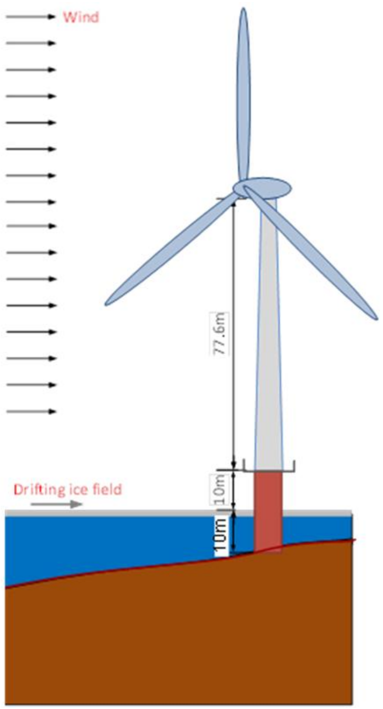


Site Specific Simulations of Drifting Sea Ice Loads on Offshore Wind Turbine

Winterwind 2017, Skellefteå 8.2.2017
Simo Rissanen, Jaakko Heinonen
VTT Technical Research Centre of Finland ltd

Content

- Motivation
- Introduction to ice conditions in Bay of Bothnia
- Tools and methods
- Input loads
- Ultimate loads
- Conclusions

Motivation

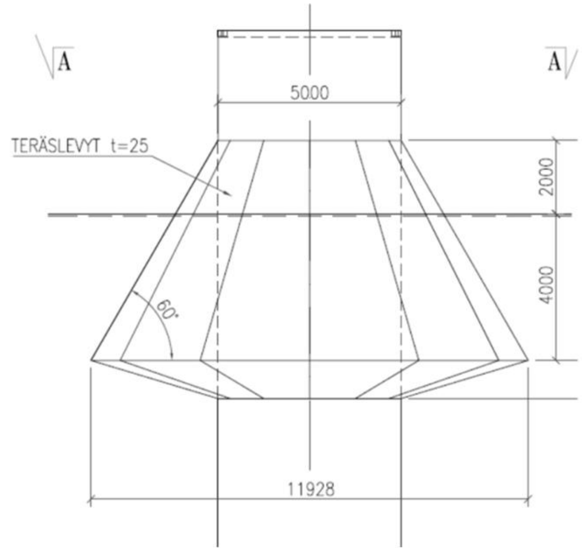
- Shape of the structure have large effect to sea ice loads*
- Structure optimization is balancing between ice and wave loads*
  - Need for ice cone depends on local ice conditions!
- Water depth changes structure dynamics*

Site specific simulations needs to be done!

WW2016: Fatigue load analysis

WW2017: Ultimate load analysis

* S. Rissanen, J. Heinonen, Simulations of drifting sea ice loads on offshore wind turbine support structures, Winterwind 2016, Åre



