Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-19, 2017

Preliminary Core Seismic Analysis for SFR Prototype Reactor

Gyeong-Hoi KOO*, Sung-Kyun KIM
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-335, Korea
**Corresponding author: ghkoo@kaeri.re.kr*

1. Introduction

In sodium-cooled fast reactors, the core assemblies are composed of several hundreds of duct subassemblies, which are in general hexagonal, such as the fuel elements, control rods, reflecting elements, neutron shield elements, and so on. These ducts have no intermediate supports and can be considered as self-standing hexagonal beams supported by a core support structure. These are submerged in liquid sodium with a very narrow gap space between the adjacent ones. Therefore, the core seismic behavior during an earthquake event may be subject to very complicated and highly non-linear characteristics due to the severe collision at the load pads and the dynamic fluid-structure interaction.

In this paper, the preliminary core seismic analysis using an algorithm of the CFAM(Consistent Fluid Added Mass) matrix approach[1], which can fully consider the fluid coupling terms by the matrix, are described for the SFR prototype reactor being on development by KAERI.

2. Core Seismic Input Motions

2.1 System Seismic Analysis

The seismic load path to the SFR core assemblies is on reactor support structure through the reactor vessel, internal components such as IHX(Intermediate Heat Exchanger) and PHTS(Primary Heat Transportation System) pump, and reactor internals. Therefore, it is needed to perform the system seismic analyses for PHTS to define the core seismic design input motions at the core support structure.

Fig.1 presents the PHTS seismic analysis model for system seismic analysis used in this paper.

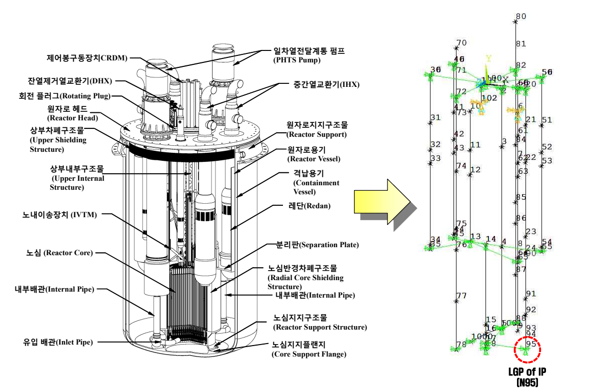

Fig. 1. PHTS seismic analysis model for system analysis

2.2 Core Seismic Design Input Motions

To perform the system seismic analysis by time history analysis method for PHTS model, the design response spectrum was generated by an assumed single degree of freedom building model with equivalent stiffness model of seismic isolation device. The design seismic isolation frequency is 0.5Hz. The used SSE ground input time history and response spectrum of horizontal EW direction complying with Reg.Guide-1.60[2] is presented in Fig.2.

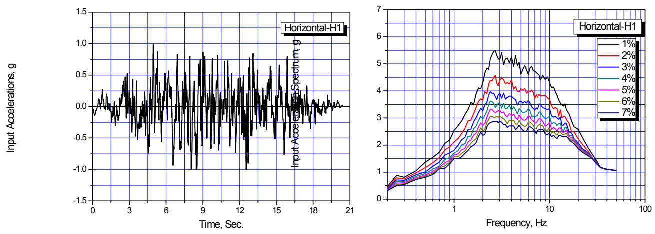

Fig. 2. Ground input motion for EW direction

Fig.3 shows the generated design time history and design response spectrum broadened peaks by ±15% complying with Reg. Guide 1.122 [3] for PHTS seismic analysis.

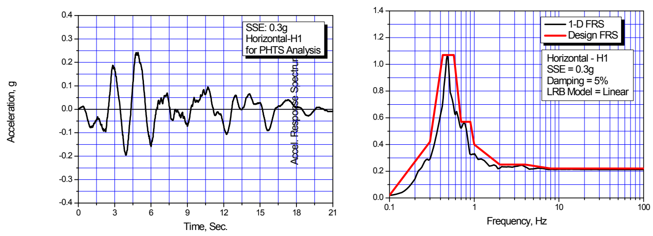

Fig. 3. Input time history and design response spectrum for PHTS seismic analysis

From the PHTS seismic analyses with design input time of Fig.3, the core seismic design input time history at the core support structure was generated as shown in Fig.4.

