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.:	**249-8323**
SRP Section:	**03.08.01 – Concrete Containment**
Application Section:	**03.08.01**
Date of RAI Issue:	**10/14/2015**

Question No. 03.08.01-15

10 CFR 50.55a and Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50, provide the regulatory requirements for the design of the concrete containment. Standard Review Plan (SRP) Sections 3.8.1 and 3.8.5, Subsection II.4, discuss the requirements of the computer programs used in the design and analysis of safety-related structures.

APR1400 DCD Tier 2, Section 3.8.1.4.2, “Containment Structure,” identifies the use of the computer program ANSYS and DCD Section 3.8A.1.4.2.3, “Analysis and Design Procedures,” identifies the use of the computer program DARTEM. The applicant stated that “The calculated design forces and moments are used as input in the concrete section design program DARTEM for the design of flexural reinforcement and shear reinforcement.” The staff could not find any description in the DCD that validates and verify the use of this computer program. Therefore, per 10 CFR 50.55a; Appendix A to 10 CFR Part 50, General Design Criteria 1, 2, 4, 16 and 50; and SRP 3.8.1 and 3.8.5, the applicant is requested to identify if any other computer programs are utilized in the analysis and design of all seismic Category I structures, and for all programs utilized describe the computer program, identify what structural evaluations it is used for, and describe how they have been validated.

Additionally, DCD Section 3.8A, Table 3.8A-2, “Section Forces of Containment Wall Design Sections,” identifies six member forces used for the containment wall design sections. The applicant is requested to explain why only six member forces are given for design and why the in-plane shear forces are not also presented.

Response – (Rev. 1)

The computer programs, utilized in the analysis and design of Seismic Category I structures, are described in Table 1 of this response. Table 1 contains the program list, the analysis method, the model which is generated and analyzed by the program, the analysis scope including loads applied, and how the program has been validated. Table 1 will be included in

DCD as Table 3.8-11 with a brief description for the table which will be added in Subsection 3.8.1.4.1.

The DARTEM & LBAP programs in the table are verified and validated using a program which satisfies the requirements of SRP 3.8.1, Section II.4.F. DCD Tier 2, Subsection 3.8.1.4.5.2 and 3.8.1.4.10 will be revised, as indicated in the attachment associated with this response.

The section forces in DCD Tier 2, Table 3.8A-2 are based on the results of the structural analysis, and are used as input to DARTEM to check the stresses of concrete and reinforcing steel. In the process of converting the results of the structural analysis to DARTEM input, tangential shear force and torsional moment are added to the membrane force and flexural moment, respectively, in order to consider the effect of tangential shear force and torsional moment. The definitions of section forces in DCD Tier 2, Table 3.8A-2 will be revised, as shown on the attachment associated with this response.

Table 1 Computer Programs for Seismic Category I Structures

Program	Analysis Method	Analysis Model	Analysis Scope	Validation & Verification
ANSYS (E-P-CE-1327-14.0/DC)	• Modal analysis	• Reactor containment building (shell & dome, internal structure)	• Eigenvalue analysis	- ANSYS was procured with a Quality Assurance Service Agreement and meets the applicable requirements of the NQA-1, Subpart 2.7, quality assurance requirements of computer software.
		• Spent fuel pool & aux. feed water storage tank	• Eigenvalue analysis	
	• Response spectrum analysis	• Reactor containment building (shell & dome, internal structure)	• Structural analysis of seismic load for RCB	
	• Static analysis	• Reactor containment building (shell & dome, internal structure)	• Structural analysis of RCB for structure design (e.g, dead and live loads, etc.)	
		• Auxiliary building (including spent fuel pool, aux. feed water storage tank)	• Structural analysis of AB for structure design (e.g., dead and live loads, etc.) • Local analysis of spent fuel pool and aux. feed water storage tank (e.g., hydrostatic and hydrodynamic loads, etc.)	
		• Emergency diesel generator building	• Structure analysis of EDGB for structure design (e.g., dead and live loads, etc.)	
		• Diesel fuel oil storage tank building	• Structural analysis of DFOT for structure design (e.g., dead and live loads, etc.)	
	• Heat transfer analysis	• Reactor containment building (shell & dome)	• Temperature analysis	
		• Spent fuel pool	• Temperature analysis	
	• Nonlinear analysis	• NI common basemat	• Structural analysis of basemat for structure design considering nonlinear soil spring (compressive only spring, reaction of superstructures)	
		• Emergency diesel generator building basemat	• Sructure analysis of EDGB for structure design considering nonlinear soil spring (compressive only spring, reaction of superstructures)	
		• Diesel fuel oil storage tank building basemat	• Structural analysis of DFOT for structure design considering nonlinear soil spring (compressive only spring, reaction of superstructures)	

