REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**183-8197**
SRP Section:	**03.07.02 – Seismic System Analysis**
Application Section:	**3.7.2**
Date of RAI Issue:	**08/31/2015**

Question No. 03.07.02-2

10 CFR 50 Appendix S requires that the safety functions of structures, systems, and components (SSCs) must be assured during and after the vibratory ground motion associated with the safe shutdown earthquake (SSE) ground motion through design, testing, or qualification methods. In accordance with 10 CFR 50 Appendix S, the staff reviews the adequacy of the seismic analysis methods used to demonstrate that SSCs can withstand seismic loads and remain functional. Per the guidance in SRP Section 3.7.2.II.12, if both the time history analysis (THA) method and the response spectrum analysis (RSA) method are used to analyze an SSC, the peak responses obtained from these two methods should be compared, to demonstrate approximately equivalency between the two methods. The comparison of the RSA and the THA methods is also important since the RSA method only utilizes the translational response spectra at the basemat of the NI as input to the containment and containment internal structures without consideration of the rotational input at the basemat. Staff review finds that while DCD Sections 3.7.2.1.1 and 3.7.2.1.2 identify the RSA and THA methods, respectively, as methods used in the analysis/design of APR1400 standard plant structures, a comparison between the peak responses obtained from these methods is not provided. Further, the staff finds that DCD Section 3.7.2.11, Comparison of Responses, is inconsistent with DCD Section 3.7.2.1.1. Specifically, DCD Section 3.7.2.1.1 states that RSA is used to compute the seismic design forces of the containment structure and internal structure in the reactor containment building using the in- structure response spectra (ISRS) at the top of basemat generated from seismic soil-structure interaction (SSI) analysis. However, DCD Section 3.7.2.11 states that only the THA method based on complex frequency response method is used for seismic Category I structures, and comparison with the RSA method is not applicable. Further, DCD Table 3.7-9, Summary of Models and Analysis Methods, state that maximum member forces and moments for the Nuclear Island (NI) are obtained from SASSI. Additionally this table does not identify the RSA as an analysis method used for the APR1400 standard plant.

Staff review also finds inconsistent information regarding the description of the analysis methods used for the auxiliary building (AB) and emergency diesel generator building (EDGB)/diesel fuel oil tank (DFOT). Specifically, while DCD Table 3.7-9 states that maximum member forces and moments for the NI (which includes the AB) and EDGB/DFOT are obtained from the SASSI analysis, DCD Sections 3.8A.2.3.1 and 3.8A.3.3.1, for the AB and EDGB respectively, indicate that an equivalent static method of analysis is performed to obtain the member forces for these structures. Further, DCD Table 3.7-9, does not identify the equivalent static method as an analysis method used for the APR1400 standard plant.

In addition, DCD Section 3.7.2.1 also describes the time history modal superposition method of analysis. However, DCD Table 3.7-9 does not identify such analysis. Based on the above, in order to assist the staff in assessing whether the acceptance criteria in SRP Section 3.7.2 II.12 have been adequately addressed, and to assist the staff in reviewing the adequacy of the analysis methods used for seismic Category I structures and the use of the respective analysis results, the applicant is requested to provide the following additional information.

a) Per SRP Section 3.7.2 II.12, provide comparisons between time history and response spectrum analysis results for the containment structure and containment internal structure and correct the inconsistencies between DCD Sections 3.7.2.1 and 3.7.2.11 regarding the use of the RSA method.

b) Update DCD Table 3.7-9 to show all the seismic analysis methods used for seismic Category I structures (including seismic analysis methods used for seismic design) and clearly identify the analysis model (including damping values used and consideration of uncracked and cracked stiffnesses), analysis method, computer program, purpose of the analysis, type of building response(s) (e.g., ISRS, member forces, displacements), and section in the DCD and/or technical reports where these are explained and figures are given for each respective model. This table should include the use of multiple models for structures such as the containment, which utilizes the global model, partial model, and containment basemat model. Further, correct inconsistencies between the information in Table 3.7-9 and respective DCD sections related to the NI and EDGB/DFOT structures, such as those mentioned above.

c) As applicable, delete DCD descriptions of analysis methods that are not currently used in the analysis of seismic Category I SSCs. As an example, while DCD Section 3.7.2.1.2 describes the time history modal superposition method of analysis, the staff has not been able to identify in the DCD and/or technical reports where this method of analysis is used. If it is used or is a candidate for use in the analysis of seismic Category I systems and components, identify the applications.