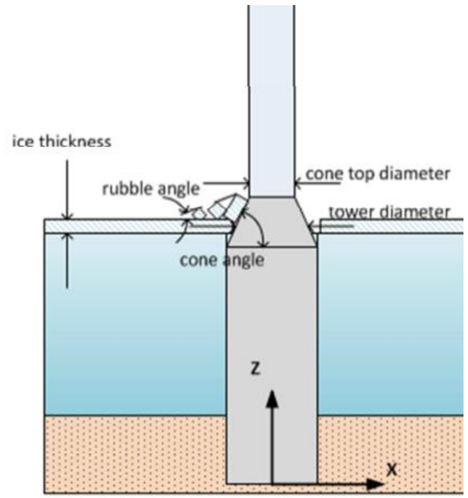


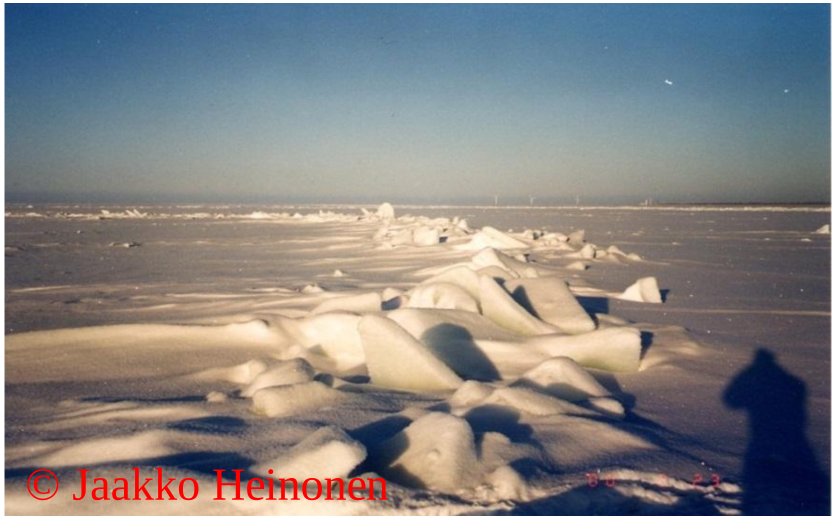
Figure: IceFloe manual

Ice conditions in Bay of Bothnia

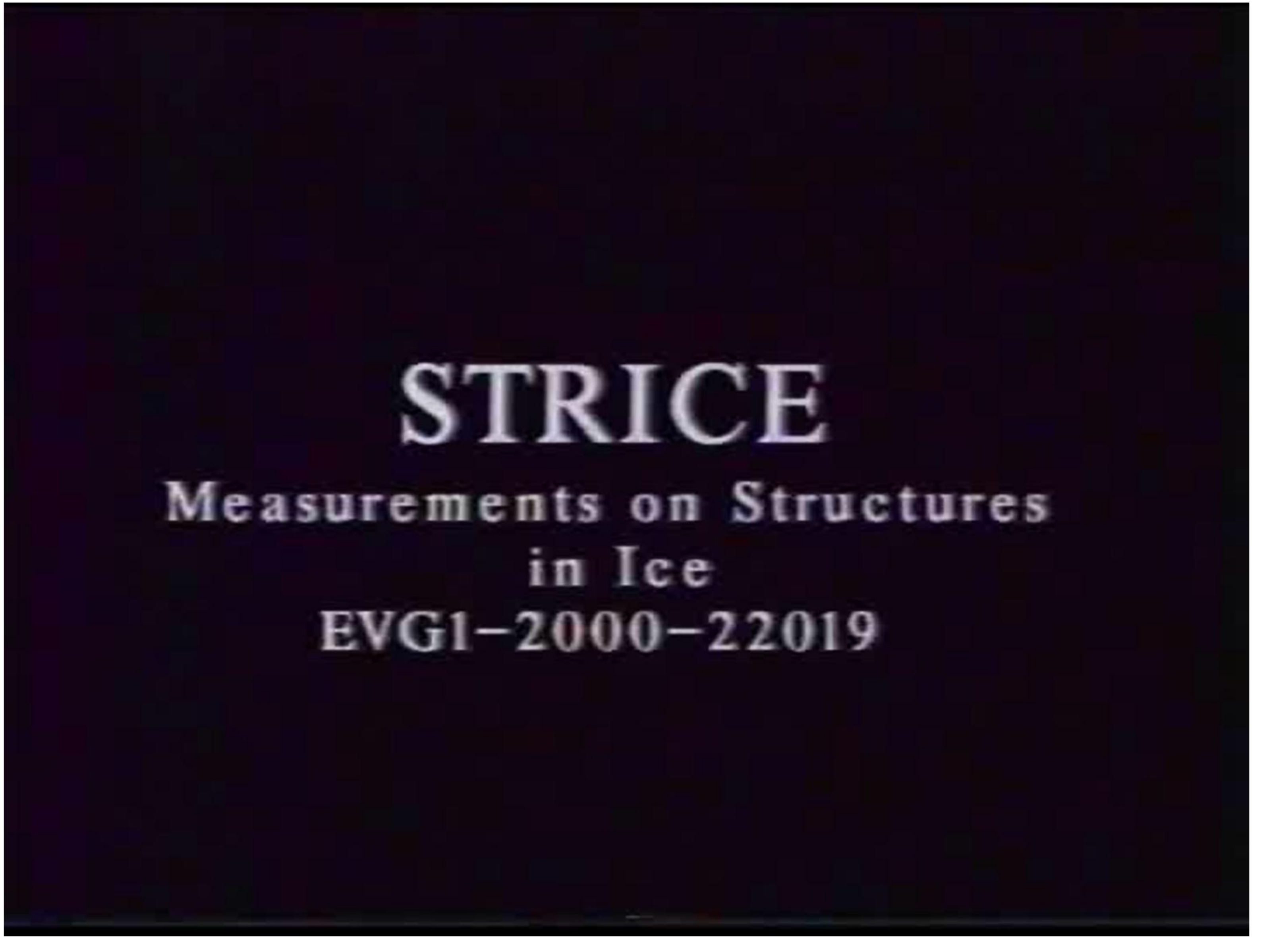
- Various ice features:
  - Land-fast ice, max thickness > 1 m
  - Drifting level ice, floe velocity up to 0.3 m/s
  - Ice ridges, typical thickness around 8m
- Driving Forces:
  - Mainly wind

Ice = Sea ice, not rotor ice!

- 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.



