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Response Spectrum and Time History Seismic Analysis of the SMART Reactor Assembly

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1. Introduction

Recently, efforts have been devoted worldwide to expand the peaceful utilization of the nuclear energy other than electricity generation. Therefore, small/ medium size multi-purpose advanced reactor draws keen attention in consideration of its adaptive nature, simplicity of reactor design, and passive safety approach. It is expected that the demand for small/medium size reactor will arise for various applications such as small capacity power production, heat generation, and energy source for seawater desalination in the near future [1].

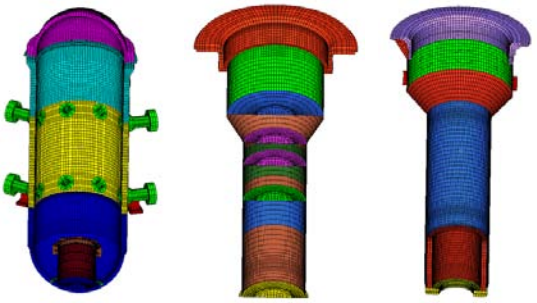
SMART of 330MWt is on the process of design [2]. The SMART RPV (reactor pressure vessel) contains internal components such as steam generators, reactor coolant pumps, pressurizer, UGS (upper guide structure), etc. in the reactor and space among the internal components is filled with reactor coolant [2]. An accurate understanding of the dynamic behavior of a complex structure submerged in or filled with fluid has received extensive attention since the middle of last century. Although plenty of work has been carried out on this topic, most of available investigations, both simulations and experiments, are limited to simple geometrical structures.

In this study, the structural integrity of a SMART reactor assembly with 330MWt against the earthquake was evaluated via the response spectrum and time history seismic analyses using the added fluid mass and substructure techniques. They were performed by ANSYS package[3].

2. Finite Element Models and Dynamic Analysis

2.1 Finite Element Models

The main sections and the developed FE(finite element) models of the SMART reactor assembly are shown in Fig. 1. FE model for the SMART reactor assembly included the principal components such as RPV, UGS, CSB, SGC, and FMHA. The solid element, Solid 45, was applied to thick components. Also, the shell element, Shell 63, was applied to thin components. Fluid 80 element was used for description of fluid and Surf 154 element was used for modeling the node-sharing between fluid & structure. Numbers of node and element for the structure are 181,915 and 154,284, respectively. Numbers of node and element for the fluid are 455,421 and 383,116, respectively. Numbers of node and element for the Surf 154 elements are 28,472 and 33,882, respectively.


(a) RPV & Head Cover (b) UGS (c) CSB

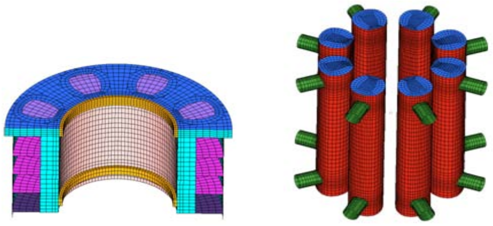

(d) FMHA (e) Steam Generator

Fig. 1. The main section and developed FE model of the SMART reactor assembly

2.2 Dynamic Analysis

Dynamic analysis was performed to investigate the fluid-structure interaction effect and validity of the super-element for the SMART reactor assembly as well as to assess dynamic characteristics of the SMART reactor assembly by using the developed elementary techniques, added fluid mass and substructure techniques. As performing the dynamic analysis, RPV nozzle supports were assumed to be fixed. The following three approach methods were utilized:

○ Method A : Block Lanczos method for the FE model without the super-elements, which was not considering the fluid-structure interaction effect
○ Method B : reduced method using 4,000 passively-selected master DOFs for the FE model without the super-elements, which was considering the fluid-structure interaction effect
○ Method C : Block Lanczos method using 4,000 passively-selective master DOFs for the

substructure model (the FE model with the super-elements), which was considering the fluid-structure interaction effect

Table 1 presents variation of natural frequency vs. the methods considering the fluid-structure interaction effect and the super-element. From Table 1, it is found that the method B has lower natural frequencies by 8~60% on the basis of the 1st mode than the method A due to the fluid-structure effect. Also, the method C had identical results to the method B. It indicates that the super-element model is valid and applicable to the time-history seismic analysis.

