Dynamic Behavior of Submerged Spent Fuel Storage Rack

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1. Introduction

Spent fuel is stored in Spent Fuel Storage Rack (SFSR, Fig. 1) in spent fuel pool. Both the pool and the SFSR are seismic Category 1 structures which are required to remain functional during and after safe shutdown earthquake condition [1]. For structural evaluation of the SFSR, fluid-structure interaction (FSI) should be considered between SFSR and pool and between guide tube of SFSR and spent fuel to obtain reliable dynamic behavior.

In this study, the modelling method to generate the reduced SFSR model under submerged condition is developed to reduce the computation time of seismic analysis and validated by comparison of modal and transient analysis results. For development of the reduced SFSR model, fluid effects are considered in the model and the results are compared to in air condition of SFSR.

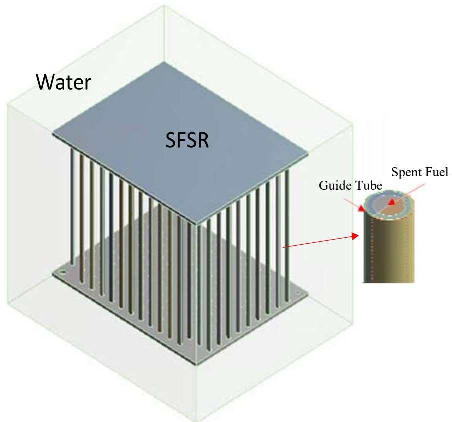


Fig. 1. Spent Fuel Storage Rack [2]

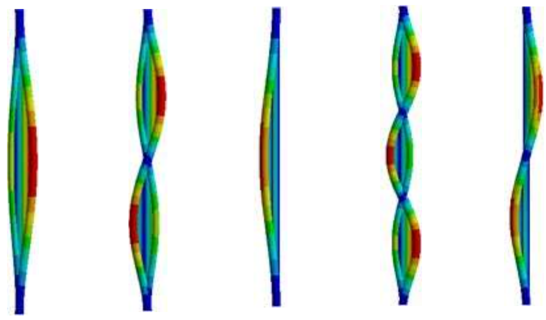
2. Methods and Results

2.1 Analysis Method

For development of reduced SFSR analysis model, fluid effects between two concentric cylinders and submerged condition are respectively assessed. Modal and transient analysis are performed for 3D FE (Finite Element) and reduced model for evaluation of those conditions. The reduced SFSR model is developed based on the results from the research for fluid effects. In this study, impact between guide tube and fuel assembly is not taken into account and all the fuel assemblies are fully loaded in the SFSR. ANSYS is used for modelling and evaluation [4].

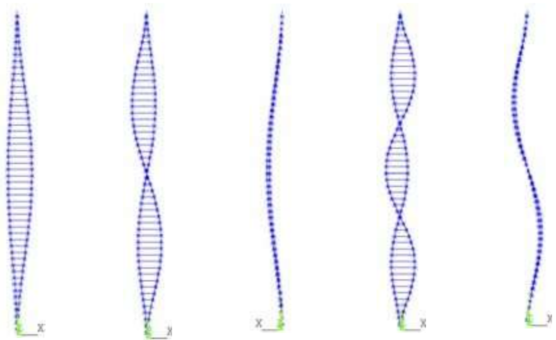
2.2 Dynamic Behaviors under Fluid Gap between Two Concentric Cylinders

For evaluation of fluid effects between two concentric cylinders, 3D FE and reduced model are developed. In general, FLUID38 and FLUID220 ANSYS elements are used to simulate fluid gaps [3]. To determine the number of FLUID38 elements, modal analyses are performed by reducing the number of the elements for 50, 25 and 10. Mode shapes for 3D FE and reduced model are presented in Fig. 2 and Fig. 3, respectively.



Mode 1 Mode2 Mode 3 Mode 4 Mode 5

Fig. 2. Mode Shapes for 3D FE Model of Two concentric cylinders with Fluid Gap



Mode 1 Mode2 Mode 3 Mode 4 Mode 5

Fig. 3. Mode Shapes for Reduced Model of Two Concentric Cylinders with Fluid Gap

The results of the modal analysis for three cases depending on the number of fluid elements are specified in Table 1.

Table 1. Natural Frequencies of Reduced Model base on the Number of Fluid Elements

Mode	Reduced Model(50) /3D FE model	Reduced Model(25) /3D FE model	Reduced Model(10) /3D FE model
1	0.99	0.98	0.96
2	0.99	0.98	0.95
3	0.99	0.98	0.95
4	0.98	0.97	0.94
5	0.99	0.98	0.95

Note) The numbers 50, 25 and 10 represent the number of FLUID38 elements

The results indicate that minimum 10 fluid elements should be used to reflect the dynamic characteristics of 3D FE model. In this study, 10 fluid elements are chosen for the reduced model. Transient analyses are performed to compare the dynamic response of generated 3D FE and reduced model to verify the reduced model. As a results of transient analysis, the maximum displacement ratio and response spectrum at X and Z directions of the middle elevation of guide tube are represented in Table 2 and Figure 4, respectively. The results of the maximum displacement at the middle elevation of guide tube show that reduced model is more conservative than 3D FE model. The results show that there are some differences in Z-dir. response between 70 Hz and 100 Hz. However, that effects are negligible on the design because major participation factors are in the lower frequencies.

