Interaction of Hydrodynamic Forces in Wave Energy Converter

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Abstract

As one of the power generation methods using wave energy, the movable-type wave power generator has been attracting attention around the world and has been the subject of various studies. (Karayaka et al., 2020, Vincent S et al., 2014, M. Lawson et al., 2015). This device generates electricity by converting the vertical motion of waves into rotational motion using a power converter inside the device. This wave power generator can be classified into two types according to the shape of the movable body and the way it is subjected to waves: the translational type and the flexural type. The translational type is the subject of this research, in which the part of the movable body in contact with the sea surface is circular and can receive waves from any direction in 360°. There are various methods for converting wave energy, such as hydraulic, gyro, and direct drive systems using linear generators. Movable animal-type wave energy generators have become the mainstream of equipment installed offshore. In this study, we investigate the energy conversion of these animal-driven wave power generators using numerical simulations. The device is roughly divided into three parts: a float, a spar, and a rocker. The effects of the presence or absence of the damping plate on the hydrodynamic coefficients of added mass, wave damping, and wave forcing, and the hydrodynamic coefficients when the float and spar are combined are obtained, and the hydrodynamic interference of the device is clarified.

Keywords : Power buoy, Reference Model 3 (RM3), Translational-motion type, Wave damping, Coefficient of hydrodynamic force, Wave Point Absorber

1. Introduction

In recent years, global temperatures have been gradually increasing due to global warming, which has begun to affect climate and sea surface temperatures. In the seas around Japan, sea surface temperatures have risen by about 0.7 to 1.6 degrees Celsius. As a result, fish that were originally caught in certain areas have moved to other areas, making fishing difficult. The occurrence of red tides has also had a significant impact on the fishing industry. Red tides caused by toxic plankton can kill fish and shellfish. However, it is not possible to obtain this information without actually visiting the sea area. In recent years, the aging of the fishing industry and the shortage of labor have placed a heavy burden on fishermen, and the cost of fuel has also become a problem. Therefore, we thought that the use of IoT technology to remotely monitor images and water temperature in the field would reduce the burden on fishermen by eliminating the need to go all the way to the field. To achieve this, an independent power source to generate electricity for IoT use offshore is necessary. Therefore, we decided to use a small, movable wave power generator as an independent power source. In order to improve the efficiency of the device, we investigate the fluid force interference that affects the motion by numerical simulation.

2. Research method

2.1 Device model

Figure 1 shows the shape, dimensions, and mass of the initial model of the wave power buoy developed in this study. The buoy consists of three parts: a doughnut-shaped float in the center, a longitudinal cylindrical spar, and a damping plate at the bottom of the spar. The moment of inertia of each is shown in Table 1.

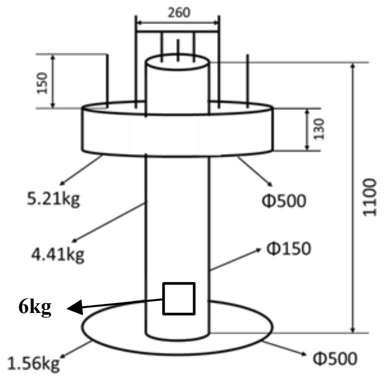

Fig.1 Model shapes and dimensions

Table 1 Inertia moment

Part	I_x (Roll) $[kg \cdot m^2]$	I_y (Pitch) $[kg \cdot m^2]$	I_y (Yaw) $[kg \cdot m^2]$
Spar	0.4656	0.4656	0.0618
Damping plate	0.3475	0.3475	0.3724
Float top surface	0.3374	0.33738	0.362
Float side	0.3202	0.32022	0.3687
Float bottom	0.1878	0.18777	0.1224
Total	3.2689	3.2667	2.9244

2.2 Numeric calculation

The equation of motion for linear motion of an object moving in a regular wave is expressed by Eq.1. The equation of motion for rotational motion is expressed by Eq.2.

$$M\ddot{x} + N\dot{x} + Cx = F \quad (1)$$

$$I\ddot{\theta} + N\dot{\theta} + C\theta = M \quad (2)$$

Assuming that the displacement of the floating body is x_j(j=1,...,6) from Equations (1) and (2), The equation of motion of a floating body in regular waves can be expressed as Eq.3.

