PO.097

Numerical Comparison of Drifting Sea Ice and Wave Loads on Different Offshore Wind Turbine Support Structures

Jaakko Heinonen, Simo Rissanen

VTT Technical Research Centre of Finland Ltd.

TECHNOLOGY FOR BUSINESS

Abstract

The Baltic Sea features a potential for large capacity wind farms because of relatively high and constant wind velocities. Mostly shallow coastal areas enable cost-efficient foundation and grid connection. However, in the northern sea area - Gulf of Bothnia - the sea freezes annually. Sea ice loads and ice-induced vibrations due to drifting ice field introduce major uncertainties in the support structure design for offshore wind turbines (OWT).

The magnitude and time variation of ice load depends on various factors, like the thickness and velocity of the ice as well as the size and shape of the structure. The ice load magnitude and time variation depends on the failure mechanism of ice, which is strongly governed by the shape of the structure at the water level. Sloped shapes like a cone induce the ice to fail by bending as vertical shapes cause the ice to fail commonly by crushing.

The ice load model was implemented into a software FAST (Fatigue, Aerodynamics, Structures and Turbulence) developed by National Renewable Energy Laboratory (NREL) in the USA for simulating the coupled dynamic response of wind turbines.

Objectives

The main objectives were

- to study the feasibility of the FAST simulation software in the structural performance studies of offshore wind turbines loaded by coincident ice and wind loads as well as by coincident wave and wind loads
- to compare the drifting ice loads on the monopile to coned structures
- to compare the wave loads to the ice loads.

The loads and displacement response were studied with different wind velocities, as wind is the main driving force for the ice and waves. Ice-induced tower vibrations depend strongly on the shape of the structure at the water level and water depth as the height of the structure plays an important role in the dynamics. Therefore, two different water depths were studied.

Methods

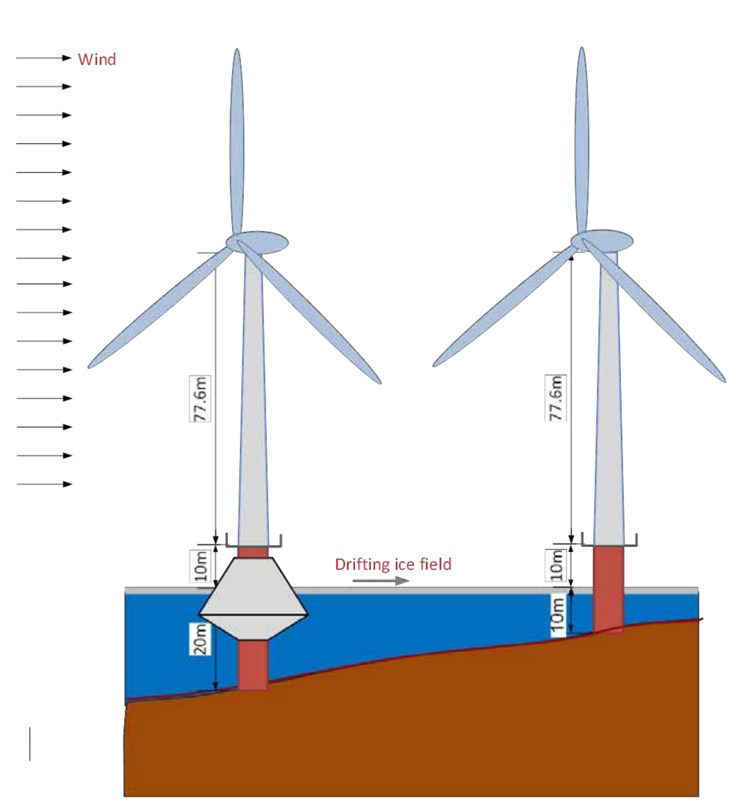
The structural model was based on the NREL offshore 5-MW baseline wind turbine with a monopile type of support structure [1]. Sea ice and wave parameters were selected to correspond typical sea conditions at Gulf of Bothnia by varying the wind velocity. Both the ice velocity and wave height depend on the wind velocity. Different structural configurations and load cases were studied:

- Water depths : 10 and 20 m
- Vertical support structure (cylindrical monopile) was compared with an inclined structure (60° cone) .

