Objectives

Floating Offshore Wind Turbine System (FOWTS) is made of light materials compared to conventional offshore structures, which results in large motion under wind and wave load. Therefore, the nonlinearity of the mooring stiffness and the dynamic interaction between wind turbine, floater and mooring system have to be considered when dynamic response analysis of FOWTS is performed.

Existing studies[1][2] on the dynamic motion of FOWTS are based on some simplifications, such as ignoring the dynamic interaction, assuming hydrostatic restoring force and linear mooring system, which may cause some errors.

The University of Tokyo has been developing a fully nonlinear FEM for the dynamic response prediction of FOWTS[3]. In this study, non-hydrostatic restoring force model was applied and verified through comparison with hydrostatic model and water tank experiment. Then the effect of heave plates was investigated with this updated model. Finally, based on this model, nonlinear mooring system considering full dynamic coupling was modeled and their effects compared to linear mooring system were simulated.

Nonlinear FEM model

The equation of motion can be written as

\[ M \ddot{u} + C \dot{u} + K u = F \]

where

\[ M = \begin{bmatrix} M_0 & 0 & 0 \\ 0 & M_0 & 0 \\ 0 & 0 & M_0 \end{bmatrix}, \]

\[ C = \begin{bmatrix} C_0 & 0 & 0 \\ 0 & C_0 & 0 \\ 0 & 0 & C_0 \end{bmatrix}, \]

\[ K = \begin{bmatrix} K_0 & 0 & 0 \\ 0 & K_0 & 0 \\ 0 & 0 & K_0 \end{bmatrix}, \]

\[ F = \begin{bmatrix} F_0 \\ F_0 \\ F_0 \end{bmatrix}. \]

The subscripts refer to Turbine, Floater and Mooring system respectively. External forces include: Gravitational force, Buoyancy force, Hydrodynamic force, Restoring force, Seaboat contact force and Aerodynamic force.

- Hydrodynamic force on cylinder members is modeled using Morison’s equation modified by Sarpkaya & Isacson[4]. This force consists of added inertia force, Froude-Krylov force and drag force.

- Hydrodynamic force on column base consists of added inertia force and damping force.

- Restoring force: Non-hydrostatic restoring force

- Seaboat contact force for nonlinear catenary mooring consists of frictional and normal force acting only on elements in contact with the sea bed. According to Jiao et al[5], it is expressed using penalty constant \( k \), frictional coefficient \( \mu \) and relative displacement in tangential and normal directions.

- Aerodynamic force is modeled using quasi-steady theory, Blade element theory and Momentum theory considering blade tip loss, hub loss and tower shadow. However, wind is not considered in this study.

Verification of the nonlinear model

A water tank experiment was conducted to verify the FEM model. The scale was 1:100 following Froude similitude. Four horizontal mooring lines connected to elastic bands were used. Waves corresponding to 4m (rated state) and 12m (extreme state) were generated and the response of the floater was observed.

Catalogy (left) and Tension Legged (right) mooring system

Total Lagrangian formulation with Newmark-\( \beta \) method is used to elastic full structure. Rayleigh damping is considered with damping ratio of 0.5%

Modeling of the FOWTS

The model was developed to predict the dynamic response of FOWTS and it was verified through water tank experiment. The experimental model was tested without (D=8m) and with heave plates (D=12m,16m).

Response with different sized heave plates (no wind)

- Heave plates reduced the heave response by up to more than 50% between 5-20 second wave period range. This is due to the shift of the resonance peak to longer period caused by the increased added mass.

- FOWTS with nonlinear catenary and tension legged mooring were modeled using the FEM and their response to regular waves with no wind was simulated. The results were compared with linear mooring assuming restoring force proportional to the displacement.

Conclusions

A fully coupled nonlinear FEM was developed to predict the dynamic response of FOWTS and it was verified through water tank experiment.

- Heave plates reduced the heave response by shifting the resonance peak to longer period.

- Simulation results showed small nonlinearity in tension legged mooring. However, the linear model overestimated the surge for catenary mooring due to the large dynamic component in the mooring force.

References


