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A STUDY ON INFLUENCE OF HEAVE PLATE ON DYNAMIC RESPONSE OF FLOATING OFFSHORE WIND TURBINE SYSTEM

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Introduction

Wind energy is the most renowned source of renewable energy. Onshore wind resources are limited and little land is available for large wind farms in Tokyo (Kanto) area of Japan. Offshore wind energy offers obvious advantages of no land usage and a more reliable wind resource. In shallow waters, bottom-mounted support is economically feasible. However, floating support systems are essential in deep waters around the Tokyo area.

In order to improve economy, smaller and lighter floater needs to be used. As a result, the dynamic response of the floater is increased and nonlinear effect becomes more dominant.

The present study investigates the influence of heave plate on dynamic response of a semi-submersible type floater with single wind turbine using a sophisticated numerical model that considers a non-hydrostatic model for restoring force. The prediction efficiency is validated through comparison with hydrostatic model and experiments. Finally, a comparison of simplified and detailed mooring system is presented.

Numerical model

- The equation of motion of the floating wind turbine system can be written as :

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=\{F_G\}+\{F_R\}+\{F_H\} \qquad (1)$$

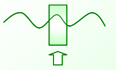
Where [M], [C], [K] is mass, damping and stiffness matrix of the system. $\{F_G\}$, $\{F_R\}$ and $\{F_H\}$ are mooring force, restoring force, and hydrodynamic force respectively; and {X} is unknown displacement vectors.

- **Mooring Force** is estimated using linear mooring stiffness as follows:

$$F_G=[K_G]\{X\} \qquad (2)$$

Where $[K_G]$ is linear mooring stiffness matrix and {X} is the displacement vector

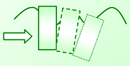
- **Restoring Force** is estimated using two types of models; Hydrostatic Model and Non-Hydrostatic Model;



$$F_R|_{HM}=-[K_R]\{X\} \quad ; \quad F_R|_{NHM}=-[K_R](\{X\}-\{\eta\}) \qquad (3)$$

Where $[K_R]$ is the first order restoring force coefficient (Motora et al., 1997) and $\{\eta\}$ is wave elevation vector that has non-zero elements in vertical direction only.

- **Hydrodynamic Force** is estimated using the Morison's equation (Morison,1950).



$$F_H=F_D+\rho_w C_M V\dot{u}-M_a\ddot{X} \qquad (4)$$

$$M_a=\rho_w(C_M-1)V \qquad (5)$$

$$F_D=0.5\rho_w C_D A|u-\dot{X}|(u-\dot{X}) \qquad (6)$$

Where ρ_w is water density; u is wave particle velocity; V,A is area, volume of element; C_D and C_M is hydrodynamic drag and inertia coefficient and M_a is hydrodynamic added mass.

- The hydrodynamic force on the vertical column is described as follows:

$$M_a=\rho_w(C_M-1)2\pi/3(D/2)^3; \quad C_M=2.0 \qquad \textit{(Haslum,2000)} \qquad (7)$$

$$F_D=-C_{ED}\dot{X}\ ; \quad C_{ED}=2\zeta\omega(M+M_a); \quad (\zeta=15\%) \qquad \textit{(Srinivasan,2005)} \qquad (8)$$

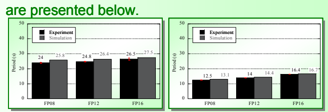
ω is the angular frequency, M and M_a are the structure mass and hydrodynamic added mass of floater, respectively.

Numerical scheme

Dynamic analysis	Newmark-β method
Element type	Beam, Truss, Spring
Formulation	Total Lagrangian formulation
Mooring force	Catenary theory
Restoring force	Hydrostatic Model [HM], Non-Hydrostatic Model [NHM]
Damping	Rayleigh damping

Finite Element Model

The floater is modeled using beam elements having 122 elements and 114 nodes. The elastic bands are modeled as linear springs and the Kevlar thread is modeled using truss elements. The whole system has 142 nodes and 150 elements. Nodal masses are considered which also incorporates difference in mass due to different floater plates (FP8, FP12 and FP16). Free vibration tests were carried out to evaluate the FE-model, the comparison of natural periods in surge and heave mode from experiment and simulation are presented below.

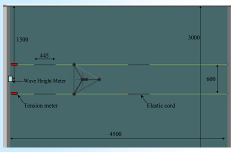


Surge   Heave

Model Test

- Considering Froude Number similarity 1:100 scale model along with two heave plates (12.0 m and 16.0 m) have been prepared.
- Displacements have been measured from a four-legged LED target fixed to the wind turbine tower, using CCD camera. Mooring tension (T_0=2.95 N) is measured through tension meter attached to Kevlar thread. Further experiment details are listed in the Table.

