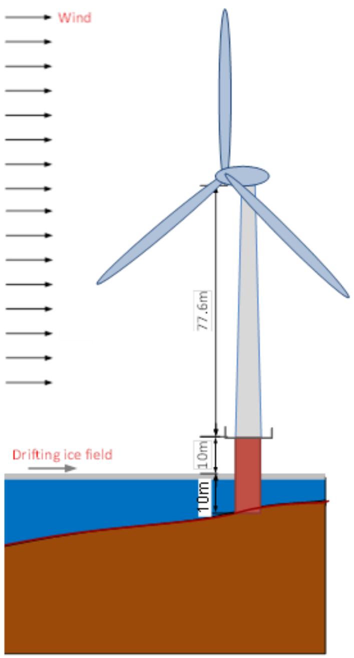


Simulations of Drifting Sea Ice Loads on Offshore Wind Turbine

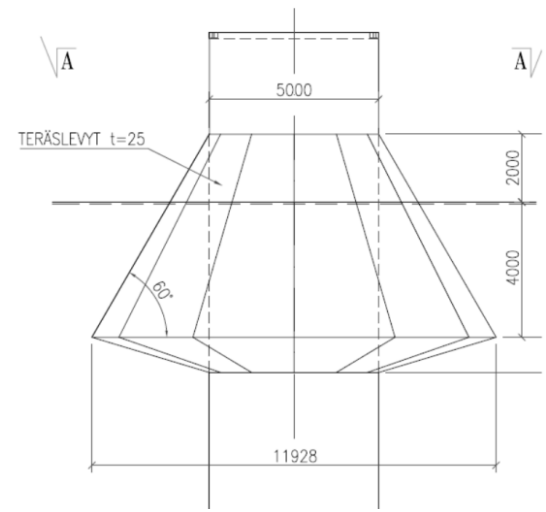
Winterwind 2016, Åre
Simo Rissanen, Jaakko Heinonen
VTT Technical Research Centre of Finland ltd

Content

- Motivation
- Introduction to Ice conditions in Bay of Bothnia
- Tools and methods
- Ice loads
- Wave loads
- Damage Equivalent Loads (DEL)
- Conclusions

Motivation

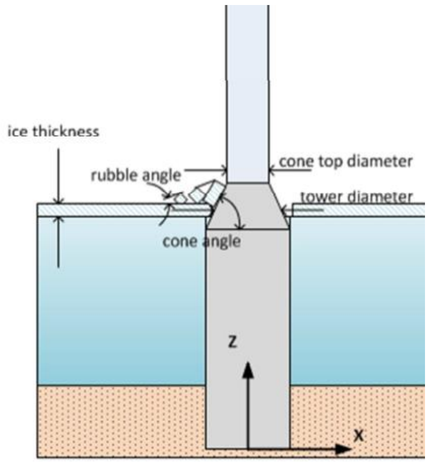
- Ice cone is known method to decrease ice loads
  - Ice failure mechanism from crushing to bending
- However, wave loads will be increased
  - Is the increase significant compared to ice loads?
- How different cone angle and water depth changes ice and wave loads?
- How turbine dynamics interact with ice loads?



Ice conditions in Bay of Bothnia

- Various ice features:
  - Land-fast ice, max thickness > 1 m
  - Drifting level ice, floe velocity up to 0.3 m/s
  - Ice ridges, typical thickness around 8m
- Driving Forces:
  - Mainly wind

- Ice load depends on
  - Floe thickness
  - Ice drift speed
  - Shape of the structure
  - Failure mode of ice
  - Crystal structure of ice
  - Flexibility of the structure at ice level
  - Etc.



Ice = Sea ice, not rotor ice!

Tools and methods (1/2)

- FAST (by NREL) and IceFloe module (DNV GL) used for dynamical simulations
- NREL 5 MW offshore model
  - Ice cone added
  - Coupled crushing ice model (modified by VTT) used for monopile
  - IEC Flexural Failure (IceFloe module) used for coned structure
  - Wave loads calculated using Pierson-Moskowitz model (Hydrodyn module)