Program	Analysis Method	Analysis Model	Analysis Scope	Validation & Verification
ANSYS (E-P-CE-1327-14.0/DC) (cont.)	• Equivalent static analysis	• Auxiliary building (including spent fuel pool, aux. feed water storage tank)	• Structural analysis of seismic load for AB	
		• Emergency diesel generator building	• Structural analysis of seismic load for EDGB	
		• Diesel fuel oil storage tank building	• Structural analysis of seismic load for DFOT	
	• Direct integration time history analysis	• IRWST hydro-dynamic analysis	• Generation of floor response spectrum (FRS) due to POSRV sparger discharge load for mechanical and piping design	
ABAQUS (E-P-CE-1245-6.10)	• Nonlinear analysis	• Reactor containment building	• Ultimate pressure capacity evaluation corresponding to RG 1.216, Position 1 using nonlinear material model • Combustible gas control inside containment evaluation corresponding to RG 1.216, Position 2 using nonlinear material model	- ABAQUS is validated in accordance with the registration procedure for computer software of KEPCO E&C.
DARTEM (E-P-CE-1139-1.1)	• Static analysis	• Reactor containment building (shell & dome, internal structure, RCB basemat)	• Structural analysis and design of reinforced concrete section subjected to mechanical and thermal loads	- DARTEM is validated in accordance with the registration procedure for computer software of KEPCO E&C.
		• Auxiliary building (Spent fuel pool)	• Structural analysis and design of reinforced concrete section subjected to mechanical and thermal loads	
LBAP (E-P-CE-1138-2.0)	• Static analysis	• Reactor containment building (liner plate anchorage system)	• Structural analysis of liner plate anchorage system when liner plate buckled	- LBAP is validated in accordance with the registration procedure for computer software of KEPCO E&C.
GTstrudl (E-P-CE-1163-31)	• Static analysis	• Auxiliary building (concrete slab analysis model)	• Structural analysis to obtain design forces for concrete slab design (e.g, dead and live loads, etc.)	- GTstrudl was procured with a Quality Assurance Service Agreement and meets the applicable requirements of the NQA-1, Subpart 2.7, quality assurance requirements of computer software.

Impact on DCD

DCD Tier 2, Subsection 3.8.1.4.1, 3.8.1.4.5.2, 3.8.1.4.10, Table 3.8A-2 will be revised, and Table 3.8-11 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

There is no impact on any Technical, Topical, or Environmental Report.

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Throughout the analysis special attention is given to, the following areas of the containment:

a. Intersection between the basemat and the cylinder

b. Intersection between the cylinder and the dome

c. Areas around large penetrations

d. Areas around polar crane brackets

e. Behavior of the base slab relative to the underlying foundation material

f. Stresses due to transient temperature in the liner plate and concrete

g. Penetrations and points of concentrated loads

h. Buttresses

A typical section of the reactor containment building is shown in Figures 3.8-10 and 3.8-11.

The computer programs utilized in the analysis and design of seismic Category I structures are described in Table 3.8-11 and Table 3.8A-40.

3.8.1.4.2 Containment Structure

The ANSYS (Reference 9) computer program is used to analyze the containment for the loads defined in Subsection 3.8.1.3.2. The analysis results of these load case analyses are combined and factored using the loading combinations defined in Subsection 3.8.1.3.3.

The analysis model of the containment consists of the dome, cylindrical wall, and a part of the basemat. No other structures are physically connected to the containment structure; therefore, the basemat is the only interfacing part in the containment model. Subsection 3.8.5 describes the modeling of the common basemat structure.

A three-dimensional, eight-node solid element that is suitable for moderately thick shell structures is used to model the containment concrete dome and cylindrical wall. Five layers of solid elements through the thickness are used to model the dome and cylindrical wall. The buttresses and thickened areas around the large penetrations are included in the

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3.8.1.4.5 Transient and Localized Loads

3.8.1.4.5.1 Analysis of Areas of Containment Wall Supporting Polar Crane Brackets

The containment wall around the crane brackets is analyzed considering the effects of crane bracket reactions. To account for potential difference in the timing between containment construction and polar crane installation, two models are used for the analyses: the overall containment full model and a partial model with only the containment cylinder.