<u>Response – (Rev. 1)</u>

a) Time history analysis (THA) is used only for the seismic analysis subjected to the SSE ground motions to generate in-structure response spectra and story shear forces. As described in the end of DCD Tier 2, Subsection 3.7.2.1.1, the response spectrum analysis (RSA) method is used to compute the seismic design forces in DCD Tier 2, Section 3.8 using the in-structure response spectra generated from the seismic soil-structure interaction analysis results. To avoid confusion regarding the use of the RSA method, DCD Tier 2, Subsection 3.7.2.1 will be revised, as indicated in the attachment associated with this response.

The story shear forces of the containment structure and the containment internal structure obtained from RSA are compared to the THA (i.e., SASSI analysis) results in Table 1, below. DCD Tier 2, Subsection 3.7.2.11 and technical report APR1400-E-S-NR-14003-P will be revised, as indicated in the attachment associated with this response, to incorporate the comparison results of the story shear forces.

Table 1. Comparison of Story Shear Forces between RSA and THA Methods

Structure	Elevation (ft)	Story Shear Force (kips)						Difference Ratio (b/a)		
		THA Method (a)			RSA Method (b)					
		Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz
CS	307.5	11954	12241	11689	11901	12855	15346	1.00	1.05	1.31
	281	23050	23652	21865	23785	25697	29413	1.03	1.09	1.35
	254.5	30470	31470	28875	33974	36713	41720	1.12	1.17	1.44
	241	34593	35860	32942	38645	41774	47816	1.12	1.16	1.45
	220	45434	47225	41715	47353	51106	59609	1.04	1.08	1.43
	200	51174	53268	48421	52462	56667	66986	1.03	1.06	1.38
	178	55865	58228	54609	57699	62448	74805	1.03	1.07	1.37
	156	59594	62051	59996	61757	66790	80814	1.04	1.08	1.35
	136	61628	65537	63572	66018	71405	87120	1.07	1.09	1.37
	125	62546	67161	64893	67211	72710	88878	1.07	1.08	1.37
	114	64974	70071	67263	68705	74329	91092	1.06	1.06	1.35
	100	66601	72022	69076	69685	75374	92542	1.05	1.05	1.34
	78	67954	73819	70984	70311	76021	93534	1.03	1.03	1.32
CIS	191	241	264	139	533	574	331	2.21	2.17	2.38
	156	7466	9499	5140	12507	10218	13281	1.68	1.08	2.58
	136.5	15585	12707	12917	19687	15713	19331	1.26	1.24	1.50
	130	18693	14400	16558	23305	19028	23162	1.25	1.32	1.40
	114	22481	16947	21329	30378	25947	30014	1.35	1.53	1.41
	100	25806	20022	26346	36058	30668	34014	1.40	1.53	1.29
	78	34098	31075	39020	47110	39472	41051	1.38	1.27	1.05
	66	34529	31630	39613	47434	39816	41728	1.37	1.26	1.05

b) The seismic analysis models/methods for the SSI analyses are different from the structural analysis models/methods for seismic load and design. For clarification, DCD Tier 2, Table 3.7-9 will be revised and Table 3.8A-40, with its description in Subsection 3.8A.1.4.1.3.1, will be added.

c) DCD Tier 2, Subsection 3.7.2.1.2 describes seismic analysis methods that are used not only in the seismic Category I systems, but also in the seismic Category I subsystems, such as the RCS components and piping systems. DCD Tier 2, Subsection 3.7.2.1.2 will be revised to clarify that the time history modal superposition method is a candidate for use in the analysis of seismic Category I structures, systems, and components.

Impact on DCD

DCD Tier 2, Subsections 3.7.2.1, 3.7.2.1.2, 3.7.2.11, 3.8A.1.4.1.3.1 and Table 3.7-9 will be revised, and Table 3.8A-40 will be added, as indicated in the attachment associated with this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical report APR1400-E-S-NR-14003-P/NP will be revised, as indicated in the attachment associated with this response.

λ_j = damping ratio for the jth mode expressed as fraction of critical damping

ω_j = circular frequency of the jth mode of the system

Γ_j = modal participation factor of the jth mode = $\frac{\{\emptyset_j\}^T\{M\}\{1\}}{\{\emptyset_j\}^T\{M\}\{\emptyset_j\}}$

The generalized maximum response of each mode is determined from:

$$Y_j(\max) = \Gamma_j \frac{S_{aj}}{\omega_j}$$

Where:

S_{aj} is the spectral acceleration corresponding to frequency ω_j.

The maximum displacement at node i relative to the base due to mode j is:

$$X_{ij}(\max) = \phi_{ij} Y_j(\max)$$

The modal response X_{ij}(max) is used to determine other modal response quantities, such as forces. The modal combination method is used to obtain the final response by the methods described in Subsection 3.7.2.7.

in Subsection 3.8.1.4.4, 3.8.3.4.1, and Appendix 3.8A

Response spectrum analysis is used to compute only the seismic design forces of the containment structure and internal structure in the reactor containment building using the in-structure response spectra at the top of basemat generated from seismic soil-structure interaction analysis. The seismic response forces obtained from the response spectrum analysis are then combined with other design loads to design structural members of the containment structure and internal structure.

