Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Dynamic Characteristics of a Cylindrical Structure According to the Submergence Conditions

Tae-Sung Kim, Chang-Gyu Park*, Jong-Bum Kim
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong Daejeon, Korea
**Corresponding author: chgpark@kaeri.re.kr*

1. Introduction

The Upper Internal Structure (UIS) of a sodium-cooled fast reactor (SFR) consists of a support cylinder, upper control rod shroud tubes, insulation and shield plates, and several thermocouple guide tubes. During the operation, the support cylinder is filled with liquid sodium and thus a fluid added mass effect on the dynamic characteristics of the structure may occur [1, 2].

In this study, the dynamic characteristic of a cylindrical structure simulating the support cylinder of UIS submerged in a fluid was investigated analytically. The commercial FEM software ANSYS [3] was used, and several analyses were carried out to investigate the effect of the fluid added mass on the dynamic characteristics of the structure.

2. Finite Element (FE) Model and Analyses

2.1 FE Analysis Model

For simplicity, the support structure of UIS was assumed as a simple cylindrical structure, as shown in Fig. 1. It is composed of an inner steel structure and outer water chamber. It is made of Type 304 Stainless Steel (304 SS), and its outer diameter, height, and thickness are 213 mm, 400 mm, and 3.5 mm, respectively. A water chamber made of acryl was prepared to contain water. The outer diameter, height, and thickness of the chamber are 400 mm, 500 mm, and 10 mm, respectively. Material properties of the target model are listed in Table I [4].

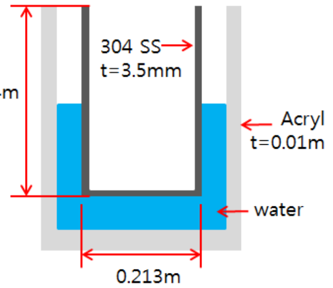


Fig. 1. Geometry of the Target Model

Table I : Material Properties

	SUS304	Water	Acryl
Young's modulus (GPa)	200	-	30
Poisson's ratio	0.3	-	0.3
Density (kg/m^3)	7930	1000	1190
Sonic velocity (m/s)	-	1481	-
Dynamic viscosity(m^2/s)	-	1.002e-3	-

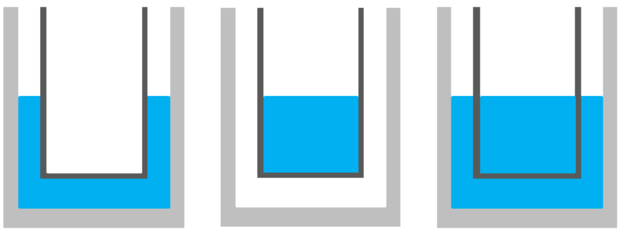
First, the modal testing was performed in air analytically and experimentally to obtain the reference data. The same test was then conducted in water under a 50% submergence condition. In the experiment, the cylindrical structure was excited by an impact hammer and an acceleration sensor was used to measure the vibrations of the structure. The Frequency Response Function (FRF) of the LMS equipment was used for the frequency analysis, and the results are shown in Table II. Table II also compares the experimental and analytical results. From Table II, one can also see that the natural frequency of the model in water with 50% submergence is lower than that in air. This is because the fluid added mass affects the dynamic characteristic of the cylindrical structure. Since the error between the analysis and the experiment is less than 1%, it is judged that the analysis can simulate the experiment exactly.

Table II : Comparison between Analyses and Test results

Water level	Natural frequency (Hz)		Difference (%)
	Experiment	Analysis	
Air	216	214.07	0.89
50%	203	202.02	0.48