3.8.1.4.5.2 Thermal Stress Analysis

To analyze the containment for thermal gradients, the nonlinear temperature profile across the containment wall thickness is obtained through the transient heat analysis using the ANSYS program. The resultant forces and moments from the thermal stresses are applied to each design section along with other appropriate axial forces and moments due to mechanical loads acting simultaneously with the thermal loads.

The stresses in the concrete and reinforcing steel are checked, [by using the DARTEM program, which is verified and validated] taking into account the self-limiting effects of thermal moments due to concrete cracking.

3.8.1.4.6 Creep and Shrinkage Analysis

The effects of concrete creep, shrinkage, elastic shortening, and tendon steel relaxation are included in the computations for prestress losses in the tendons.

a. Concrete creep strain

   1) Vertical direction = 592×10^{-6} mm/mm (in/in)

   2) Horizontal direction = 930×10^{-6} mm/mm (in/in)

b. Concrete shrinkage strain = 120×10^{-6} mm/mm (in/in)

c. Poisson’s ratio = 0.17

by using the LBAP program, which is verified and validated

The liner anchorage system is analyzed, ~~which includes~~ calculating the force and deflection at anchorage points. The design of the liner anchorage conforms with the force and displacement allowables in Subarticle CC-3730 of Section III of the ASME Code.

For the structural design of containment liner plates, the stresses at formworks are calculated for basemat liner, shell liner, and dome liner, respectively. The lowest ratio of allowable stress to induced stress for each part is shown in Table 3.8-12 as margins of safety for the design.

3.8.1.4.11 Ultimate Pressure Capacity

The ultimate pressure capacity (UPC) of the containment is evaluated based on the design results of the structure. The UPC is estimated based on attaining a maximum global membrane strain away from discontinuities of 0.8 percent. This strain limit is applied to the tendons, rebars, and liner. When the pressure capacity contribution is calculated from the tendons, the above-specified strain limit is applied to the full range of strain. The UPC analysis is performed considering material nonlinear behaviors for the reinforced concrete.

The stress-strain curves for the reinforcing steel and tendon are based on the code-specified minimum yield strength. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendon, respectively. The stress-strain curves are developed for the design basis accident temperature.

The ultimate pressure capacity of the containment is a pressure of 1.269 MPa (184 psi) at which the maximum strain of the liner plate and horizontal tendon is approximately 0.8 percent.

3.8.1.4.12 Severe Accident Capability

The safety of the containment under severe accident conditions is assessed and demonstrated to conform with the allowable values in Subarticle CC-3720 of the ASME Code.

Based on the results of the analyses, all of the tendons and rebars are still in the elastic stage. At the maximum pressure loading level of the critical severe accident scenario, the

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Table 3.8A-2 (2 of 2)

Equipment Hatch

N_Φ (kip/ft)	M_Φ (kip-ft/ft)	$Q_{R\Phi}$ (kip/ft)	N_θ (kip/ft)	M_θ (kip-ft/ft)	$Q_{R\theta}$ (kip/ft)	Remark
633.51	-900.58	59.89	443.77	-582.97	107.87	Meridional Inside
633.51	1,391.59	59.89	443.77	1,347.08	107.87	Meridional Outside
327.89	-375.99	-62.95	984.87	-1,121.67	-39.04	Hoop Inside
400.38	1,127.27	-14.59	682.06	1,119.63	-10.57	Hoop Outside

Personnel Airlock

N_Φ (kip/ft)	M_Φ (kip-ft/ft)	$Q_{R\Phi}$ (kip/ft)	N_θ (kip/ft)	M_θ (kip-ft/ft)	$Q_{R\theta}$ (kip/ft)	Remark
742.23	-641.62	47.73	821.82	-538.01	17.70	Meridional Inside
596.38	1,586.38	66.48	830.83	687.51	38.89	Meridional Outside
595.99	-678.43	58.22	855.75	-615.76	-6.09	Hoop Inside
595.99	1,558.64	58.22	855.75	621.13	-6.09	Hoop Outside

N_Φ = Meridional Force ← with Tangential Shear Force

M_Φ = Meridional Moment ← with Torsional Moment

$Q_{R\Phi}$ = Meridional Radial Shear Force

N_θ = Hoop Force ← with Tangential Shear Force

M_θ = Hoop Moment ← with Torsional Moment

$Q_{R\theta}$ = Hoop Radial Shear Force

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Add Table 3.8-11 in the next pages to page 3.8-109 of DCD.

