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Development of a Seismic Analysis Model for SMART

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1. Introduction

KAERI has been developing SMART(System-integrated Modular Advanced ReacTor) for an environment-friendly reactor that gives freshwater from the sea as well as electric power.

The purpose of this study is to develop a 3-D stick model in order to assess the structural safety of SMART against the seismic load using the modal and seismic analyses. The FE models of the reactor vessel and the internal structures have been simplified as a stick model. Since the stick model is required to be equivalent to the 3-D solid model, it is derived from the modal and static analyses of 3-D solid models of critical structures by evaluating their natural frequencies and stiffness. Results of all stick models are compared with those of the respective 3-D solid models, and then this study integrates every 3-D stick model with the equivalent constraint or coupling conditions. Finally, this study shows the results of the modal analysis including fluid-structure interaction.

2. Development of a Seismic Analysis Model

2.1 Analysis of 3-D Solid Model

Since the stick model is composed of many beams, lumped masses, rigid and spring elements, it cannot help but have a lot of assumptions and idealizations on imposing the section information, the boundary or constraint conditions between components so as to simplify as an installed structure. This study has performed the modal and static analyses with 3-D solid model prior to development of the stick model.

Fig. 1(a) shows the external appearance and the internal components of SMART. In this paper, the critical structures have been selected as RVA(reactor vessel assembly), CSB(core support barrel), UGS(upper guide structure), CRDM(core rod drive mechanism), SG(steam generator), FMHA(flow mixing header assembly), FWN(feed water nozzle), Flow-Skirt and ICI support structure, which affect on the natural frequencies and the mode shapes of SMART as a whole. Above 3D solid FE models have been substituted with a Timoshenko beam element which is able to consider shear deformation effect. One carried out the modal analyses of 3-D solid models so as to get the natural frequency of the internal components. FWN was modeled as a spring element after obtaining the stiffness from the static analysis with 3-D solid model, and the connection between RVA and FWN/SN/RCP adopted a rigid beam element.

2.2 3-D Stick Models of each component

RVA, CSB, UGS and CRDM are able to be characterized as the main parts for the function of the reactor. Since the ratio of the diameter to height for RVA is about is 0.33, and those of CSB, UGS and CRDM are slightly lower than that of RVA, these components are able to be categorized as stubby and thick structures. Hence, this study employs beam188 element without mass which is based on the Timoshenko beam theory which includes shear deformation effect. The cross-section details of the beam188 element are provided via the section data such as an inner radius and outer radius. And their respective mass is distributed at the corresponding position as a lumped mass element so that the moment of inertia of mass for each structure can be kept. The others such as FWN, FMHA, Flow-Skirt, SG and ICI support structure are modeled as a combination of rigid, spring and lumped mass elements. In the case of FWN, the previous section already simulated the static analysis for obtaining the stiffness.

2.3 FE-Model Updating Method

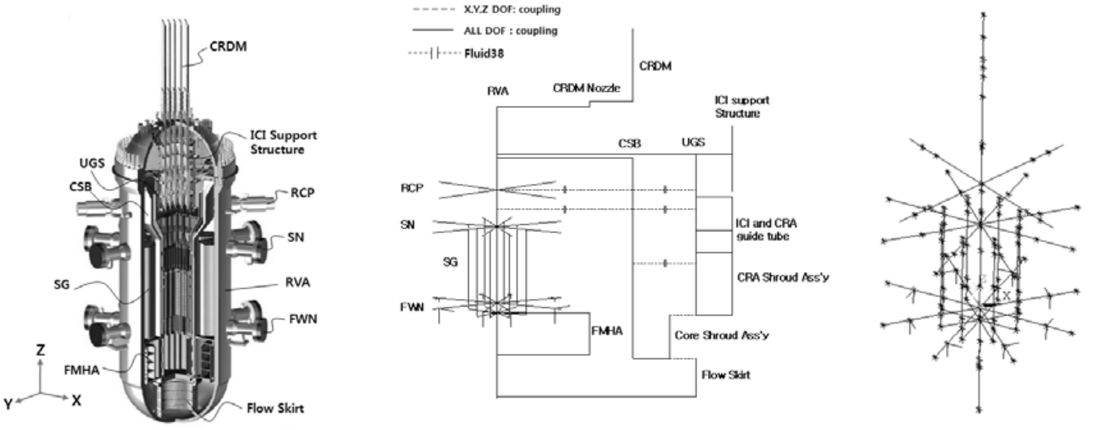
There are deviations of the natural frequency between the 3-D solid models and 3-D stick models in RVA, CSB, UGS and CRDM. The other components give a good agreement results in comparison with 3-D solid model and 3-D stick model. It is need to update the 3-D stick models in RVA, CSB, UGS and CRDM to get more accurate results. The paper adopts the FE model updating method to produce more acceptable and reliable natural frequencies and mode shapes. The FE model updating procedure is carried out using a least-square approach which is efficient and common way to solve the updating problem[1].

