Calculation of Added Mass for Submerged Reactor with Complex Shape

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1. Introduction

Kijang Research Reactor (KJRR) is currently under construction. Its reactor is located on the bottom of a reactor pool which is filled with water to a depth of 12m. Some components are installed on or inside the reactor and their structural integrity and safety performance need to be verified under seismic situations. For the verification, time history data or Floor Response Spectrum (FRS) on their support location, which is the reactor, should be obtained [1]. Therefore, transient response analyses for the reactor should be performed during earthquake events.

It is well known that the dynamic characteristics of submerged structures are affected a lot by water. A Finite Element (FE) model with fluid elements can give very accurate results for the matter; however, it costs too many resources and takes too much time for the transient analyses. In order to make the model more efficient and simple, added masses are often used to simulate the effect of water instead of the fluid elements. Many literatures introduce methods to calculate the added mass according to the exterior shape of structures [2,3]. However, most of them are for only simple shapes, such as rectangular, circle, etc. In this paper, how to obtain the added masses for the reactor with complex shape is presented.

2. Description of Reactor

Reactor Structure Assembly (RSA) for KJRR is shown in Fig. 1. It has a simple rectangular cross section from the bottom to the middle. On the other hand, its upper part has a quite complex shape of which added mass cannot be easily estimated.

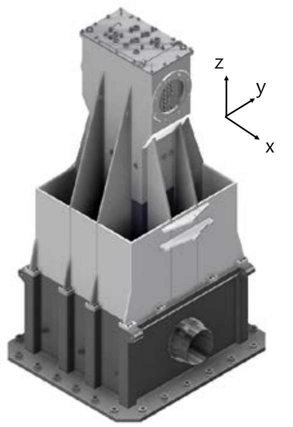


Fig. 1. Reactor structure assembly for KJRR

3. Method for calculation of added mass

2.1 Basic concept

When an object moves in fluid, resistance forces proportional to its acceleration are exerted on it. The forces function as added masses in dynamic equations of the system.

Let's think about a single degree of freedom (SDOF) system in fluid and assume that its natural frequency can be obtained somehow. The natural frequency, f_n, can be expressed as below;

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m+\alpha}} \tag{1}$$

where, m and k denotes mass and stiffness, α means the added masses due to fluid. If the mass and stiffness are known, the added masses can be obtained using the equation.

2.2 Calculation of total added mass outside RSA

A SDOF system was constituted with RSA as a mass in fluid elements using ANSYS (ver. 15.0) as shown in Fig. 2. The hole of RSA was blocked in order to obtain the added masses due to the fluid only outside RSA. Degrees of freedom were set to be zero except a single direction and a spring element was located along the direction. Finally, its natural frequency was calculated and total added masses for RSA were obtained according to the equation (1) and shown in Table I.

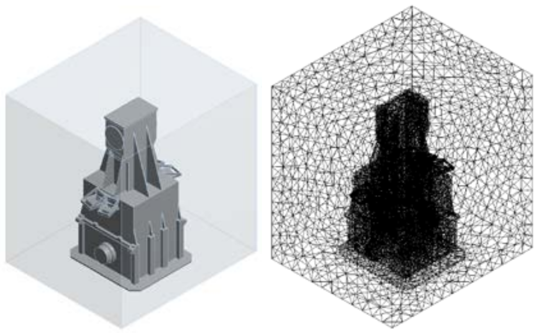


Fig. 2. SDOF RSA FE model in fluid

Table I: Total added masses due to water outside RSA

	x-direction	y-direction
Added mass [kg]	7452	6791

2.3 Calculation of partial added mass

Total added masses were calculated in the previous section, however, some problems still remain. They are; where & how much should the added masses be applied? To resolve the problems, RSA was divided into three parts as shown in Fig. 3. Subsequently, same analyses as the entire RSA in the previous section were performed respectively, and the obtained added masses are shown in Table II.

Summations of the partial added masses are different from the total added masses in Table I. It seems to be caused by the dividedness. Therefore, the total added masses in Table I were divided based on the ratio in Table II and applied to the three parts as shown in Fig. 4.