$$\sum_{j=1}^{6}\left[\left(M_{ij} + m_{ij}(\omega)\right)\ddot{x}_j(t) + N_{ij}(\omega)\cdot\dot{x}_j(t) + C_{ij}(\omega)x_j(t)\right] = F_{\omega i}\cdot e^{i\omega t} \quad (3)$$

where ω: wave frequency, M_{ij}: mass of floating body, $m_{ij}(\omega)$: added mass, x: displacement of floating body, $\dot{x}$: velocity, $\ddot{x}$: acceleration, $N_{ij}(\omega)$: wave-making attenuation coefficient, K: restoring force, $F_{\omega i}$: wave-forcing force. From Equation (3), the added mass $m_{ij}(\omega)$ and the wave damping $C_{ij}(\omega)$ are obtained by the Nemoh software. The obtained hydrodynamic force coefficients are non-dimensionalized as in (4), (5) and (6).

$$\bar{m}_{ij} = \frac{m_{ij}}{\rho L^k} \quad (4)$$

$$\bar{C}_{ij} = \frac{C_{ij}}{\rho L^k \omega} \quad (5)$$

$$\bar{F}_{\omega i} = \frac{F_{\omega i}}{\rho L^k g} \quad (6)$$

where ρ: density of water, L: device length, g: gravitational acceleration. Also, k=3 for i,j=1,2,3, k=4 for i=1,2,3, j=4,5,6 or i=4,5,6, j=1,2,3 and k=5 for i,j=4,5,6.

3. Calculation Results

Figure 2 shows the effects of the plate on the added mass $m_{ij}(\omega)$, the wave damping $C_{ij}(\omega)$, and the wave forcing $F_{\omega i}$, with and without the plate. The effects on the added mass $m_{ij}(\omega)$, the wave damping $C_{ij}(\omega)$, and the exciting force $F_{\omega i}$ are shown in Figure 3, comparing the case with a single float, the case with a float and a spar, and the case with a float, a spar, and a damping plate.