Coordinate system and analysed signals

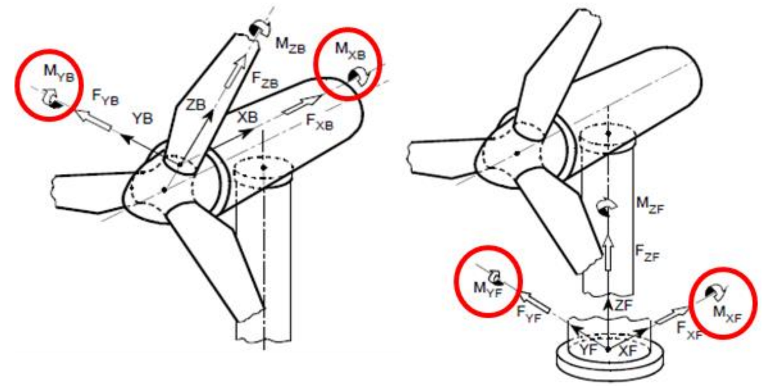
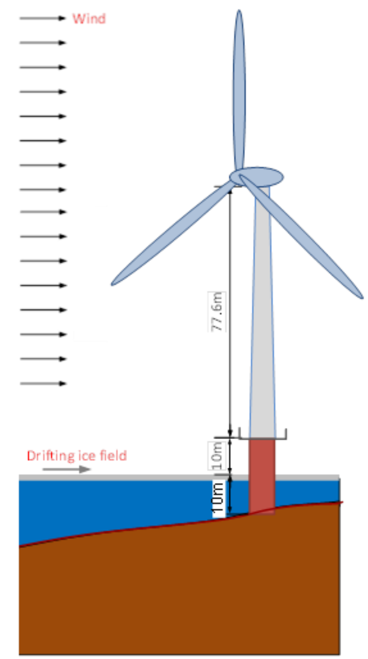


Figure: Germanischer Lloyd, *Guideline for the certification of wind turbines*

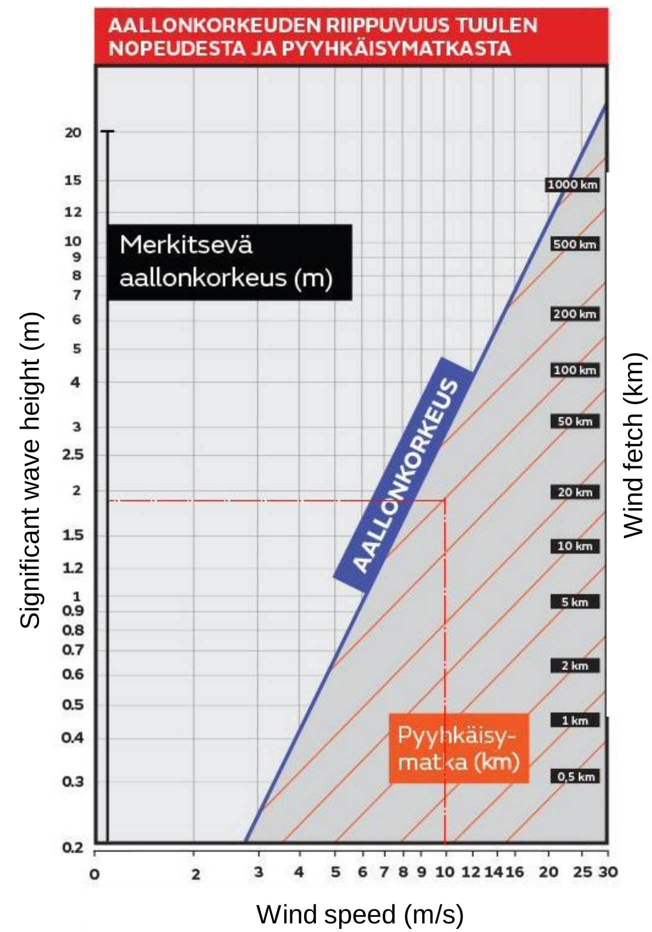


Tools and methods (2/2)

- Simplifyed approach:
  - 0.6 m ice thickness
  - 3 months ice/year
  - 4 - 25 m/s constant hh wind speeds simulated (with wind shear)
  - Weibull wind speed distribution
  - Ice velocity: 2% of wind speed (10m elevation)
  - Significant wave height from figure

Simulation cases:

- Monopile, water depth 10 m & 20 m
- 60 deg cone, water depth 10 m & 20 m
- 50 deg cone, water depth 10 m & 20 m
- All simulated with ice and waves separately
- 132 simulations!



Source: http://blogi.foreca.fi/2015/01/tuuli-ja-aallonkorkeus/

Ice loads: monopile vs cone (1/2)

