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.:	**226-8235**
SRP Section:	**03.07.02 – Seismic System Analysis**
Application Section:	**3.7.2**
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Question No. 03.07.02-5

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. In Sections 3.2.5, 3.2.7, and 4.2.9 in APR1400-E-S-NR-14002-P, the applicant discusses that the weight of the RCS, the hydrodynamic masses of IRWST (i.e. both impulsive and convective masses), and hydrodynamic masses for the AFW and FHA tanks that are included in the finite element models (FEMs) for use in SSI analysis. However, in contrast with the information in APR1400-E-S-NR-14002-P, in Section 6.1 of APR1400-E-S-NR-14003-P the applicant states that the RCS masses and the convective (sloshing) hydrodynamic masses for the first and second horizontal sloshing modes of IRWST were not included in the maximum building seismic response forces and moments obtained from the SSI analysis. This section also states that, for the structural design, the maximum seismic response RCS support reaction forces and moments and the maximum hydrodynamic pressures generated from the maximum seismic response of the horizontal sloshing modes of IRWST, AFW and FHA tanks are added to the maximum building seismic response forces and moments that are computed.

To assist the staff in evaluating whether the aforementioned masses and their effect have been adequately considered in the seismic analysis and design, the staff requests the applicant to clarify if these masses are included in or excluded from the FEMs used in the SSI analyses. If the hydrodynamic masses were included in the FEMs used in the SSI analyses, describe the process used to estimate the slosh height. If the masses described in the paragraph above are excluded from the FEMs used in the SSI analyses, describe the process (including a numerical example) for developing design loads that correspond to these masses and how these loads are combined with the seismic design loads. Additionally and as necessary, correct any inconsistencies between the aforementioned technical reports.

Response

The RCS masses are automatically incorporated in the finite element models for use in SSI analysis through modeling the major RCS components.

The hydrodynamic effect of significant mass interacting with the structure for IRWST, AFW and FHA tanks are included in the FEMs used in the SSI analysis. Both convective (sloshing) and impulsive horizontal masses and frequencies are calculated for modeling of hydrodynamic effect on tank walls.

The analytical approach used to model the horizontal hydrodynamic effect on the annular cylindrical tank, IRWST, is based on the formulations given by Tang, et.al. (Reference 1). From the formulation given by Tang et al., the hydrodynamic effects on the rigid tank are simplified to equivalent mechanical models consisting of impulsive and convective parts similar to those previously formulated by Housner (Reference 2) for cylindrical and rectangular tanks.

Using the formulation given by Tang et al., the hydrodynamic properties of equivalent mechanical models for IRWST, such as impulsive mass for the impulsive part, and sloshing frequencies and masses for the convective part, are calculated. The characteristic values, ξ_n, for sloshing mode, n, are calculated first, and the sloshing frequencies from ξ_n and corresponding Eigen functions are obtained. From these values and related coefficients, impulsive mass and its height from the tank base, as well as convective mass and the height, are calculated.

To implement the horizontal hydrodynamic model developed for IRWST, as described above, the horizontal impulsive mass computed is distributed into lumped masses in a circular ring. The ring is located at the height of the impulsive mass, and the distributed lumped water masses in the circular ring are linked circumferentially by rigid beams. Each distributed lumped water mass in the circular ring is then connected by a radial beam element to a corresponding node on the IRWST inner wall. For the horizontal convective hydrodynamic masses associated with the first two sloshing modes, the lumped total sloshing mass for each mode is placed at the center of the IRWST at the height for each mode. The lumped sloshing water mass for each mode is then connected to every node on the inner wall of the IRWST by radial beam elements.

For the vertical vibration, all of the water in the tank is assumed to move vertically as a rigid body with the vertical motion of the tank base. Thus, all of the vertical water mass in the tank is uniformly distributed as lumped masses attached to structural nodes at the bottom of the tank.

The Hounser's formulas, and the similar approach described above, are also applied separately for two orthogonal horizontal directions to model the horizontal responses of water in the AFW and FHA tanks inside the auxiliary building. Hydrodynamic effects from these water tanks are included with horizontal hydrodynamic mass and support stiffness to simulate the horizontal sloshing (convective) mass of water. The mass is attached with flexible springs to the upper portion of the tank wall. Horizontal impulsive hydrodynamic mass is calculated as lumped masses attached rigidly to the lower portion of tank wall. In the vertical direction, the total water mass is lumped at the bottom slab of the tank.

