MITSUBISHI HEAVY INDUSTRIES, LTD.
16-5, KONAN 2-CHOME, MINATO-KU
TOKYO, JAPAN

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Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-11150

Subject: Mark-up of the Technical Report MUAP-11002 associated with SRP 3.7.2.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") provides to the U.S. Nuclear Regulatory Commission ("NRC") the mark-up changed for the next revision (Revision 1) of the Technical Report "Turbine Building Model Properties, SSI Analyses, and Structural Integrity Evaluation" (MUAP-11002).

MHI is planning to incorporate changes in relation to the conformance with Standard Review Plan (SRP) 3.7.2 in Revision 1 of MUAP-11002 that also includes the gap assessment between structures.

As requested by the NRC Staff to provide revised material on the docket for review, MHI is submitting the mark-up showing changes reflecting the conformance of Turbine Building seismic analysis with SRP 3.7.2. The Staff's request was discussed at the May 19, 2011 Public Meeting between MHI and the NRC.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure:

1. Mark-up of MUAP-11002 R1_SRP3.7.2.

CC : J. A. Ciocco
C. K. Paulson

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NRO

Contact Information

C. Keith Paulson, Senior Technical Manager
Mitsubishi Nuclear Energy Systems, Inc.
300 Oxford Drive, Suite 301
Monroeville, PA 15146
E-mail: ck_paulson@mnes-us.com
Telephone: (412) 373-6466

Enclosure 1

UAP-HF-11150
Docket No. 52-021

Mark-up of MUAP-11002 R1_SRP3.7.2.

June, 2011

Turbine Building Model Properties, SSI Analyses, and Structural Integrity Evaluation

~~January~~September 2011

Prepared:

Tomofumi Shimizu, Manager
Turbine Plant Engineering Section
Nuclear Turbine Plant Engineering Department

Date

Reviewed:

Toshiki Kojima, Manager
Turbine Plant Engineering Section
Nuclear Turbine Plant Engineering Department

Date

Approved:

Hideo Tateishi, Section Manager
Turbine Plant Engineering Section
Nuclear Turbine Plant Engineering Department

Date

Revision History

Revision	Page	Description
0	All	Original Issue
1	5 thru 7, 17, 28, 95 thru 113	Section 1 was changed to supersede ASCE 4-98 by SRP3.7.2. Section 5.3 was changed to delete ASCE 4-98. Appendix A was added to provide the conformance of T/B seismic analysis with SRP 3.7.2.

Mitsubishi Heavy Industries, Ltd.
16-5, Konan 2-chome, Minato-ku
Tokyo 108-8215 Japan

Abstract

The purpose of this technical report is to present the structural models, soil-structure interaction (SSI) analyses, and structural integrity evaluation of the US-APWR Standard Plant Turbine Building (T/B) and Electrical Room as referenced by US-APWR Design Control Document (DCD), Chapter 3 (Reference 11).

Appendices

ACRONYM/SYMBOL LIST

AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
CSDRS	Certified Seismic Design Response Spectra
DCD	Design Control Document
d_{max}	The maximum recommended thickness of a subsurface profile layer with a given shear wave velocity
ESWPT	Essential Service Water Pipe Tunnel
FE	Finite Element
f_n	Highest (or cut-off) frequency of analysis
g	gravity
H1	North-South, Y Direction
H2	East-West, X Direction
Hz	Hertz
MHI	Mitsubishi Heavy Industries, Ltd
NRC	Nuclear Regulatory Commission
NUREG	US Nuclear Regulatory Commission Regulation
PS/B	Power Source Building
R/B	Reactor Building
SRP	Standard Review Plan
SSE	Safe Shutdown Earthquake
SSI	Soil-Structure Interaction
T/B	Turbine Building
TFI	Transfer function interpolated
TFU	Transfer function un-interpolated
TI	Turbine Island
US-APWR	United States - Advanced Pressurized Water Reactor
V	Vertical, Z direction
V_s	Shear Wave Velocity
3-D	Three dimensional

1.0 INTRODUCTION

This report documents the soil-structure interaction (SSI) analyses of the Turbine Island (TI), which includes the Turbine Building (T/B), Electrical Room, Turbine Pedestal, and a section of the Essential Service Water Pipe Tunnel (ESWPT) located under the north end of the T/B and Electrical Room of the United States - Advanced Pressurized Water Reactor (US-APWR) standard plant. The SSI analyses were performed to estimate the lateral displacement of the T/B and Electrical Room relative to the Reactor Building (R/B) and one of the Power Source Buildings (PS/B) of the Nuclear Island.

Also presented in this report are stress ratios for select T/B and Electrical Room steel members estimated using GT STRUDL and ACS SASSI based on the fixed-base condition, and results of a sliding and overturning analysis of the T/B and Electrical Room.

As stated in US-APWR Design Control Document (DCD), Revision 2, Subsection 3.7.2.4 (Reference 11), SSI effects are considered in the seismic response analysis of all major Seismic Category I and Seismic Category II buildings and structures that are part of the US-APWR standard and non-standard plants. The ACS SASSI computer program was used for the SSI analyses described in this report. The SSI analyses were conducted using methods and approaches consistent with Standard Review Plan (SRP) 3.7.2 ~~ASCE 4-98~~ (Reference 14 ~~8~~). Appendix A describes how the T/B seismic analysis has satisfied the acceptance criteria of SRP 3.7.2. The ESWPT is classified as a Seismic Category I structure, and the T/B and Electrical Room are classified as Seismic Category II structures. The Turbine Pedestal is classified as a non-seismic structure.

