The computed behavior in any particular problem degrades with a decrease in mesh refinement in a relatively uniform manner, but not in an unstable manner, as identified in some SASSI SM solutions.

Since the SM requires only the nodes on the outer perimeter of the excavated soil volume to be interaction nodes, the compatibility of dynamic motions between the free-field soil and excavated soil volume is enforced only at the perimeter where the structural basement nodes and interaction nodes are in common. Thus, total motion compatibility is imposed only at these perimeter nodes. As a result, the interior nodes of the excavated soil volume can move differently from the interior nodes of the free-field soil subsystem. Due to this motion incompatibility among the interior nodes, the dynamic properties of the excavated free-field soil subsystem, resulting from the substructure deletion using the SM, can deviate from those of the true free-field soil subsystem with an open excavation pit. For a number of SSI problems, References 3, 9, and 10 document anomalies in the results generated by the SASSI SM, when compared to the direct method, as interpreted by experienced practitioners. The reported anomalies are caused by spurious resonances associated with the interior region of the excavated soil volume, as discussed in further detail in Appendices A, B, and C of Reference 11. The SM was not addressed as part of the SASSI V&V project, so the use of the SM has not been sanctioned by the SASSI V&V project peer review team. SASSI users are cautioned against use of the SM.

In 2010, in response to the SM anomalies noted above, a modification to the subtraction method, known as the modified subtraction method, or extended modified subtraction method (herein combined as EMSM), introduced additional interaction nodes to the finite element mesh. Results using the EMSM have been shown to converge with the direct method solution over a larger frequency range than those of the subtraction method (for example, Reference 12). The EMSM adds interaction nodes to the excavated soil volume, often at the ground surface elevation. As the EMSM increases the number of interaction nodes over that of the SM, more constraints are imposed on the motion compatibility between the free-field soil subsystem without the excavation pit and the excavated soil volume. As a result, EMSM solutions converge toward direct method solutions.

After reviewing all information available concerning the SASSI SM and EMSM, the SASSI V&V project peer review team drew the following conclusions (Reference 11):

- Within the analytical framework of the SASSI analysis methodology, the SASSI direct method is the analytically more rigorous and preferred approach to performing SSI analyses.
- Within the analytical framework of the SASSI analysis methodology, the SASSI SM, and EMSM are relaxed, approximations to the SASSI direct method. The SASSI EMSM is a less relaxed and, thus, less approximate method than the SM.
- If the SASSI direct method is incapable of analyzing a particular SSI problem due to limitations on the size of the problem and/or computer run times for the problem, then the SASSI EMSM approach may be used as the preferred choice (with SASSI SM as a second choice). Use of the SASSI EMSM (or SASSI SM) is considered acceptable only if careful benchmarking of the SASSI EMSM (or SASSI SM) solution with the direct method solution covering the parameter value ranges important to the problem is successfully performed for essentially the particular problem to be analyzed. This benchmarking can be performed on a simpler model that contains the essential features and parameter value ranges of the SSI problem to be analyzed. This benchmarking shall be subject to peer review at early stages in the project execution. Reference 9 provides an evaluation of a number of cases implementing the SM or EMSM approach from which recommendations for benchmarking the SM or EMSM results are given. Also, Reference 13 provides guidance on benchmarking SM and EMSM models with the direct method models for site-specific applications when necessary.

SQA Requirements Associated with DOE Nuclear Facilities

DOE has established quality assurance (QA) requirements and guidance through Federal regulation and DOE directives that also require the use of national or international consensus standards to implement the QA requirements. DOE's QA requirements are defined in the 10 Code of Federal Regulations (CFR) Part 830 Subpart A, Quality Assurance Requirements and DOE Order 414.1D, Quality Assurance (aka the QA Order). Contractors and subcontractors doing work associated with a DOE facility must meet DOE QA requirements as specified in any and all contractual agreements and regulations. In most instances the SQA requirements are associated with 10 CFR 830 Subpart A and DOE O 414.1D.

The first step in determining what SQA requirements must be met is to determine the applicability of nuclear safety software definitions to the use of the SASSI software. When the expected use of the SASSI software meets one of the definitions of nuclear safety software, most likely "safety and hazard analysis software and design software," nuclear safety SQA requirements including the ten SQA "work activities" in Attachment 4 of O 414.1D (or later release) must be reviewed for applicability. Applicability of the requirements should consider whether the SASSI software is a custom variation or acquired software. The contractor's or subcontractor's QA program and procedures should contain the detailed processes for implementing all SQA requirements for either the custom variation or acquired software. If the contractor's or subcontractor's use does not meet the definition of nuclear safety software then the ten QA Criteria in Attachment 2 of O 414.1D must be reviewed for applicability.