Calculations of hydrodynamic sloshing heights for the annular cylindrical IRWST tank are based on formulas for annular tanks given also by Tang et al. The sloshing heights which come from the vertical surface displacements at outer and inner tank walls are based on tank dimensions,

water height, and sloshing frequencies. From the sloshing height calculation, it is checked that sloshing water does not reach the tank roof.

Calculations of hydrodynamic sloshing heights for rectangular AFW and FHA tanks are based on Housner's formulas for rectangular tanks, and are also based on tank dimensions and sloshing frequencies of water contained in the tanks. From the vertical sloshing displacements, it is identified whether water will reach the tank roof or spill over the top of an open tank.

The in-house post-processor calculates the mass matrix and multiplies it with the nodal accelerations from the SSI analysis to obtain the building story shear forces and overturning moments. Therefore, only mass that contributes to the building shear and overturning moment for the component under consideration is included. For this reason, the RCS masses and the convective (sloshing) hydrodynamic masses of the IRWST, AFW and FHA tanks are not included in the calculation of seismic response forces and moments. For the structural design, the effects from the RCS masses and hydrodynamic masses are considered separately. However, the ISRS developed from the SSI analysis already includes the RCS masses and hydrodynamic mass effects on tank walls.

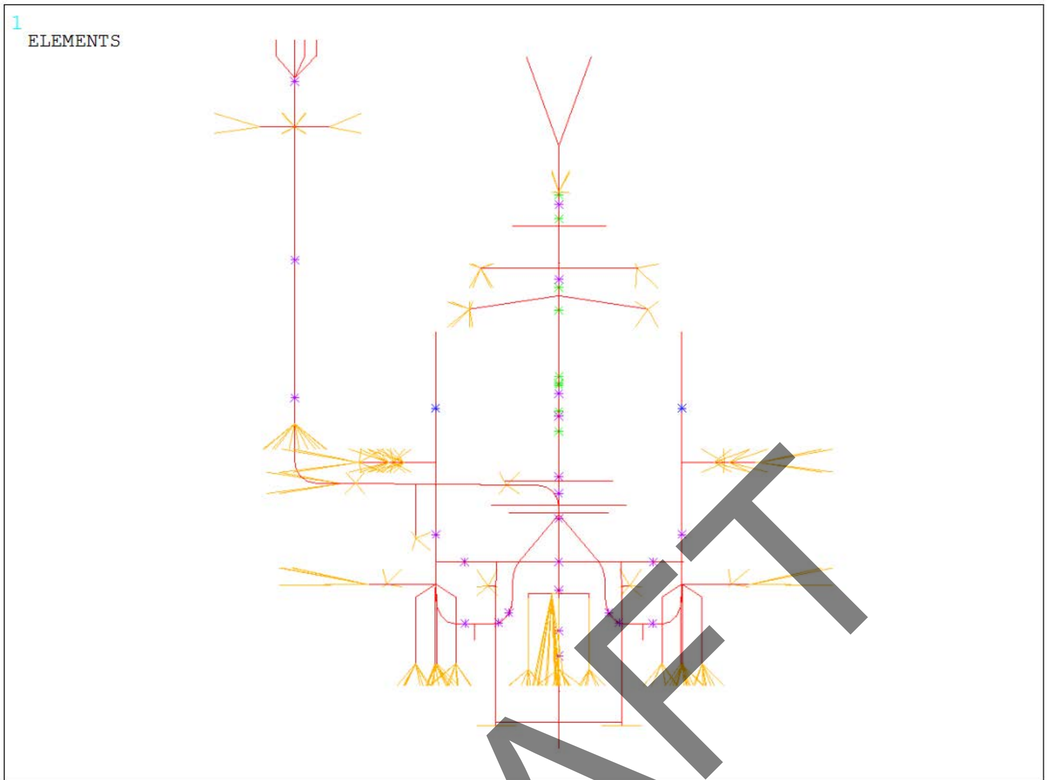
As described above, the SSI analysis model for the nuclear island structures includes the RCS masses, convective (sloshing) hydrodynamic masses of the IRWST, AFW, and FHA tanks as well as the masses of the structures themselves. But, the calculations of the building story shear and moments do not include the RCS masses or the convective masses of the tanks.