Norströmsgrund lighthouse – ice load measurements

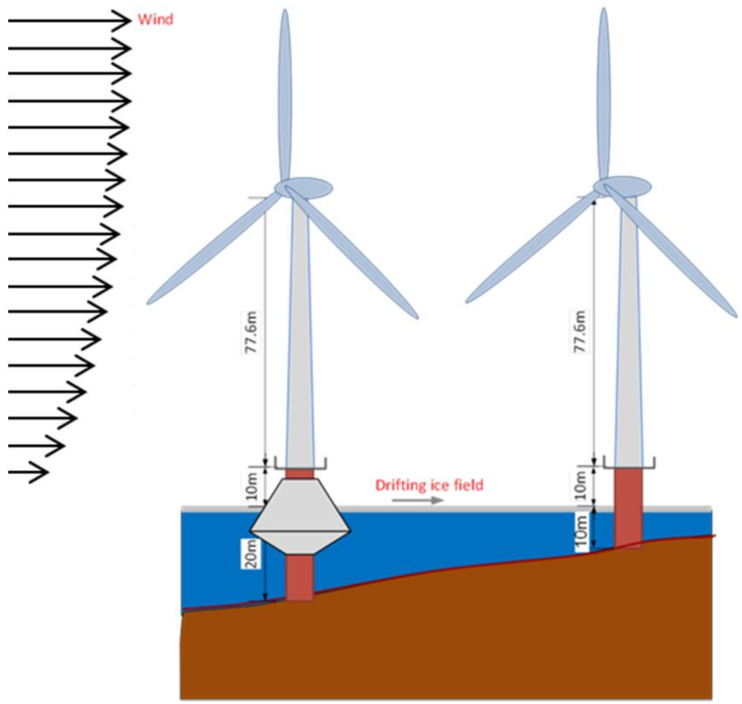


Video

- 21.2.2003
- Ice thickness ~ 50 cm

Tools and methods

- 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
  - ISO Flexural Failure (IceFloe module) used for coned structure
  - Wave loads calculated using JONSWAP model (Hydrodyn module)
  - Turbulent wind field



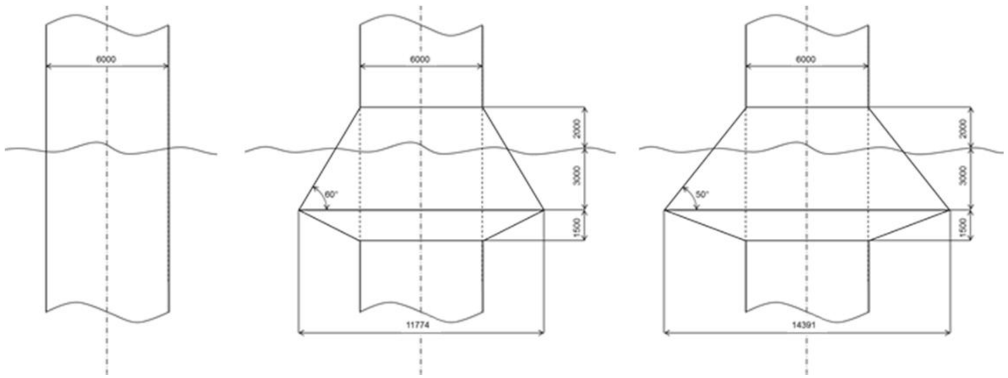
Ultimate load analysis based on IEC 61400-3

- DLC E3 for sea ice loads (power production)
  - NTM, V_{out} only (25 m/s)
  - Ice velocity: 0.05, 0.075, 1,1.25,1.5 and 1.75 m/s
  - Ice thickness: ave, 10 year max, 50 year max
- DLC 1.6 for waves
  - NTM, V_{out} 25 m/s
  - Significant wave height (H_s): ave, 10 year max, 50 year max
  - Max individual wave 1.86 x H_s