Table 1 Variation of natural frequency vs. the methods considering the fluid-structure interaction effect and the super-element

mode	method A	method B		method C	
	frequency (Hz)	frequency (Hz)	difference$^{note)}$ (%)	frequency (Hz)	difference$^{note)}$(%)
1	14.36	9.54	33.56	9.54	33.56
2	14.36	9.54	33.56	9.54	33.56
3	16.79	15.47	7.86	15.47	7.86
4	16.79	15.49	7.74	15.49	7.74
5	38.64	15.62	59.57	15.62	59.57

note) the relative differences with the frequencies calculated by the method A

3. Seismic Analysis

3.1Response Seismic Analysis

The model used in response spectrum seismic analysis was identical to the one used in the dynamic analysis by the method B. The mode combination method is SRSS and the used damping ratio is 4%. El Centro earthquake response spectrum data were used in this analysis. The response spectrum data were applied to the constraint locations (RPV nozzle supports) with gravitational direction.

Maximum displacements occur on the top parts of UGS with 0.13mm. Fig. 2 shows von Mises effective stress distribution of the SMART reactor assembly. As shown in the Fig. 2, maximum stresses occur on the RPV nozzle supports with 1.7MPa. It is found that the structural integrity of the SMART reactor assembly against earthquake is reliable because the maximum displacements are insignificant and the maximum stresses are relatively much lower than design stress intensity (SA508 Gr.3 Cl.1: 198MPa at 350℃, SA240 Type 321: 110MPa at 350℃).

3.2Time History Seismic Analysis

The model used in time history seismic analysis was identical to the one used in the dynamic analysis by the method C. The inertial load approach method, which is using time-dependent gravity load, was also used. ITS (Integrated time stepping) was used on the basis of auto time stepping. The used damping ratio is 4%. El Centro earthquake time domain input data were used in this analysis.

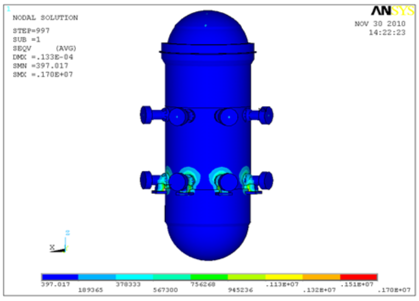
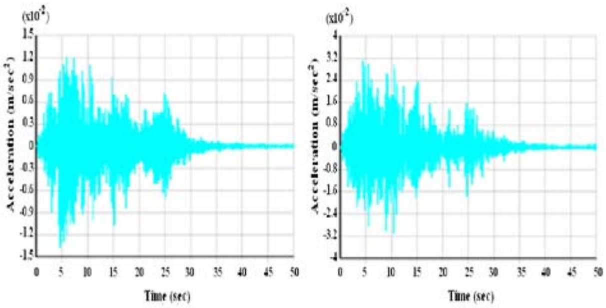


Fig. 2. von Mises effective stress distribution

Fig. 3 depicts the response spectra at two points. As depicted in Fig. 3, it is identified that the structural integrity of the SMART reactor assembly against earthquake is reliable because the magnitudes of response spectra are insignificant.



(a) node 133840 (b) node 96953

Fig. 3. The response spectra at the two evaluation points

3. Conclusions

The following conclusions are found via the study about seismic analysis of the SMART reactor assembly with 330MWt:

○ The fluid-structure interaction effect has to be considered when evaluating the structural integrity of the SMART reactor assembly against earthquake,
○ The super-element model for the SMART reactor assembly is valid and applicable to the time-history seismic analysis,
○ The SMART reactor assembly has sufficient seismic safety margin in the viewpoint of the response spectrum and time history seismic analyses.

REFERENCES

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