LEARNING FROM FIELD TEST REGARDING DAMPING OF A FLOATER MOTION -2MW FOWT "FUKUSHIMA MIRAI"-

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In Fukushima Demonstration Project, 2MW FOWT "Fukushima Mirai" has produced electricity for four years since November 2013 without major trouble. During the demonstration, field test data have been obtained and analyzed. In WT emergency shutdown test the floater was in free roll condition and decay of motion was recorded. The data was used to modify a numerical model. In this pater damping of floater motion is compared between water tank test and field test. Discussion on damping was given and the design based on the tank test is found to be in safe side.

Keywords: floating wind turbine, 2MW downwind type, damping, Fukushima

INTRODUCTION

A 2MW floating wind turbine was installed at 20km off coast of Fukushima Pref., Japan, in August 2013[1]. It started producing electricity in November 2013. Since then it has been four years and meaningful field data have been obtained.

Interesting data is decay motion time history obtained in WT shutdown test. In a case of floating offshore WT(FOWT) roll and pitch motion is important for safety and protection of WT. Identification of damping character is especially important in design to predict floater response. Viscous damping is usually investigated in tank test but scale effect between tank test and real structure has been reported in few papers.

In this paper comparison between field and tank test data regarding to damping is shown and discussion is given on scale effect.

PARTICULARS OF FUKUSHIMA MIRAI

Fukushima Mirai is a 2MW floating wind turbine. Table 1 shows principle particulars of the floater. Figure 1 shows Fukushima Mirai installed 20 km off the coast of Fukushima pref., Japan. This floater has the following features.

1) It has a center column, three corner columns. The three corner columns are connected to the center column with pontoons, braces and upper deck beams. The heave plates are installed at the keel of the corner columns and the pontoons to reduce heave, pitch and roll motions of floater.
2) The wind turbine is 2MW downwind type (Hitachi HTW2.0-80). It is positioned on the top of the center column.
3) The floater is moored to the seabed using catenary 6 lines. Six mooring lines spread equally 120 degrees around the platform.

The particulars of the mooring system are listed in Table 2.

Figure 1. "Fukushima Mirai"

Table 1. Principle Particular

Floater type	Semi-submersible
Length	57.2m
Width	64.2m
Depth	32.0m
Design draft	16.0m
Class	Nippon Kaiji Kyokai
Water depth	120m

Table 2. Mooring system

Mooring chains	
Diameter	132mm
Grade	R3S
Minimum Breaking Force	14,500kN
Anchor Type	drag anchor

MODEL EXPERIMENTS

Experimental setup

The water tank test was conducted at the Akishima laboratory in Tokyo. The scale of the model is 1/60. Figure 2 shows the experimental setup. In extreme condition, the turbine is in waiting and the blade is fully feathered. So the turbine does not generate electricity, a steady wind load was applied at the tower of which height was adjusted to be equal to the overturning moment.

Figure 2. Experimental setup

Numerical analysis

The numerical analyses of motion were carried out by using Bladed™. Bladed is the fully coupled dynamic analysis for floating offshore wind turbines, including aero-hydro-servo-elastic interactions. The hydrodynamic forces due to heave plate can be expressed using a Morison formulation. The added mass coefficient Ca and drag coefficient Cd were determined from experimental results.

Experimental results

For example, Figure 3 shows time series of the heave and pitch motion during the free decay test. The results calculated by Bladed are also plotted. These comparison results show a good agreement of the damping force applied to the numerical model.

Examples of the response amplitude operators (RAOs) are shown in Figure 4. It is obvious that the calculation results are in good agreement with model experiments.

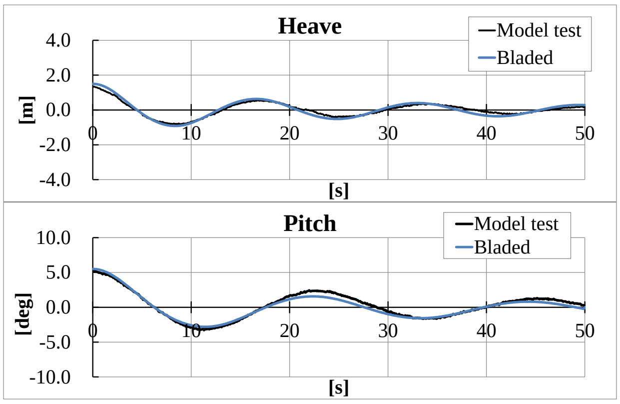

Figure 3. Comparison of the experimental and simulated free-decay motions of heave and pitch

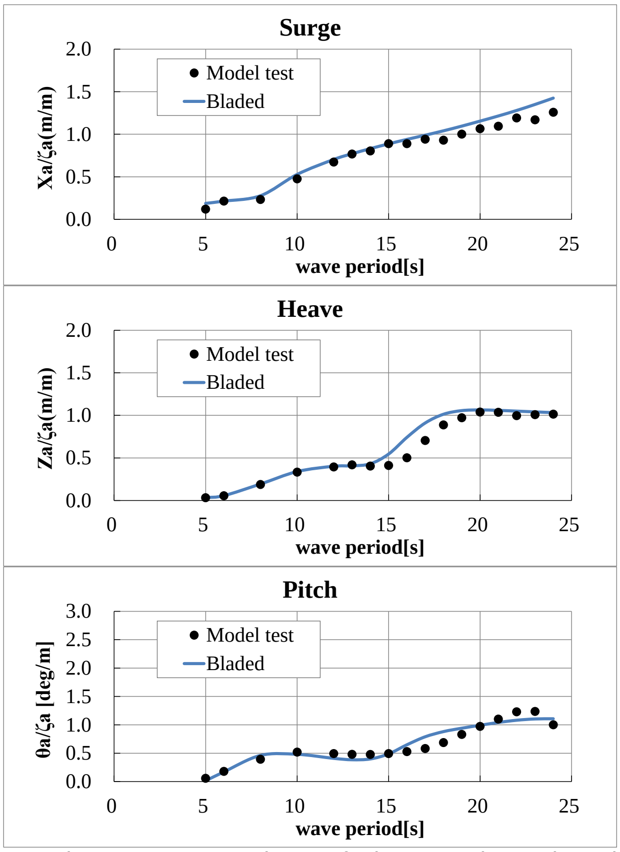

Figure 4. Comparison of the experimental and simulated RAOs of surge, heave and pitch of floater