The design input ground motion and generic subsurface profiles used in the SSI analyses were developed in Reference 3. The design input ground motion consists of three time history components compatible to the US-APWR certified seismic design response spectra (CSDRS) for a safe shutdown earthquake (SSE) event with a peak ground acceleration of 0.3g. The time histories were developed in full compliance with the criteria of Standard Review Plan 3.7.1 (Reference 1), Subsection 3.7.1.II.1B. The generic subsurface profiles were modified for compatibility with the configuration of the structures analyzed.

Finite element (FE) structural models were created using the software package GT STRUDL, Version 30.0. The GT STRUDL FE models included detailed models of the T/B, Electrical Room, and a section of the ESWPT, and a simplified representation of the Turbine Pedestal. Although not part of the standard plant, a section of the ESWPT was included in the model only to determine the localized effect the tunnel may have on the TI analysis. The GT STRUDL FE structural model was then converted into ACS SASSI format for performing the SSI dynamic analysis. Validation analyses results are presented in Section 6, demonstrating the GT STRUDL structural model is accurately represented by the ACS SASSI model for dynamic vibration.

The results of the SSI analyses are presented as the maximum displacements relative to the free-field ground motion (herein referred to as relative displacement) at multiple locations of the T/B, and the Electrical Room adjacent to the R/B and PS/B of the Nuclear Island. The approach used to estimate the maximum relative displacements are discussed. The maximum relative displacements of the TI were combined with the maximum relative displacements of R/B and PS/B from Reference 10 to evaluate if the space between the buildings is sufficient to prevent contact of the buildings during a 0.3g SSE event. The 0.3g SSE is for a 0.3g peak ground acceleration for the two horizontal directions and the vertical direction.

The condensate pump foundation is a mass concrete structure with pipe and pump-can openings, which was modeled with solid elements.

Along a portion of the west side and all of the south edge of the T/B, the first floor slab is cantilevered out from the basement walls. As the TI SSI was performed as a surface structure ~~in accordance with American Society of Civil Engineers (ASCE) 4-98 (Reference 8)~~, the space below the cantilevered portions of the first floor slab to the bottom elevation of the T/B substructure was modeled as engineered backfill material which satisfies the DCD, Revision 2, Section 3.7.1.1 (Reference 11) requirements for competent material. The engineered backfill material was modeled using solid elements.

For the Electrical Room substructure model, engineered backfill material was placed from the bottom of the reinforced concrete slab-on-grade to the bottom of the substructure of the T/B. The engineered backfill material was modeled using solid elements and satisfies the DCD, Revision 2, Section 3.7.1.1 (Reference 11) requirements for competent material. The solid elements for the engineered backfill material below the T/B cantilever on the west side of the T/B and for the engineered backfill material below the Electrical Room were connected using joint ties. Additionally, the engineered backfill below the Electrical Room that is adjacent to the T/B substructure concrete, is connected to the substructure concrete using joint ties.

The ESWPT FE mesh spacing was established to align the model joints longitudinally with the pipeline locations in the ESWPT, and the mesh is evenly spaced between openings in the ESWPT adjacent to the R/B. The ESWPT foundation was modeled with plate elements that account for both bending and shear deformations, and yield both plate stress and plate bending results. Since tunnel walls, roof, and floor are relatively thin, the plate elements were modeled at the center of the walls, roof, and floor.

5.4 Development of ACS SASSI Model of TI

Once the GT STRUDL models for structural design were completed, the T/B and Electrical Room substructure model was modified to reduce the model size to facilitate running in ACS SASSI. Primarily, the mesh size for the T/B and Electrical Room substructure concrete elements was increased to reduce the number of nodes and elements, resulting in a coarser FE mesh. This coarse mesh structural model was then translated from GT STRUDL to ACS SASSI.

The reinforced concrete T/B and Electrical Room substructure coarse element dimensions were increased. A horizontal coarse mesh size of approximately 13 by 13 feet was adopted depending on column row spacings. For the engineered backfill material, the mesh size was also increased, with the horizontal mesh size set to match that of the overlying concrete.

In the fine mesh T/B substructure model, the plate elements used to represent the bottom of the substructure basemat were located at the center of the basemat's vertical dimension; therefore, the model did not extend to the full depth of the T/B substructure. For the coarse mesh T/B substructure model, to appropriately simulate the soil-structure interaction, the basemat plate elements were shifted to the physical bottom of the substructure basemat. To connect the lowered substructure basemat elements, a single row of T/B substructure wall plate elements were modeled extending from the top to the bottom of the basemat. The wall plate elements properties were set to represent those of the basemat.

9.0 REFERENCES

1. Seismic Design Parameters, NUREG-0800 Section 3.7.1, Revision 3, U.S. Nuclear Regulatory Commission, Washington DC, March 2007.

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3. Seismic Design Bases of the US-APWR Standard Plant, MUAP-10001, Revision 1, Mitsubishi Heavy Industries, Ltd., May 2010.

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5. Protection Against Low-Trajectory Turbine Missiles, Regulatory Guide 1.115, Revision 1, U.S. Nuclear Regulatory Commission, Washington DC, July 1977.

6. Specification for the Design, Fabrication and Erection of Steel Safety-Related for Nuclear Facilities, ANSI/AISC N690-1994 (R2004), American Institute of Steel Construction, October 2004.

7. Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, ACI 349-01/349R-01, American Concrete Institute, January 2001.

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9. Seismic System Analysis, NUREG-0800 Section 3.7.2, Revision 3, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

10. Black & Veatch, Request for Information, Request No.: MHI-RFI-2010-0094, Revision 0, Subject: Deflection of Nuclear Island Structures, File No.: 164475.18.9270, Date Requested: 9/15/2010.

11. Design Control Document for the US-APWR, Revision 2, Mitsubishi Heavy Industries, LTD, October 2009.

12. Foundations, NUREG-0800 Section 3.8.5, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

13. Comparison T/B Height in the Analysis with DCD

14. Seismic System Analysis, NUREG-0800 Section 3.7.2, Revision 3, U.S. Nuclear Regulatory Commission, Washington DC, March 2007.

