ClassNK

Implementation of potential flow hydrodynamics to time-domain analysis of flexible platforms of floating offshore wind turbines

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1. Introduction

In the design of supporting platforms of floating offshore wind turbines, global response analysis is essential to predict the response under various loads from wave, wind, moorings and the wind turbines. However, the literature of the global analysis of floating offshore wind turbines combining flexible modelling of the supporting platform and the potential flow theory for hydrodynamic evaluation is limited. In this study, first the framework implementing the potential flow hydrodynamics to the time-domain analysis of the three-dimensional frame model for offshore wind turbines is developed using modal decomposition for the hydrodynamic evaluations. The number of modes can be limited to those with larger contributions, which can lead to the reduction of the calculation cost. Next, a spar-type floating offshore wind turbine is modelled to verify the developed code when only the rigid mode motions are considered for hydrodynamic loadings.

2. Theoretical Backgrounds

The floating offshore wind turbine is discretized into structural beam elements with N number of nodes.

$$\{M\}_{6N,6N}\{\ddot{x}\}_{6N,1}+\{C\}_{6N,N}\{\dot{x}\}_{6N,1}+\{K\}_{6N,6N}\{x\}_{6N,1}=\{F^{hydro}+F^{lines}+F^{buoyancy}+F^{aero}\}_{6N,1}$$

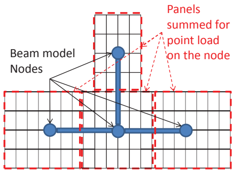
To reduced the calculation cost, it is assumed that only limited modes of the floater response contribute to hydrodynamic forces

$$\{F^{radiation}\}_{6N,1}=-\begin{bmatrix}A_{1,1}(\infty) & \cdots & A_{1,M}(\infty)\\ \vdots & \ddots & \vdots\\ A_{6N,1}(\infty) & \cdots & A_{6N,M}(\infty)\end{bmatrix}\begin{Bmatrix}\ddot{u}_1\\ \vdots\\ \ddot{u}_M\end{Bmatrix}-\int_{-\infty}^{t}\begin{bmatrix}L_{1,1}(t-\tau) & \cdots & L_{1,M}(t-\tau)\\ \vdots & \ddots & \vdots\\ L_{6N,1}(t-\tau) & \cdots & L_{6N,M}(t-\tau)\end{bmatrix}\begin{Bmatrix}\dot{u}_1(\tau)\\ \vdots\\ \dot{u}_M(\tau)\end{Bmatrix}d\tau$$

$$\{u\}_{m,1}=[\phi]_{m,6N}\{x\}_{6N,1}$$

$$\{F^{radiation}\}_{6N,1}=-\begin{bmatrix}A_{1,1}(\infty) & \cdots & A_{1,m}(\infty)\\ \vdots & \ddots & \vdots\\ A_{6N,1}(\infty) & \cdots & A_{6N,m}(\infty)\end{bmatrix}[\phi]_{m,6N}\{\ddot{x}\}_{6N,1}-\int_{-\infty}^{t}\begin{bmatrix}L_{1,1}(t-\tau) & \cdots & L_{1,m}(t-\tau)\\ \vdots & \ddots & \vdots\\ L_{6N,1}(t-\tau) & \cdots & L_{6N,m}(t-\tau)\end{bmatrix}\begin{Bmatrix}\dot{u}_1(\tau)\\ \vdots\\ \dot{u}_m(\tau)\end{Bmatrix}d\tau$$

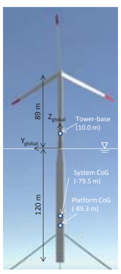
Hydrodynamic coefficients assigned to each node by summing the coefficients of the related panels



