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Marin Lab

Wave-induced loads between a spar-buoy floating wind turbine and installation vessel

David Lande-Sudall, Thomas Høyven, Kjell Herfjord, Thore Thuestad

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DeepWind ‘20

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Contents

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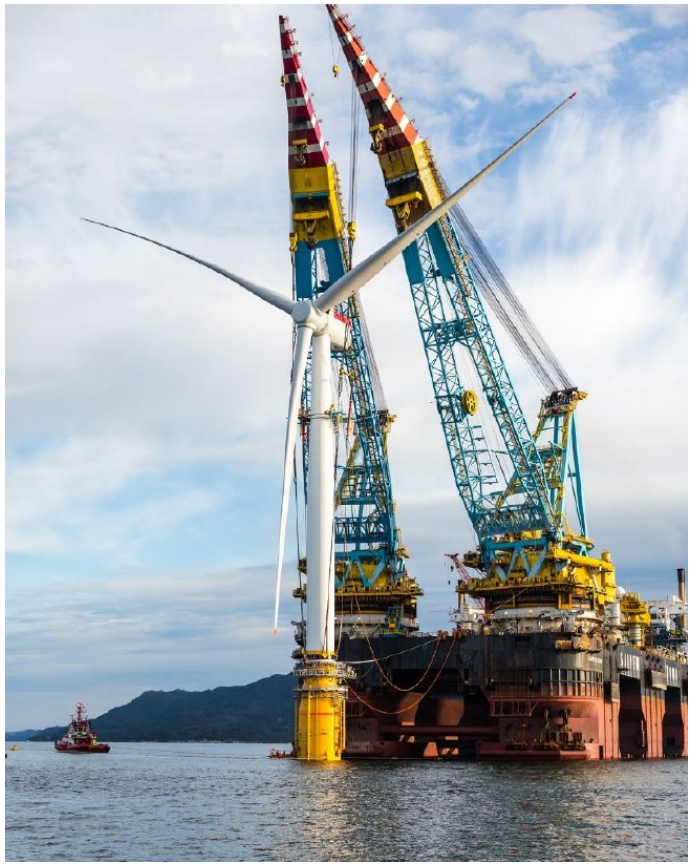
Background



All pictures - Equinor ASA

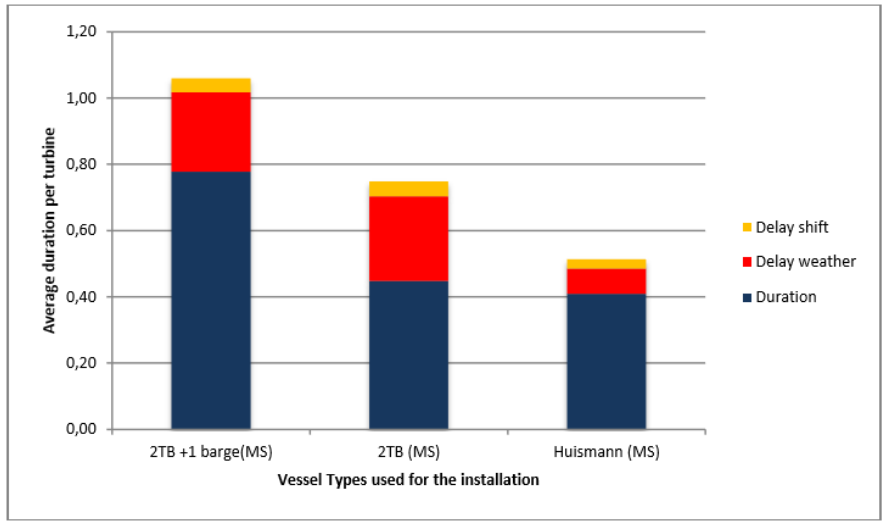
Installation limitations

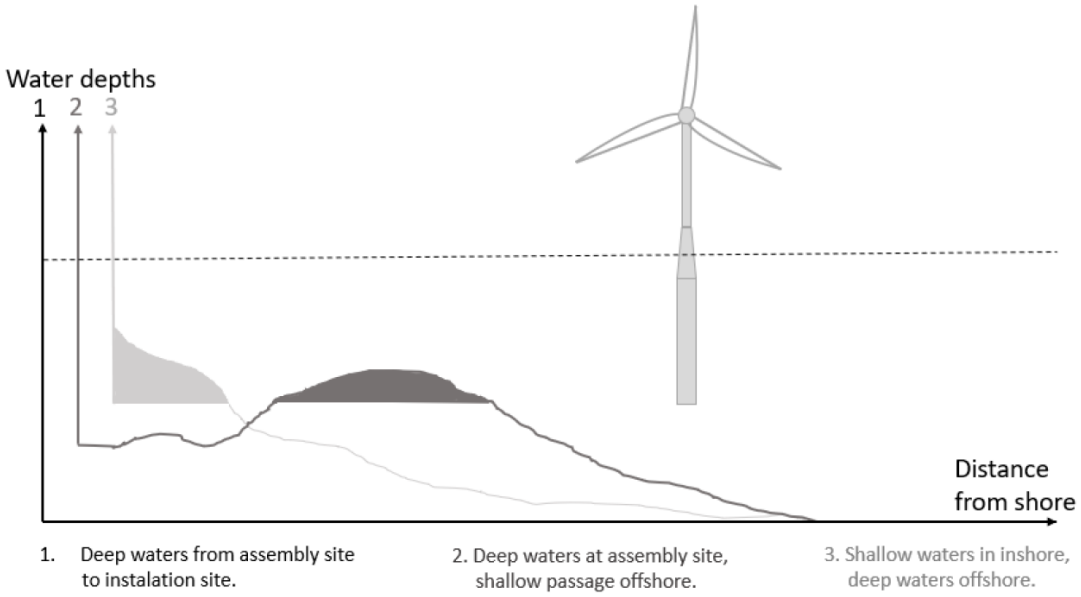
Availability/cost of heavy-lift equipment