Appendix A: Conformance of T/B Seismic Analysis with SRP 3.7.2.

The T/B seismic analysis is in conformance with SRP3.7.2. The following pages contain a comparison form showing the conformance of the T/B seismic analysis with SRP 3.7.2. On the left hand side of the form is the Acceptance Criteria from SRP 3.7.2 starting at page 3.7.2-6 of SRP 3.7.2 and on the right hand side is the response describing how the T/B seismic analysis has satisfied the SRP requirements.

Acceptance Criteria from Standard Review Plan (SRP) 3.7.2 Seismic System Analysis	Conformance with SRP 3.7.2
1. Seismic Analysis Methods. The seismic analysis of all seismic Category I SSCs should use either a suitable dynamic analysis method or an equivalent static load analysis method, if justified. The SRP acceptance criteria primarily address linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of as-built structures), reliance on limited inelastic/nonlinear behavior when appropriate is acceptable to the staff. Analysis methods incorporating inelastic/nonlinear considerations and the analysis results are reviewed on a case-by-case basis.	
A. Dynamic Analysis Method. When calculating seismic responses of Category 1 structures, dynamic analysis (response spectrum analysis method or time history analysis method) should be performed. To be acceptable, dynamic analyses should consider the following: i. Use of appropriate methods of analysis (time history analysis method [time domain solution and frequency domain solution]; response spectrum analysis method), accounting for the effects of SSI, if applicable. In general, the response spectrum analysis method is not suitable for SSI analysis.	1A(i). Yes. Time history analysis in frequency domain solution is used to account for SSI effects.
ii. Seismic analysis should be performed for three orthogonal (two horizontal and one vertical) components of earthquake ground motion.	1A(ii). Yes. Two horizontal and one vertical ground motions were considered.
iii. Consideration of the torsional, rocking, and translational responses of the structures and their foundations (including footings, basemats and buried walls).	1A(iii). Yes. SASSI FE model considered torsional, rocking, and translational responses of the structures and their foundations.
iv. Use of an adequate number of discrete mass degrees of freedom in dynamic modeling. The adequacy of the number of discrete mass degrees of freedom can be confirmed by (1) preliminary modal analysis, and (2) correlation between static analysis results using the dynamic model and static analysis results using a distributed mass representation.	1A(iv). Yes. An adequate number of discrete mass degrees of freedom is used in dynamic modeling.
(1) It is important to ensure that, for each excitation direction (2 horizontal and vertical), all modes with frequencies less than the ZPA (or PGA) frequency of the corresponding spectrum are adequately represented in the dynamic solution. Preliminary modal analysis should be performed to establish that a sufficient number of discrete mass degrees of freedom have been included in the dynamic model to (a) predict a sufficient number of modes, and (2) produce mode shapes that are reasonably smooth. If a mode shape exhibits rapid change in modal displacement between adjacent mass degrees of freedom, additional mass degrees of freedom should be added until reasonably smooth mode shapes are obtained for all modes to be included in the dynamic analysis.	1A(iv)(1). Yes. All modes with frequencies less than the ZPA (or PGA) frequency of the corresponding spectrum are adequately represented in the dynamic solution.
(2) After completion of (1), simple 1g static analyses of the dynamic model should be performed for each of the three (3) excitation directions, and compared to the corresponding results obtained from static analyses that utilize a distributed mass representation. Lack of correlation, particularly in the vicinity of and at support locations, is indicative of an insufficient number of discrete mass degrees of freedom.	1A(iv)(2). Yes. 1g static analyses of the dynamic model were performed for each of the three (3) excitation directions, and the corresponding results were compared.

v. When using either the response spectrum method or the modal superposition time history method, responses associated with high frequency modes (i.e., f >= ZPA [or PGA] frequency) should be included in the total dynamic solution using the guidance and methods described in Regulatory Guide 1.92, Revision 2, Regulatory Positions C.1.4 and C.1.5. vi. Consideration of maximum relative displacements between adjacent supports of seismic Category I SSCs. vii. Inclusion of significant effects such as piping interactions, externally applied structural restraints, hydrodynamic (both mass and stiffness effects) loads, and nonlinear responses. B. Equivalent Static Load Method. An equivalent static load method is acceptable if: i. Justification is provided that the system can be realistically represented by a simple model and the method produces conservative results in terms of responses. Typical examples or published results for similar structures may be submitted in support of the use of the simplified method. ii. The simplified static analysis method accounts for the relative motion between all points of support. iii. To obtain an equivalent static load for an SSC that can be represented by a simple model, a factor of 1.5 is applied to the peak spectral acceleration of the applicable ground or floor response spectrum. A factor less than 1.5 may be used, if adequate justification is provided.	1A(v). Not applicable. Time history analysis in frequency domain solution is used. 1A(vi). Yes. Maximum relative displacements between Nuclear Island and Turbine Island are considered. 1A(vii). Not applicable. No other significant effects. 1B(i to iii). Not applicable. Equivalent static load method is not used.
2. Natural Frequencies and Responses. To be acceptable, the following information should be provided: A. A summary of modal masses, effective masses, natural frequencies, mode shapes, modal and total responses for the Category I structures, including the containment structure, or a summary of the total responses if the method of direct integration is used. B. The calculated time histories (two horizontal and one vertical), or other parameters of motion, or response spectra (two horizontal and one vertical) used in design, at the major plant equipment elevations and points of support. C. For the multiple time history analysis option, procedures used to account for uncertainties (by variation of parameters) and to develop design responses, including justification for the statistical relationship between input design time histories and output responses. (For example, if the average response spectra generated from the multiple design time histories are used to envelop the design response spectra, then the average responses generated from the multiple analyses are used in design.)	2A. The method of direct integration is not used. Modal superposition method is used for the GT STRUDL fixed-base analysis. A summary of modal masses, effective masses, natural frequencies, for the Turbine Island structures are provided. 2B. The maximum relative displacements at the points of interest are provided. 2C. Not applicable. The multiple time history analysis option is not used.