Table 3.8-11 (1 of 3)

Computer Programs for Seismic Category I Structures

Program	Analysis Method	Analysis Model	Analysis Scope	Validation & Verification
ANSYS	• Modal analysis	• Reactor containment building (shell & dome, internal structure)	• Eigenvalue analysis	- ANSYS was procured with a Quality Assurance Service Agreement and meets the applicable requirements of the NQA-1, Subpart 2.7, quality assurance requirements of computer software.
		• Spent fuel pool & aux. feed water storage tank	• Eigenvalue analysis	
	• Response spectrum analysis	• Reactor containment building (shell & dome, internal structure)	• Structural analysis of seismic load for RCB	
	• Static analysis	• Reactor containment building (shell & dome, internal structure)	• Structural analysis of RCB for structure design (e.g, dead and live loads, etc.)	
		• Auxiliary building (including spent fuel pool, aux. feed water storage tank)	• Structural analysis of AB for structure design (e.g., dead and live loads, etc.) • Local analysis of spent fuel pool and aux. feed water storage tank (e.g., hydrostatic and hydrodynamic loads, etc.)	
		• Emergency diesel generator building	• Structural analysis of EDGB for structure design (e.g., dead and live loads, etc.)	
		• Diesel fuel oil storage tank building	• Structural analysis of DFOT for structure design (e.g., dead and live loads, etc.)	
	• Heat transfer analysis	• Reactor containment building (shell & dome)	• Temperature analysis	
		• Spent fuel pool	• Temperature analysis	
	• Nonlinear analysis	• NI common basemat	• Structural analysis of basemat for structure design considering nonlinear soil spring (compressive only, reaction of superstructures)	
		• Emergency diesel generator building basemat	• Structural analysis of EDGB for structure design considering nonlinear soil spring (compressive only spring, reaction of superstructures)	

Table 3.8-11 (2 of 3)

Program	Analysis Method	Analysis Model	Analysis Scope	Validation & Verification
ANSYS (Cont.)	• Nonlinear analysis	• Diesel fuel oil storage tank building basemat	• Structural analysis of DFOT for structure design considering nonlinear soil spring (compressive only spring, reaction of superstructures)	
	• Equivalent static analysis	• Auxiliary building (including spent fuel pool, aux. feed water storage tank)	• Structural analysis of seismic load for AB	
		• Emergency diesel generator building	• Structural analysis of seismic load for EDGB	
		• Diesel fuel oil storage tank building	• Structural analysis of seismic load for DFOT	
	• Direct integration time history analysis	• IRWST hydro-dynamic analysis	• Generation of floor response spectrum (FRS) due to POSRV sparger discharge load for mechanical and piping design	
ABAQUS	• Nonlinear analysis	• Reactor containment building	• Ultimate pressure capacity evaluation corresponding to RG 1.216, Position 1 using nonlinear material model • Combustible gas control inside containment evaluation corresponding to RG 1.216, Position 2 using nonlinear material model	- ABAQUS is validated in accordance with the registration procedure for computer software of KEPCO E&C.
DARTEM	• Static analysis	• Reactor containment building (shell & dome, internal structure, RCB basemat)	• Structural analysis and design of reinforced concrete section subjected to mechanical and thermal loads	- DARTEM is validated in accordance with the registration procedure for computer software of KEPCO E&C.
		• Auxiliary building (Spent fuel pool)	• Structural analysis and design of reinforced concrete section subjected to mechanical and thermal loads	
LBAP	• Static analysis	• Reactor containment building (liner plate anchorage system)	• Structural analysis of liner plate anchorage system when liner plate buckled	- LBAP is validated in accordance with the registration procedure for computer software of KEPCO E&C.

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Table 3.8-11 (3 of 3)

Program	Analysis Method	Analysis Model	Analysis Scope	Validation & Verification
GTstrudl	• Static analysis	• Auxiliary building (concrete slab analysis model)	• Structural analysis to obtain design forces for concrete slab design (e.g, dead and live loads, etc.)	- GTstrudl was procured with a Quality Assurance Service Agreement and meets the applicable requirements of the NQA-1, Subpart 2.7, quality assurance requirements of computer software.