Main parameters of the OWT structure and loads are presented in Table 1.

Table 1. Turbine dimensions and simulation parameters

Simulation parameters	Values
Ice Thickness	0.6 m
Tower height	77.6 m
Transition level	+ 10m
Blade length	63 m
Wind	4-25 m/s laminar
Ice velocity	2.5 % of wind speed (10m elevation)
Wave model	JONSWAP
Wave height H	estimated from [5]
Peak wave period	$5.3\sqrt{H}$



Coupled crushing ice load model - used for the monopile – was based on modified Määttänen-Blenkarn model [2],[3] including some stochastic variations in the ice crushing strength. The ice load model for the cone was based on the flexural ice failure model according to ISO 19906 [4].

Results

Drifting sea ice induces dynamic load on the substructure. (Fig. 1). Especially for the monopile, significant vibrations occur when the wind velocity is below 16 m/s. Both the amplitude and frequency content depends on the ice velocity. The cone reduces the ice load level and vibrations significantly compared to the monopile, especially in terms of the tower root moment. However, due to a larger diameter and cross-section area, the cone has considerably higher wave loads (Fig. 2). Significant ice-induced vibration occurs at the blade tip in a fatigue point of view (Fig. 3), especially in the water depth of 20 m.

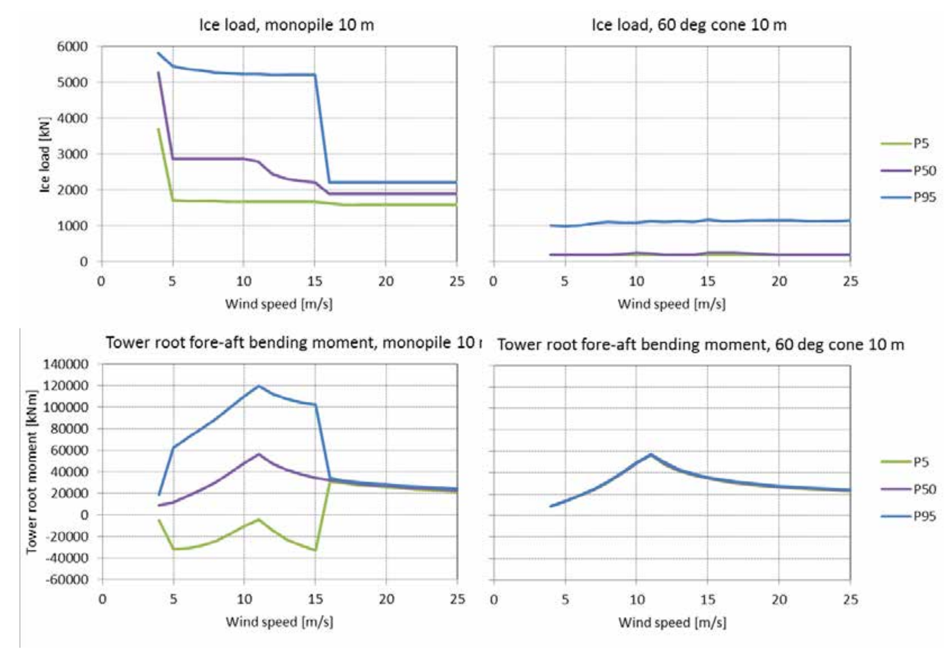


Figure 1. Ice load (top) and tower root bending moment (bottom) as a function of wind speed. Quantiles of 5%, 50% and 95% characterize the minimums, medians and maximums.