3. Procedures Used for Analytical Modeling. A nuclear power plant facility consists of very complex structural systems. To be acceptable, the stiffness, mass, and damping characteristics of the structural systems should be adequately incorporated into the analytical models. Specifically, the following items should be considered in analytical modeling:	
A. Designation of Systems Versus Subsystems. Category I structures that are considered in conjunction with the foundation and its supporting media are defined as "seismic systems." Other Category I SSCs that are not designated as "seismic systems" should be considered as "seismic subsystems."	3A. The Turbine Building is classified as a Category II structure, however it's analyzed as a Category I structure.
B. Decoupling Criteria for Subsystems. It can be shown, in general, that frequencies of systems and subsystems have a negligible effect on the error due to decoupling. It can be shown that the mass ratio, Rm, and the frequency ratio, Rf, govern the results where Rm and Rf are defined as: $R_m = \frac{\text{Total mass of the supported subsystem}}{\text{Total mass of the supporting system}}$ $R_f = \frac{\text{Fundamental frequency of the supported subsystem}}{\text{Dominant frequency of the support motion}}$ The following criteria are acceptable: i . If $R_m < 0.01$, decoupling can be done for any R_f. ii . If $0.01 \le R_m \le 0.1$, decoupling can be done if $0.8 \ge R_f \ge 1.25$. iii . If $R_m > 0.1$, a subsystem model should be included in the primary system model. If the subsystem is rigid compared to the supporting system, and also is rigidly connected to the supporting system, it is sufficient to include only the mass of the subsystem at the support point in the primary system model. On the other hand, in case of a subsystem supported by very flexible connections, e.g., pipe supported by hangers, the subsystem need not be included in the primary model. In most cases, the equipment and components, which come under the definition of subsystems, are analyzed (or tested) as a decoupled system from the primary structure and the seismic input for the former is obtained by the analysis of the latter. One important exception to this procedure is the reactor coolant system, which is considered a subsystem but is usually analyzed using a coupled model of the reactor coolant system and primary structure.	3.B i. Individual subsystems are not modeled, since the mass ratio for any single subsystem does not exceed 0.01, and the estimated mass for all subsystems is included in the structural model.

C. Modeling of Structures. Two types of structural models are widely used by the nuclear industry: lumped-mass stick model and finite element model. Either of these two types of modeling techniques is acceptable if the following guidelines are met: i. Lumped-Mass Stick Model For a lumped-mass model, the eccentricities between the centroid (the neutral axis for axial and bending deformation), the center of rigidity (the neutral axis for shear and torsional deformation), and the center of mass of structures should be included in the seismic model. For selecting an adequate number of discrete mass degrees of freedom in the dynamic modeling to determine the response of all seismic Category I and applicable non-seismic I structures, the acceptance criteria given in Subsection II.1.a.iv of this SRP section are acceptable. ii. Finite Element Model The type of finite element used for modeling a structural system should depend on the structural details, the purpose of the analysis, and the theoretical formulation upon which the element is based. The mathematical discretization of the structure should consider the effect of element size, shape, and aspect ratio on solution accuracy. The element mesh size should be selected on the basis that further refinement has only a negligible effect on the solution results. iii. In developing either a lumped-mass stick model or a finite element model for dynamic response, it is necessary to consider that local regions of the structure, such as individual floor slabs or walls, may have fundamental vibration modes that can be excited by the dynamic seismic loading. These local vibration modes should be adequately represented in the dynamic response model, in order to ensure that the in-structure response spectra include the additional amplification. Also, the additional seismic loading on the overall structure and on the local region is needed for detailed structural design.	3C. A combined FE model of the Turbine Building and Electrical Room superstructures, together with their respective foundations, was used in the SSI analysis model.
D. Representation of Floor Loads, Live Loads, and Major Equipment in Dynamic Model. In addition to the structural mass, mass equivalent to a floor load of 50 pounds per square foot should be included, to represent miscellaneous dead weights such as minor equipment, piping, and raceways. Also, mass equivalent to 25 percent of the floor design live load and 75 percent of the roof design snow load, as applicable, should be included. The mass of major equipment should be distributed over a representative floor area or included as concentrated lumped masses at the equipment locations.	3D. All loads were included in the GTSTRUDL FE model of the Turbine Building.