For the structural design of the reactor containment building, the separate response spectrum analysis using the detail structural analysis model, which includes the RCS model and hydrodynamic masses of the IRWST, is used to obtain the structural design forces and moments associated with seismic load. It is subjected to in-structure response spectra extracted from SSI analyses at the basemat. Section 6.1 of APR1400-E-S-NR-14003 will be modified to state this description.

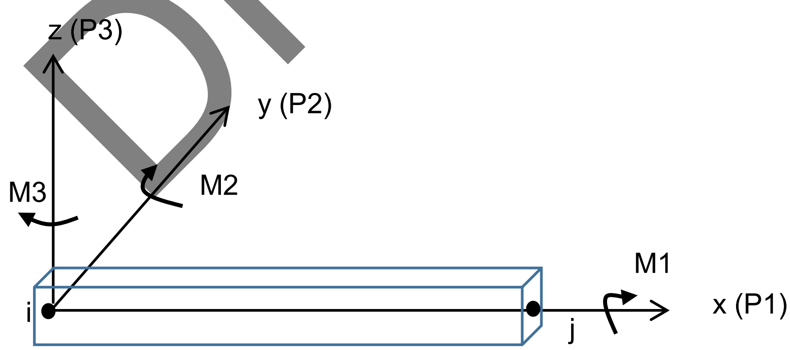
Using peak broadened in-structure response spectra that envelop all SSI analysis cases in the response spectrum analysis is expected to produce more conservative structural design forces and moments than those resulting from the SSI analyses. The building story shear forces and moments from SSI analyses are not used in the structural design.

The RCS FE model (same as in SSI model) is included in the structural analysis model for the internal structure in order to consider the effect of RCS mass, as shown in Figure 1. It is made up of beam elements (BEAM4 in ANSYS) and mass elements. To connect the RCS model and internal structure, the rigid beams shown in yellow in Figure 1 are used. Table 1 summarizes the comparison of member end forces from the SSI analysis to those from the structural analysis at the major RCS frame supports.

Since the results of member end forces in the structural analysis are greater than those in the SSI analysis, the RCS masses are adequately considered in the structural design.



A. RCS FE model



B. Local coordinates in BEAM4 element

Figure 1 The FE model for RCS in SSI and structural analyses

Table 1 Comparison of Member End Forces from SSI and Structural Analyses at Major RCS Frame Supports

A. Structural (RSA) Analysis Result (kips, ft)							
Description	Element Number	P1	P2	P3	M1	M2	M3
RV COLUMN BOTTOM	1909	1,313.2	16.4	38.0	16.4	216.6	166.7
	2909	1,192.9	16.3	38.5	15.0	238.2	168.0
	4909	1,287.2	16.7	35.8	15.1	198.5	171.1
	5909	1,406.0	14.7	42.3	15.9	256.0	143.8
SG BOLT CIRCLE LOADS	70	2,831.0	1,281.3	0.0	3,967.8	8,305.6	2,595.6
	3070	2,389.1	1,063.9	0.0	1,903.5	9,191.4	4,790.4
RCP MOTOR MOUNT FLANGE	1102	177.3	461.1	622.7	0.0	4,760.4	3,524.7
	2102	185.4	312.3	409.7	0.0	3,131.6	2,387.1
	4102	200.9	479.7	665.3	0.0	5,086.1	3,667.2
	5102	184.9	373.8	513.6	0.0	3,925.9	2,857.5
B. Seismic (SSI) Analysis Result (kips, ft)							
Description	Element Number	P1	P2	P3	M1	M2	M3
RV COLUMN BOTTOM	1909	1,042.8	10.9	25.2	10.8	148.5	106.5
	2909	970.2	10.8	35.9	12.6	224.9	106.4
	4909	994.7	10.8	34.5	12.4	214.2	105.9
	5909	993.6	10.7	28.4	12.0	170.9	104.7
SG BOLT CIRCLE LOADS	70	1,614.5	1,070.4	3.3	1,362.9	9,271.9	7,254.8
	3070	1,606.2	1,051.9	5.6	1,454.4	9,020.5	7,363.3
RCP MOTOR MOUNT FLANGE	1102	129.2	74.0	434.5	0.0	3,287.2	547.8
	2102	126.0	391.9	85.6	0.0	649.5	2,998.8
	4102	123.4	357.0	82.9	0.0	643.4	2,688.8
	5102	120.7	79.2	475.3	0.0	3,631.9	597.9
C. Ratio of A / B							
Description	Element Number	P1	P2	P3	M1	M2	M3
RV COLUMN BOTTOM	1909	1.26	1.51	1.50	1.52	1.46	1.57
	2909	1.23	1.51	1.07	1.19	1.06	1.58
	4909	1.29	1.55	1.04	1.21	0.93	1.62
	5909	1.41	1.38	1.49	1.32	1.50	1.37
SG BOLT CIRCLE LOADS	70	1.75	1.20	-	2.91	0.90	0.36
	3070	1.49	1.01	-	1.31	1.02	0.65
RCP MOTOR MOUNT FLANGE	1102	1.37	6.23	1.43	-	1.45	6.43
	2102	1.47	0.80	4.79	-	4.82	0.80
	4102	1.63	1.34	8.03	-	7.90	1.36
	5102	1.53	4.72	1.08	-	1.08	4.78

