Evaluation of D.O.E. SASSI Subtraction Method Analysis Recommendations

In the June 2011 **Soil-Structure Interaction Team Report**, the D.O.E. has proposed a series of recommendations for the use of SASSI where the Subtraction Method(SM) or Modified Subtraction Method (MSM) has been used. The design and supporting analyses for STP 3&4 satisfy all of the proposed recommendations, both for facilities for which the SSI analysis has been completed, as well as for future analyses.

For facilities that have already been analyzed with SASSI SM, the DOE letter recommends that the analysis be reviewed by an experienced analyst, and, if there are concerns,[1] confirmatory analyses should be conducted based on review of criteria listed in Table 1. The analyses conducted in response to RAI 3.07.01-29 satisfy the two D.O.E. proposed criteria for such an evaluation:[2]

1. If the evaluation does not conclusively determine that the design parameters obtained using the subtraction method are acceptable, the analyses should be performed using the direct method or the MSM to confirm the previous results.

   The only SSI or SSSI analyses that were not done using the Direct Method (DM) are the 3-DSSI analyses of the DGFOSV and UHS/RSWPH, and the 2D SSSI analyses. The analyses for the DGFOSV have been redone using the MSM, and In Structure Response Spectra (ISRS) are revised and there is no impact on structural design. Selected cases of the UHS/RSWPH analyses have been re-run using the MSM, and all SM results have been scaled upwards to reflect instances where the MSM resulted in higher responses. It is concluded that the structural design was not impacted, however, the ISRS are revised. An SSSI study for a representative section including the RB, RSW Tunnel and RWB using the DM has demonstrated that the original SM results are sufficiently accurate for design.
2. If necessary, smaller sub-models may be used for this purpose. If the MSM is used, the applicability of the number and location of the added interaction nodes needs to be evaluated to demonstrate that all frequencies of interest are included and result in responses appropriate for engineering accuracy.

   The MSM has been verified for this site by reanalyzing the Control Building (CB), which was originally analyzed using the DM. The results from MSM and DMare very close. All SSI analyses using MSM incorporate all surface nodes of the excavated soil as additional interaction nodes.

[1] The D.O.E. report proposes that the presence of five separate conditions be checked, and if any condition is present then confirmatory analyses are warranted.

[2] In what follows, text in blue is excerpted from the subject D.O.E. report.

The analyses conducted in response to RAI 3.07.01-29 also satisfy the five D.O.E. proposed criteria for future SASSI analyses (in addition to the requirement of using experienced SASSI analysts).

1. For embedded or partially embedded structures, use the direct method if feasible. Until the cause of the subtraction error is identified, the subtraction method can be used as long as additional evaluations suggested below are made to ensure the design parameters are not impacted.

   The DM has been used for SSI analyses, wherever feasible. The DGFOSV and the UHS/RSWPH models are too large (too many excavation nodes) to be run using the DM, and therefore they have been analyzed using MSM (verified against DM for the CB as described below). The SM results are being used for the 2D SSSI soil pressures because a study of the RB-RSW Tunnel-RWB demonstrated that the total resultant soil pressure force is similar to that from the DM.
2. An experienced analyst must review the transfer functions for evidence of anomalous response such as that depicted in Figure 4 and other figures to determine if the anomalies are in the structural frequency range of interest.

   Transfer functions from all SM and MSM analyses have been reviewed by very experienced SASSI analysts (with more than 20 years SASSI experience), who determined that transfer functions resulted in reasonable seismic responses.
3. Analysts need to consider the frequency range of interest, excavated soil layer frequency f_{SL}, and energy content of the input time history in the frequency range of interest.

   All of these issues have been considered for all SASSI analyses. (For example, see Table 1 for UHS/RSWPH.)
4. Sensitivity analyses should be performed when the subtraction or the MSM is used. Sensitivity analyses could include:
   a. rerunning the problem with additional interaction nodes such as the MSM and comparing the transfer functions and the in-structure response spectra

      All MSM analyses have been performed with all excavation surface nodes designated as interaction nodes. Experience has shown that this is sufficient for obtaining accurate MSM results for soil conditions at STP 3&4 (as demonstrated by comparison of CB results from MSM and DM).
   b. use symmetry conditions to investigate behavior of smaller models with similar characteristics or applicable sub-models.