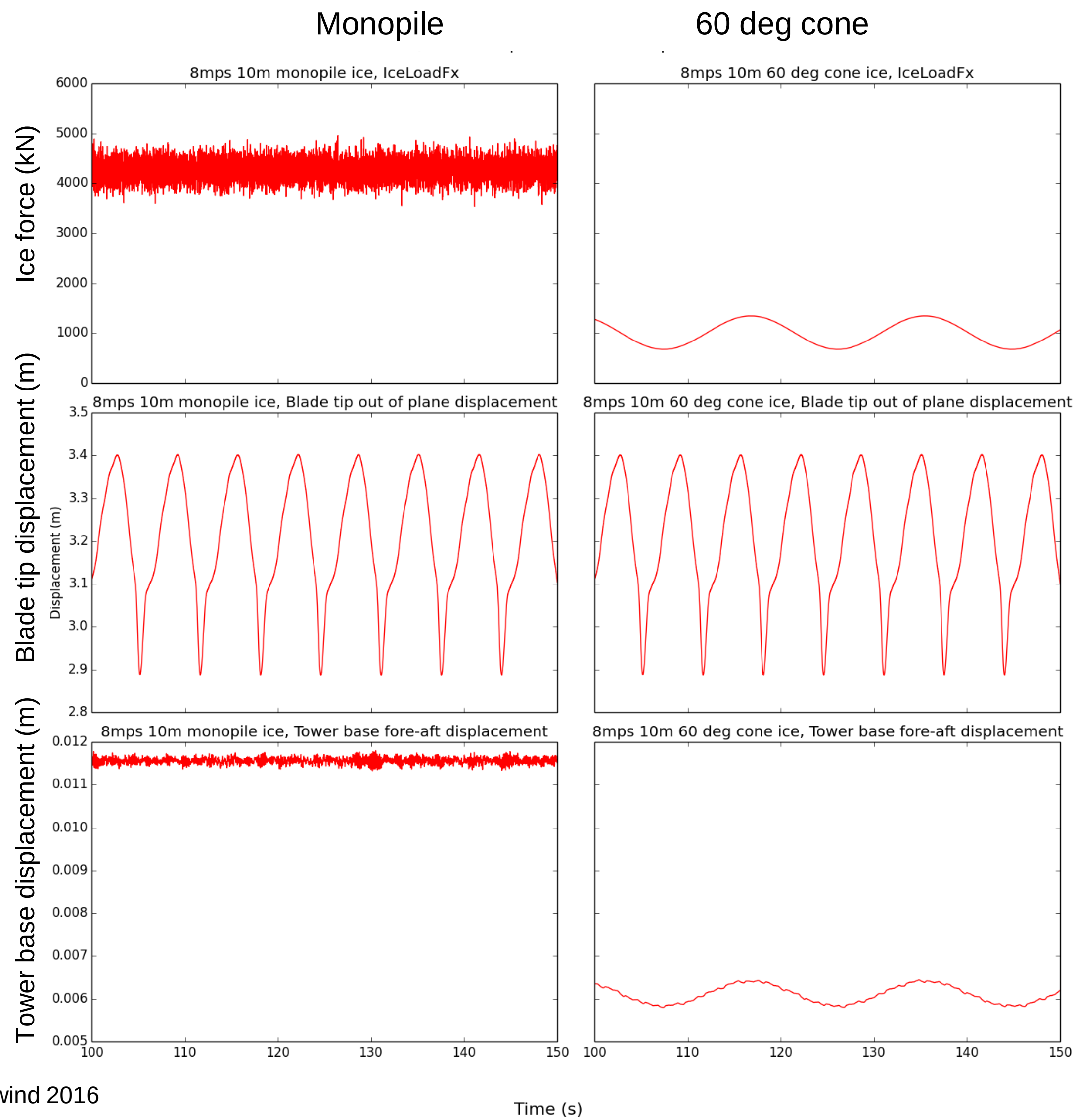
Monopile:

- failure mechanism: continuous random crushing
- Ice crushes several times per second -> high frequency dynamic load

Cone:

- Flexural (IEC), bending failure of ice
- Average ice load level and frequency are lower!
- Frequency dependent on ice velocity and thickness. Typically below eigenfrequencies.