The hydrodynamic pressure in the IRWST which results from seismic excitation can be considered as impulsive and convective modes depending on the depth, simultaneously, but not in phase with each other. The impulsive pressure is associated with inertial force produced by acceleration of the wall, and the convective pressure is produced by the oscillations of the fluid. The impulsive mode primarily acts to stress the wall, whereas the convective mode acts primarily to uplift the wall. However, the sloshing due to the convective mode could increases and decreases the fluid pressure on the wall, the fluid pressure due to the sloshing effect is smaller than that due to the impulsive effect. Therefore, considering the impulsive mode over the water level for the IRWST is more conservative than considering both impulsive and convective modes. Based on these characteristics of water, in the IRWST analysis, the water is considered as a mass which represents the weight of the water, and is not considered as a fluid element. The structural analysis for internal structure seismic loading, including the IRWST water mass, is performed using the in-structure response spectra.

In the SSI analyses of the auxiliary building, the convective masses in the tanks are excited by smaller accelerations than the accelerations acting on the structure at the corresponding level, because the fundamental frequencies of convective modes of the fluid tanks in the auxiliary building are much lower than those of the building structure. Therefore, the equivalent accelerations computed from the building story forces, which neglect the convective masses, are greater than those from the building story shear forces which consider the convective masses.

For the structural design of the auxiliary building including the AFW and FHA tanks, the global structural analysis considers the impulsive mode over the water level for the AFW and FHA tanks. The analysis is performed using equivalent accelerations computed from the building story shear forces of SSI analyses to obtain the structural design forces and moments. Section 6.1 of APR1400-E-S-NR-14003 will be modified to state this description. The equivalent static force is computed as the product of the total fluid weight and the seismic acceleration value applicable to the side nodes of each tank wall. The seismic acceleration values corresponding to the level of the AFW and FHA, EL.120′-0″ for AFW and EL.137′-6″ for FHA, are applied. These kinds of forces are taken into account in the form of a point load at the nodes.

In addition, the local structural analyses for the AFW and FHA tanks are carried out with inclusion of the impulsive and convective forces of water. The appropriate hydrodynamic pressures corresponding to the impulsive and convective forces are calculated and then applied to the local finite element model for the AFW and FHA tanks. The hydrodynamic pressures for impulsive and convective modes are calculated in accordance with TID-7024 and ACI 350.3. Member forces obtained from the global structural analysis of the auxiliary building are added to the member forces from the local analysis of the AFW and FHA tank models to determine the design forces.

For example, the horizontal tensile force of 2.4 kip/ft determined in the global analysis is added to the horizontal tensile force of 12.4 kip/ft determined in the local analysis at the same element. The local FE model has the same mesh configuration as the corresponding part of the global FE model. As a result, 14.8 kip/ft is used to calculate the required horizontal re-bar area. For the EDGB/DFOT structures, there are no portions of the structures which are tanks.

In the detailed calculation of hydrodynamic pressures on side walls and bottom slabs of the AFW and FHA tanks, for the convective and impulsive modes due to horizontal and vertical

seismic excitations, the procedures outlined in TID-7024 and ACI 350.3 are used with the horizontal and vertical in-structure response spectra to obtain spectral accelerations at corresponding frequencies, instead of the acceleration time histories.