Not required in IEC 61400-3

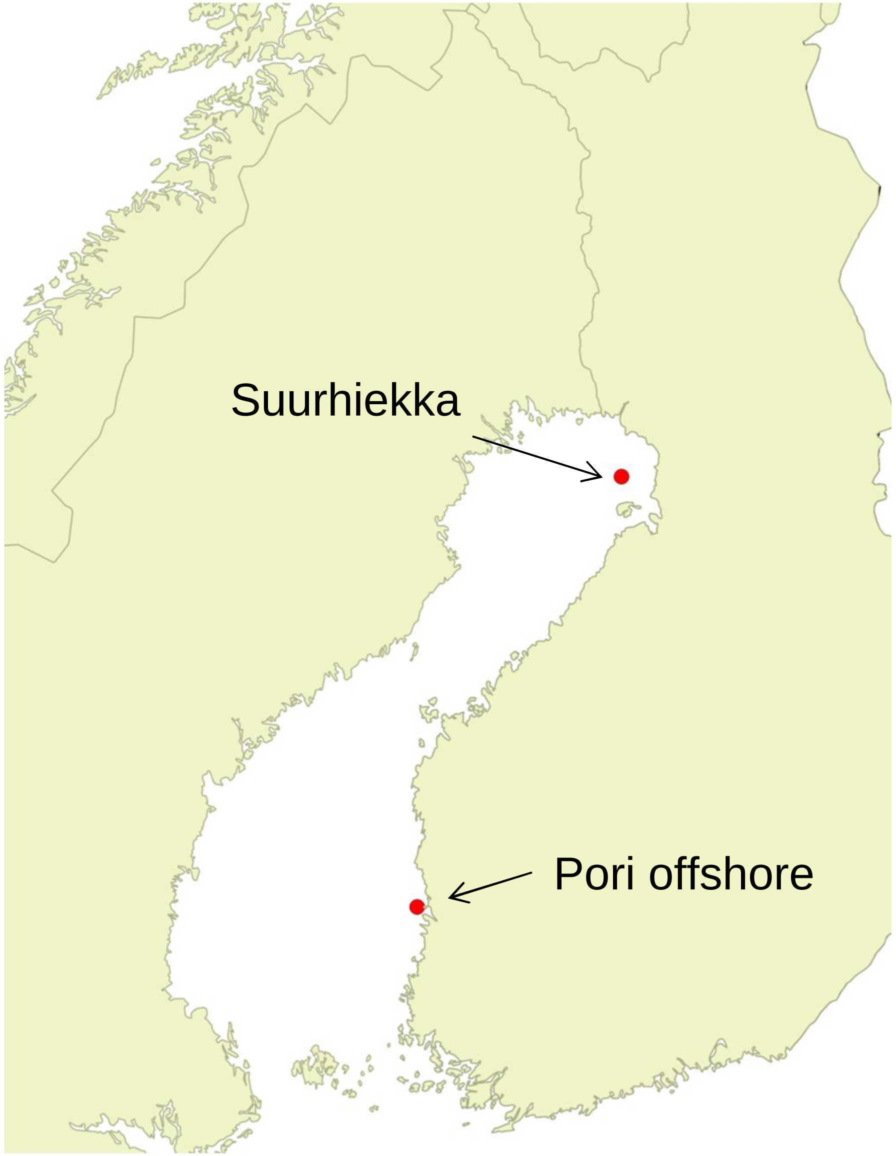
Simulation cases:

- Monopile
- Monopile with 50 deg ice cone
- Monopile with 60 deg ice cone



Site specific analysis

- Data sources
  - Ice thickness: FMI*
  - Wave data: FMI*
  - Water depth: The Finnish Transport Agency
- 2 example sites: Pori offshore and Suurhiekka



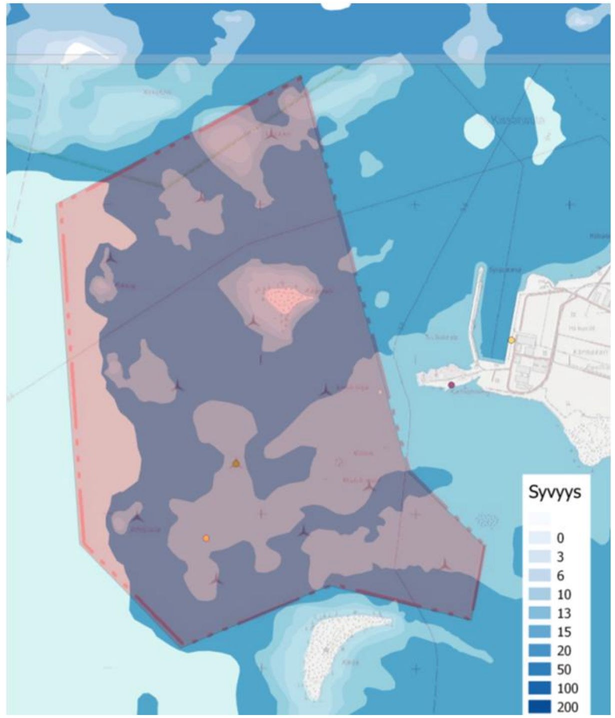
* Finnish meteorological institute, data analysed in VTT

Site 1. Pori offshore

- Pori offshore 1, first offshore wind turbine in Finland
- 10 x 4 MW under construction
  - Caisson foundations
  - Simulated foundation is monopile!