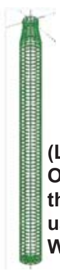
$$\omega^2 A_{i,j}=\begin{cases}\sum_{s_i}\mathrm{Re}(p_s^r)(\phi_j\cdot n_s)\,ds & (n=1,2,3)\\ \sum_{s_i}\mathrm{Re}(p_s^r)(\phi_j\cdot n_s)\cdot r_s ds & (n=4,5,6)\end{cases}\quad \omega^2 B_{i,j}=\begin{cases}\sum_{s_i}\mathrm{Im}(p_s^r)(\phi_j\cdot n_s)\,ds & (n=1,2,3)\\ \sum_{s_i}\mathrm{Im}(p_s^r)(\phi_j\cdot n_s)\cdot r_s ds & (n=4,5,6)\end{cases}\quad P_j^d=\begin{cases}\sum_{s_i}p_s^d(\phi_j\cdot n_s)\,ds & (n=1,2,3)\\ \sum_{s_i}p_s^d(\phi_j\cdot n_s)\cdot r_s ds & (n=4,5,6)\end{cases}$$

3. Numerical model for verification

The spar-type floater with the 5MW reference wind turbine used in OC3 project is used for the verification of the developed code.



(Left) Outline of the spar-type floating offshore wind turbine



(Left) Outline of the panels used in WAMIT

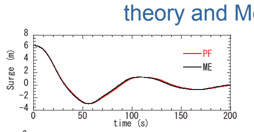
(Left) Outline of the frame model in NK-UTWind

Table. Principal particulars of the spar-type floating platform

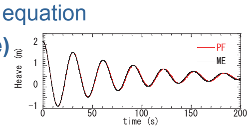
Platform mass	7466.3 ton	Depth of platform base	-120 m
Platform CoG height	-89.9 m	Platform diameter below taper	9.5 m
System CoG height	-75.5 m	Platform diameter above taper	6.5 m
Platform bending stiffness	3290GNm^2	Platform roll / pitch inertia about CoG	4.23Mtonm
Platform axial stiffness	301GN		

Calculated free-decay process showed similar results for potential flow theory and Morison's equation

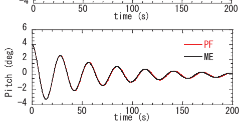
(Surge)



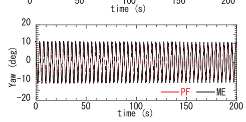
(Heave)



(Pitch)



(Yaw)



4. Results

Developed calculation framework is verified by comparing the calculated results with those calculated with Morison's equation.

	Wind	Wave	Wind Turbine
LC.3	$U=11.3$ m/s, $I_u=7$ % Mann model	Irregular airy JONSWAP, H_s=3.25, T_s=10 sec	Operating

Calculated results were similar for the two hydrodynamic models. The difference in the low frequency region may be attributed to the steady and low frequency external forces introduced in the Morison's equation by considering the instantaneous position of the floater.

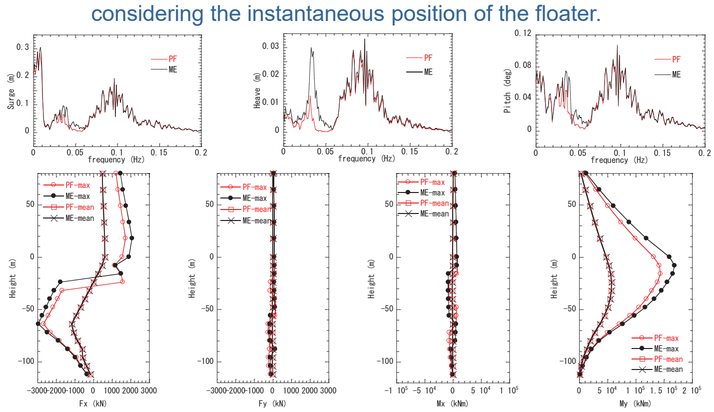


Table. Calculation time of the developed framework

	Potential Flow Theory (Rigid mode only)	Morison's Equation
Irregular wave without wind	179.4 min	43.95 min
Irregular wave with operational wind turbine	875.4 min	739.5 min