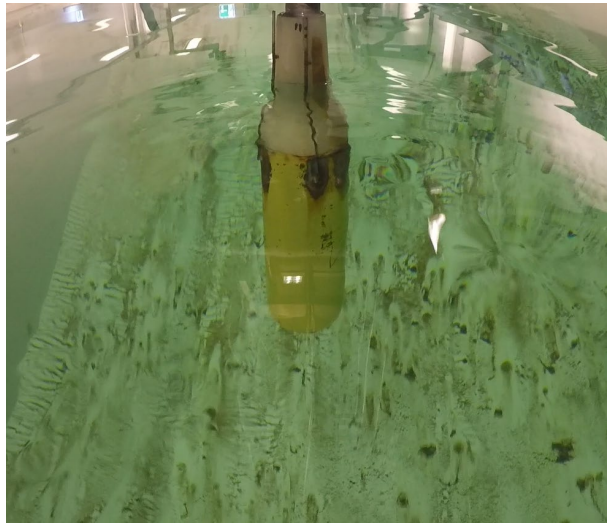
Accessibility to deep water ports

Weather windows

VIM







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Proposed installation methods

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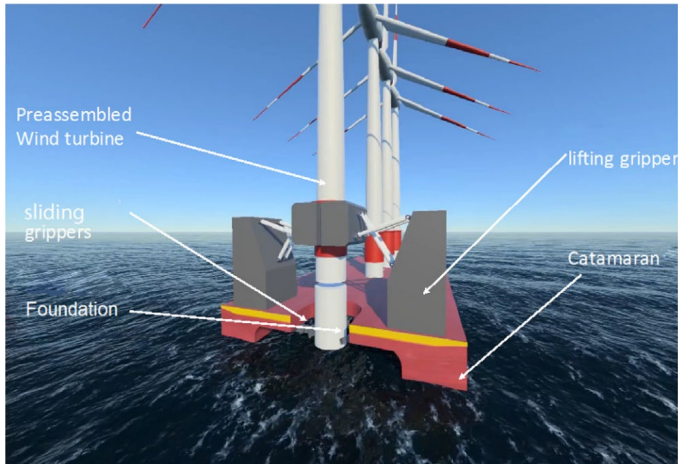

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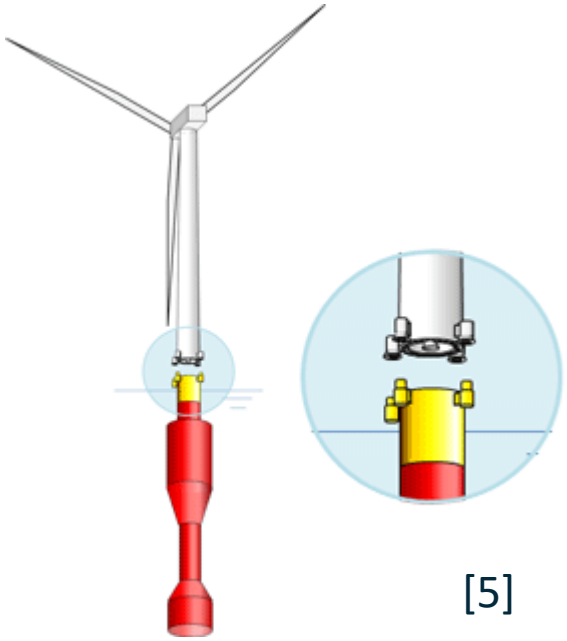