		Pori	Suurhiekka
Distance from shore		~1 km	20-25 km
Water depth		~10 m	2-15m
Ice thickness	average	0.2 m	0.65 m
	10 year max	0.4 m	0.85 m
	50 year max	0.6 m	1.05 m
Significant wave height (H_s)	average	0.74 m	0.65 m
	10 year max	5.75 m	4.75 m
	50 year max	6.73 m	5.4 m

Source: http://hyotytuuli.fi/tuulipuistot/tahkoluodon-merituulipuistohanke/



Site 2. Suurhiekka

- Planned site, 80 x 5 MW
- 10 m water depth selected

		Pori	Suurhiekka
Distance from shore		~1 km	20-25 km
Water depth		~10 m	2-15m
Ice thickness	average	0.2 m	0.65 m
	10 year max	0.4 m	0.85 m
	50 year max	0.6 m	1.05 m
Significant wave height (H_s)	average	0.74 m	0.65 m
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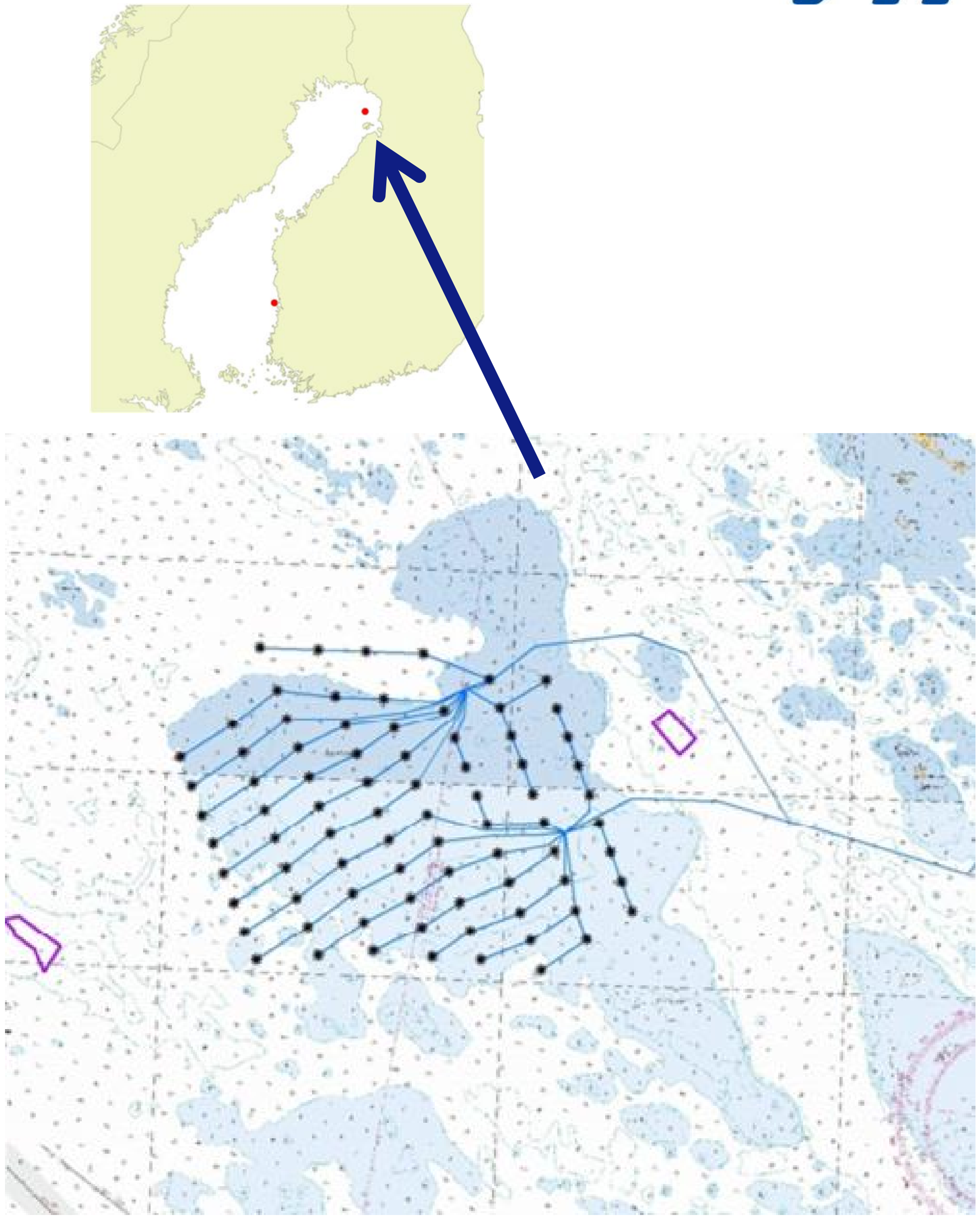
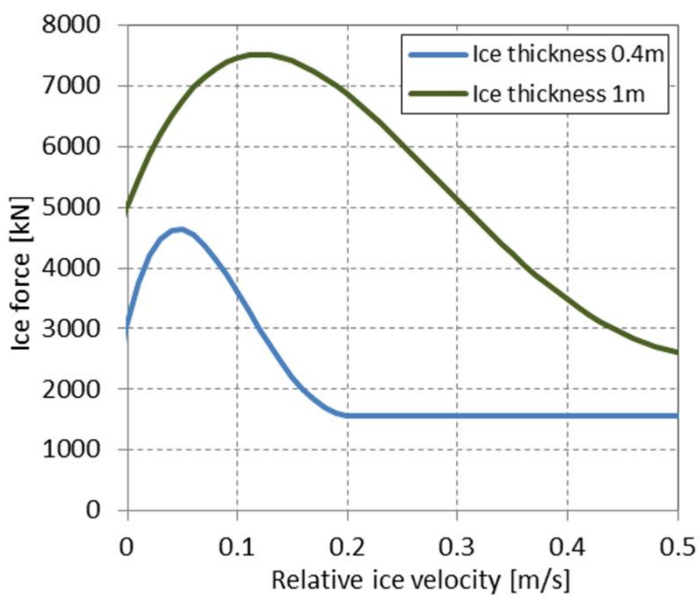