E. Special Consideration for Dynamic Modeling of Structures. It has been common practice that the dynamic model used to predict the seismic response of a structure is not as detailed as the structural model used for the detailed design analysis of all applicable load combinations. Therefore, a methodology is needed to transfer the seismic response loads determined from the dynamic model to the structural model used for the detailed design analysis of all applicable load combinations. This is reviewed for technical adequacy on a case-by-case basis.	3E. The superstructure model used for the SSI analysis is identical to the one used for the detailed design. Member forces from the SSI analysis were combined with the member forces from the other loadings in the detailed design for code checking.
4. Soil-Structure Interaction. A complete SSI analysis should properly account for all effects due to kinematic and inertial interaction for surface or embedded structures. Any analysis method based on either a direct approach or a substructure approach can be used provided the following conditions are met: A. The structure, foundation, and soil are properly modeled to ensure that the results of analyses properly capture spatial variation of ground motion, three dimensional effects of radiation damping and soil layering, as well as nonlinear effects from site response analyses. B. The design earthquake ground motions used as input to the SSI analyses should be consistent with the design response spectra as defined in SRP Section 3.7.1. It is noted that there is enough confidence in the current methods used to perform the SSI analysis to capture the basic phenomenon and provide adequate design information; however, the confidence in the ability to implement these methodologies is uncertain. Therefore, in order to ensure proper implementation, the following considerations should be addressed in performing SSI analysis : A. Perform sensitivity studies to identify important parameters (e.g., potential separation and sliding of soil from sidewalls, non-symmetry of embedment, location of boundaries) and to assist in judging the adequacy of the final results. These sensitivity studies can be performed by the use of well-founded and properly substantiated simple models to give better insight; B. Through the use of some appropriate benchmark problems, the user should demonstrate its capability to properly implement any SSI methodologies; and C. Perform enough parametric studies with the proper variation of parameters (e.g., soil properties) to address the uncertainties (as applicable to the given site) discussed in subsection I.4 of this SRP section.	4A (Analysis Method). Yes. A 3D finite element model is generated for the Turbine Building structure including the basemat foundation. Horizontal layers of soil with strain compatible properties are used. ACS SASSI was used to perform the SSI analysis. 4B (Analysis Method). Yes. The design ground motions are developed in accordance with SPR 3.7.1. See MUAP 10001 Rev 2. 4A (SSI Analysis). Yes. Sensitivity studies were performed to investigate the impact of the Radius of central zone value on the SSI analysis. 4B (SSI Analysis). Yes. The ACS SASSI computer program was validated in accordance with Black & Veatch's Nuclear Quality Assurance Manual. The validation includes the verification of 31 problems in the ACS SASSI NQA Verification Manual Rev.2. The 31 problems include some specific benchmark cases, e.g. "Pressure Water Reactor Building Structure Subjected to Coherent and Incoherent Seismic Motions" and "Lotung Experiment for a Reduced-Scale Embedded Reactor Building Model Subjected to Ground

	Shaking". 4C (SSI Analysis). Yes. Uncertainties in soil properties were studied. Eight generic layered soil profiles are used to account the soil uncertainty. See MUAP 10001 Rev. 2.
For sites where SSI effects are considered insignificant and fixed base analyses of structures are performed, bases and justification for not performing SSI analyses are reviewed on a case-by-case basis. If the SSI analysis is not required, the input motion at the base of the structures will be the design motion reviewed in SRP Section 3.7.1.	
The acceptance criteria for the constituent parts of the entire SSI system are summarized as follows: A. Modeling of Structure. The acceptance criteria given under subsection II.3 of this SRP section are applicable.	4A (constituent parts). See Section II.3 above.
B. Modeling of Supporting Soil. The effect of embedment of structure, groundwater effects, and the layering effect of soil should be accounted for. For the half-space modeling of the soil media, the lumped parameter (soil spring) method and the compliance function methods are acceptable provided that frequency variations and layering effects are incorporated. For the method of modeling soil media with finite boundaries, all boundaries should be properly simulated and the use of types of boundaries should be justified and reviewed on a case-by-case basis. Finite element and finite difference methods are acceptable methods for discretization of a continuum. The properties used in the SSI analysis should be those that are consistent with soil strains developed in free-field site response analyses.	4B (constituent parts). Soil layering effect is accounted for in the SASSI model. The subsurface material in the SASSI computer program is assumed to consist of horizontal soil layers overlying a halfspace. The subsurface material properties are assumed to be visco-elastic. The properties used in the SSI analysis are those that are consistent with soil strains developed in free-field site response analyses.

For structures founded on materials having a shear wave velocity of 8,000 feet per second or higher, under the entire surface of the foundation, a fixed base assumption is acceptable.	
C. Input Ground Motion. The acceptance criteria for generating the input ground motion to be used in the SSI analysis are summarized in the following:	
i. If the design earthquake ground motion is defined from generic response spectral shapes (e.g, Reg. Guide 1.60 or NUREG-0098), the location of the ground motion should be consistent with the properties of the soil profile. For profiles consisting of competent soil or rock, with relatively uniform variation of properties with depth, the ground motion should be located at the soil surface at the top of the finished grade. For profiles consisting of one or more soft and/or thin soil layers overlaying competent material, the ground motion should be located at an outcrop (real or hypothetical) at the top of the competent material in the vicinity of the site.	4C(i to ii). Yes. See MUAP 10001 Rev 2.
ii. If the design earthquake ground motion is defined from site-specific evaluations of uniform hazard spectra, the location of the ground motion should be at the ground surface in the free-field. In developing the ground motion at the surface, the potential effects of soft soil layers need to be considered. For sites with soil layers near the surface that will be completely excavated to expose competent material, the ground motion response spectra are specified on an outcrop or a hypothetical outcrop that will exist after excavation. Motions at this hypothetical outcrop should be developed as a free surface motion, not as an in-column motion. Competent material is defined as in-situ material having a minimum shear wave velocity of 1,000 feet/second (fps).	
iii. When the guidance for SSI analysis presented above is not completely implemented, the spectral amplitude of the acceleration response spectra (horizontal component of motion) in the free field at the foundation depth shall be not less than 60 per cent of the corresponding design response spectra at the finished grade in the free field. When variation in soil properties are considered (as required by the "Specific Guidelines for SSI Analysis" below), the 60 percent limitation may be satisfied using an envelope of the three spectra corresponding to the three soil properties. If the accompanying rotational components of the input motion are ignored, no reduction is permitted in the horizontal component at the foundation level.	4C(iii). The CSDRS is used for the standard plant Turbine Island SSI analysis.