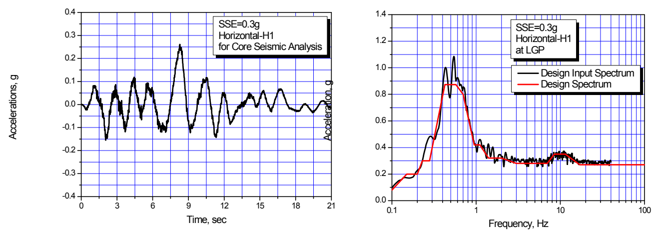

Fig. 4. Generated Core seismic design input motion (EW)

3. Fluid Added Mass Matrix

The fluid added mass effects between duct assemblies were evaluated by using the FAMD computer code [4]. The used total duct assemblies for the finite element analysis is 19 and the fluid gap size is 4mm. Table 1 reveals the calculated fluid added mass matrix. AS presented in table, the maximum fluid added mass occurs center duct and its coupling fluid added masses with others (off-diagonal terms) are significantly reduced as falling away.

Table 1. Calculated CFAM

Duct No.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	101	-58	-17	-8	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	-58	163	-61	-22	-8	-3	0	0	0	0	0	0	0	0	0	0	0	0	0
3	-17	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0	0	0	0	0	0
4	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0	0	0	0	0
5	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0	0	0	0
6	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0	0	0
7	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0	0
8	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0	0
9	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0	0
10	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0	0
11	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0	0
12	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0	0
13	0	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0	0
14	0	0	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3	0
15	0	0	0	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8	-3
16	0	0	0	0	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-22	-8
17	0	0	0	0	0	0	0	0	0	0	0	0	-3	-8	-22	-61	171	-61	-17
18	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-8	-22	-61	163	-58
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-3	-8	-17	-58	101

4. Preliminary Core Seismic Analysis and Results

4.1 Core Seismic Analysis with CFAM

The governing equation of a seismic motion including the fluid effects can be expressed with a simple lumped mass, damping, stiffness matrix, and the fluid reaction force as follows;

$$[M]\{\ddot{x}_r + \ddot{x}_g\} + [C]\{\dot{x}_r\} + [K]\{x_r\} + \{F_f\} = 0 \qquad (1)$$

where $\{x_r\}$ is the relative displacement for the input motion and $\ddot{x}_g$ is the seismic input acceleration.

The fluid reaction force term in Eq.(1) can be represented by using the CFAM matrix as follows;

$$[F_f] = [\mathbf{CFAM}]\{\ddot{x}_r + \ddot{x}_g\} = [M_f]\{\ddot{x}_r + \ddot{x}_g\} \qquad (2)$$

After substituting Eq.(2) into Eq.(1) and arranging the equation, Eq.(1) can be rewritten as follows;

$$[M + M_f]\{\ddot{x}_r\} + [C]\{\dot{x}_r\} + [K]\{x_r\} = -[M + M_f]\{\ddot{x}_g\} \qquad (3)$$

In the above equation, the obtained CFAM matrix, $[M_f]$ of each grid can be globally assembled step by step with the system mass matrix, $[M]$ for a core seismic analysis.

Fig. 5 shows the core seismic analysis model applying a single row technique. In this model, the gap stiffness and damping values are calculated through the detailed finite element analysis for hexagonal section. The calculated gap stiffness and the gap damping are 33.1MN/m and 735kN·Sec/m respectively.

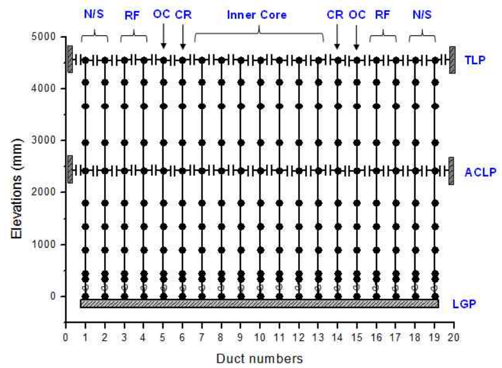

Fig. 5. Core seismic analysis model

4.2 Relative Seismic Displacement Responses

Fig. 6 shows the relative displacement response time history at top load pad of duct no. 1(neutron shield). Because the outermost duct assemblies are restrained by the former ring structure, the maximum displacement of duct no.1 is limited to left direction up to the gap size of 4mm. The maximum relative displacement for CRDM assembly is 15mm. Fig. 7 presents the maximum relative displacement responses at each duct load pad.