2.4 Integration of 3-D Stick Model for SMART

So far, this study has explained the development process of 3-D stick model for each component based on 3-D solid model. Since the acceptable models of each component were obtained as in the previous section, this study drew the schematic diagram of the 3-D stick model for SMART. Except for SG, all components are connected by the given constraint conditions between each component so that their positions can be coaxial as illustrated in Fig. 1(b).

2.5 Considering Fluid-Structure Interaction

SMART includes fluid-coupled cylindrical structures between CSB-UGS and RVA-CSB. It is reported that the fluid-structure interaction may significantly reduce the natural frequencies of such structures due to the



(a) (b) (c)

Fig. 1 Seismic analysis model for SMART: (a) Internal components; (b) Schematic diagram of stick model; (c) FE model.

Table Ⅰ: Natural frequencies, effective mass and vibration modes of SMART including fluid-structure interaction

Mode	Frequency(Hz)	Effective Mass(%)			Remark
		X	Y	Z	
1~2	6.69	1	1	0	1st bending(CRDM)
3~4	10.80	22	22	0	tilting(SG)
5~6	12.11	1	1	0	1st bending(CSB,UGS) out of phase
7~8	13.70	34	34	0	1st bending(CSB,UGS) in phase
9~10	17.08	3	3	0	2nd bending(CRDM)
11~12	18.70	18	18	0	2nd bending(CRDM), 1st bending(FlowSkirt)
13	19.98	0	0	5	translation vertical(ICI Support Structure)
14~15	26.69	0	0	0	2nd bending(CSB,UGS) out of phase
16	28.25	0	0	33	translation vertical(SG)
17~18	34.13	11	11	0	tilting(RVA), out of phase RVA-CSB(1st bending)
19~20	39.67	6	6	0	tilting(RVA), out of phase RVA-CSB(2nd bending)
21	41.63	0	0	49	translation vertical(RVA)
22~23	50.65	0	0	0	2nd bending(CSB,UGS,Flow Skirt) in phase
24~25	59.30	0	0	0	3rd bending(CSB,UGS) out of phase

hydrodynamic mass of fluid. In this paper, the FE model of the fluid-structure interaction utilizes the Fluid38 element whose theory is based on the Fritz's paper. The element is able to apply to the problem where axial flow by the relative lateral motion of two concentric cylinders is insignificant. Hence, it is possible to employ the Fluid38 element since the assembled configurations of CSB-UGS and RVA-CSB are coaxial and the axial flow is negligible as shown in Fig. 1(c).

3. Modal Analysis of a Seismic Analysis Model

So far, this paper explained the development processes for a seismic analysis of SMART including fluid-structure interaction. The 3-D stick model is utilized for the modal analysis, and the fixed boundary conditions are also imposed on the ends of the spring elements for FWM. As a result, the natural frequencies of CRDM are 6.69 and 17.08Hz, these frequencies are almost same with the results not considering the fluid-structure interaction. However, the frequencies of CSB and UGS are 12.11Hz with out-of-phase and 13.70Hz with in-phase, respectively. The fluid-structure interaction between CSB and UGS reduced the frequencies about 40% and 33% in out-of- phase mode and in-phase mode.

4. Conclusions

This paper presented the development process of 3-D stick model of a reactor for a seismic analysis in order to assess the structural safety against the seismic load. Since there were deviations of the natural frequencies between 3-D solid model and initial 3-D stick models of RVA, CSB, UGS and CRDM, the FE model updating method was adopted to get accurate stick models. And the other components gave a good agreement with results compared with 3-D solid model in the initial stick model. The 3-D stick model for SMART includes fluid-coupled effects between CSB-UGS and RVA-CSB with Fluid38 element. The fluid-structure interaction between CSB and UGS reduced the frequencies about 40% and 33% in out-of- phase mode and in-phase mode, respectively.

REFERENCES

[1] B. Jaishi, H. J. Kim, M. K. Kim, W. X. Ren, and S. H. Lee, "Finite Element Model Updating of Concrete-filled Steel Tubular Arch Bridge under Operational Condition using Model Flexibility", Mechanical Systems and Signal Processing, Vol. 21, pp. 2406-2426, 2007.