Specific Guidelines for SSI Analysis	
The following specific guidelines are provided here to facilitate the review and draw the attention of reviewers to some important aspects of the SSI analysis. These guidelines are not necessarily requirements for the acceptance of any methodologies or an SSI analysis.	
• The behavior of soil, though recognized to be nonlinear, can often be approximated by linear techniques. Truly nonlinear analysis is not required unless the comparison of results from large-scale tests or actual earthquakes and analytical results indicate deficiencies that cannot be accounted for in any other manner. The nonlinear soil behavior may be accounted for by the following:	
- Using equivalent linear soil material properties typically determined from an iterative linear analysis of the free-field soil deposit. This accounts for the primary nonlinearity, or	Primary nonlinearity of the soil was taken into account using equivalent linear strain compatible material properties from the free-field iterative linear site response analysis.
- Performing an iterative linear analysis of the coupled soil-structure system. This accounts for the primary and secondary nonlinearities.	Secondary nonlinearity is not account for in the SSI analysis. This is consistent with the Nuclear Island SSI analysis.
In the event the nonlinear analysis is chosen, the results of the nonlinear analysis should be judged on the basis of the linear or equivalent linear analysis (NUREG/CP-0054).	
• Superposition of horizontal and vertical response as determined from separate analyses is acceptable (assuming nonlinear effects are not important) considering the simple material models now available.	For the relative displacements, the resultant relative displacement time history is obtained from algebraic summation of the three component responses at each time step. SRSS method is used to calculate the resultant forces and moments in the beam elements.
• The strain-dependent soil properties (e.g., shear modulus, damping) estimated from analysis of the seismic motion in the free field shall be consistent with the geotechnical information reviewed in SRP Section 2.5.4.	Strain compatible subsurface properties are used in the SSI analysis.
• For cases using standard plant designs, where the site specific spectra fall below the standard plant design spectra, the SSI evaluations are addressed in the standard plant design.	Not applicable. This is for COLA review.

• Enough SSI analyses should be performed so as to account for the effects of the potential variability in the properties of the soils and rock at the site. At least three soil/rock profiles should be considered in these analyses, namely, a best estimate (BE) profile, a lower bound (LB) and an upper bound (UB) profile in the evaluation of SSI effects. The properties of each layer of the site profile are typically defined in terms of its low-strain shear modulus and strain-dependent modulus degradation and strain-dependent hysteretic damping properties. These may be determined from dynamic laboratory testing of the site materials, information obtained from the published literature, or both. The set of properties appropriate for a given soil is reviewed for its adequacy. For a particular site, the iterated shear modulus and damping values are typically determined from the results of a number of free-field site response analyses, which are intended to account for the effects of the site-specific design ground motions as well as the site nonlinear properties. If only a single site response calculation is performed, with the low strain property of each material layer selected at its BE value, the resulting iterated property is then determined. The upper and lower bound values of soil/rock shear modulus (G) can then be defined in terms of their best estimate values as: $G_{LB} = G_{BE} / (1+COV)$ $G_{UB} = G_{BE} \text{ X } (1+COV)$ where COV is the coefficient of variation considered appropriate for the site materials. The corresponding damping properties should be defined at the compatible strains associated with the shear moduli. If many site response calculations are performed (30 to 60 site response calculations) using Monte Carlo techniques to develop site properties, these calculations are typically used to determine the BE, LB and UB iterated site properties. The BE properties are determined from the mean of the resulting properties and the UB and LB values selected from the +/- one sigma values. A sufficient number of site response calculations need to be performed, to ensure that a stable value of sigma for each material of the profile is obtained.	For standard plant design, only the best estimate (BE) soil profile is used. Soil properties were studied using the eight generic layered soil profiles to account for uncertainties in the soil properties. See MUAP 10001 Rev 2. This is consistent with the Nuclear Island SSI analyses

For well-investigated sites (see RGs 1.132 and 1.138), the COV should be no less than 0.5. For sites that are not well investigated, the COV for shear modulus shall be at least 1.0. These COV requirements apply to the "single site response calculation", as well as the "many site response calculations" described above. In no case should the lower bound shear modulus be less than that value consistent with standard foundation analysis that yields foundation settlement under static loads exceeding design allowables. The upper bound shear modulus should not be less than the best estimate shear modulus defined at low strain and as determined from the geophysical testing program. In no case should the material soil damping as expressed by the hysteretic damping ratio exceed 15 percent (NUREG/CR-1161).	
For the case of analyses using generic broad-banded ground motion spectra, the best estimate shear modulus and damping of each material of the site profile can be defined in terms of its low strain values. The upper and low bound shear moduli can then be defined at twice and one-half the best estimate values, with damping maintained at its low strain value. Alternate approaches can be reviewed on a case-by-case basis.	Not applicable. Only horizontal soil layers were considered for the standard plant SSI analysis.
- For dipping soil and rock strata, it is necessary to account for the coupling between the horizontal and vertical degrees of freedom in the stiffness and free-field seismic motion definitions. Also, there may be sites where the reactor building or a seismic Category I structure may have an embedded foundation close to an embankment or a natural slope that preclude the assumption of uniform foundation condition. For such sites, modeling and analysis techniques are reviewed on a case-by-case basis.	ACS SASSI computer program is used for SSI analysis. The SASSI program performs the SSI analysis using time history analysis in frequency domain.
- Finite Boundary Modeling or Direct Solution Technique The direct solution method is characterized as follows: - Each analysis of the soil and structures is performed in one step. - Finite element or finite difference discrete methods of analysis are used to spatially discretize the soil-structure system.	Not applicable.

- Definition of the motion along the boundaries of the model (bottom and sides) is either known, assumed, or computed as a precondition of the analysis. Dynamic analysis can be performed using either frequency-domain (limited to linear analysis) or time-integration methods. The mesh size should be adequate for representing the static stress distribution under the foundation and transmitting the frequency content of interest. The following limitations should be observed for deep soil sites: - The model depth, generally, should be at least twice the base dimension below the foundation level, which should be verified by parametric studies. - The fundamental frequency of the soil (or backfill) stratum should be well below the structural frequencies of interest. - All structural modes of significance should be included. ▪ Half Space or Substructure Solution Technique The half space or substructure approach generally comprises the following steps: (1) Determine the motion of the massless foundation, including both translational and rotational components. (2) Determine the foundation stiffness in terms of frequency-dependent impedance functions. (3) Perform SSI analysis. The procedures, modeling assumptions and analytical bases adopted for performing the half space or substructure analysis, including use of frequency-independent soil spring parameters, and the spring and damping coefficients, will be reviewed on a case-by-case basis.	Not applicable.