3.7.2.1.2 <u>Time-History Methods</u>

The solution of the equation of motion given in Subsection 3.7.2.1.1 is obtained using one of three methods: modal superposition, direct integration, or complex frequency response in the frequency domain.

The method utilizes mode superposition or direct integration for time-history analysis and is used for as an alternative analysis option for seismic Category I systems and subsystems. The seismic responses of the systems and subsystems that are seismic Category I SSCs are obtained using the finite element method. The analyses of all of the systems are performed for three orthogonal (two horizontal and one vertical) components of in-structure response time histories at the points of attachment.

Modal Superposition Method

The modal superposition method is used when the equations of motion can be decoupled as given in Subsection 3.7.2.1.1. Then the decoupled equation of motion for each mode is integrated using a proven technique, such as those listed in Table 3.2-1 of ASCE 4-98 (Reference 12) and the total response is obtained by superposition method.

The modal superposition method may be used in dynamic analyses of seismic Category I SSCs.

Direct Integration Method

In this method, the direct integration of the equations of motion by implicit or explicit methods of numerical integration is used to solve the equations of motion. In general implicit methods, ΔT is not larger than 1/10 of the shortest period of interest. The direct integration method is used to validate coarse mesh model to be used in the seismic analysis of the nuclear island structures versus fine mesh model under the fixed-base condition.

Complex Frequency Response Method

The equation of motion can also be solved in the frequency domain using the complex frequency response method. In this method, the transfer functions are first determined and the applied forces are then transformed into the frequency domain. The fast Fourier transform (FFT) algorithm is commonly used for the transformation between the time domain and frequency domain. To facilitate the FFT operation, the total number of digitized points of the excitation time history that is used is a power of 2, which can be achieved by a process known as zero padding, which involves adding trailing zeros to the input ground motion. For damped systems, the trailing zeros also serve as a quiet zone, which allows the transient response motions to die out at the end of the duration to avoid cyclic overlapping in the discrete Fourier transform procedure.

The selected locations where the floor response spectra are obtained in analysis models and resultant floor response spectra enveloping the 20 analysis cases for the nuclear island structures are provided in Technical Report, APR1400-E-S-NR-14003-P (Reference 22).

3.7.2.9 Use of Constant Vertical Static Factors

The safety-related main structural systems are analyzed in the vertical direction using the methods described in Subsection 3.7.2.1. The vertical component is considered to occur simultaneously with the two horizontal components and consistently combined with the horizontal components of the seismic motion as described in Subsection 3.7.2.6. Therefore, a constant vertical static factor is not used for the seismic design of seismic Category I structures.

3.7.2.10 Methods Used to Account for Torsional Effects

Because the structural models used for seismic Category I structures are constructed with finite elements containing 6 degrees of freedom per node, incorporating torsional effects into the models, the mathematical models include sufficient mass points and corresponding dynamic degrees of freedom to provide a three-dimensional representation of the dynamic characteristics of the structure.

Torsional effects are also accounted for in the structural models used to generate floor response spectra. An additional eccentricity of 5 percent of the maximum building dimension, perpendicular to load direction that results in an accidental torque, is applied to the static finite element structural model to calculate element forces due to accidental torsion. Accidental torsion is considered in both the E-W and N-S directions.

3.7.2.11 Comparison of Responses

~~Since only the time-history analysis method based on complex frequency response method, is used for the seismic Category I structures, comparison of the responses between the time-history analysis method and the response analysis spectrum method is not applicable.~~

The time-history analysis method based on complex frequency response method is used for the seismic analysis of seismic Category I structures. The response spectrum analysis is used to compute the seismic design forces of the containment structure and internal structure in the reactor containment building using the in-structure response spectra at the top of the basemat generated from the seismic soil-structure interaction analysis. The responses from these two methods are compared and provided in Technical Report, APR1400-E-S-NR-14003-P (Reference 22).

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Table 3.7-9 (1 of 2)

Revise to Table in next page.

