Introduction

The added mass and drag coefficients are two critical parameters for accurate prediction of hydrodynamic forces on the floats. For the dynamic response analysis of floating offshore wind turbine (FOWT), the added mass coefficient is usually calculated by using the boundary element method (BEM) and the drag coefficient is used as a constant value as mentioned in the references [1] and [2]. It implies that the effect of KC number on the hydrodynamic coefficients is neglected in the previous studies.

In this study, a model is developed to estimate global hydrodynamic coefficients for a semisubmersible FOWT from the added mass and drag coefficients for each element, considering effects of interaction of elements, KC number and wave frequency in the hydrodynamic coefficients. The proposed model is validated by the global hydrodynamic coefficients and dynamic responses obtained from the water tank tests.

Water tank tests

The motions and mooring tensions for a 2MW semisubmersible FOWT located at Fukushima offshore site are investigated by the water tank tests. The Froude scaling law is used and the scale factor is 1:50. The model is positioned by 4 catenary mooring lines of 10.3 m anchored on the bottom of water tank at a depth of 2.5 m as shown in Fig.1. The origin of coordinate locates at the centerline of column of floaters on the water surface and the reference point for the floater motions is defined at the gravity center. The global hydrodynamic coefficients are measured by the forced oscillation test using the same model.

Hydrodynamic coefficients

The hydrodynamic coefficients are different for each floater because they are affected by interaction of elements, KC number and frequency of wave. A model is proposed to calculate hydrodynamic coefficients for a semisubmersible FOWT from those for each element considering these factors.

Hydrodynamic coefficients of each element

The hydrodynamic coefficients of each element can be expressed as a function of interaction of elements ($\beta$), KC number ($KC$) and normalized frequency of wave ($\eta$):

$$c^x_\beta(KC,\eta) = \frac{c^x_{\beta}(KC_0,\eta_0)}{\beta} \times \frac{c^{x_0}(K_0,\eta_0)}{c^{x_0}(K_0,\eta_0)} \times f(KC,\eta) \times g(KC,\eta)$$

where $i$ denotes the number of element for a floater; $k$ indicates the normal and tangential directions for an element, $\eta$ presents correction factors. $c^x_{\beta}(KC_0,\eta_0)$ and $c^{x_0}(K_0,\eta_0)$ are the added mass and drag coefficients at a specified $KC_0$ and $\eta_0$. The normalized frequency $\eta$ is defined as a ratio of wave frequency to a typical wave frequency $\omega_{\text{typical}}$, which is 0.62 Hz for a typical wave period of 10s in full scale.

The hydrodynamic coefficients of the floater shown in Fig.1 are investigated by using the horizontal and vertical forced oscillations with CFD [1] for various $KC$ number and frequency of wave. $C_m$ and $C_d$ for each element at a specified $KC_0$ and $\eta_0$, shown in Ref. [1] are used to model $C_m$ and $C_d$ for different $KC$ and $\eta$ in this study.

Interaction correction factor

The interaction correction factor for each element is defined in [1] as a ratio of hydrodynamic coefficient between each element and the referenced one at $KC_0$ and $\eta_0$:

$$\gamma_i^x(KC,\eta) = \frac{c^x_i(KC,\eta)}{c^x_{\beta}(KC_0,\eta_0)}$$

$KC$ number correction factor

$C_m$ and $C_d$ for each element vary with $KC$ number related to the amplitude of floater motion. The $KC$ number correction factor, $\gamma_i^x(KC)$, is defined as a ratio of the hydrodynamic coefficients of element to those at a specified $KC_0$ and $\eta_0$.

The predicted and measured $C_m$ and $C_d$ for a square, cylinders with different aspect ratios and a heave plate are compared as shown in Fig.2 and are used for calculation of $C_m$ and $C_d$ of a whole floater.

$$\gamma_i^x(KC) = \frac{c_i^x(KC)}{c_i^x(KC_0)}$$

In Fig.2, the experimental data is fitted as function of $KC$ number shown as solid line. Upper two figures present variation of hydrodynamic coefficients for isolated circular cylinder with different aspect ratio and square cylinder. Other two figures shows $C_m$ and $C_d$ of heave plates in varied $KC$ number.

Frequency correction factor

The frequency of wave is an important factor which affects hydrodynamic coefficients and dynamic responses of floater as shown in [2]. The frequency correction factor, $\gamma_i^x(\eta KC)$, is introduced to account the effect of wave frequency on the hydrodynamic coefficients for each element at a $KC$ number.

$$\gamma_i^x(\eta KC) = \frac{c^x_i(\eta KC)}{c^x_{\beta}(KC_0,\eta_0)}$$

It is noticed that the frequency correction factors for each component are the same as that for the whole floater as shown in [2]. This factor can also be assumed as a constant value except for the drag coefficient in the surge direction, which is expressed as a function of $KC$ number:

$$\gamma_i^x(\eta KC) = \begin{cases} 1 & 1.19 - 0.6m - \frac{2.7}{Kc} - 3.8 & \text{for } Kc \leq 6.62 \text{ and } Kc \geq 9.26 \text{ for } Kc \\ \text{Linear Interpolation} & 6.62 < Kc < 9.26 \text{ for } Kc \end{cases}$$

Hydrodynamic coefficients for a semisubmersible FOWT located at Fukushima offshore site are investigated by the water tank tests. The Froude scaling law is used and the scale factor is 1:50. The model is positioned by 4 catenary mooring lines of 10.3 m anchored on the bottom of water tank at a depth of 2.5 m as shown in Fig.1. The origin of coordinate locates at the centerline of column of floaters on the water surface and the reference point for the floater motions is defined at the gravity center. The global hydrodynamic coefficients are measured by the forced oscillation test using the same model.

Validation

Global hydrodynamic coefficients

The formulas shown in Ref. [2] are used to calculate the global hydrodynamic coefficients from the proposed hydrodynamic coefficients for each element. Predicted global hydrodynamic coefficients by the proposed model are compared with those obtained from the forced oscillation tests. The effect of wave frequency on $C_m$ in the surge direction is significant as shown in Fig.3.

Dynamic responses

The added mass and drag coefficients calculated by the proposed model as well as the diffraction force and radiation damping obtained by BEM are used to predict the dynamic responses of the floater. Cd of cylinders without consideration of KC number dependency as shown in OC4 project is also used to investigate the effect of KC number on the dynamic responses of FOWT. From Fig.4, the effect of KC number dependency of Cd appears at the periods near the natural period of motion in the heave direction. The predicted RAOs by the proposed model show good agreement with those from the water tank tests.

Conclusion

In this study, a model is proposed to estimate global hydrodynamic coefficients for a semisubmersible FOWT, considering interaction between elements, KC number and frequent dependencies.

1. The predicted global coefficients from added mass and drag coefficients of each element by proposed model show good agreement with those obtained from the water tank tests.
2. The predicted dynamic responses in different wave heights by proposed global hydrodynamic coefficients agree well with those from the experiments.

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Reference