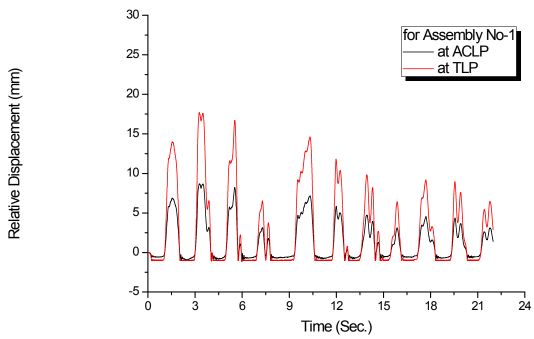

Fig. 6. Relative displacement time history at duct no. 1

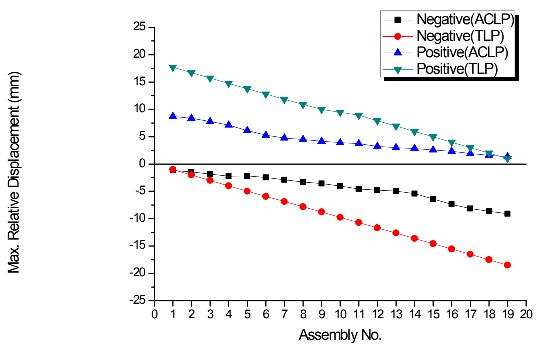

Fig. 7. Maximum relative displacement for each duct

4.3 Absolute Seismic Acceleration Responses

In acceleration response calculations, there can be a numerical noise during the impact. Therefore, it is general method to introduce the low pass filtering more than 50Hz [5]. Fig.8 shows the filtered acceleration response at top load pad of duct no. 11(fuel assembly). The maximum absolute acceleration is about 10m/s^2.

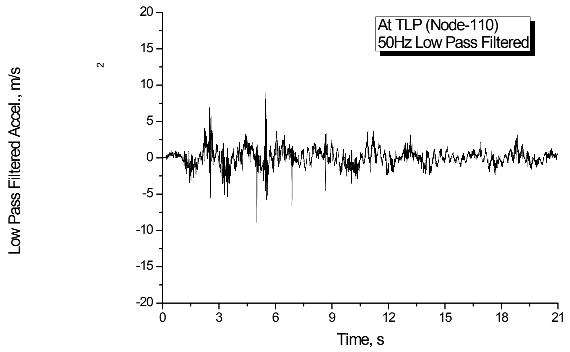

Fig. 8. Acceleration response time history at fuel assembly

4.4 Impact Seismic Responses

Impact responses at TLP(Top Load Pad) and ACLP(Above Core Load Pad) for all duct assemblies are presented in Fig. 9 and Fig.10 respectively. As shown in figures, the impact loads at ACLP is not severe compared with those at TLP. The maximum impact loads are about 50kN at TLP. The impact force between the outermost duct and the former ring is about 35kN.

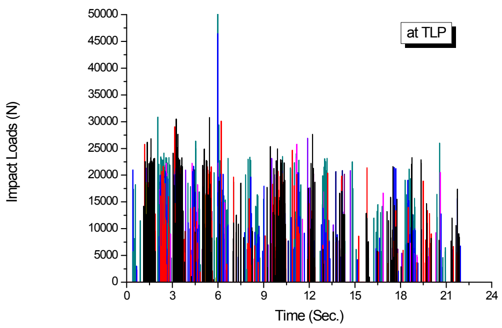

Fig. 9. Impact loads at TLP for each duct assembly

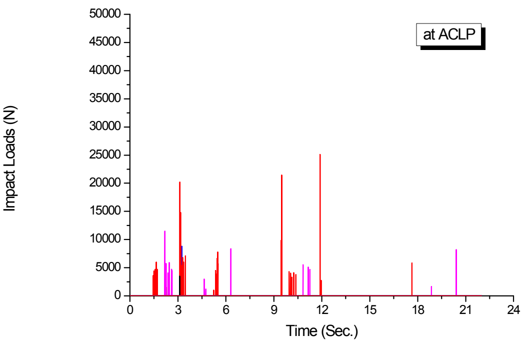

Fig. 9. Impact loads at ACLP for each duct assembly

5. Conclusions

In this paper, the preliminary core seismic analysis is described for SFR prototype design being on development. The procedures and methodologies used in this analysis are well established but the input motions and PHTS system model are need to be updated. The results of the preliminary core seismic analysis should be reviewed in detail to assure the design feasibility in points of reactivity change, reactor trip functions of CRDM, and structural integrity of duct assemblies and core restraint structures.

Acknowledgement

This study was supported by the National Research Foundation of Korea grant funded by the Korea government (Ministry of Science, ICT and Future Planning

REFERENCES

[1] G.H. Koo and J.H. Lee, “Fluid Effects on Core Seismic Behavior of Liquid Metal Reactor,” KSME International Journal, Vol.18, No.12, 2004.
[2] Design Response Spectra for Seismic Design of Nuclear Power Plants, Reg. Guide 1.60, 1973.
[3] Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components, Reg. Guide 1.122, 1987.
[4] G.H Koo and J.H. Lee, “Development of FAMD Code to Calculate the Fluid Added Mass and Damping of Arbitrary Structures Submerged in Confined Viscous Fluid,” KSME International Journal, Vol.17, No.3, pp.457-466, 2003.
[5] Inter-comparison of Liquid Metal Fast Reactor Seismic Analysis codes, IAEA-TECDOC-882, IAEA, 1996.