Summary of Models and Analysis Methods

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
Reactor containment building fine-mesh model	• Modal analysis • Direct integration time-history analysis	ANSYS	To verify the mesh sizes of reactor containment building coarse-mesh model
Auxiliary building fine-mesh model	• Modal analysis • Direct integration time-history analysis	ANSYS	To verify the mesh sizes of auxiliary building coarse-mesh model
Reactor containment building coarse-mesh model	• Modal analysis • Direct integration time-history analysis	ANSYS	To create and verify SASSI reactor containment building model
Auxiliary building coarse-mesh model	• Modal analysis • Direct integration time-history analysis	ANSYS	To create and verify SASSI auxiliary building model
SASSI reactor containment building model	• Complex frequency response analysis	ACS SASSI	To create SASSI combined nuclear island model
SASSI auxiliary building model	• Complex frequency response analysis	ACS SASSI	To create SASSI combined nuclear island model
SASSI combined nuclear island model	• Complex frequency response analysis	ACS SASSI	• To perform seismic analyses for nine generic soils and one fixed-base case • To develop time histories for generating plant design in-structure response spectra • To obtain maximum absolute nodal acceleration • To obtain maximum displacements relative to basemat and free-field • To obtain maximum member forces and moments

Table 3.7-9 (1 of 2)

Summary of Models and Analysis Methods

Model	Analysis Method/Damping	Program	Type of Dynamic Response/Purpose	DCD/TeR Subsections
Reactor containment building fine-mesh model for seismic analysis (Uncracked stiffness model)	• Modal analysis • Direct integration time- history analysis • OBE damping	ANSYS	To verify the mesh sizes of the reactor containment building coarse-mesh model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 3
Auxiliary building fine-mesh model for seismic analysis (Uncracked stiffness model)	• Modal analysis • Direct integration time- history analysis • OBE damping	ANSYS	To verify the mesh sizes of the auxiliary building coarse-mesh model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 4
Reactor containment building coarse-mesh model for seismic analysis (Uncracked stiffness model)	• Modal analysis • Direct integration time- history analysis • OBE damping	ANSYS	To create and verify the SASSI reactor containment building model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 3
Auxiliary building coarse-mesh model for seismic analysis (Uncracked stiffness model)	• Modal analysis • Direct integration time- history analysis • OBE damping	ANSYS	To create and verify the SASSI auxiliary building model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 4
SASSI reactor containment building model for seismic analysis (Uncracked stiffness model)	• Complex frequency response analysis • OBE damping	ACS SASSI	To create the SASSI combined nuclear island model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 5
SASSI auxiliary building model for seismic analysis (Uncracked stiffness model)	• Complex frequency response analysis • OBE damping	ACS SASSI	To create the SASSI combined nuclear island model for seismic analysis	Technical Reprot APR1400-E-S-NR-14002-P, Section 5
SASSI combined nuclear island model for seismic analysis (Cracked and uncracked stiffness models)	• Complex frequency response analysis • OBE damping for uncracked stiffness model • SSE damping for cracked stiffness model	ACS SASSI	• To perform seismic analyses for nine generic soil profiles and one fixed-base case • To develop time histories for generating plant design in-structure response spectra • To obtain maximum absolute nodal acceleration • To obtain maximum displacements relative to the basemat and the free-field • To obtain maximum story shear forces and moments	Technical Reprot APR1400-E-S-NR-14002-P, Section 6

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Revise to Table in next page.

Table 3.7-9 (2 of 2)

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
EDG building (include DFOT room) model	Modal analysis	GTSTRUDL	• To create and verify SASSI EDG building (including DFOT room) model
SASSI EDG building (include DFOT room) model	• Complex frequency response analysis	ACS SASSI	• To perform seismic analyses for nine generic soils and one fixed-base case • To develop time histories for generating plant design in-structure response spectra • To obtain maximum absolute nodal acceleration • To obtain maximum displacements relative to basemat and free-field • To obtain maximum member forces and moments

Table 3.7-9 (2 of 2)

Model	Analysis Method/Damping	Program	Type of Dynamic Response/Purpose	DCD/TeR Subsections
EDG building (include DFOT room) model for seismic analysis (Uncracked stiffness model)	• Modal analysis • OBE damping	GTSTRUDL	• To create and verify the SASSI EDG building (include DFOT room) model for seismic analysis	DCD Tier 2, Subsection 3.7.2.3.3.2
SASSI EDG building (include DFOT room) model for seismic analysis (Cracked and uncracked stiffness models)	• Complex frequency response analysis • OBE damping for uncracked stiffness model • SSE damping for cracked stiffness model	ACS SASSI	• To perform seismic analyses for nine generic soil profiles and one fixed-base case • To develop time histories for generating plant design in-structure response spectra • To obtain maximum absolute nodal acceleration • To obtain maximum displacements relative to the basemat and the free-field • To obtain maximum story shear forces and moments	DCD Tier 2, Subsection 3.7.2.3.3.2

liner plate is not designed as a structural member to resist structural loads on the containment. It is, therefore, not included in the FEM.

The computer programs described in Section 3.8 are summarized in the Table 3.8A-40.