- There are advanced analytical methods that are being considered by the nuclear industry (e.g., the effects of incoherent ground motion) to reduce the potential effects of high frequency ground motion input. These might be used when a site acceptability determination is performed as discussed in subsection 11.4 of SRP Section 3.7.1. If incoherency is used to reduce the high frequency response, the potential effects of increasing other responses (e.g., overturning and torsional responses) shall be considered. When approved for use by the NRC, via issuance of interim staff guidance, it should be noted that the effects of incoherent ground motion may be considered either at the Design Certification stage, or at the site-specific application stage, but not both. If any advanced analytical methods are utilized, the technical basis and analysis results are subject to detailed review on a case-by-case basis.	Not applicable.
5. Development of In-Structure Response Spectra. RG 1.122 describes methods generally acceptable to the staff for developing the two horizontal and the vertical in-structure response spectra (e.g., floor response spectra) from the time history motions resulting from the dynamic analysis of the supporting structure. The topics addressed are A . SRSS Combination of the three in-structure response spectra in a given direction (e.g., x direction), developed from the output time histories from separate analyses of the three directions (x, y, z) of input motion. SRSS combination is not applicable, if the three directions of the input motion are applied simultaneously in a single analysis. B. Frequency increments for calculation of spectral accelerations. C. Spectrum smoothing and broadening to account for uncertainty. The guidance in RG 1.122 is augmented as follows: (1) SRSS combination applies to all cases where the three directions of input motion are analyzed separately. There is no longer a distinction made between symmetric and unsymmetric structures. (2) The 3 Hz frequency increment in the last row of RG 1.122, Table 1, applies up to the highest frequency of interest. This typically will be the PGA frequency of the design ground response spectrum, which in some cases may significantly exceed 33 Hz.	Not applicable. The turbine building in-structure response spectra are not generated.

(3a) When a single set of three artificial time histories is used as the input motion to the supporting structure, the in-structure response spectra are smoothed and broadened in accordance with the provisions of RG 1.122, to account for uncertainty.

(3b) When multiple sets of three time histories, derived from actual earthquake records, are used as the input motion to the supporting structure, the multiple sets of in-structure response spectra already account for some of the uncertainty. Therefore, the provisions of RG 1.122, to account for uncertainty, do not strictly apply.

The use of multiple sets of time histories to generate in-structure response spectra is reviewed and accepted on a case-by-case basis. Particularly, the basis for procedures used to account for uncertainties (by variation of parameters) are evaluated.

The same acceptance criteria apply to the in-structure response spectra as apply to the design ground response spectrum, reviewed in subsection II.I.B of SRP Section 3.7.1. As an example, if the average of the multiple response spectra generated from the multiple design time histories is used to envelop the design ground response spectrum, then the average of the multiple in-structure response spectra generated from the multiple analyses (each of which used one of the multiple design time histories) are used in design.

An evaluation of the statistical correlation between the input ground response spectrum and the output in-structure response spectra should also be provided.

The methods used for direct generation of in-structure response spectra are reviewed and accepted on a case-by-case basis.

6. <u>Three Components of Earthquake Motion</u>. RG 1.92, describes acceptable methods for combining the responses due to three components of earthquake motion, for both the response spectrum method and the time history method. Use of alternate methods are evaluated on a case-by-case basis for acceptability. When the three components of earthquake motion are applied simultaneously, using a set of three artificial time histories, the statistical independence of the time histories should be demonstrated. See subsection II.1.B of SRP 3.7.1 for the acceptance criteria to demonstrate statistical independence.	For the relative displacements, the resultant relative displacement time history is obtained from algebraic summation of the three component responses at each time step. SRSS method is used to calculate the resultant forces and moments in the beam elements.
7. <u>Combination of Modal Responses</u>. RG 1.92, describes acceptable methods for combination of modal responses, including consideration of closely-spaced modes and high-frequency modes, when the response spectrum method of analysis is used to determine the dynamic response of damped linear systems. Use of alternate methods are evaluated on a case-by-case basis for acceptability. When the modal superposition time history method of analysis is used, modal responses are combined algebraically, at each output time step. In accordance with RG 1.92, only modes with natural frequencies less than or equal to the ZPA frequency of the input spectrum are included in the modal superposition time history analysis. The contribution of the higher frequency modes to the total response is calculated by the missing mass approach. Since this contribution is in-phase with the input time history, it is treated as one additional modal response, that is scaled by the input time history normalized to the ZPA, and combined algebraically with the modal superposition time history solution at each output time step.	The SSI analysis is in the frequency domain. This criterion is not applicable.

