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A SIMPLIFIED ADDED MASS MODELING AND SEISMIC RESPONSES OF SUBMERGED REACTOR ASSEMBLY OF KI-JANG RESEARCH REACTOR

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ABSTRACT

Dynamic characteristics of the Reactor Assembly (RA) of Ki-Jang Research Reactor (KJRR, 15MWth, pool water cooled) submerged in the Reactor Pool should be set up from the finite element (FE) modeling. The seismic responses of the RA and its safety related components can be influenced by the modal properties of the RA and input motions at its support, the bottom of the Reactor Pool.

Added mass effects on the modal properties are compared between the full FE modelling of RA and the simplified one. The seismic responses of the both models of the RA in the form of Floor Response Spectrum (FRS) (ie, FRS2 from the full FE model, and FRS3 from the simplified FE model) calculated by linear time history transient analyses are also compared to verify the simplified FE model could be used to seismically qualify its safety components.

INTRODUCTION

Seismic design and analyses for seismic qualification of safety class components submerged into the fluids in nuclear facilities are dependent upon fluid structure interactions (FSI) and Design Basis Earthquakes. Numerical models of FSI analysis for Advanced Reactors such as Sodium Cooled Fast Reactor, Lead-cooled Reactor, etc., had been developed by many authors (M. Jeltsov, Yu, and others).

This paper presents two FE modeling methods of the fully water submerged RA to generate FRS for seismic qualification for the safety components attached to it. Dynamic characteristics and seismic responses of two FE modeling methods of the RA are compared.

FE MODELING OF REACTOR ASSEMBLY

The RA is Safety Class 3 and Seismic Category Ⅰ structure of KJRR, composed of Outlet Plenum Assembly, Grid Plate, Core Box, Upper Guide Structure Assembly (UGS), Reactor Cover Assembly (RCA), Control Absorber Rod/Second Shutdown Rod (CAR/SSR), Guide tube, Expansion Joint, and Neutron Detector Housing Assembly (NDHA). Note that the definition of 'Reactor Assembly' in this paper does not include the components located under the pool bottom such as penetration parts and drive mechanisms of CARs and SSRs.

General model, full FE model, and simplified FE model of RA (with H4.33m x W2.155m x D2.422m) submerged in the Reactor Pool (with H13m x W5m x D5m, with water depth of 12m) are shown in Figure 1 using ANSYS.

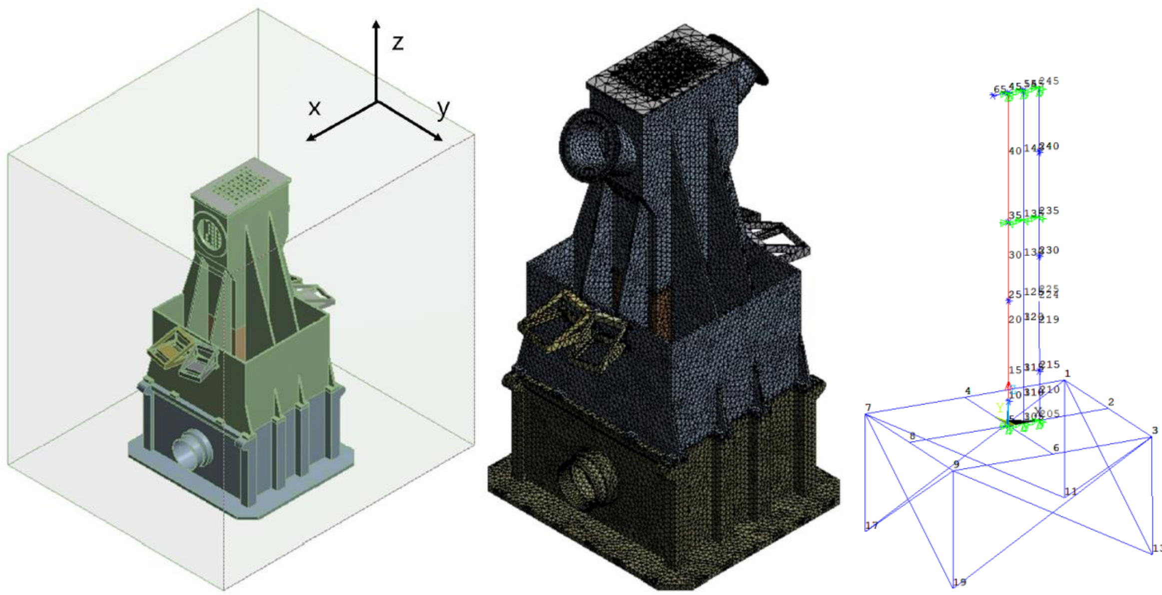


Figure 1 General model, full FE model, and simplified FE model of Reactor Assembly
(EW x- direction- Nozzle, NS y- direction perpendicular to Nozzle, VT z-direction))

Fluid structure interaction (FSI) is considered that external added masses as 7452kg in x direction and 6791kg in y direction, and internal ones as 5693kg in both x and y directions are respectively applied for the FE model of the RA, which is fully submerged into the water in the Reactor Pool.