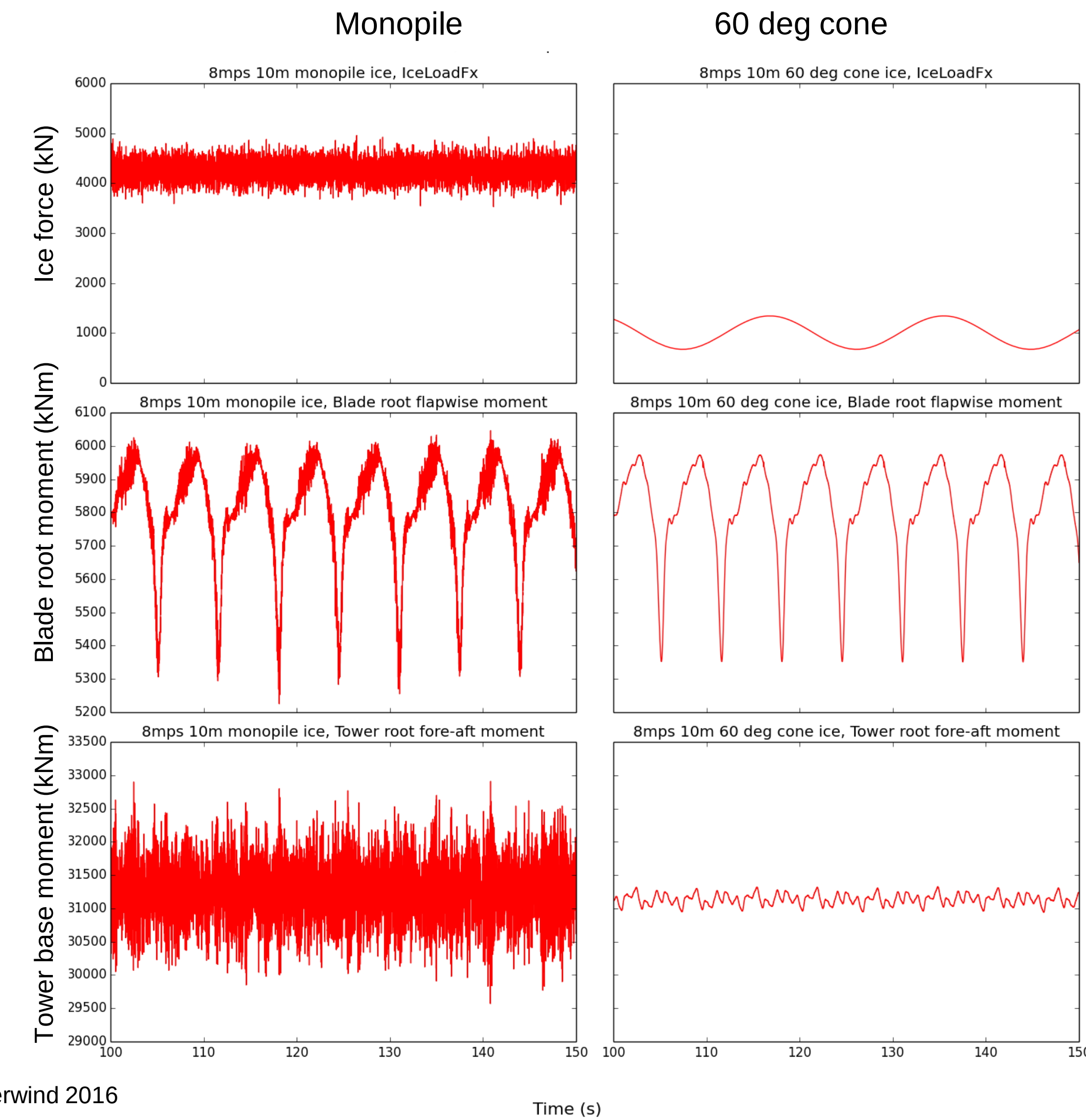
Changes in tower root, but not in blade tip displacement



Ice loads: monopile vs. cone (2/2)

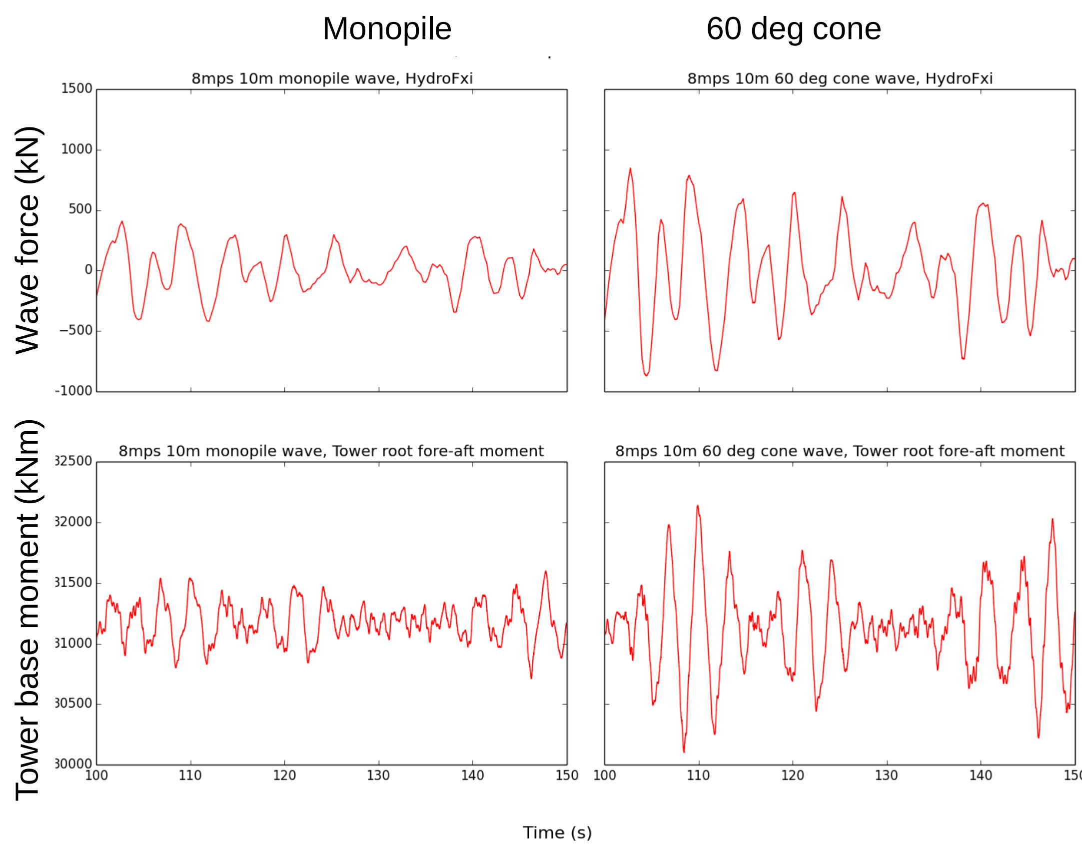
Monopile:

