Improved Simulation of Wave Loads on Offshore Structures in Integral Design Load Case Simulations

M.J. de Ruiter, T.J.J. van der Zee

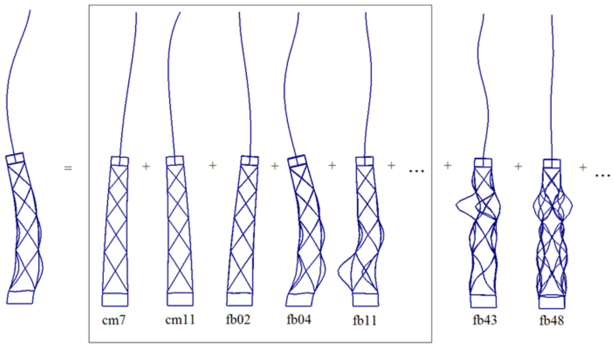
m.j.deruiter@wmc.eu, T. +31 227 504941

Motivation

Integrated wind turbine design benefits from rapid load case evaluation since it allows faster design iterations. This is achieved by reduced model simulation. The model reduction focuses on global wind turbine behaviour, omitting details. These details are significant for e.g. member response in offshore support structures. This project obtains improved accuracy at limited calculation costs.

Approach

The Craig Bampton method reduces the model size by using modal amplitudes, and truncating the number of modal amplitudes used in the simulation. This project recovers the truncated forces for correction.



Finite Element evaluation

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Wave load = modal forces + surplus forces

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Efficient simulation using reduced number of modes	Finite Element solution using the support structure model

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Deformation = modal displacements + surplus displacements

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Finite Element solution using the support structure model

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Time series of the desired member response

Wave loads

The wave loads are evaluated using Morison's equation:

$$F = \rho\, V\, \dot{w} + \rho\, C_a\, V\, (\dot{w} - \ddot{u}) + \tfrac{1}{2}\rho\, C_d\, A\, (w - \dot{u})|w - \dot{u}|$$

involving data available at different stages of the solution

Wave loads are evaluated using FE.

Tower motion is evaluated at simulation time.

The evaluation can be postponed to simulation time by rewriting Morison's equation in modal form and separating water motion w and tower motion $\dot{u}$ and evaluating the coefficients, writing

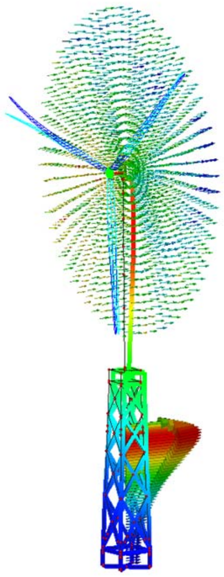
$$F_{modal} = R_{(w)} + S_{(w)}\, \ddot{u}_{modal} + wT_{(w)}\, \dot{u}_{modal} + \dot{u}^{T}_{modal}\, T_{(w)}\, \dot{u}_{modal}$$

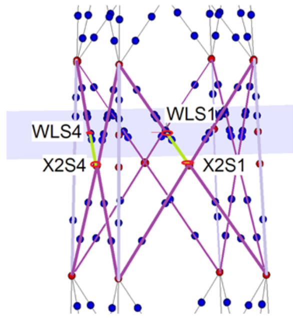
where

$$\begin{aligned} R_{(w)} &\sim \rho\, V\, \dot{w} + \rho\, C_a\, V \dot{w} + \tfrac{1}{2}\rho\, C_d\, A\, |w|^2 \\ S_{(w)} &\sim -\rho\, C_a\, V \\ wT_{(w)} &\sim \tfrac{1}{2}\rho\, C_d\, A\, |w| \\ T_w &\sim \tfrac{1}{2}\rho\, C_d\, A \end{aligned}$$

Application

The new method has been applied to a model of the XEMC Darwind XD115 5 MW wind turbine on top of the OC4 jacket experiencing North Sea 50 m deep water conditions.





Response sensors

The response has been evaluated at water level (WL) and X-joint in bay 2 (X2), at side 1 (S1, lateral) and side 4 (S4, downstream).

Fatigue loads

Using Palmgren-Miner's hypothesis, the damage is calculated for in-plane (ip) and out-of-plane (oop) bending of the member. Locations and load cases are put in classes based on the damage ratios.

	Cumulative damage	WLS4 oop	WLS4 ip	WLS1 oop	WLS1 ip	X2S4 oop	X2S4 ip	X2S1 oop	X2S1 ip
Grid loss	0 %	4	1	-1	-1	4	0	1	1
Normal operation	99 %	1	0	0	0	2	0	0	1
Yaw or pitch issues	0.4 %	1	0	0	0	2	0	0	1
Start	0 %	4	1	-1	-2	4	1	1	4
Stop	0 %	4	1	-1	-2	4	1	1	4
Idling	0.3 %	4	1	0	0	4	0	1	3

Damage ratio New/Trad	0.70	0.80	0.90	1.10	1.25	1.60	3	more
Class	-2	-1	0	1	2	3	4	

Extreme loads

The maximum stresses are calculated for in-plane and out-of-plane bending. Locations and load cases are put in classes based on the stress ratios.

	WLS4 oop	WLS4 ip	WLS1 oop	WLS1 ip	X2S4 oop	X2S4 ip	X2S1 oop	X2S1 ip
NTM, power production, SSS	0	0	0	0	0	0	0	0
NTM, power production, SWH	1	0	0	0	0	0	0	0
EWM50, idling upwind, SSS	2	0	1	0	2	0	2	0
RWM50, idling upwind, EWH	2	1	2	0	2	0	2	0
EWM50, idling, failed yaw,EWH	2	0	1	0	2	0	2	0

Maximum stress ratio New/Trad	0.90	1.20	1.4	more
Class	0	1	2	

Conclusions

- The new method can be used to obtain more accurate member results.
- The most fatigue damage occurs in normal operation, where the new method finds 32% more damage.
- The highest extreme load case stresses occur in the 50 year recurrence period, with up to 57% more stress.
- The new method performs efficiently. The additional time requirement is 80% of the reduced modal system simulation time.

FLOW Far and Large Offshore Wind innovation program

XEMC DARWIND

Knowledge Centre WMC

Kluisgat 5, 1771 MV Wieringerwerf, Netherlands T: +31 227 504949 E: info@wmc.eu W: www.wmc.eu