The full FE model is made up of solid187 element for RA, fluid221 element for water. Both are the 2nd order tetrahedron elements and the total number of elements is 1,364,719.

The simplified FE model is made up of beam elements and lumped masses including added mass.

The safety components of the Reactor Assembly to be seismically qualified are fuel assemblies, CAR/SSR Control and Shutdown mechanisms, Reflector Assemblies and Gamma Shielding, and Penetration Assembly, and need the FRS at their support positions such as Grid Plate, Out-core reflector support plate, CAR/SSR Guide Tube and UGS Flanges.

Typical material properties and mass of safety components are as shown in Table 1.

Table 1: Material properties and mass of safety components of Reactor Assembly

No	Components	ea	material	density [kg/m^3]	Elastic Modulus [GPa]	Poisson ratio	mass [kg]
1	Outlet plenum assembly	1	S30403 (SA240 304L)	7900	187.8	0.300	7825.
2	Grid plate	1	S30403 (SA240 304L)	7900	187.8	0.300	
3	Core box	1	R60804 (Zircaloy-4)	6550	87.46	0.365	

4	UGS	1	A96061 (AL6061)	2713	64.8	0.330	1450.
5	Reactor Cover Ass'y	1	A96061 (AL6061)	2713	64.8	0.330	
6	CAR/SSR guide tubes	6	A96061 (AL6061)	2713	64.8	0.330	-
7	NDHAs	4	A96061 (AL6061)	2713	64.8	0.330	
8	Out-core reflector support plates	8	A96061 (AL6061)	2713	64.8	0.330	
9	Flow tubes	6	S30403 (SA240 304L)	7900	187.8	0.300	-
10	CARs	6	-	12573	137.0	0.29	-
11	FFAs	6	-	1393	11.5	-	-
12	ESAs/ESs	6	S30403 (SA240 304L)	7900	187.8	0.300	
13	etc						
	Total mass						~11700.

SEISMIC INPUT MOTIONS AT REACTOR ASSEMBLY BOTTOM

The enveloped seismic input FRS1 as a Safe Shutdown Earthquake (SSE) at the bottom location of the RA which envelopes 18 cases of 3 directions (NS, EW, VT), 3 soil properties (BE, UB, LB), and 2 building conditions (un-cracked, and cracked) are shown in Figure 2 (EW-x and VT-z directions only). Noting that 18 case FRS1 are generated using compatible time histories to Design Ground Response Spectrum of Zero Period Acceleration (ZPA) of 0.3g by soil structure interaction (SSI) analyses of KJRR.

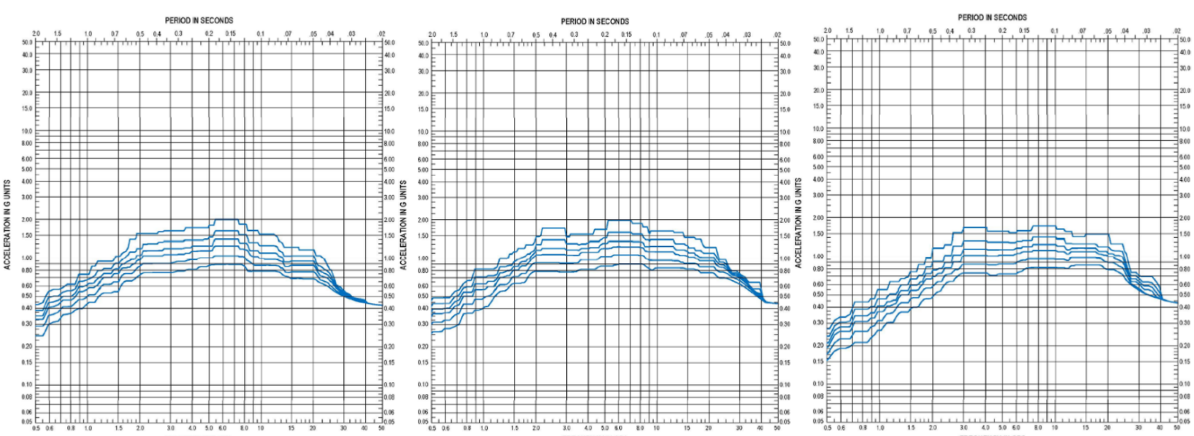


Figure 2 Enveloped 18 case FRS1 (EW-x, NS-y, VT-z, and 2, 3. 4, 5, 7, 10% damping) at Reactor Assembly Bottom in Reactor Pool

ZPAs of FRS1 at the Bottom of the Reactor Pool are 0.418g in EW-x, 0.435g in NS-y, and 0.424g in VT-z directions, respectively.