The SASSI V&V test problems may be used to supplement applicable SQA work activities that ensure SASSI produces correct results. Other key SQA work activities most likely will be associated with ensuring the SASSI software modules are placed under configuration control and restricted from modification unless changes are approved as specified in the contractor's or subcontractor's procedures. Most likely, additional SQA work activities will apply in addition to the two mentioned above. Such activities will be specified in the contractor's or subcontractor's SQA program. The contractor or subcontractor is responsible for implementing all applicable DOE SQA requirements for either its custom variation or acquired SASSI software.

Conclusion

SASSI is a widely used, valuable tool for SSI analyses. However, the software must be properly validated for use with the input parameters selected for a given structural analysis. Moreover, analyses for DOE nuclear facilities shall be performed only with a SASSI variation that clearly conforms to DOE SQA requirements. Analyses for DOE facilities should also employ seasoned SSI analysts, either to perform the analyses or peer review the analyses. Questions on the SASSI V&V test problems, or this SASSI guidance, can be directed to Dr. Brent Gutierrez at the Savannah River Operations Office (803-208-6040, brent.gutierrez@srs.gov) or Dr. Stephen McDuffie with the EM Chief of Nuclear Safety staff (509-373-6766, stephen.mcduffie@rl.doe.gov).

References

1. F. Ostadan, "SASSI2000 - A System for Analysis of Soil-Structure Interaction," Version 3, Users Manual, August 2009.
2. J. Lysmer, M. Tabatabaie-Raissi, F. Tajirian, S. Vahdani, and F. Ostadan, "SASSI A System for Analysis of Soil-Structure Interaction," Report No. UCB/GT/81-02, Department of Civil Engineering, University of California, Berkeley, April 1981.
3. G. Mertz, I. Cuesta, A. Maham, and M. Costantino, "Seismic Response of Embedded Structures Using the SASSI Subtraction Method," LA-UR-10-05302, Los Alamos National Laboratory, July 2010.
4. Letter from P. Winokur, DNFSB to D. Poneman, DOE, April 8, 2011.
5. Letter from D. Poneman, DOE, to P. Winokur, DNFSB, July 29, 2011.
6. DOE Memorandum from D. Chung to Distribution, August 4, 2011.
7. W. S. Tseng, "Flexible Volume Method vs. Substructure Subtraction Method of SASSI Soil-Structure Interaction Analysis Methodology," personal correspondence, November 17, 2010.
8. C. C. Chin, "Substructure Subtraction Method and Dynamic Analysis of Pile Foundations," Ph.D. Dissertation, Department of Civil Engineering, University of California, Berkeley, 1998.
9. Gutierrez, B., "U.S. Department of Energy, Soil-Structure Interaction Report," July 2011.
10. G. Mertz, M. Costantino, T. Houston, and A. Maham, "The SASSI Subtraction Method Anomaly," Carl J. Costantino and Associates, Report No. CJC-SVV-M-002, August 19, 2014 (originally Position Paper CJCA-004, October 4, 2011).
11. SASSI Verification and Validation Project: Participatory Peer Review Team (PPRT) Summary and Conclusions, March 31, 2015 Letter, PPRT to Dr. Brent Gutierrez.
12. M. Tabatabaie, "The Accuracy of the Subtraction Model Examined in $^{MTR/}$SASSI (Part I)," SC Solutions, Walnut Creek, California, June 20, 2011.
13. American Society of Civil Engineers (ASCE), "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," ASCE 4-15, American Society of Civil Engineers, Reston, Virginia, 2015.

Distribution:

Jack Craig, Manager, Savannah River Operations Office
Stacy Charboneau, Manager, Richland Operations Office
Kevin Smith, Manager, Office of River Protection
Jose Franco, Manager, Carlsbad Field Office
William Murphie, Manager, Portsmouth/Paducah Project Office
John P. Zimmerman, Deputy Manager for Idaho Cleanup Project
Susan Cange, Manager, Oak Ridge Office of Environmental Management
Ralph Holland, Acting Director, Environmental Management Consolidated Business Center

cc:
Monica Regalbuto, EM-1
Mark Whitney, EM-1
James Hutton, EM-40
James McConnell, NA-50
Don Nichols, NA-51
Charles Keilers, NA-511
Joseph McBrearty, SC-3
Andrew Delapaz, SC-3
John Kotec, NE-1
Kelli Markham, NE-3