A study on dynamic response of a semi-submersible floating wind turbine considering combined wave and current loads

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Introduction

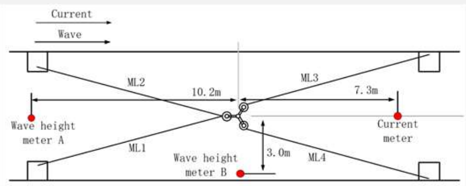
The current loads on floating structures and mooring lines are known to be essential and are recommended to be included in the design as required by international standards. In modeling hydrodynamic loads, the drag force in the Morison's equation is widely used to account for the viscous effect. Many experiments showed that the drag coefficient (C_d) for a circular cylinder in the oscillating flow is different from that in a steady flow. It is crucial to select appropriate drag coefficients for the prediction of hydrodynamic loads on floating structures and mooring lines. Liu and Ishihara [1] proposed a method to determine the hydrodynamic coefficients of a FOWT based on the forced oscillation tests. However, this method was validated by the wave-only water tank tests, and its performance in the combined wave and current condition was not examined.

In this study, the responses of a FOWT in the combined wave and current condition is investigated using a 1:50 scale semi-submersible model, which was used in the Fukushima FORWARD project. Firstly, a water tank test is carried out to investigate the influence of current on the responses of the FOWT. A hydrodynamic force model is then proposed to predict drag force in the combined wave and current condition. Finally, the proposed model is validated by the water tank tests for several load cases.

Water tank tests

The motions and mooring tensions of a 1:50 scale semisubmersible FOWT for the Fukushima FORWARD project are investigated by the water tank tests. The model is positioned by 4 catenary mooring lines of 10.3 m anchored on the bottom of the water tank at the depth of 2.5 m as shown in Fig.1. The origin of coordinate locates at the centerline of center column of the floater on the water surface and the reference point of motions is defined at the gravity center of the floater . Both wave and current are generated from the left side. The current velocity is measured at the location 7.3m away from the floater.

(a) Overview of 1:50 scale model of the platform



(b) Arrangement of the mooring lines

Figure 1 Configuration of the water tank test

Hydrodynamic force model

❑ Drag coefficient C_d for a circular cylinder

Fig. 2 shows the drag coefficient C_d of a circular cylinder in steady and oscillatory flows in the water tunnel and forced oscillation tests. It changes with the increase of Reynolds number and shows different values in the steady and oscillatory flows.

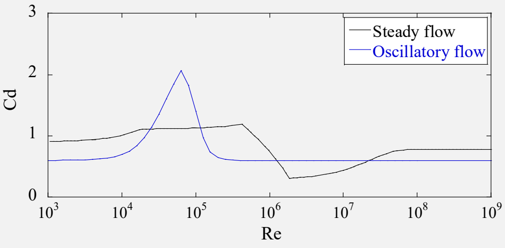


Figure 2 C_d of a circular cylinder in the steady and oscillatory flows

❑ A combined hydrodynamic force model

In this study, the C_d obtained from the forced oscillation test is assumed to be appropriate for predicting the floater motions in the wave only case.

Since C_d of a cylinder in the oscillating flow is different from that in the steady flow, a combined hydrodynamic force model is proposed to calculate the drag force contributed from the wave and current based on the Morison's equation as:

$$F_d = \frac{1}{2}\rho A C_d (v + v_c)|v + v_c| + \frac{1}{2}\rho A (C_{dc} - C_d) v_c |v_c|$$

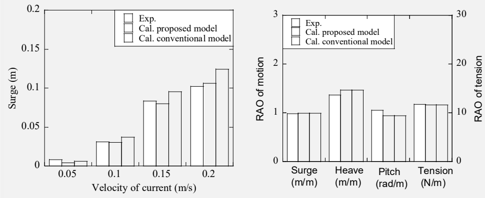
where C_d is the drag coefficient of cylinder obtained from the forced oscillation test and is a function of KC number, frequency and interaction effect between the cylinders [1]. C_{dc} means the drag coefficient of the cylinder measured in the steady flow and is a function of Reynolds number. v_c and v denote the current velocity and the relative velocity without the current component, respectively. In the wave-only and current-only cases, the drag forces by the proposed formula are the same as those by the conventional Morison's equation. In the combined wave and current condition, the current-induced forces are calculated using C_{dc} from the steady flow, while the wave and motion induced forces are predicted using C_d from the forced oscillation test.

Validation

The proposed model is validated through a comparison between predicted and measured motions of the platform and tensions of the mooring lines in the current-only, wave-only and combined wave and current conditions. The result by the conventional model using C_d by the forced oscillation tests is also investigated.

❑ Current only and wave only condition

The simulations are conducted using Orcaflex. Fig.3 shows the comparison of predicted responses by the proposed and conventional models. In the current-only case as shown in Fig.3 (a), the conventional model overestimates the surge motions due to the large value of C_d from the forced oscillation tests, while the predicted responses by the proposed model show good agreement with the experiment. In the wave-only case, both models predict RAOs well as shown in Fig.3 (b) since the same C_d obtained in the oscillatory flow is applied in the two models.



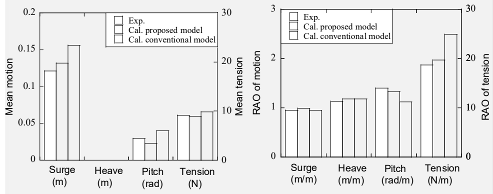
(a) Mean surge in the current only case

(b) RAO in the wave only case (H=0.06m, T=2.5s)

Figure 3 Comparison of predicted responses by the proposed and conventional models in the wave-only and current-only cases

❑ Combined wave and current condition

Fig. 4 presents the predicted mean and dynamic responses by the two models in the combined current and wave case. The conventional model overestimates the mean surge, which is consistent with the conclusion in the current-only case. The predicted RAO of mooring tension is overestimated due to the overestimation of the mean surge and the predicted RAO of pitch is underestimated by the conventional model. The predicted responses by the proposed model match well with the experimental data.



(a) Mean response

(b) RAOs

Figure 4 Comparison of predicted responses by the proposed and conventional models in the wave and current case (H=0.06m, T=2.5s, v=0.2m/s)

Conclusion

In this study, a combined hydrodynamic force model is proposed to estimate the drag force on the floating platform in the combined wave and current condition.

1. A combined hydrodynamic force model to predict the drag force of the floater is proposed to consider the difference of drag coefficients for a cylinder in the wave only and current only conditions.
2. The predicted mean and dynamic responses of floater motion and mooring tension by the proposed model show good agreement with the experimental data, while those by the conventional model are overestimated or underestimated when the current is existing.

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Reference

[1] Liu, Y., Ishihara, T. , 2019. Prediction of dynamic response of semi-submersible floating offshore wind turbines by a novel hydrodynamic coefficient model. *Journal of Physics: Conference Series*, 1356, 12035