      Item 4.b. not used – see Item 4.a. above
5. Further studies are required to resolve the differences between the subtraction method and direct method, and, if feasible, to modify the code to increase the reliability of the subtraction method to be applied to a broader set of problems.

   For STP3&4, sufficient confirmatory analyses have been performed using MSM and DM to validate and, where necessary, modify the analysis results.

Verification and Validation of the SASSI software used for analysis of STP 3&4 structures meets the four proposed criteria of the D.O.E. letter:

1. The SASSI software should be fully verified in accordance with an approved quality assurance program. A set of generic verification and validation problems should also be developed and provided to DOE for review.
   All SASSI analyses were done by either S&L or SGH. Both firms have V&V packages prepared in conformance with approved QA Programs. These packages include a sufficient number of verification problems. These V&V packages have been reviewed and audited by NRC for STP 3&4.
2. Some design firms have changed the program and added additional features for their use. For this reason, an appropriate set of verification and validation problems needs to be developed by the design firms to be tested and made available for DOE review. The verification problems must be executed on the same computer platform used for the production analysis.
   S&L has neither changed the SASSI2000 Program nor added features. SASSI2000 Ver.3.0_SGH has been validated using standard SGH V&V package and it has been additionally validated by comparing responses to those calculated using commercial SASSI2000 Ver.3.0 for the UHS/RSWPH model.
3. The SASSI software also needs to be verified and validated for project-specific features; for example, very soft or stiff soil conditions, or unusual embedment geometry that may deviate from the expected norm for which the software was originally intended.
   Soft soils at the STP site were addressed in the V&V process by verifying results for soft soil sites (e.g., Lotung). STP has relatively uniform soil profile without significant reversal of shear wave velocity. In addition to the V&V packages, the MSM was validated by comparing results from analysis of the Control Building using both the MSM and DM using site soils, and demonstrating that results are very close.
4. Additional validation and verification documentation for each project-specific application of SASSI may be required. Because of its specialized focus, the project needs must be reviewed by an experienced SASSI user in addition to a QA reviewer.
   Additional verification problems were added to the SASSI V&V packages to demonstrate adequacy of the total V&V packages for STP 3&4. These were reviewed by very experienced SASSI analysts.

Table 1

Specific UHS/RSWPH Responses to Recommendations in the DOE June 2011 **Soil-Structure Interaction Team Report** Regarding Assessment of Completed SASSI Subtraction Method.

Recommendations for Facilities Already Analyzed with SASSI	**SSI Analyses using Subtraction Method**	**SSI Analyses using Modified Subtraction Method**
The transfer functions exhibit peaks and valleys not justified by expected structural and SSI responses. In examining the transfer functions, the frequency limitations discussed below must be considered.	Some of the transfer functions for UHS exhibited peaks and valleys above 10 Hz that can't easily be related to SSI frequencies that are generally below 6 Hz or structural frequencies.	Transfer functions for UHS are generally much smoother without peaks and valleys.
The frequency of interest for seismic responses is above the frequency of the excavated soil layer $f_{SL}= V_S/4H$, where V_S is shear wave velocity and H is depth of excavated volume.	f_{SL} for UHS is 4 Hz to 6 Hz for LB to UB soil condition. These frequencies are below the frequency of interests for the structural responses.	Not Applicable
The frequency of interest for seismic responses is near or above the frequency of the excavated volume (f_{EV}), modeled by a solid finite element model fixed at interaction nodes.	The frequency of excavated volume is about 5 Hz to 7 Hz, which is below frequency of interests for the structural responses.	Frequency of excavated volume increases due to additional interaction nodes at the free field level.
The input motion has significant energy above the frequency of excavated soil, f_{SL}.	More than 98% of energy of input motion is below 15 Hz, which is higher than f_{SL}.	More than 98% of energy of input motion is below 15 Hz.
The seismic responses of interest include ISRS with significance above f_{SL}.	The ISRSs do have significant peaks above f_{SL}	Not Applicable.