Source: http://www.wpd-finland.com/fi/tuulivoimaprojektit/merituulivoima/li-suurhiekka.html

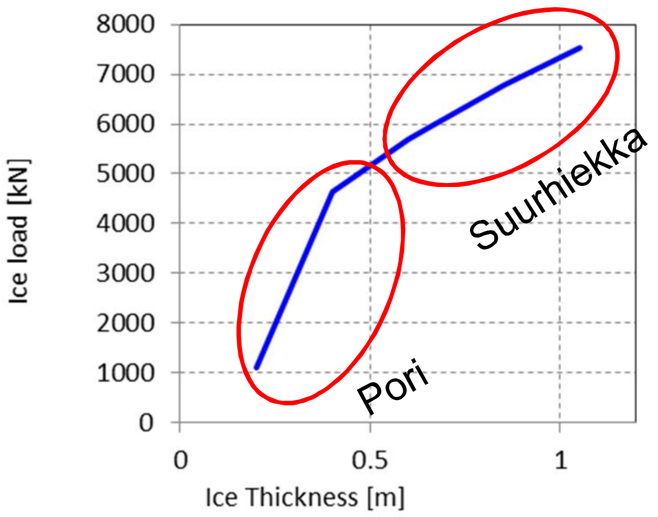
Input loads (1/2)

- Ice load depends on ice thickness and drift speed
- Monopile: tower vibration change the ice force
- Ice cone: Average force is low, occasional peaks