The 3 directional artificial time histories compatible to FRS1 as shown in Figure 3 (EW-x direction only) are generated using P-CARES.

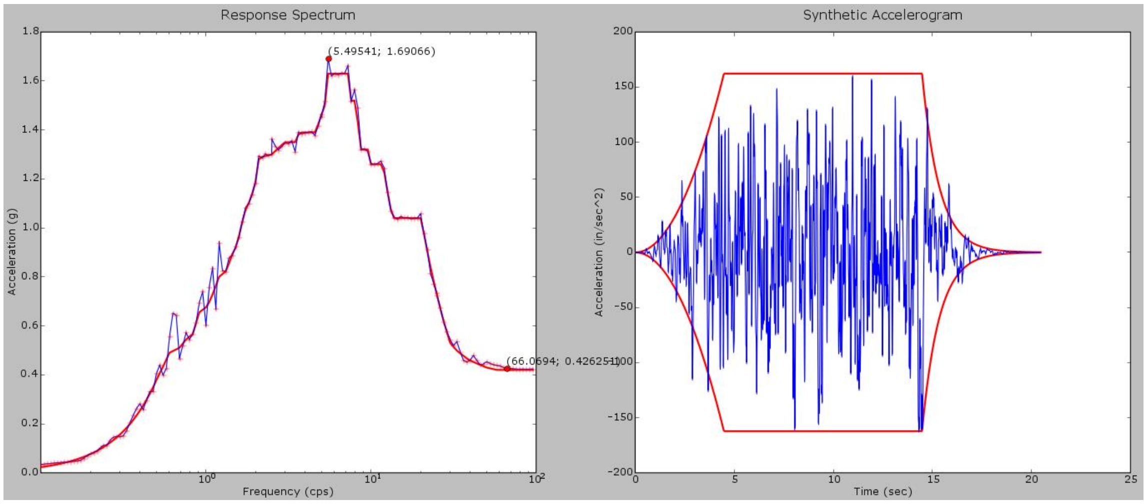


Figure 3 Comparison of calculated Spectra (3% damping) with given FRS1 at Reactor Assembly Bottom and its Artificial Time History in EW x-direction

DYNAMIC CHARATERISTICS AND FRS GENERATION

The natural frequencies of the full FE model are as 22.7 Hz, 29.1 Hz, and 72.9 Hz in x, y, z directions, and those of the simplified FE model are as 25.24 Hz, 28.44 Hz, and 71.3 Hz, in x, y, z directions, respectively.

Both FRS2 of full FE modeling and FRS3 of simplified FE one are generated using the same seismic input time histories compatible to the enveloped FRS1 by a transient time history analysis at the support positions of the safety components such as Grid Plate, Out-core reflector support plate, RA Top Plate (for internal Tubes) and Piping Flanges.

The FRS2 results of the full model, for example at Grid Plate and RS Top Plate, are compared with the FRS3 of the simplified one before broadening the calculated spectra by 15% to cover uncertainties in modeling and material properties, as shown in Figures 4 & 5.

At the Grid Plate,

1) Peak spectral acceleration and ZPA in FRS2 (5% damping) are 1.5g in 5-6 Hz, and 0.5g, and those in FRS3 are 1.49g in 5-6 Hz, and 0.47g, respectively, in horizontal EW x- and NS y-directions.
2) Peak spectral acceleration and ZPA in FRS2 are 1.16g in 4-9. Hz, and 0.47g, and those in FRS3 are 1.15g in 4-11 Hz, and 0.45g, respectively, in VT z- direction.