- Vibrations seen in tower and blade root moments



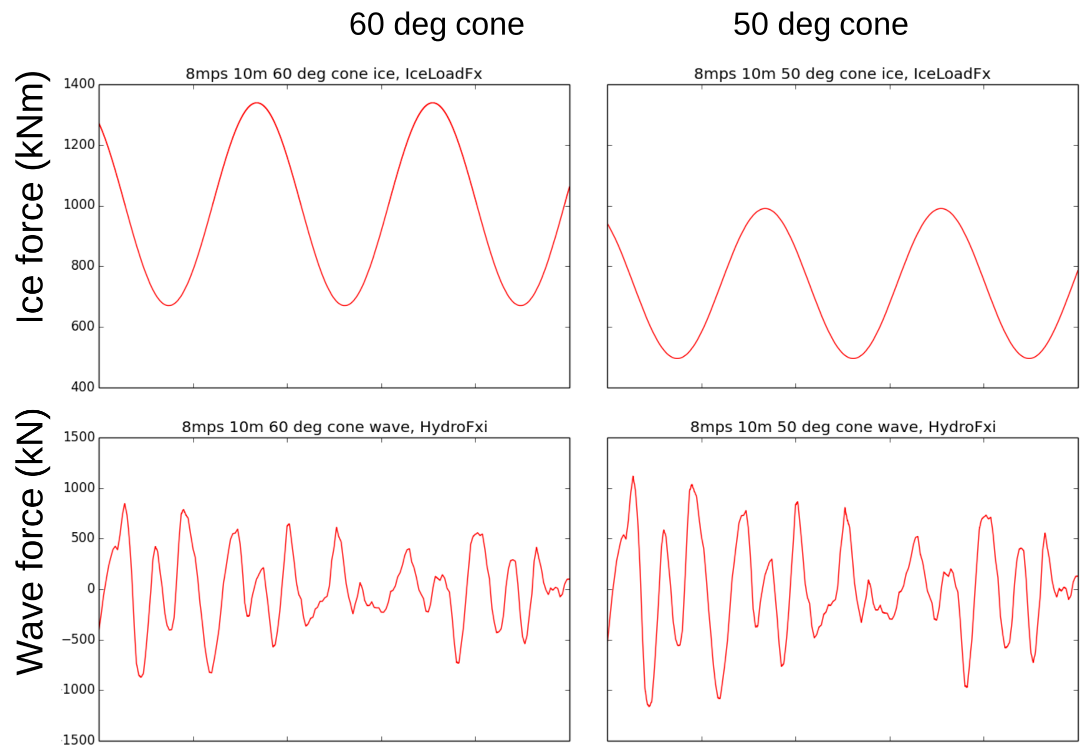
Wave loads: monopile vs. 60 deg cone

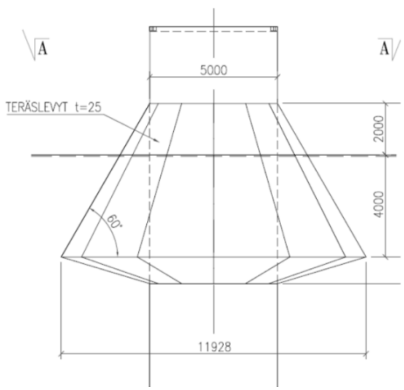
- Cone increases wave load amplitude!
- tower root load amplitude is larger