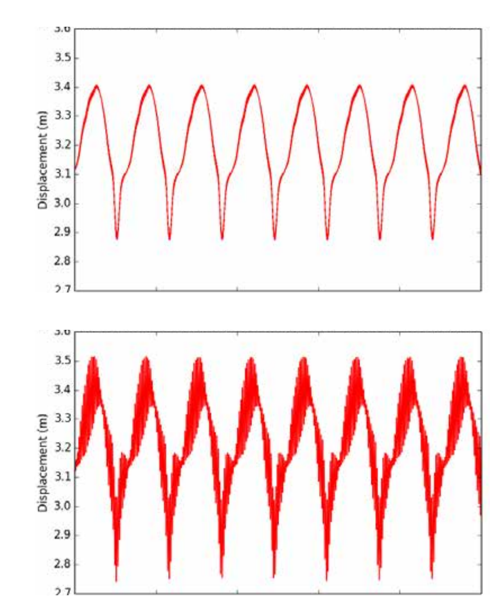


Figure 3. Example of the time history of blade tip out-of-plane displacement for 10m (top) and 20 m (bottom) monopile.

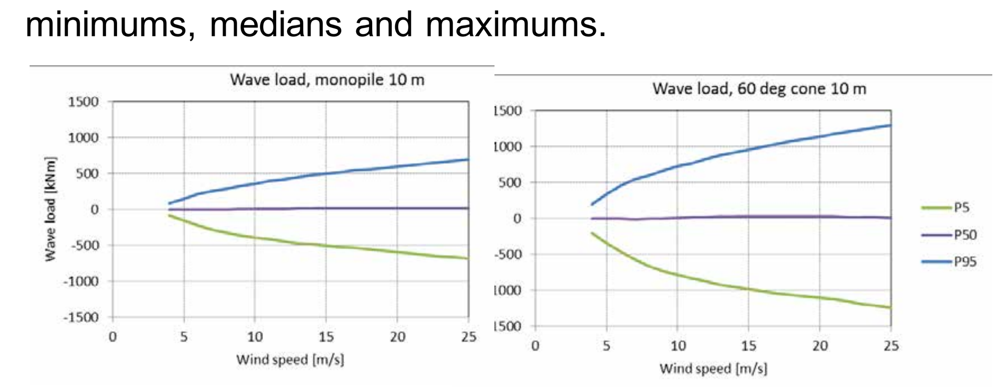


Figure 2. Wave load and tower root bending moment as a function of wind speed.

Conclusions

Coupling between the ice/wave, wind and structural response is a necessary step in terms of cost-efficient structural design.

FAST simulation tool creates a suitable development platform for OWT. Available IceFloe and IceDyn modules form already a good basis to consider various ice load scenario. In addition, open programming interface in FAST enables implementation of in-house ice load models.

Even though modified Määttänen-Blenkarn -ice-structure interaction model estimates the complex ice interaction process in a simplified way, one may find out following observations:

- Site-specific ice conditions (ice thickness and velocity) are essential for the ice load design
- Ice induces severe loads and vibrations on the support structures (ultimate and fatigue loads). For the monopile, the ice loads and displacement amplitude at the water level and tower top depends strongly on the ice velocity
- The cone reduces the ice load level and vibrations significantly compared to the monopile (mean and peak loads). On the other hand, the wave loads increase with the cone.
- Ice induces significant vibration at the blade tip in a fatigue point of view
- Deeper foundation is more sensitive to vibrations.

References

1. Jonkman J., Definition of a 5-MW Reference Wind Turbine for Offshore System Development, http://www.nrel.gov/docs/fy09osti/38060.pdf
2. Määttänen, M., 1999. Numerical model for ice-induced vibration load lock-in and synchronization, Proceedings of the 14th International Symposium on Ice, Potsdam/New York/Usa/27-31 July 1998, Vol. 2, pp. 923-930, Balkema , Rotterdam 1999 , ISBN 9054109718
3. Heinonen J, Hetmanczyk S, Strobel M. 2011. "Introduction of Ice Loads in Overall Simulation of Offshore Wind Turbines". Proceedings of the 21st International Conference on Port and Ocean Engineering under Arctic Conditions, July 10–14, 2011, Montréal, Canada. POAC11-024, ISSN 2077–7841.
4. DNV-GL, U.S. Department of Energy, 2014, Ice Load Project Final Technical Report, https://nwtc.nrel.gov/system/files/DDRP0133-IceLoadFinalReport2014_10_30.pdf
5. http://blogi.foreca.fi/2015/01/tuuli-ja-aallonkorkeus/