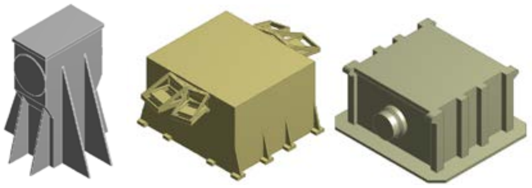
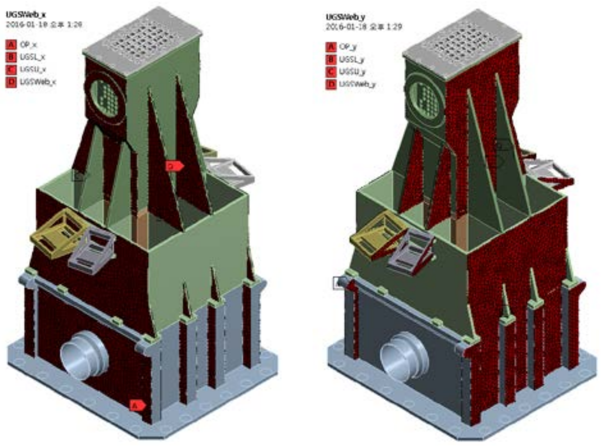


Fig. 3. Three divided parts of RSA

Table II: Added masses for the three divided parts

	x-direction		y-direction	
	Mass [kg]	Ratio	Mass [kg]	Ratio
Upper	1680	0.32	2010	0.40
Middle	1629	0.31	1391	0.28
Lower	1925	0.37	1621	0.32
Sum	5233	1.00	5022	1.00



(a) for x-direction (b) for y-direction

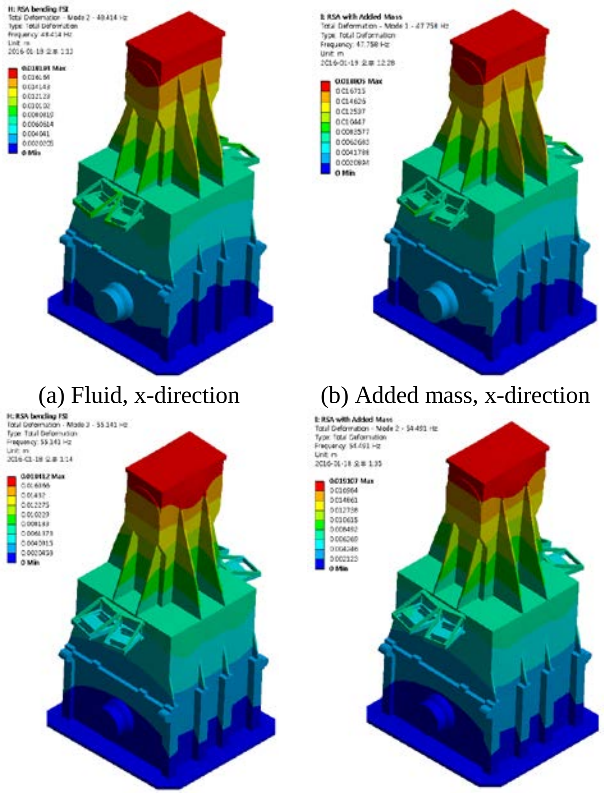
Fig. 4. Surfaces where added masses are applied

4. Verification of added masses

The added masses obtained in the previous chapter were verified through calculations of the natural frequencies of RSA. Natural frequencies of RSA using fluid elements and the added masses were calculated and shown in Table III. Their mode shapes are also shown in Fig. 5. The errors of the natural frequencies are -1.2% and -1.1%, respectively, for each direction and their mode shapes are very similar to each other. Therefore, it can be concluded that the added masses were properly calculated and can simulate the effects of the water.

Table III: Natural frequencies of RSA using fluid elements and added masses

	Using fluid elements	Using added masses
x-direction	48.4 Hz	47.8 Hz
y-direction	55.1 Hz	54.5 Hz



(a) Fluid, x-direction (b) Added mass, x-direction

(c) Fluid, y-direction (d) Added mass, y-direction

Fig. 5. Mode shapes of RSA using fluid elements and added masses

5. Conclusions

In this paper, how to calculate added masses for complex shaped structure was suggested. The proposed method was applied to RSA for KJRR and its accuracy was verified through comparison of the natural frequencies of RSA with fluid elements and the added masses. They showed the differences less than 1.5% between two models. Finally, it is concluded that the proposed method is quite useful to obtain added masses for complex shaped structure.

6. Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (2012M2C1A1026910).

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