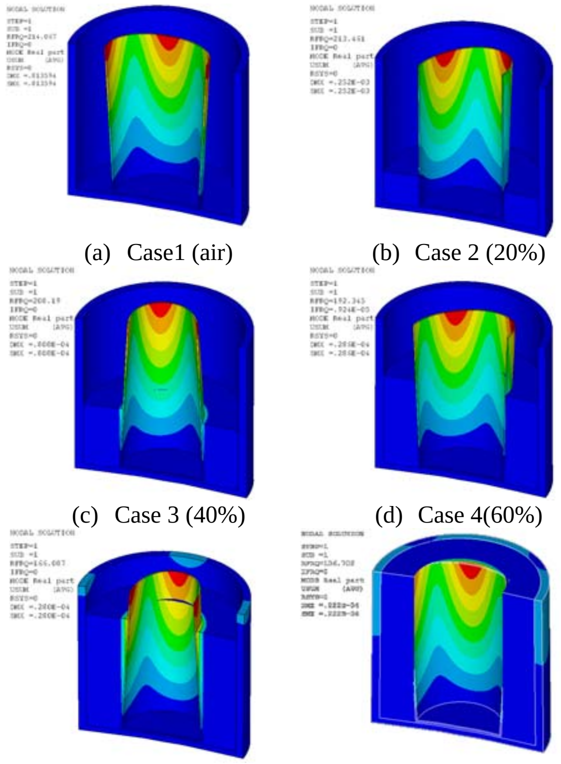
2.2 Modal Analysis Result

To precisely investigate the dynamic characteristics of a submerged cylinder, several FEM analyses were performed according to the variation of the water level. For analysis, three types of analytical models having different water filling conditions, shown in Fig. 2, were considered: i) Type A water is filled between the cylindrical structure and water chamber, ii) Type B water is filled only in the cylindrical structure, and iii) Type C water is filled in the cylindrical structure and the chamber. For each analysis model, six kinds of water levels were applied, i.e., 0%, 20%, 40%, 60%, 80%, and 100%.



(a) Type A (b) Type B (c) Type C

Fig. 2. Analysis models with different water filling conditions



(a) Case1 (air) (b) Case 2 (20%)

(c) Case 3 (40%) (d) Case 4(60%)

(e) Case 5(80%) (f) Case 6(100%)

Fig. 3. Mode shapes of cylindrical structures (1st mode) for Type A with different water levels.

The mode shapes and natural frequencies of the cylindrical structure for Type A with different water levels are shown in Fig. 3 and Table III. From the results, one can see that mode shapes of all cases are similar to each other, while the natural frequencies are quite different. For instance, the natural frequency was 214.07 Hz for Case 1 (in air), whereas the natural frequency was 136.7 Hz for Case 6 where the structure was fully submerged. The natural frequency of the fully submerged structure was nearly 1.6-times lower than that in air. This is because the fluid added mass effect on the dynamic characteristic of the structure increases as the water level increases. From Table III, one can also see that Type C, which has the largest mass of water, has the highest reduction property on the natural frequency. The relationship between the water level and natural frequency is shown in Fig. 4. The natural frequency rapidly decreases in a higher water level while a small variation is observed in a lower water level. The natural frequencies of Case 2 are almost the same as the air condition, and thus fluid added on it mass is negligible.

Table III : Natural frequencies of all analytical models (1st mode)

Cases		Natural frequency (Hz)		
		Type A	Type B	Type C
1	0%	214.07	214.07	214.07
2	20%	213.46	213.43	212.82
3	40%	208.19	208.11	202.59
4	60%	192.35	193.41	176.81
5	80%	166.09	170.67	143.80
6	100%	136.70	145.42	113.96

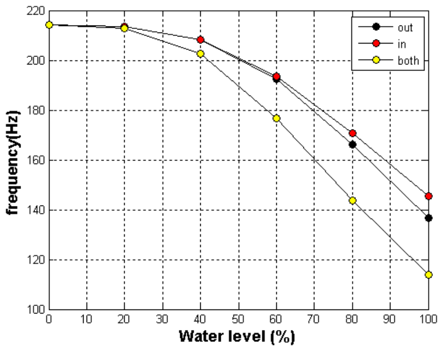


Fig 4. Relation between water level and natural frequency (1st mode)

3. Conclusions

The effect of the fluid added mass on the cylindrical structure simulating the support structure was investigated analytically using ANSYS software. Three types of analytical models having different water filling conditions were considered, and six cases of water levels were applied for each type. The results showed that the high water level decreases the natural frequency of the structure. In addition, the rapid reduction of the natural frequency was observed in a high water level. Although only the simple structure was considered here, this research can be a basic study for a detailed analysis of a complex structure.

ACKNOWLEDGEMENTS

This work was supported by the National research foundation (NRF: No. 2012M2A8A2025636) by Korea government (Ministry of Science, ICT and Future Planning).

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