60 deg cone vs. 50 deg cone

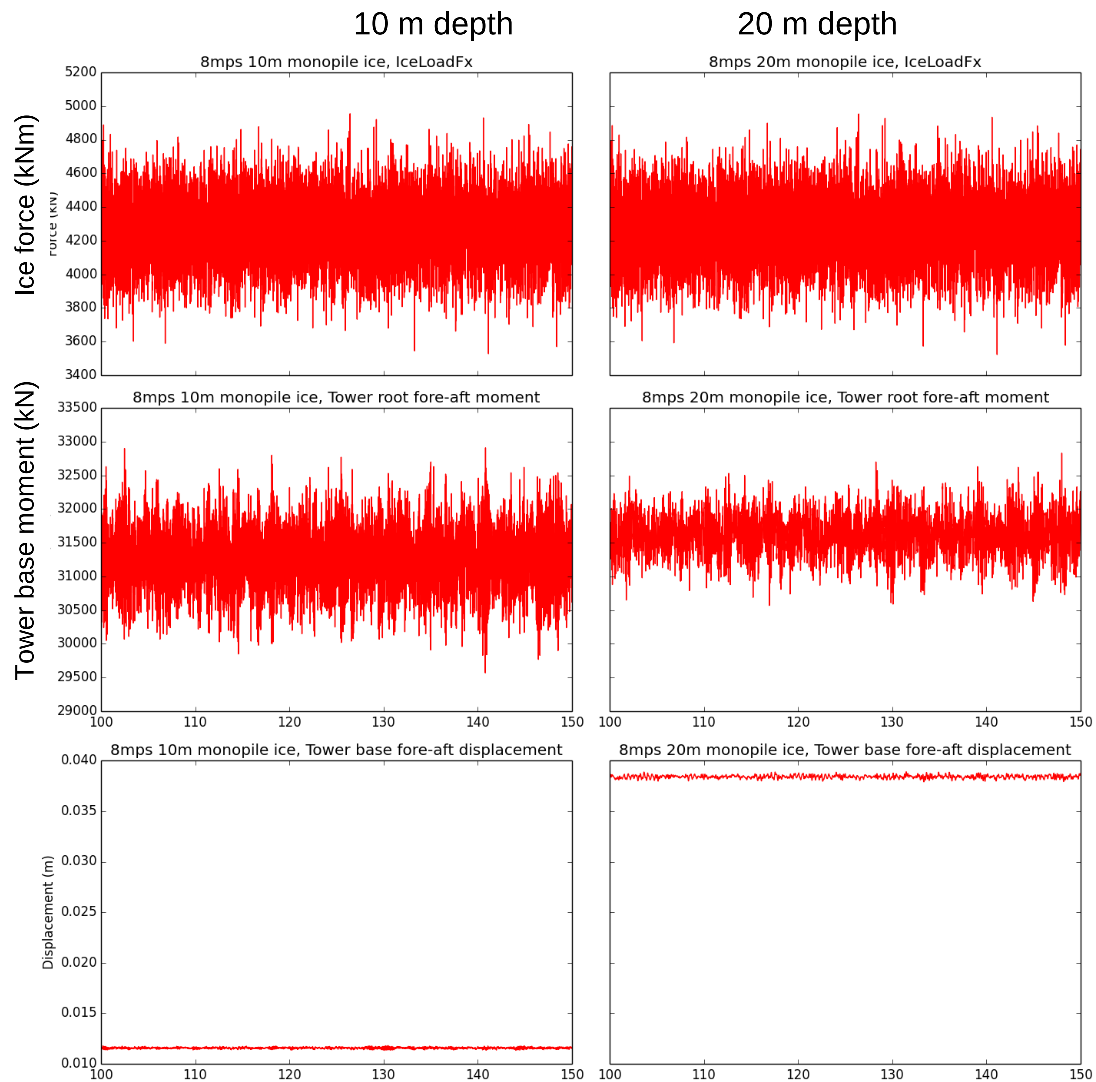
- 50 deg cone:
  - Ø 14.4 m
  - smaller ice load amplitude
  - wave load amplitude larger
- 60 deg cone:
  - Ø 11.8 m