8.	Interaction of Non-Category I Structures with Category I SSCs. All non-Category I structures should be assessed to determine whether their failure under SSE conditions could impair the integrity of seismic Category I SSCs, or result in incapacitating injury to control room occupants. Each non-Category I structure should meet at least one of the following criteria: A. The collapse of the non-Category I structure will not cause the non-Category I structure to strike a Category I SSC. B. The collapse of the non-Category I structure will not impair the integrity of seismic Category I SSCs, nor result in incapacitating injury to control room occupants. C. The non-Category I structure will be analyzed and designed to prevent its failure under SSE conditions, such that the margin of safety is equivalent to that of Category I structures. The disposition of each non-Category I structure should be formally documented. For criterion (b), it is necessary to provide the technical basis for the determination that collapse of the non-Category I structure is acceptable. This should include a description of any additional loads imposed on the Category I SSCs and the method used to conclude that these loads are not damaging. Also, any protective shields installed to prevent direct impact on Category I SSCs should be described.	Although the Turbine Building and Electrical are non-Category I, they have been designed to meet the Category I criteria. 8A. N/A. As a Category II structure the T/B is not designed to collapse into or strike a Category I SSC. 8B. N/A. As a Category II structure the T/B is not designed to collapse into a Category I SSC nor result in any incapacitation of the control room occupants. 8C. Yes.
9.	Effects of Parameter Variations on Floor Response Spectra. Consideration should be given in the analysis to the effects on floor response spectra (e.g., peak width) of expected variations of structural properties, damping values, soil properties, and SSI. The acceptance criteria for the consideration of the effects of parameter variations are provided in subsection 11.5 of this SRP section. In addition, for concrete structures, the effect of potential concrete cracking on the structural stiffness should be specifically addressed.	9. See section II.5 of this SRP. Concrete cracking in not currently considered. The methodology will be assessed for consistency with other Category 1 reinforced concrete structures.
10.	Use of Equivalent Vertical Static Factors. The use of equivalent static load factors to calculate vertical response loads for the seismic design of Category I SSCs, in lieu of the use of a vertical seismic system dynamic analysis, is acceptable only if it can be demonstrated that the SSC is rigid in the vertical direction, or the acceptance criteria in subsection 3.7.2.II.1.b of this SRP section are satisfied. The criterion for rigidity is that the lowest frequency in the vertical direction is higher than the ZPA frequency of the input ground or in-structure spectrum.	10. Not applicable. Equivalent static load method is not used.

11. <u>Methods Used to Account for Torsional Effects</u>. An acceptable method to account for torsional effects in the seismic analysis of Category I structures is to perform a dynamic analysis that incorporates the torsional degrees of freedom. An acceptable alternative, if properly justified, is the use of static factors to account for torsional accelerations in the seismic design of Category I structures. To account for accidental torsion, an additional eccentricity of ± 5 percent of the maximum building dimension shall be assumed for both horizontal directions. The magnitude and location of the two eccentricities is determined separately for each floor elevation.	11. The FE model for the SSI analysis includes rotational degrees of freedom about all three global axes. Accidental torsion is not considered in the SSI analysis since the goal of the SSI analysis is to check whether the gap between the Reactor/Power Source Buildings and the Turbine Building is large enough to prevent contact of the two buildings. The accidental torsion is considered in the stress analysis in GTSTRUDL.
12. <u>Comparison of Responses</u>. If both the time history analysis method and the response spectrum analysis method are used to analyze an SSC, the peak responses obtained from these two methods should be compared, to demonstrate approximate equivalency between the two methods.	12. Not applicable. The response spectrum analysis method is not used.
13. <u>Analysis Procedure for Damping</u>. Either the composite modal damping approach or the modal synthesis technique can be used to account for element-associated damping. Use of composite modal damping for computing the response of systems with nonclassical modes may lead to unconservative results (Miller, et al., 1985). Therefore, the composite modal damping approach is acceptable provided the composite modal damping is limited to 20 percent. One of the other methods mentioned below is generally applicable if the composite modal damping exceeds 20 percent. A. Time domain analysis using complex modes/frequencies, B. Frequency domain analysis, or C. Direct integration of uncoupled equation of motion. For the composite modal damping approach, two techniques of determining an equivalent modal damping matrix or composite damping matrix are commonly used. They are based on the use of the mass or stiffness as a weighting function in generating the composite modal damping. The formulations lead to:	13. The SSI analysis was performed in the frequency domain using the program ACS SASSI. The full effects of the damping were included in the frequency domain analysis with no limitation.

$$\bar{\beta}_j = \{\phi\}^T [\bar{M}] \{\phi\} \qquad (1)$$

$$\beta_j = \frac{\{\phi\}^T [\bar{K}] \{\phi\}}{K^*} \qquad (2)$$

where

$K^* = \{\phi\}^T [K] \{\phi\}$,

$[K]$ = assembled stiffness matrix,

$\bar{\beta}_j$ = equivalent modal damping ratio of the jth mode,

$[\bar{K}], [\bar{M}]$ = the modified stiffness or mass matrix constructed from element matrices formed by the product of the damping ratio for the element and its stiffness or mass matrix, and

$\{\phi\}$ = jth normalized modal vector.

For models that take SSI into account by the lumped soil spring approach, the method defined by equation (2) is acceptable. For fixed base models, either equation (1) or (2) may be used. Other techniques based on modal synthesis have been developed and are particularly useful when more detailed data on the damping characteristics of structural subsystems are available. The modal synthesis analysis procedure consists of (1) extraction of sufficient modes from the structure model, (2) extraction of sufficient modes from the finite element soil model, and (3) performance of a coupled analysis using the modal synthesis technique, which uses the data obtained in steps (1) and (2) with appropriate damping ratios for structure and soil subsystems. This method is based upon satisfaction of displacement compatibility and force equilibrium at the system interfaces and uses subsystem eigenvectors as internal generalized coordinates. This method results in a nonproportional damping matrix for the composite structure, and equations of motion have to be solved by direct integration or by uncoupling them by use of complex eigenvectors.

Other techniques for estimating the equivalent modal damping of a SSI model are reviewed on a case-by-case basis.

14. <u>Determination of Seismic Overturning Moments and Sliding Forces for Seismic Category I Structures</u>. To be acceptable, the determination of the design overturning moment and sliding force should incorporate the following items: A. Three components of input motion. B. Conservative consideration of the simultaneous action of vertical and horizontal seismic forces.	14. Seismic overturning moments and sliding forces were calculated for Turbine Building based on fixed-base condition only.