IDENTIFICATION OF NON-LINEAR DAMPING FROM FREE DECAY TEST

Procedure for free decay test

Emergency shutdown test was conducted on October 2nd, 2017. Before shutdown the floater had an inclination due to WT thrust force. After shutdown the floater began oscillating in free. During shutdown test the sea was very calm. Therefore floater motion due to wave can be neglected. Figure 5 shows free motion in roll.

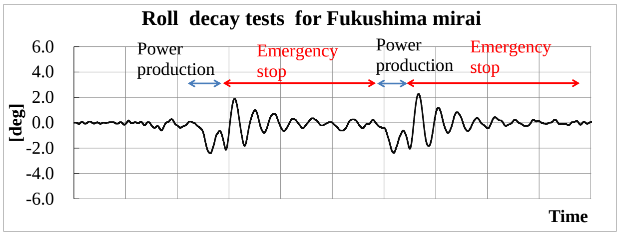

Figure 5. Time series of the rolling decay tests

Comparison of extinction property

Figure 6 is the extinction property obtained in tank test and shutdown test at sea. The decay curve is fitted using a two-degree polynomial:

$$\Delta\theta = a\theta_m + b{\theta_m}^2 \quad (1)$$

The coefficients a and b shown in Table 3, are called decay coefficients. The influence of drag forces appear in the quadratic coefficient$b$. Seeing Table 3, the coefficient b of full scale is about 1.8 times larger than the one in water tank test.

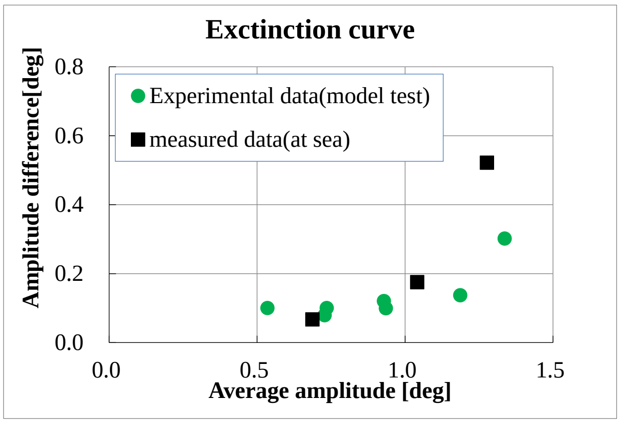

Figure 6. Comparison of extinction property

Table 3. Decay coefficients

	a	b
full scale	0.025	0.236
tank test	0.023	0.130

DISCUSSION

The heave plate increases the hydrodynamic damping arising from vortex shedding at the edges and the flow separation. The principal parameters characterizing the flow around the heave plate are the Keulegan-Carpenter number (KC) and Reynolds number (Re). They are defined as:

$$\mathrm{KC} = 2\pi a/D \quad (2)$$

$$\mathrm{Re} = 2\pi a D/\nu T \quad (3)$$

where D is the diameter of plate, a and T are the amplitude and period of the oscillation, ν is the kinematic viscosity of the fluid. The frequency parameter (β) given by the ratio of Re and KC as:

$$\beta = Re/KC \quad (4)$$

In the tank test and shutdown test at sea, the both of these KC numbers are in the same range of 0.16 to 0.3. Also the damping coefficient of heave plate is not so sensitive for frequency parameter β of some fixed KC[2]. Therefore, drag coefficient difference may not come from effect of KC number nor β.

On the other hand, Tao[3] and Xin Li et al.[4] show that the thinner plate could provide more damping. In the tank test, the plate like a heave plate is relatively thicker than full-scale in order to have sufficient strength. It seems that the thickness ratio of heave plate has influenced the damping coefficient.

Other than these factors, damping forces due to the WT or chain may have some effects. However the aerodynamic damping is small when the turbine is shut down. Also, when observing mooring lines attached the floater in free roll motion, amplitudes of each part of the lines are small.

CONCLUSION

The hydrodynamic damping properties of “Fukushima Mirai” have been investigated with tank test and shutdown test at sea. It has been confirmed that the drag force obtained in full-scale floater is larger than the tank test. Here, we discussed the factors of this difference, but it will be necessary to continue examining them more. However, it can be said that the floater design based on tank test becomes in safe side because of smaller drag coefficient.

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REFERENCES

[1] A. Imakita, “Design, Construction and Installation of 2MW Floating Wind Turbine Fukushima Mirai”, *Grand Renewable Energy*. 2014

[2] T. Xin-liang et al., “Effects of Reynolds Number on the Hydrodynamic Characteristics of Heave Damping Plate”, *Journal of Ship Mechanics*, **17**, 2013, pp.1392-1401.

[3] L. Tao et al., “Heave motion suppression of a spar with a heave plate”, *Ocean Engineering*, 2004

[4] T. Xin-liang et al., “Hydrodynamic coefficients of oscillating flat plates at 0.15< KC < 3.15”, *Journal of Marine Science and Technology*, 2016