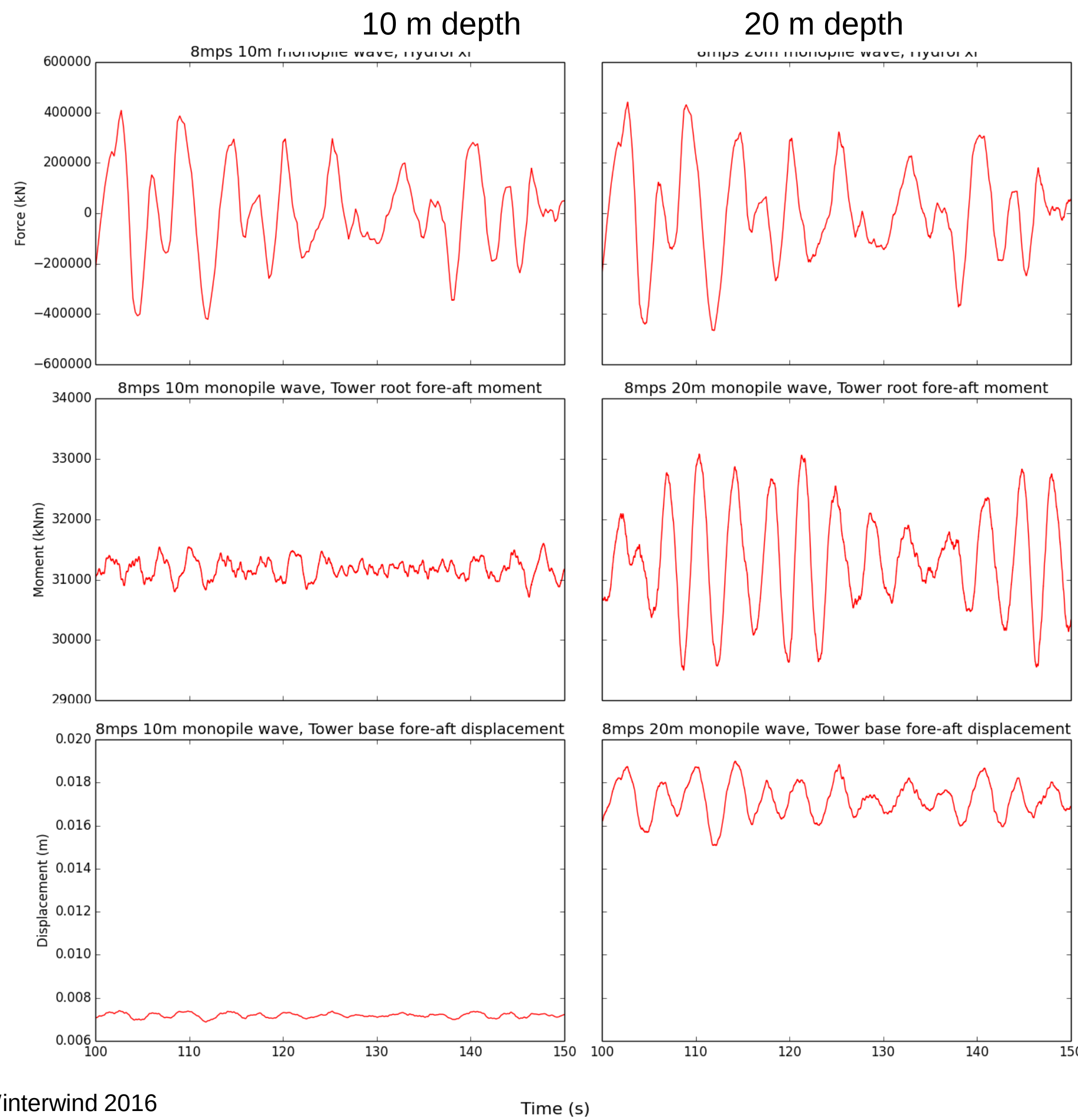
Ice loads: 10 m vs. 20 m water depth

- 20m water: tower base load amplitude decreased (at this ice velocity, does't mean that 20 m depth is better!)
- Changes in eigenfrequencies!



Wave loads 10m vs. 20 m water depth

- 20m water: tower base load amplitude increased
- Changes in eigenfrequencies!



Damage equivalent loads

- DEL (Damage Equivalent Load) is simplified method to compare fatigue of different time series
  - Based on rainflow counting
  - Mean load level is ignored
  - Amplitude of 1 Hz load which causes similar fatigue
  - From time series to one number

DEL, ice loads vs. wave loads

- Relative lifetime DEL (ice/wave)
- Tower base fore-aft is the most affected signal
- Small changes in tower base side to side moment

	TBMx (side to side)	TBMy (fore-aft)	Bl root edge	Bl root flap
monopile	105.3 %	745.7 %	101.3 %	103.3 %
cone1	102.3 %	69.0 %	100.0 %	100.0 %
cone2	104.3 %	56.3 %	100.0 %	100.0 %

> 100% = bigger ice loads
< 100% = bigger wave loads

DEL, monopile vs. 60 deg cone combined ice&wave loads

- Relative lifetime DEL (monopile/cone)
- Tower base fore-aft is the most affected signal
- Only small changes on other signals

	TBMx (side to side)	TBMy (fore-aft)	Bl root edge	Bl root flap
12 months ice	99.4 %	696.0 %	101.3 %	103.3 %
3 months ice	97.4 %	322.4 %	100.3 %	100.9 %
0 months ice	96.6 %	64.4 %	100.0 %	100.0 %

> 100% = cone is better
< 100% = monopile is better

Relative lifetime DEL, 60 deg cone vs. 50 deg cone and water depth

- 60deg vs. 50deg:
  - larger diameter increases wave loads!
  - Also ice loads increased
- Water depth:
  - 10 m -> 20 m: ice loads decreased, wave loads increased?