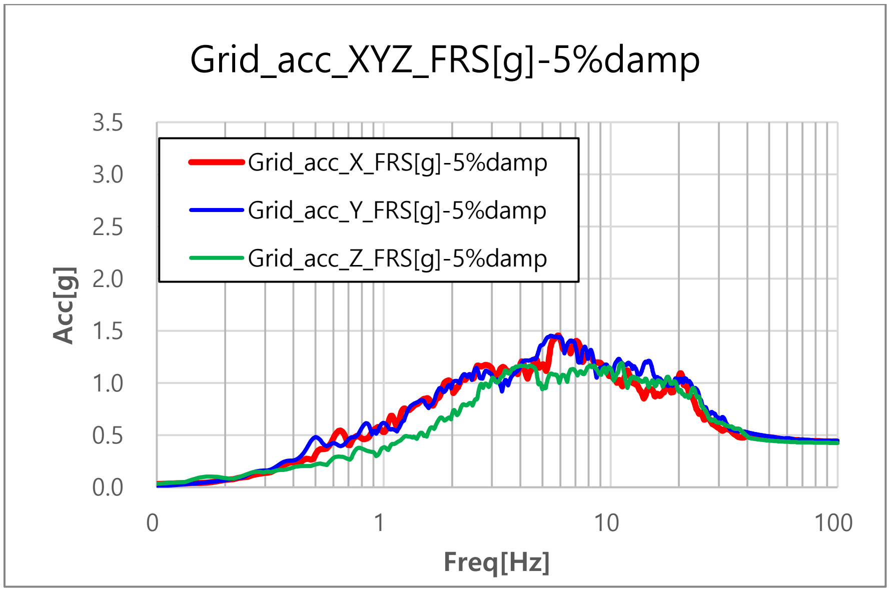
Peak spectral accelerations and ZPA of FRS3 are similar to those of FRS2 at the Grid Plate in both horizontal and vertical directions.

At the Top plate, similarly,

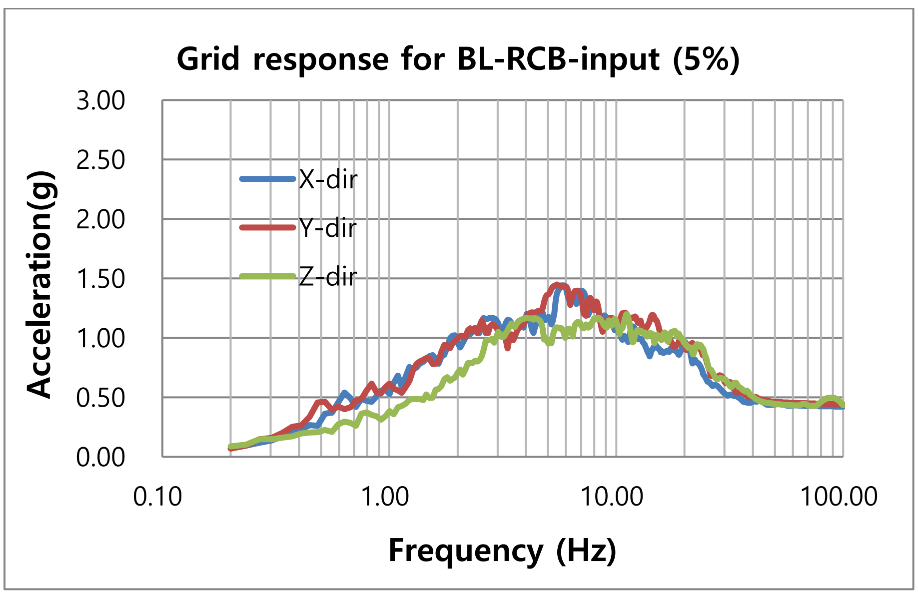
3) Peak spectral acceleration and ZPA in FRS2 (5% damping) are 5.44g at 21.7 Hz in EW-x, 3.3g at 21.3Hz in NS-y, and 0.9g, and those in FRS3 are 3.5g at 21.5Hz in EW-x, 3.5g in 26.1 Hz, in NS-y, and 0.84g, respectively, in horizontal EW x- and NS y-directions.
4) Peak spectral acceleration and ZPA in FRS2 are 1.16g in 4-11 Hz, and 0.48g, and those in FRS3 are 1.16g in 4-11 Hz, and 0.46g, respectively, in VT z- direction.

Peak spectral acceleration of FRS3 in horizontal EW-x direction is smaller than those of FRS2 by 35%, while peak accelerations and ZPA of FRS3 in NS-y and vertical direction are similar to those of FRS2.

Seismic responses in vertical direction for both models are little amplifying due to high vertical fundamental frequency of 71.3Hz much higher than cut-off frequency of 33Hz.

