Predication of dynamic response of floating offshore wind turbine with improved CAsT

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1. Introduction

Hydrodynamic force and modeling of mooring system are significant to predict dynamic response of floating offshore wind turbine (FOWT).

In evaluation of hydrodynamic loads, Morison equation based theory and potential flow theory are widely used. Potential theory has a good accuracy in predication of hydrodynamic loads on large bodies (FAST). But, distributed force on each component of FOWT cannot be predicted with potential flow theory. Otherwise, Morison equation is well known to predict in-line hydrodynamic force on slender members and it can evaluate distributed loads on each immerse member which makes it possible to capture resonance of elastic floating system (Phuc and Ishihara, 2007; Bladed v4.6, 2014). But, it does not consider the radiation damping effect. Also, conventional Morison equation does not evaluate loads on axial-direction. Ishihara et al. (2013) considered dynamic pressure on axial-direction of members for heave plates, however, effect of dynamic pressure on those slender members were ignored. Therefore, it is necessary to investigate the effect of radiation damping and axial force for slender members on dynamic response of FOWT.

As for modeling of mooring system, Waris and Ishihara (2012) used non-linear dynamic model to analysis the catenary and tension leg mooring line. Otherwise, a quasi-static model is generally used to solve the catenary mooring system (Bladed v4.6, 2014; FAST v8.08, 2014). But, quasi-static model ignores the inertia and damping of the mooring system. Effect of dynamic behavior of mooring system on predication of dynamic motion and tension in mooring system should be investigated.

In this paper, effects of radiation damping, dynamic pressure and dynamic behavior of mooring system were investigated with improved in-house code.

2. Approach

In this study, 1/50 scale water tank test was conducted to verify the simulation with CAsT (Computer-Aided Aerodynamic and Aero-elastic Technology) which is developed by the University of Tokyo.

Firstly, in order to clarify the effect of radiation damping, radiation damping force was

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implemented into conventional Morison equation. Then the free decay test in surge direction was simulated with and without radiation damping and was compared with measurement data.

Secondly, in order to clarify dynamic pressure effect on dynamic response of FOWT, CAsT was modified to consider dynamic pressure effect on slender members. Then the motion of floater was predicted with and without dynamic pressure and was compared with measurement data.

Thirdly, tension in mooring line was calculated using quasi-static model and dynamic model and compared with measurement data in order to clarify effect of dynamic behavior of mooring system.

3. Main body of abstract

Firstly, frequency dependent added damping matrices were calculated with potential flow theory. Then linear radiation damping was evaluated and implemented into Morison equation. Figure 2 exhibits measured and predicated time series of free decay in surge direction with and without radiation damping effect. Damping ratio from measurement was 6.63%. Without radiation damping effect, predicated damping ratio was 4.94% and it was increased to be 6.87% with radiation damping effect. Error in terms of damping ration predication was reduced from -25.5% to 3.62%. It was found that radiation damping effect is important.

Secondly, axial-direction force on slender members due to dynamic pressure difference was implemented into CAsT. Figure 3 shows measured and predicated dynamic RAO (Response Amplitude Operator) and phase difference between motion and incident wave in pitch direction in regular wave. Without consideration of dynamic pressure, pitch RAO was underestimated in low wave period region and phase difference was underestimated. It was found that dynamic pressure is critical in dynamic response of FOWT. Figure 4 exhibits measured and predicated power spectrum of incident irregular wave and dynamic response. The peak at around 0.33Hz corresponds to natural pitch frequency of floating system and the resonance phenomenon was excited by low wave frequency components in irregular wave. The peak at around 0.7 Hz corresponds to peak period of incident wave and the wave-induced response was improved since the underestimation of predicated dynamic RAO in low wave period region was solved. Detailed explanation about dynamic pressure contribution will be provided in whole paper.
Finally, tension in mooring line was analyzed using quasi-static model and dynamic model. Figure 5 shows the measured and predicted tension RAO and phase difference between tension and incident regular wave in mooring line T1. The error was evaluated as an average for all wave period region, it was found that quasi-static model overestimates tension RAO by 374.6% while dynamic model in CAsT gives -16.3% difference compared with measured tension. Predicted phase difference was also improved in dynamic model. Therefore, dynamic behavior of mooring system is considerably significant in tension prediction.

(a) Normalized tension RAO  
(b) Phase  

Figure 5: Measured and predicted (a) dynamic tension RAO and (b) phase difference between time series of tension and incident wave in regular wave (H=0.1m).

4. Conclusions

Effects of radiation damping, dynamic pressure and dynamic behavior of mooring system were investigated with improved CAsT in this paper. Main conclusions are as follows,

1. Without radiation damping effect, predicated damping ratio was 4.94% and with radiation damping effect it was predicted to be 6.87%. Error in terms of damping ratio predication was reduced from -25.5% to 3.62%.

2. Predication of dynamic response and phase difference of FOWT were improved in low wave period region with consideration of dynamic pressure effect on slender members. In irregular wave, wave-induced response was improved in low wave period region.

3. Predicted tension by using quasi-static model overestimates by 374.6%. Dynamic model gives -16.3% difference between measured and predicted tension. Dynamic behavior of mooring system is considerably significant in tension prediction.
5. Learning objectives

The effect of radiation damping, dynamic pressure and dynamic behavior of mooring system were clarified by comparing simulation result with experimental data.

References:

[5]. FAST version 8.08, NERL, 2014.