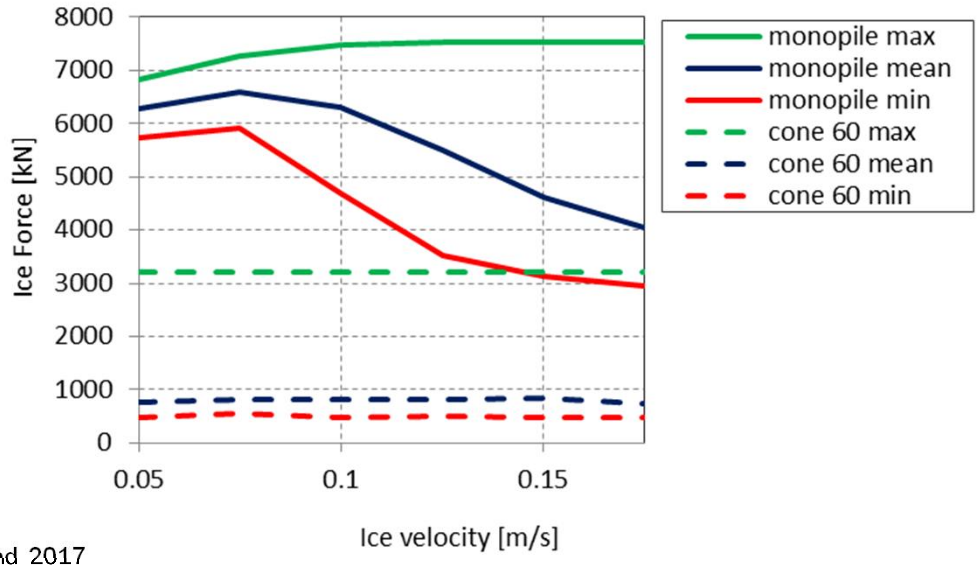
Coupled crushing ice model



Simulated max ice force vs. ice thickness

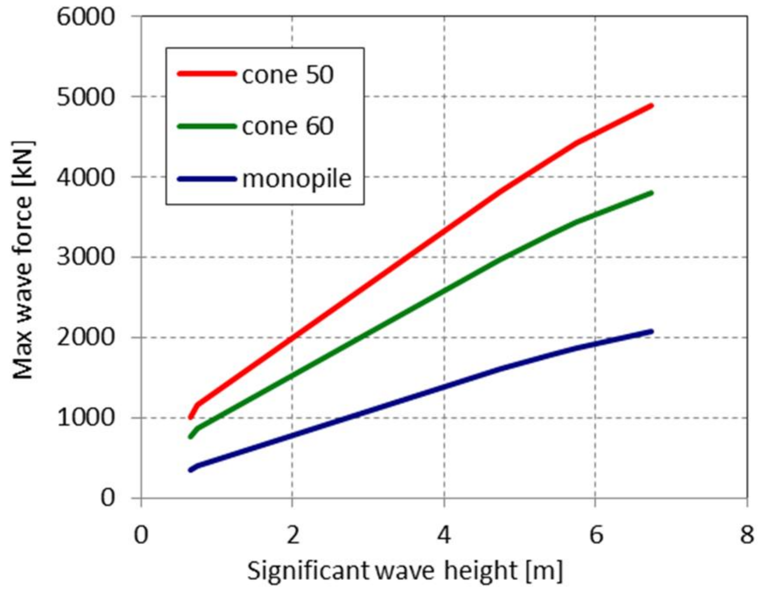


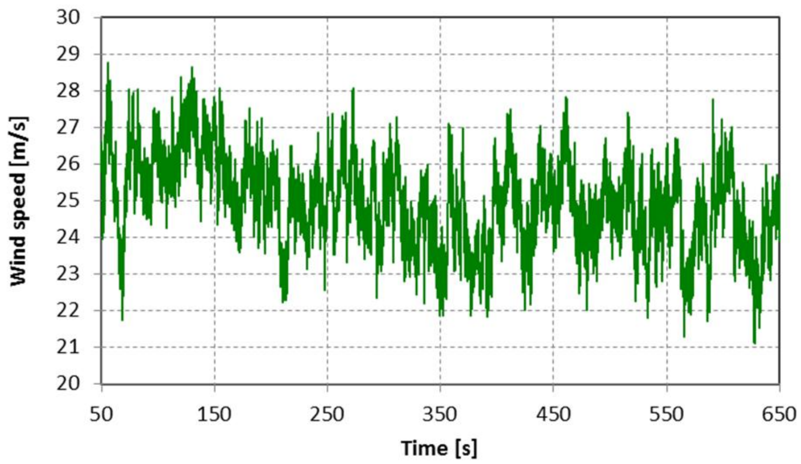
Simulated ice force vs. ice velocity

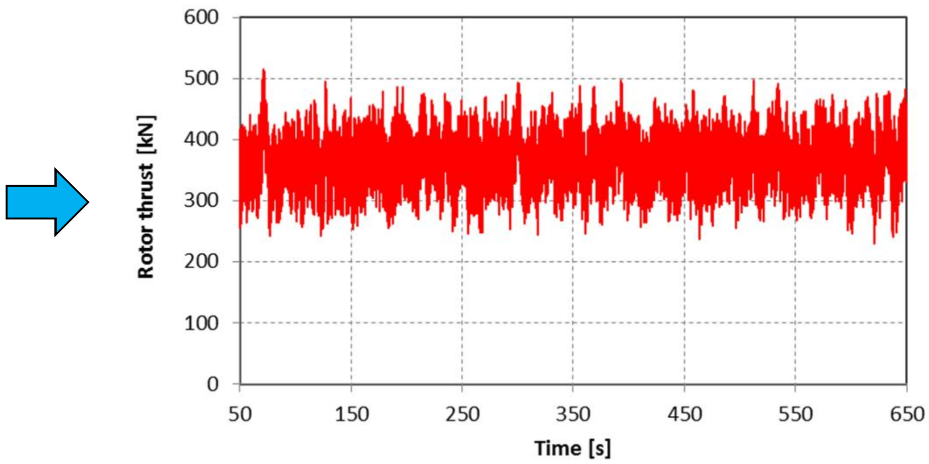


Input loads (2/2)

- Wave load
  - Ice cone increases max values
  - Lower than ice loads on monopile
- Turbulent wind -> rotor thrust
  - Leveled by blade pitch control







