Advanced time-domain simulation of jackets for offshore wind turbines

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Motivation

The introduction of complex substructures for offshore wind turbines (OWT), such as jackets, evoked enhancements to simulation methods and codes, particularly to capture the dynamic coupling of local jacket modes and rotor-nacelle assembly modes. Results of simulation-based studies verified these coupled modes numerically. Additionally, a detailed investigation of jacket measurement data from alpha ventus has been started by comparison of measured and simulated strains and accelerations at the mudline jacket braces. During these investgations, a significant influence of the time-domain simulation setup using the Newmark integration scheme has been observed and gave rise for this numerical study as a preperative step. The work presented shall contribute to a deeper undestanding of the Newmark parameters on results of higher-order jacket dynamics, whereas accelerations are of special interest.

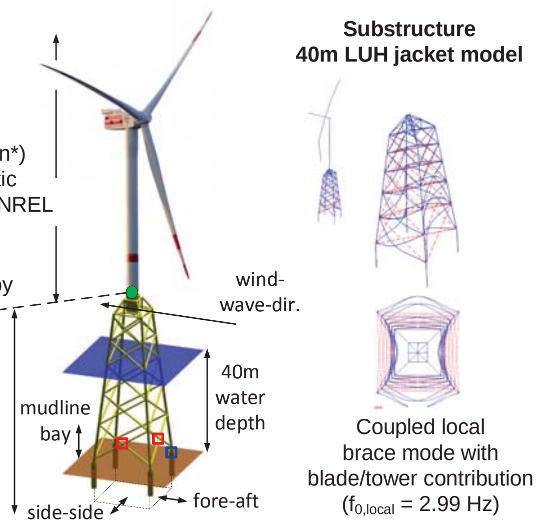
Offshore wind turbine model with jacket substructure

NREL 5MW baseline OWT model

Flex 5:
(Senvion-Version*) aero-servo-elastic model of 5 MW NREL baseline OWT

codes coupled by interface node

POSEIDON:
jacket substructure with hydro-dynamic loads and soil-model



Types and locations of sensors in the model:
- axial forces of jacket leg (global response)
- strain, acceleration, displacement (braces out-of-plane)

Fig. 1: Model with output sensors and local dynamics of the NREL 5MW baseline OWT with 40 m LUH Jacket

Newmark scheme for time-domain simulation

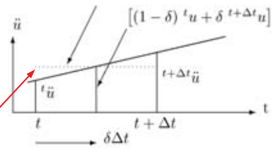
- Newmark method implemented in most OWT simulation codes
- Newmark integration scheme for

velocities $\quad \dot{u}^{t+\Delta t} = \dot{u}^{t} + \left[(1-\delta)\ddot{u}^{t} + \delta \cdot \ddot{u}^{t+\Delta t}\right]\Delta t$

displacements $\quad u^{t+\Delta t} = u^{t} + \Delta t \cdot \dot{u}^{t} + 0.5 \cdot \left[(1-\delta)\ddot{u}^{t} + \delta \cdot \ddot{u}^{t+\Delta t}\right] \cdot \Delta t^{2}$

- Numerical stability and accuracy despends on the integration parameters α and δ, time step size ΔT and max. element freq. $f_{0,max}$
- **Modification of newmark scheme by simple change of α and δ**

Influence of approximate integration with constant accelerations?



Integration scheme	δ	α	stability	Δt limit
Newmark const accel.	1/2	1/4	always	-
Newmark linear accel.	1/2	1/6	cond. stable	$\Delta t \leq 0.55 / f_{0,max}$
Central differences	1/2	0	cond. stable	$\Delta t \leq 0.32 / f_{0,max}$

- Default setup of integration parameters in simulation codes with constant acceleration (for stability reasons)
- Typical time step size from 0.01 to 0.05 seconds

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Simulation parameters and time step size limitations

Integration scheme and time step size

- Newmark setup with constant accelerations (NCA)
  linear acceleration (NLA)
  modified to central difference scheme (CD)
- Time step size Δt 0.005, 0.01, 0.015, 0.025, 0.050, 0.075 seconds

Load cases with co-dir. wind/waves

	Wind speed	Seastate	
LC	v_{hub} m/s	Hs m	Tz sec.
1	6.0	0.75	4.00
2	8.0	1.25	4.00
3	11.0	1.75	5.00
4	14.0	3.50	7.00
5	17.0	5.00	8.00
6	20.0	5.00	8.00
7	24.0	7.00	9.00

- Smaller time step size leads to a higher resolution of wind turbulence, respectively wind loads, at the same time!
- Stability of linear acceleration approach might be achieved without reducing the load step size significantly

Simulation results

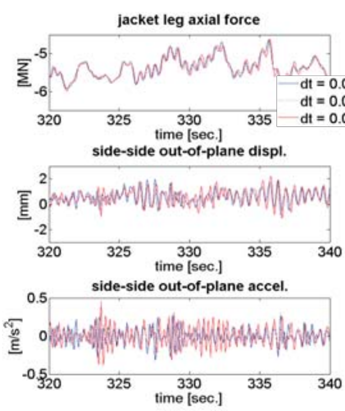

Fig. 2: Global and local jacket response for LC 5 | wind speed 17m/s

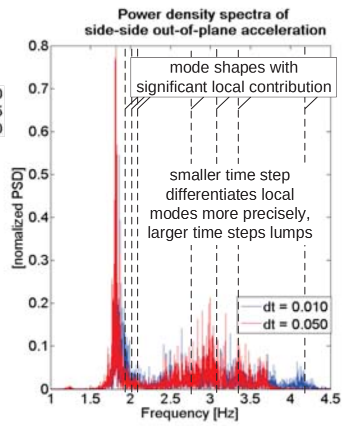

Fig. 3: Frequency content of side-side out-of-plane acceleration for LC 5 | wind speed 17m/s

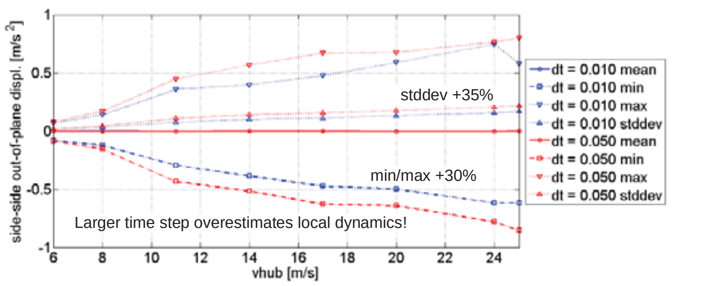

Fig. 4: Statistics of side-side out-of-plane acceleration vs. Wind speed for Δt = 0.010/0.050 sec.

Conclusions

- Time step size affects response of members with higher modes, particularly accelerations (typically measured at OWT test sites)
- Setup of time integration scheme essential for model validation against acceleration measurements in time domain → for simulation of global or local response: $\Delta t_{global} \leq 0.025$ sec. | $\Delta t_{local} \leq 0.010$ sec.
- PSD-interpretation of local system response requires concise comparison of numerous load cases (measurement assignment tough!)

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