Experiment Setup



Wave Height	Rated: 4.0 cm {3.9 m} Extreme: 12.0 cm {12. m}
Wave Period	0.6~3.0 sec @ 0.20 sec {6.0~30.0 sec}

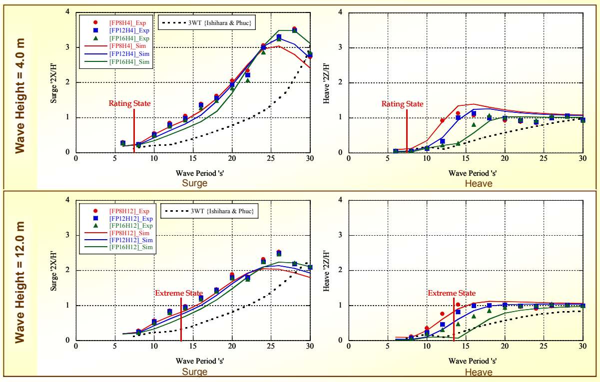
{*} Values for prototype scale

Wind is not considered

Influence of heave plates on floater response

Ishihara & Phuc (2007) have proposed a three wind turbine semi-submersible floater [3WT], verifying its stability through experiment and simulation. Their prototype, however impose a strong wake influence on the wind turbines. To resolve this problem, a single wind turbine floater is proposed in this study and heave plates are used to obtain results comparable with [3WT]. Two heave plate sizes, 1.5 and 2.0 times diameter ([FP12] and [FP16] respectively) of original floater [FP8] have been investigated. Comparison of surge and heave response for wave height of Rated and Extreme state (4.0 m & 12.0 m respectively) is shown.

- The surge response floater system is not sensitive to the presence of heave plates.
- The heave response indicate a shift in resonance peak with increase in heave plate diameter and its amplitude at shorter periods is reduced due to this shift. The reduction in heave response is inversely proportional to area of the heave plate.
- The Predicted response for surge and heave response is found to provide good agreement with experiment.
- Comparison with [3WT] indicates that the response of proposed single wind turbine floater can be reduced to similar magnitude by using heave plates.



Surge   Heave

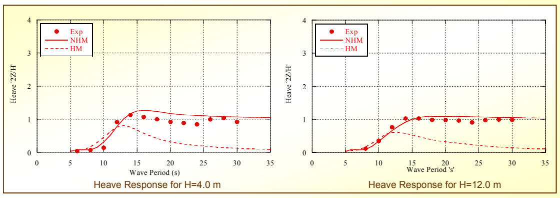
Surge   Heave

Prediction of dynamic response

Non-Hydrostatic Model

A comparison of the hydrostatic [HM] and non-hydrostatic [NHM] model for the original model FP8 at 4.0 and 12.0 m wave heights is presented.

- The results indicate that hydrostatic model underestimate heave response after natural period (12.5 sec), whereas the non-hydrostatic model gives essentially good agreement with experiment.
- The difference in owing to underestimation of restoring force by hydrostatic model.

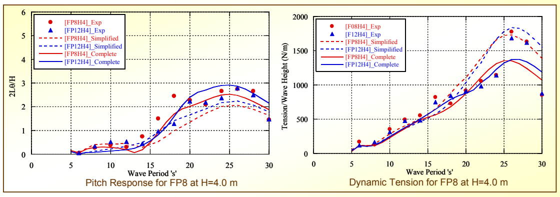


Heave Response for H=4.0 m   Heave Response for H=12.0 m

Mooring System

A 'Simplified' model for mooring system considering mooring stiffness only is prepared and compared with 'Complete' model used in this research. Mooring tension for 'Simplified model' has be estimated as $[K_G]$.{X}. Tension is normalized w.r.t wave height to consider its variation in experiment.

- Surge and heave response are identical (not show here). Which indicate that the external force on mooring system has no significant influence on dynamic response of floater.
- The predicted pitch response for 'complete' model provides better comparison with experiment than 'simplified' model.
- Comparison of mooring tension indicates that 'Simplified' model over estimates the mooring line tension, especially for larger periods, whereas 'Complete' model provides good comparison.



Pitch Response for FP8 at H=4.0 m   Dynamic Tension for FP8 at H=4.0 m

Conclusion

A sophisticated numerical code, that considers a non-hydrostatic model [NHM] for the restoring force is used to investigate the influence of heave plates on dynamic response of semi-submersible type single wind turbine floater. Two heave plate sizes are considered under wave height for rating and extreme state. Its performance verified against experiment and hydrostatic model [HM].

- Numerical prediction of response shows that non-hydrostatic model shows good agreement whereas hydrostatic model fails to show agreement for heave.
- Heave plates causes resonance peak in the heave mode to move towards higher periods, thus decreasing the response at rating and extreme conditions.
- The influence of considering actual mooring system instead of simple mooring stiffness is discussed and it is found to improve response and line tension prediction.

Reference

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