Table 3.8A-40 shows the types of models, analysis methods, computer programs, and purposes of the structural analyses of the nuclear island structures, the emergency diesel generator building, and the diesel fuel oil storage tank building.

The acceptance criteria for the design of the containment wall and dome are defined based on the requirements in Article CC-3000 of ASME Section III, Division 2, and described in Subsection 3.8.1.5. Table 3.8A-1 shows the allowable stresses of concrete and reinforcing steel for service and factored loads, respectively.

3.8A.1.4.1.3.2 Analysis Model

Configuration of Containment Wall and Dome

The overall configuration of the containment wall and dome is shown in Figures 3.8-1 and 3.8-2. The representative dimensions of the containment wall and dome are as follows:

a. Inside diameter of the containment wall: 45.72 m (150.0 ft)

b. Inside height from the top of basemat to the dome apex: 76.66 m (251.5 ft)

c. Height from the top of the basemat to the springline: 53.80 m (176.5 ft)

d. Thickness of the containment wall: 1.37 m (4.5 ft)

e. Thickness of the containment dome: 1.22 m (4.0 ft)

An equipment hatch, two personnel airlocks, main steam line penetrations, and three buttresses are included in the analysis model. The locally thickened sections around the equipment hatch and personnel airlock are shown in Figure 3.8-3.

Global Model

The global model consists of solid elements for the concrete, truss elements for the tendon, and shell elements for the brackets of the polar crane. An eight-node, linear, solid element (SOLID185) in the ANSYS program is used to model the concrete part of containment wall and dome, including large thickened penetration areas and buttresses. Figure 3.8A-1 shows the schematic view of equipment hatch and personnel airlocks in the FEM. The basemat of

Table 3.8A-39

EDG & DFOT buildings Differential Settlements According to Site Profiles (Static)

Location	Node #1	Node #2	Distance (ft)	Differential Settlement (inches)		
				Soil #1	Soil #4	Soil #8
EDG	4451	4036	41.291	0.177	0.101	0.042
	4036	4774	36.867	0.175	0.032	0.030
	4036	131	47.734	0.151	0.076	0.029
	4036	97	47.734	0.075	0.002	0.015
	131	8308	47.734	0.148	0.074	0.029
	8308	97	47.734	0.078	0.004	0.015
	8308	8678	41.291	0.178	0.101	0.042
	8308	8953	41.291	0.044	0.026	0.031
	4460	8923	33.253	0.032	0.006	0.002
Total Max. Differential Settlement				0.178	0.101	0.042
DFOT	5876	794	45.881	0.233	0.078	0.009
	5860	7068	25.836	0.199	0.073	0.013
	5858	7066	25.836	0.266	0.094	0.015
	63	304	26.023	0.164	0.038	0.007
	5881	5861	26.023	0.235	0.063	0.004
	76	7061	25.836	0.284	0.110	0.021
	5858	7059	25.836	0.207	0.081	0.016
	107	6027	26.023	0.150	0.026	0.012
	63	5872	26.023	0.223	0.052	0.008
	6479	6581	14.916	0.148	0.054	0.009
	6604	6509	14.916	0.138	0.044	0.003
Total Max. Differential Settlement				0.284	0.110	0.021

New Table Added (3.8A-40)

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Add Table.

Table 3.8A-40 (1 of 3)

Summary of Models and Analysis Methods

Model	Analysis Method	Program	Purpose	DCD/TeR Subsections
Reactor containment building analysis model (Uncracked stiffness model)	• Modal analysis • Response spectrum analysis (SSE damping) • Static analysis • Heat transfer analysis	ANSYS	To generate the design forces of the reactor containment building shell and dome	DCD Tier 2, Subsection 3.8.1.4.2
Reactor containment building internal structure model (Uncracked stiffness model)	• Modal analysis • Response spectrum analysis • Static analysis • SSE damping	ANSYS	To generate the design forces of the reactor containment building internal structure walls	DCD Tier 2, Subsection 3.8A.3.4.1
Reactor containment building - IRWST hydro-dynamic analysis model (Uncracked stiffness model)	• Direct integration time history analysis	ANSYS	To generate the floor response spectrum due to the POSRV sparger discharge load	DCD Tier 2, Subsection 3.8A.1.4.3.1.3
NI building common basemat analysis model (Uncracked stiffness model)	• Static analysis • Nonlinear Analysis	ANSYS	To generate the design forces of the NI common basemat	DCD Tier 2, Subsection 3.8.5.4
Auxiliary building structural analysis model	• Static analysis • Equivalent static analysis	ANSYS	To generate the design forces of the auxiliary building shear walls	DCD Tier 2, Subsection 3.8.4.4
Auxiliary building - SFP hydro-dynamic analysis model (Uncracked stiffness model)	• Modal analysis • Static analysis	ANSYS	To create the auxiliary building SFP hydro-dynamic force	DCD Tier 2, Subsection 3.8A.2.4.2
Auxiliary building - SFP, local analysis model (Uncracked stiffness model)	• Heat transfer analysis • Static analysis	ANSYS	To generate the design forces of the auxiliary building SFP walls	DCD Tier 2, Subsection 3.8A.2.4.2
Auxiliary building - aux. feed water storage tank hydro-dynamic analysis model (Uncracked stiffness model)	• Modal analysis • Static analysis	ANSYS	To create the auxiliary building AFWT hydro-dynamic force	DCD Tier 2, Subsection 3.8A.2.4.2