The associated potential for vertical amplification in the fluid column is not considered in the calculation of hydrodynamic pressures of the tanks because the water depths of the tanks in the nuclear island are less than 50 ft. According to ASCE 4-98, the additional effects of water mass due to the compressibility of water under vertical direction seismic excitation do not need to be considered in tanks where water depth is less than 50 ft.

Even though the RCS masses and convective masses are not included in the computations of story shear forces and moments from the SSI analyses, the consecutive structural analyses to design structural members conservatively considers the effects of the RCS masses and convective masses.

References

1. Tang, Yu, Grandy, C., and Seidensticker, R., "Seismic Response of Annular Cylindrical Tanks," Nuclear Engineering and Design, 240(2010), 2614 - 2625.

2. TID-7024, “Nuclear Reactor and Earthquakes,” Chapter 6 and Appendix F.

Impact on DCD

There is no impact on the DCD.

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 (Section 6.1) will be revised.

computed at various designated elevations for the RCB (CS, PSW, and SSW) and AB. The results of each of the ten (10) cracked-concrete SASSI analysis cases and the envelopes of the results for the ten (10) cases are tabulated and plotted in Appendix B of this report.

The calculations of the maximum building seismic response forces and moments described above have included all building masses except the RCS masses and the convective (sloshing) hydrodynamic masses for the first and second horizontal sloshing modes of IRWST and the horizontal sloshing mode of AFW and FHA tanks. ~~Thus, for the structural design, the maximum seismic response RCS support reaction forces and moments and the maximum hydrodynamic pressures generated from the maximum seismic response of the horizontal sloshing modes of IRWST, AFW and FHA tanks are added to the maximum building seismic response forces and moments that are computed.~~

However, for the structural design of the reactor containment building, the RCS model and hydrodynamic masses of the IRWST are included in the structural analysis model, and the separate response spectrum analysis using ISRS obtained from SSI analysis is performed in order to obtain maximum structural design forces and moments associated with seismic load. Also, for the structural design of the auxiliary building, the impulsive mode over the water level for the AFW and FHA tanks as hydrodynamic masses are included in the structural analysis model, and the equivalent static analysis using equivalent accelerations computed from the building story shear forces of SSI analysis is performed to obtain the structural design forces and moments.

6.2 In-Structure Response Spectra

summarized in Tables 6-6 and 6-7. Table 6-6 lists the selected nodal points on each designated floor area at the shear wall locations of each designated floor elevation for which ISRS for seismic response motions in all three directions, X (E-W), Y (N-S), and Z (vertical), are generated. Table 6-7 lists the selected nodal points on the floor slabs of each designated floor area of each designated floor elevation for which ISRS for the vertical (Z) seismic response motions are generated. The locations of the selected nodes on the designated elevations are shown on plots in Appendix C of this report.

The ISRS generated for each analysis case at all selected nodal points on each designated structure elevation are firstly enveloped to generate the enveloped ISRS for the elevation and are then widened by ± 15% in frequency (Reference 22). The enveloped and widened ISRS for each elevation generated for all six (6) constant damping values are generated for each individual SASSI analysis case. The ISRS generated are finally enveloped for all twenty (20) cases. The ISRS curves that are generated are plotted in the figures shown in Appendix D.

6.3 Maximum Seismic Response Relative Displacements

Two (2) sets of maximum seismic response relative displacements are generated for the RCB and AB from the SASSI analysis results for all twenty (20) SASSI analysis cases. The first set consists of the displacements relative to the free-field ground surface. The second set consists of the displacements relative to the basemat. For the RCB, the second set consists of the displacements relative to the region of basemat under the RCB footprint. Because of the massive concrete pedestal in the lower portion of the internal structure, the basemat under the RCB footprint is rigid and responds almost as a rigid basemat. Thus, the second set of displacements relative to the basemat is obtained from the first set of relative displacements with respect to the free-field ground surface by removing the rigid basemat rotations computed for the region of basemat under the RCB footprint. For the AB, the second set of displacements relative to the basemat is obtained from the first set of relative displacements with respect to the free-field ground surface by subtracting the basemat displacements at the containment centerline relative to the free-field ground surface from the first set of relative displacements.

For the first set of relative displacements, which are displacements relative to the free-field ground surface, the post-processing procedure used to generate these displacements for the selected nodal