Ice loads

Coordinate system

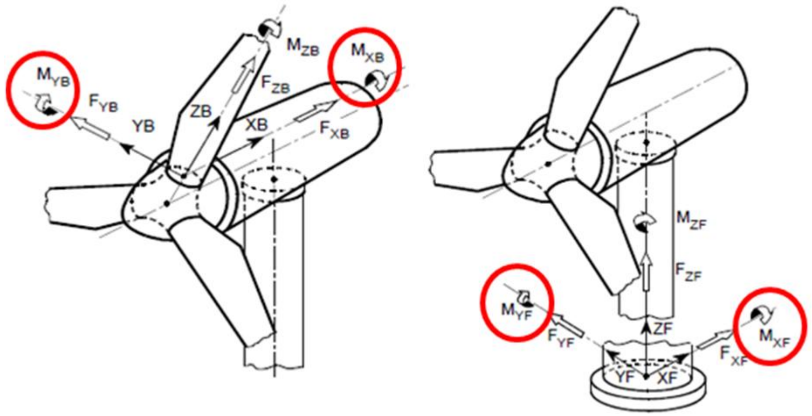


Figure: Germanischer Lloyd, *Guideline for the certification of wind turbines*

- Compared to reference case (monopile and wind, but no ice or wave loads)
- Monopile: tower ultimate loads increased
  - Similar results in fatigue loads WW2016*
- Ice cones: Ultimate loads close to ref case, foundation root moment increased

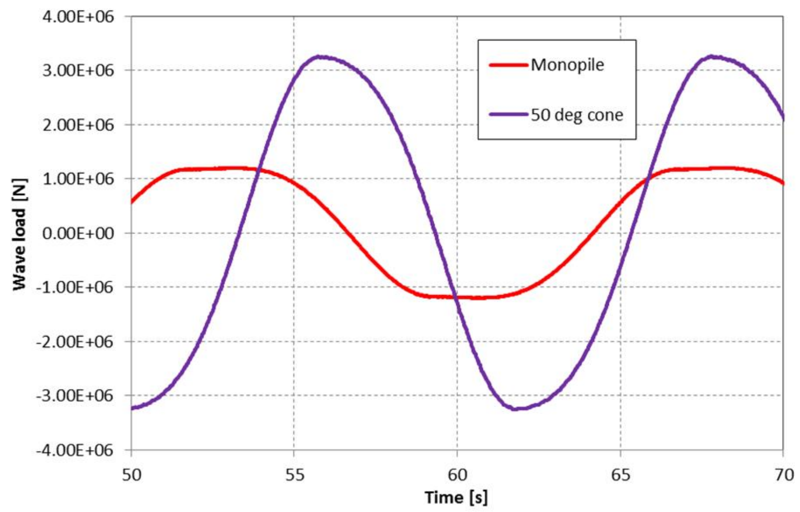
Site	Foundation	TBFx	TBMy	TTMy	BLMe	BLMf	FBMy
Pori	mono	499 %	194 %	359 %	137 %	128 %	331 %
Pori	cone60	100 %	99 %	99 %	99 %	92 %	135 %
Pori	cone50	100 %	99 %	98 %	99 %	92 %	116 %
Suurhiekka	mono	505 %	202 %	382 %	135 %	131 %	326 %
Suurhiekka	cone60	100 %	102 %	99 %	100 %	93 %	172 %
Suurhiekka	cone50	100 %	102 %	99 %	100 %	93 %	145 %

TBFx = Tower base fore-aft force
TBMy = Tower base fore-aft moment
TTMy = Tower top fore-aft moment
BLMe = Blade root edgewise moment
BLMf = Blade root flapwise moment
FBMy = Foundation base fore-aft moment

* S. Rissanen, J. Heinonen, Simulations of drifting sea ice loads on offshore wind turbine support structures, Winterwind 2016, Åre

Wave loads

- Compared to reference case (monopile and wind, but no ice or wave loads)
- Cone increases loads in foundaton
- Other signals are close to ref case
  - WW2016: Ice cone increases fatigue loads*



Site	Foundation	TBFx	TBMy	TTMy	BLMe	BLMf	FBMy
Pori	mono	100 %	100 %	100 %	100 %	100 %	113 %
Pori	cone60	102 %	101 %	99 %	100 %	101 %	137 %
Pori	cone50	103 %	101 %	99 %	100 %	101 %	150 %
Suurhiekka	mono	100 %	100 %	100 %	100 %	100 %	113 %
Suurhiekka	cone60	102 %	101 %	99 %	100 %	101 %	134 %
Suurhiekka	cone50	103 %	101 %	99 %	100 %	101 %	146 %

TBFx = Tower base fore-aft force
TBMy = Tower base fore-aft moment
TTMy = Tower top fore-aft moment
BLMe = Blade root edgewise moment
BLMf = Blade root flapwise moment
FBMy = Foundation base fore-aft moment

* S. Rissanen, J. Heinonen, Simulations of drifting sea ice loads on offshore wind turbine support structures, Winterwind 2016, Åre

Conclusions

- Monopile
  - All analysed signals increased due to ice
- Ice cones
  - Ultimate loads not increased, except foundation base moment
  - However, ice cone increases fatigue loads [WW2016]
- Wave loads
  - Ultimate loads not increased, except foundation base moment
  - However, ice cone increases fatigue loads [WW2016]
- Shape of the structure have larger effect to ultimate loads than site specific input data
  - Site specific values can be more important for fatigue analysis and structure optimization

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