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Table 3.8A-40 (1 of 2)

Summary of Models and Analysis Methods

Model	Analysis Method	Program	Purpose	DCD/TeR Subsections
Reactor containment building analysis model (Uncracked stiffness model)	• Modal analysis • Response spectrum analysis (SSE damping) • Static analysis • Heat transfer analysis	ANSYS	To generate the design forces of the reactor containment building shell and dome (e,g dead, live, seismic thermal load, etc.)	DCD Tier 2, Subsection 3.8A.1.4.1
Reactor containment building internal structure model (Uncracked stiffness model)	• Modal analysis • Response spectrum analysis (SSE damping) • Static analysis	ANSYS	To generate the design forces of the reactor containment building internal structure walls (e,g dead, live, seismic thermal load, etc.)	DCD Tier 2, Subsection 3.8A.1.4.3
Reactor containment building - IRWST hydro-dynamic analysis model (Uncracked stiffness model)	• Direct integration time history analysis	ANSYS	To generate the floor response spectrum due to the POSRV sparger discharge load	DCD Tier 2, Subsection 3.8A.1.4.3.1.3
NI building common basemat analysis model (Uncracked stiffness model)	• Nonlinear Analysis	ANSYS	To generate the design forces of the NI common basemat (e,g dead, live, seismic load, etc.)	DCD Tier 2, Subsection 3.8A.1.4.2, 3.8A.2.4.1
Auxiliary building structural analysis model	• Static analysis (Equivalent static method)	ANSYS	To generate the design forces of the auxiliary building shear walls (e,g dead, live, seismic load, etc.)	DCD Tier 2, Subsection 3.8A.2.3, 3.8A.2.4.2
Auxiliary building - SFP hydro-dynamic analysis model (Uncracked stiffness model)	• Modal analysis • Static analysis	ANSYS	To create the auxiliary building SFP hydro-dynamic force	DCD Tier 2, Subsection 3.8A.2.4.2
Auxiliary building - SFP, local analysis model (Uncracked stiffness model)	• Heat transfer analysis • Static analysis	ANSYS	To generate the design forces of the auxiliary building SFP walls	DCD Tier 2, Subsection 3.8A.2.4.2
Auxiliary building - aux. feed water storage tank hydro-dynamic analysis model (Uncracked stiffness model)	• Modal analysis • Static analysis	ANSYS	To create the auxiliary building AFWT hydro-dynamic force	DCD Tier 2, Subsection 3.8A.2.4.2

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Add Table.

Table 3.8A-40 (2 of 3)

Model	Analysis Method	Program	Purpose	DCD/TeR Subsections
Emergency diesel generator building structural analysis model (Uncracked stiffness model)	• Static analysis • Equivalent static analysis • Nonlinear Analysis	ANSYS	To generate the design forces of the emergency diesel generator building shear walls	DCD Tier 2, Subsection 3.8.4.4
Diesel fuel oil storage tank building structure analysis model (Uncracked stiffness model)	• Static analysis • Equivalent static analysis • Nonlinear analysis	ANSYS	To generate the design forces of the diesel fuel oil storage tank building shear walls	DCD Tier 2, Subsection 3.8.4.4
Reactor containment building – combustible gas control inside containment analysis model (Uncracked stiffness model)	• Static analysis • Nonlinear analysis	ABAQUS	To evaluate the structural integrity of the reactor containment building under severe accident pressure in accordance with ASME CC-3720	DCD Tier 2, Subsection 3.8.1.4.12
Reactor containment building - ultimate pressure capacity analysis model	• Static analysis • Nonlinear analysis	ABAQUS	To evaluate the ultimate pressure capacity of the reactor containment building	DCD Tier 2, Subsection 3.8.1.4.11
Reactor containment building - reinforced concrete section model	• Static analysis	DARTEM	To calculate stress and strain of reinforced concrete sections under mechanical and temperature loads	DCD Tier 2, Subsection 3.8A.1.4.1.3.7, 3.8A.1.4.2.3
Auxiliary building - SFP reinforced concrete section model	• Static analysis	DARTEM	To calculate stress and strain of reinforced concrete sections under mechanical and temperature loads	DCD Tier 2, Subsection 3.8A.2.4.2, 3.8A.2.4.3
Reactor containment building - liner plate anchorage system model	• Static analysis	LBAP	To calculate maximum anchor forces and displacements in the liner anchorage systems attached to concrete walls	Not described in DCD
Reactor containment building - liner plate model	• Static analysis	GTSTRUDL	To calculate stresses of the liner plate system	Not described in DCD
Reactor containment building - liner plate model	• Static analysis	ABAQUS	To calculate stresses of the liner plate system	Not described in DCD