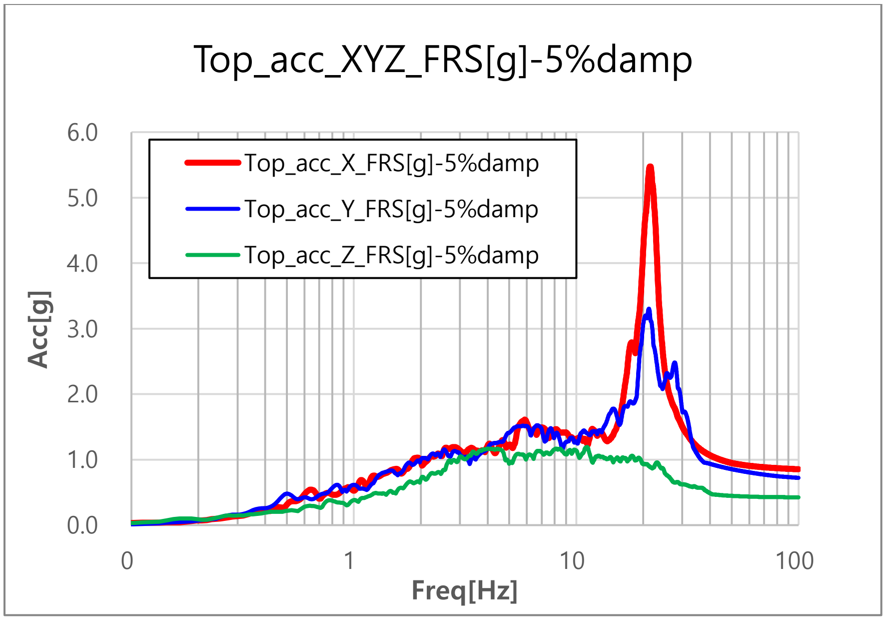


a) FRS2 at Grid Plate of Full FE Model

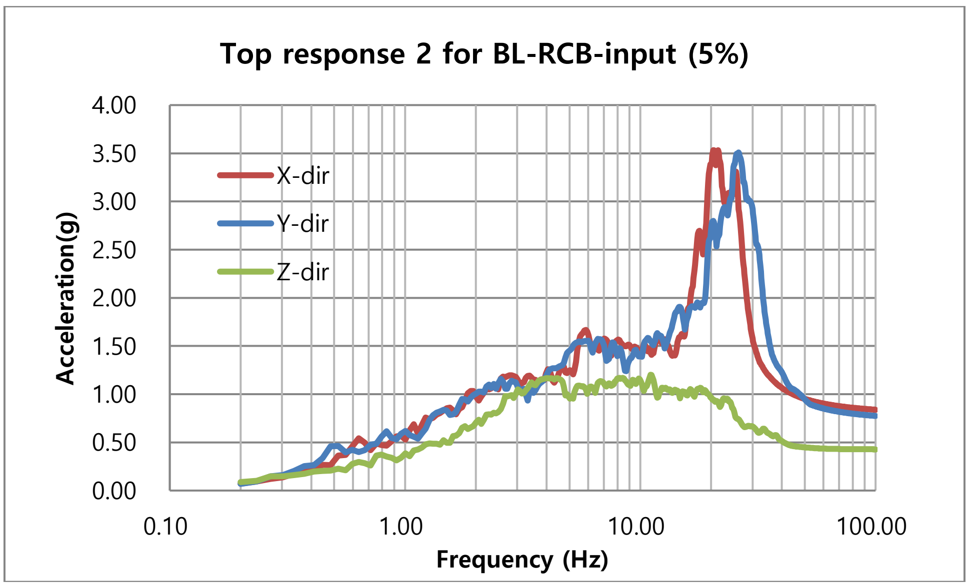


b) FRS3 at Grid Plate of Simplified FE Model

Figure 4 FRS2 and FRS3 (5% damping value) at Grid Plate in Full FE model and Simplified FE Model of Reactor Assembly



a) FRS2 at Reactor Cover Plate of Full FE Model



b) FRS3 at Reactor Cover Plate of Simplified FE Model

Figure 5 FRS2 and FRS3 (5% damping value) at Reactor Cover Plate in Full FE model and Simplified FE Model of Reactor Assembly

CONCLUSION

The full FE modeling and the simplified FE modeling of the RA are compared to understand the effects of added mass and seismic input motions on dynamic characteristics and seismic responses, here in FRS2 and FRS3, respectively.

The natural frequencies of the simplified FE model, 25.24 Hz, 28.44 Hz, and 71.3 Hz, in x, y, z directions are in good agreement with those of the full FE model as 22.7 Hz, 29.1 Hz, and 72.9 Hz in x, y, z directions, respectively.

Either FRS2 or FRS3 could be used for the seismic qualification for the safety components attached to the Reactor Assembly.

The simplified FE modeling method proposed can reduce remarkably computing and post processing times, and provide with reasonable seismic responses for the seismic qualification for the safety components in the Reactor Assembly.

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