Table 2 Maximum Displacement Ratio

Maximum Displacement	Reduced model/3D FE Model
X-dir.	1.1
Z-dir.	1.3

Note) The ratio above is the result at the middle of guide tube elevation.

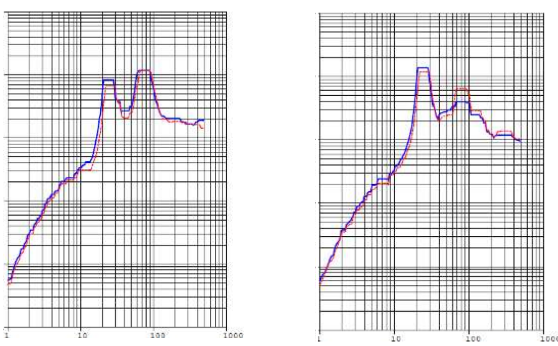


Fig. 4. Response Spectrum (X dir., Z-dir., 5% damping) of 3D FE and Reduced Model at the middle of Guide Tube Elevation

2.3 Dynamic Characteristics under Submerged Condition for Two Concentric Cylinders

Two concentric cylinder models of 3D FE and reduced model under submerged condition are shown in Fig. 5. Modal analysis is performed to assess the dynamic characteristics for 3D FE and reduced model.

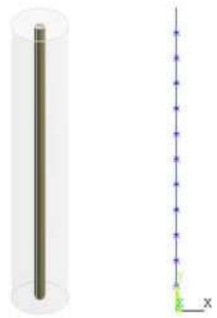


Fig. 5. 3D FE and Reduced Model of Submerged Condition

The results of modal analysis for 3D FE and reduced model are tabulated in Table 3. The ratio of the natural frequencies is similar to that of fluid models with 10 fluid elements. Therefore, the generated reduced model can be used for reduced SFSR model.

Table 3. Natural Frequencies of Reduced Model under Submerged Condition

Mode	Reduced Model/3D FE model
1	0.96
2	0.95
3	0.96
4	0.95
5	0.95

2.4 Reduced SFSR model under Submerged Condition

Reduced SFSR model under submerged condition is generated based on the results from Secs. 2.2 and 2.3. The model is shown in Fig. 6.

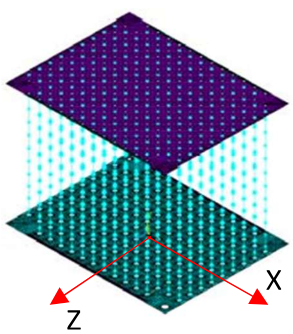
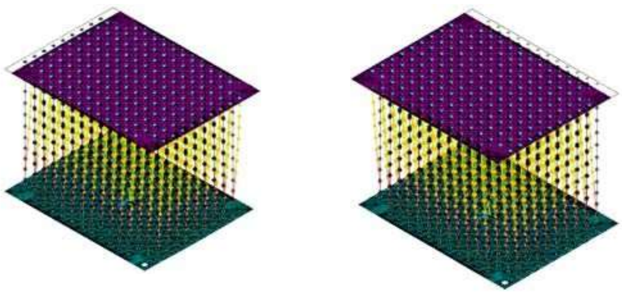


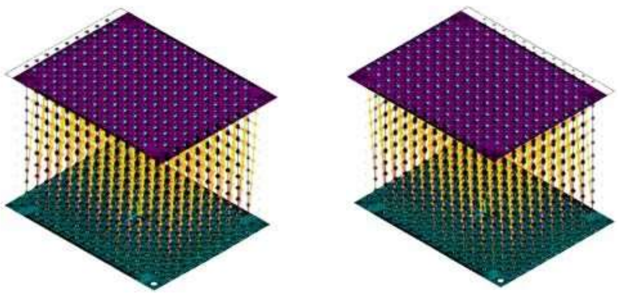
Fig. 6. Reduced SFSR Model under Submerged Condition

Modal analysis is performed for the reduced SFSR model under submerged condition. The results are compared to in air condition of SFSR. For the reduced SFSR model, SHELL181, BEAM188 and MASS21 ANSYS elements are used. The results are presented in Fig. 7, Fig. 8 and Table 4.



(a) X-dir. Mode (b) Z-dir. Mode

Fig. 7. Mode shape of reduced SFSR in air condition



(a) X-dir. Mode (b) Z-dir. Mode

Fig. 8. Mode Shape of reduced SFSR under Submerged Condition

Table 4. Natural Frequency Ratio of reduced SFSR under submerged and in air condition

Item		Ratio(submerged/in air condition)
Natural Frequencies (Hz)	X-dir.	0.7
	Z-dir.	0.7

The reduced SFSR model is generated using the results from Secs. 2.2 and 2.3. The resultant model can be used for future dynamic analysis.

3. Conclusions

This study is to assess the dynamic response of SFSR under submerged condition to develop the reduced SFSR model for dynamic analysis. FSI effect on two concentric cylinders are studied. And then, the reduced SFSR model under submerged condition is developed based on the results from two concentric cylinders. The results are compared to in air condition of SFSR. The analyses results show that the generated reduced SFSR model can be effectively applicable for dynamic analysis.

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[3] Youngin Choi, Jongbum Park, No-Cheol Park, Young-Pil Park, Kyoung-Su Park & Kyeong- Hoon Jeong, Application of seismic analysis methodology to small modular integral reactor internals, Journal of Nuclear Science and Technology, 19 Aug 2014.

[4] ANSYS, Finite Element Analysis Program, Ver. 18.0