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Model	Analysis Method	Program	Purpose	DCD/TeR Subsections
Emergency diesel generator building structural analysis model (Uncracked stiffness model)	• Static analysis (Equivalent static method) • Nonlinear Analysis	ANSYS	To generate the design forces of the emergency diesel generator building shear wall and basemat (e,g dead load, live load, seismic load, etc.)	DCD Tier 2, Subsection 3.8A.3.4.1, 3.8A.3.4.2
Diesel fuel oil storage tank building structure analysis model (Uncracked stiffness model)	• Static analysis (Equivalent static method) • Nonlinear analysis	ANSYS	To generate the design forces of the diesel fuel oil storage tank building shear wall and basemat (e,g dead load, live load, seismic load, etc.)	DCD Tier 2, Subsection 3.8A.3.4.1, 3.8A.3.4.2
Reactor containment building – combustible gas control inside containment analysis model (Uncracked stiffness model)	• Nonlinear analysis	ABAQUS	To evaluate the structural integrity of the reactor containment building under severe accident pressure in accordance with ASME CC-3720	DCD Tier 2, Subsection 3.8.1.4.12
Reactor containment building - ultimate pressure capacity analysis model	• Nonlinear analysis	ABAQUS	To evaluate the ultimate pressure capacity of the reactor containment building	DCD Tier 2, Subsection 3.8.1.4.11
Reactor containment building - reinforced concrete section model	• Static analysis	DARTEM	To calculate stress and strain of reinforced concrete sections under mechanical and temperature loads	DCD Tier 2, Subsection 3.8A.1.4.1.3.7, 3.8A.1.4.2.3
Auxiliary building - SFP reinforced concrete section model	• Static analysis	DARTEM	To calculate stress and strain of reinforced concrete sections under mechanical and temperature loads	DCD Tier 2, Subsection 3.8A.2.4.2, 3.8A.2.4.3
Reactor containment building - liner plate anchorage system model	• Static analysis	LBAP	To calculate maximum anchor forces and displacements in the liner anchorage systems attached to concrete walls	DCD Tier 2, Subsection 3.8.1.4.10
Auxiliary building – concrete slab analysis model	• Static analysis	GTSTRUDL	To generate the design forces for the concrete slabs of the auxiliary building	DCD Tier 2, Subsection 3.8A.2.4.3

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Table is deleted. Add Table.

Table 3.8A-40 (3 of 3)

Model	Analysis Method	Program	Purpose	DCD/TeR Subsections
Reinforced concrete section model for Steam Generator pedestal	• Static analysis	PCACOL	To evaluate the capacity of concrete pedestal under axial and moment loads	Not described in DCD
Analysis model for Steam Generator bracket support	• Static analysis	GTSTRUDL	To calculate stress of bracket support under design and service leve D condition	Not described in DCD
Emebedment plate analysis model for Steam Generator keyway support	• Static analysis	EPAAD	To evaluate the structural integrity of the emebedment for Steam Generator keyway support	Not described in DCD
Emebedment plate analysis model for Pressurizer keyway support beam	• Static analysis	EPAAD	To evaluate the structural integrity of the emebedment for Pressurizer keyway support beam	Not described in DCD
Reactor containment building – concrete slab analysis model	• Static analysis	GTSTRUDL	To generate the design forces for the concrete slabs of the reactor containment building	Not described in DCD
Auxiliary building – concrete slab analysis model	• Static analysis	GTSTRUDL	To generate the design forces for the concrete slabs of the auxiliary building	DCD Tier 2, Subsection 3.8A.2.4.3

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(5) The basemat rotation about the coordinate axis *"q"* due to seismic input in the direction *"p,"* designated by the symbol $R^{p}_{\theta q}(f_j)$, can be computed as follows:

$$R^{p}_{\theta q}(f_j) = [\ H^{d}_{Z}(f_j)^{A}_{q} - H^{d}_{Z}(f_j)^{B}_{q}\ ] / D \qquad (6\text{-}10)$$