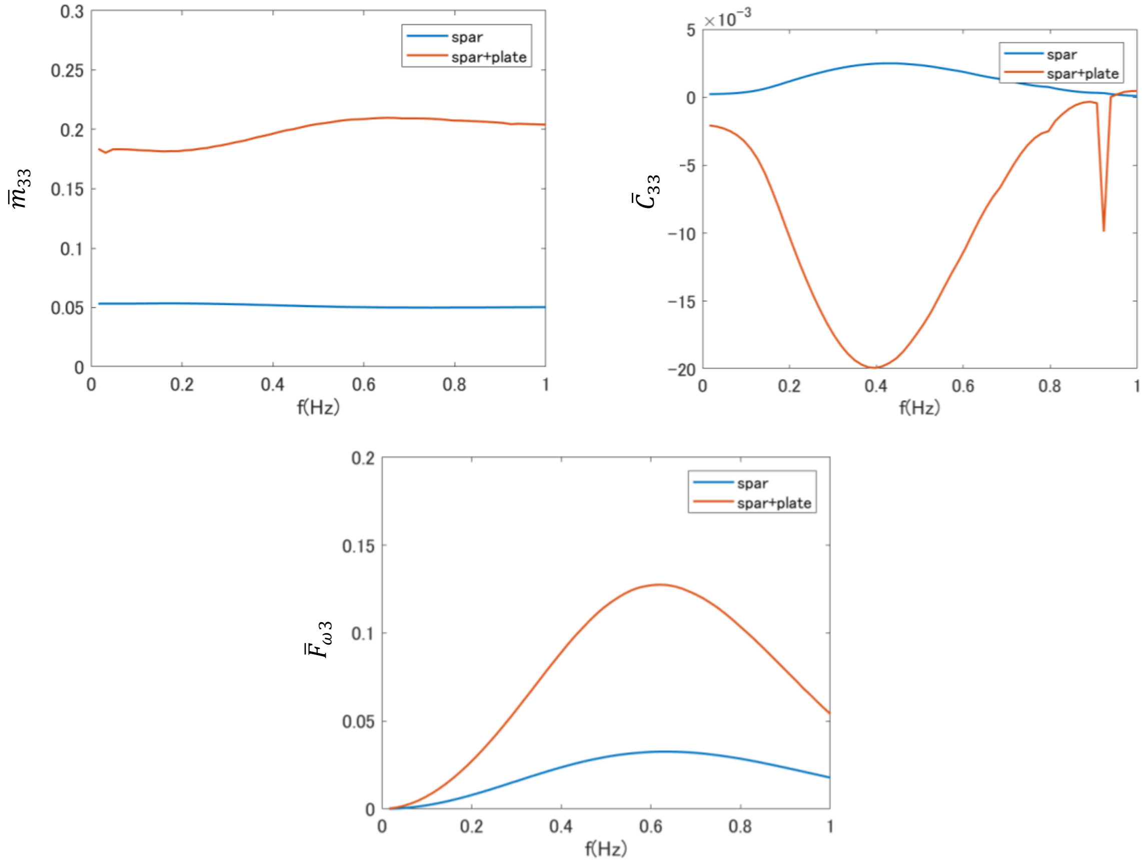

Fig. 2 Change in coefficient of hydrodynamic force with and without damping plate

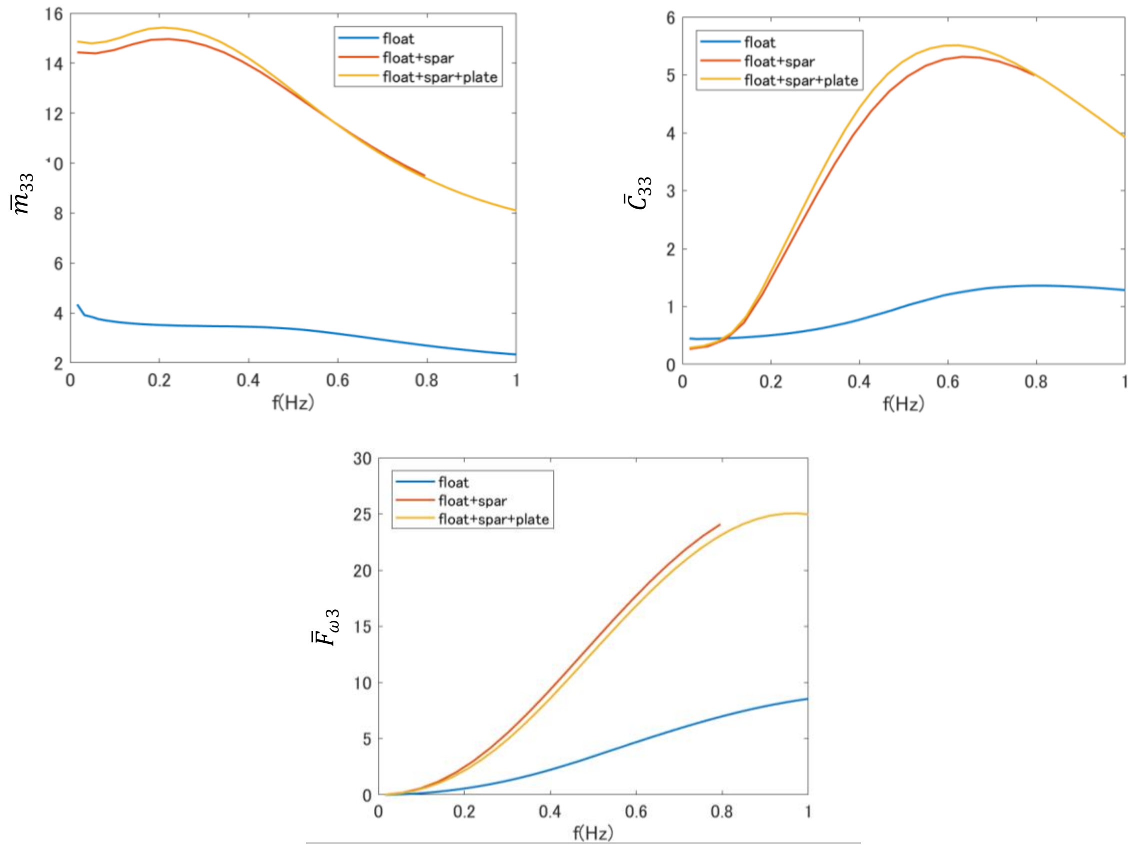

Fig. 3 Variation of hydrodynamic force coefficients in floats and spars

4. Conclusion

From Figure 2, it was found that the effect of the plate on the hydrodynamic force is larger when the rocker is attached, thus proving the effectiveness of the plate. Figure 3 shows that the interference of hydrodynamic forces between the float and the spar is clearly observed.

We have clarified the hydrodynamic interaction of the wave energy converter with a movable body in this study, we would like to obtain the motion of the device under various conditions and investigate the shape of the device to increase the energy conversion.

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