	60deg/50deg TBMy (fore-aft)	10m/20m TBMy (fore-aft)
12 months ice	98.5 %	200.8 %
3 months ice	81.7 %	160.9 %
0 months ice	80.4 %	39.4 %

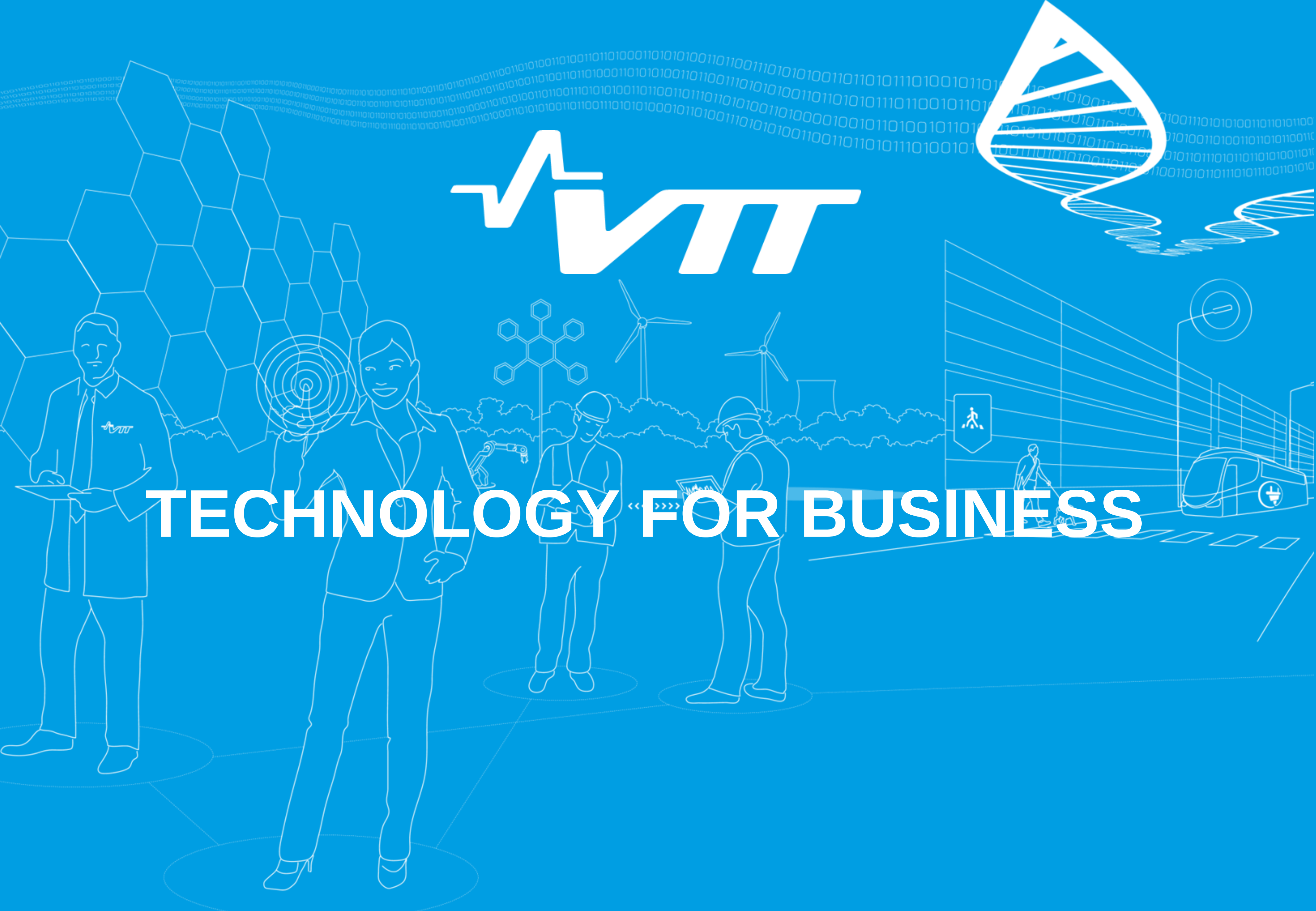
Conclusions

- Feasibility study, simplifyed analysis
  - Only tower and blade root loads analysed
- Tower base
  - Ice cone decreases TBMy ice loads significantly
  - Ice cone increases TBMy wave loads
  - Larger cone diameter: more expensive and larger wave loads

→ Need for ice cone depends on local ice condition

- Blade root DEL
  - Edgewise: dominated by gravity
  - Flapwise: dominated by wind shear

→ Waves or ice not dominant in this case



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