(6) For a designated nodal point *"i"* on a designated structure elevation *"l"* with height h_l, the transfer function of displacement relative to the basemat, designated as $H^{d}_{b}(f_j)^{q}_{p}$, can be computed from the transfer function of displacement relative to the free-field ground surface $H^{d}(f_j)^{q}_{p}$ computed at frequency f_j as follows:

$$H^{d}_{b}(f_j)^{q}_{p} = H^{d}(f_j)^{q}_{p} - R^{p}_{\theta q}(f_j) \times h_l \qquad (6\text{-}11)$$

(7) The transfer function of displacement relative to the basemat $H^{d}_{b}(f_j)^{q}_{p}$ computed from Eq. (6-11) at calculated frequency f_j can be interpolated and convolved with the seismic input time history in the direction *"p"* to generate the response time history $d^{q}_{bp}(t)$, from which the maximum absolute response value can be obtained, designated as $d^{q}_{bp\ \max}$. The maximum displacements relative to the basemat generated for the seismic input in all three directions can be combined using the SRSS combination rule to obtain the maximum displacements relative to the basemat due to all three directions of input, designated as $d^{q}_{b\ \max}$.

(8) The maximum displacements relative to the basemat $d^{q}_{b\ \max}$ generated for all nodal points on each designated elevation *"l"* are enveloped to give the enveloped maximum displacement relative to the basemat for the designated elevation for the response direction *"q."*

The maximum displacements relative to the basemat obtained from Step (5) above for all designated elevations in the RCB are tabulated in Appendix E in a format that is similar to that for the maximum displacements relative to the free-field ground surface.

6.4 Maximum Seismic Response Accelerations

The maximum seismic response absolute accelerations obtained as the zero period acceleration (ZPA) values for the designated structure elevations in the RCB and AB, for twenty (20) individual SASSI analysis cases, are tabulated in Appendix F. The ZPA values tabulated for each designated elevation in the tables in Appendix G are the values enveloped of the ZPA values obtained for all selected nodes on that elevation.

← Add Subsection 6.5 from the next page.

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6.5 Comparison of Story Shear Forces between THA (ACS SASSI Analysis) and RSA Results

The response spectrum analysis (RSA) is used to compute the seismic design forces of the CS and IS in the RCB using the in-structure response spectra at the top of the basemat generated from the seismic SSI analysis. To demonstrate approximate equivalency between the time-history analysis (THA) method based on complex frequency response method used in the SSI analysis and the RSA method, the story shear forces obtained from the two methods are compared and provided in Table 6-8. As indicated in the comparison results in Table 6-8, the story shear forces obtained from the RSA method are generally greater than those obtained from the THA method.

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Table 6-8

Comparison of Story Shear Forces between THA and RSA Methods

Structure	Elevation (ft)	Story Shear Force (kips)						Difference Ratio (b/a)		
		THA Method (a)			RSA Method (b)					
		Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz
CS	307.50	11954	12241	11689	11901	12855	15346	1.00	1.05	1.31
	281.00	23050	23652	21865	23785	25697	29413	1.03	1.09	1.35
	254.50	30470	31470	28875	33974	36713	41720	1.12	1.17	1.44
	241.00	34593	35860	32942	38645	41774	47816	1.12	1.16	1.45
	220.00	45434	47225	41715	47353	51106	59609	1.04	1.08	1.43
	200.00	51174	53268	48421	52462	56667	66986	1.03	1.06	1.38
	178.00	55865	58228	54609	57699	62448	74805	1.03	1.07	1.37
	156.00	59594	62051	59996	61757	66790	80814	1.04	1.08	1.35
	136.00	61628	65537	63572	66018	71405	87120	1.07	1.09	1.37
	125.00	62546	67161	64893	67211	72710	88878	1.07	1.08	1.37
	114.00	64974	70071	67263	68705	74329	91092	1.06	1.06	1.35
	100.00	66601	72022	69076	69685	75374	92542	1.05	1.05	1.34
	78.00	67954	73819	70984	70311	76021	93534	1.03	1.03	1.32
IS	191.00	241	264	139	533	574	331	2.21	2.17	2.38
	156.00	7466	9499	5140	12507	10218	13281	1.68	1.08	2.58
	136.50	15585	12707	12917	19687	15713	19331	1.26	1.24	1.50
	130.00	18693	14400	16558	23305	19028	23162	1.25	1.32	1.40
	114.00	22481	16947	21329	30378	25947	30014	1.35	1.53	1.41
	100.00	25806	20022	26346	36058	30668	34014	1.40	1.53	1.29
	78.00	34098	31075	39020	47110	39472	41051	1.38	1.27	1.05
	66.00	34529	31630	39613	47434	39816	41728	1.37	1.26	1.05