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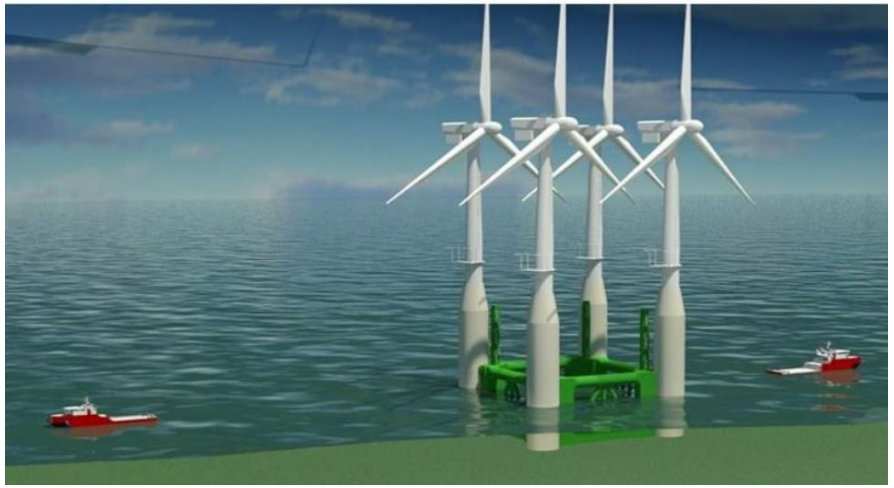

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Aim & Objectives

Experimentally investigate overturning moments and possible collision loads between a vessel and turbine (FWT) in order to evaluate feasibility of the installation method.

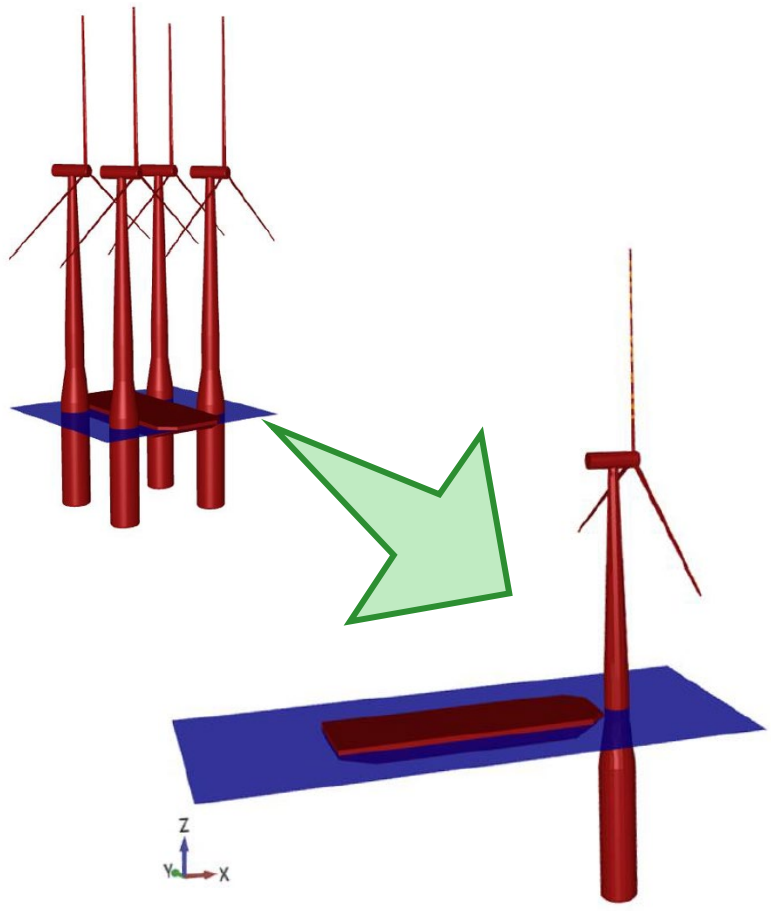
Simplified model

Full and reduced draft

Overturning moments in operational irregular seas, Hs=1.5-3m, Tp=6.5-16.5 s

Collision loads in regular head seas: H=1.5-2.9 m, T=6.5-16.5 s

H_s, m	T_p, s																			
	0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	Sum
0-1	0.114	2.418	6.729	5.854	4.875	3.218	1.926	1.313	0.737	0.404	0.199	0.108	0.041	0.025	0.008	0.002	0.003			27.974
1-2		0.037	3.409	9.017	8.295	6.478	4.941	3.276	2.402	1.599	0.810	0.369	0.158	0.070	0.023	0.006	0.002			40.891
2-3			0.040	0.912	4.574	4.792	3.116	2.155	1.282	0.902	0.731	0.376	0.147	0.081	0.020	0.008	0.005			19.140
3-4				0.003	0.387	1.671	2.298	1.552	0.860	0.357	0.250	0.132	0.091	0.041	0.013	0.003	0.001	0.001	0.001	7.660
4-5					0.010	0.108	0.675	0.903	0.641	0.287	0.098	0.061	0.032	0.014	0.009	0.003				2.841
5-6						0.003	0.073	0.277	0.321	0.231	0.074	0.037	0.008	0.006	0.003					1.033
6-7							0.002	0.036	0.085	0.107	0.066	0.028	0.008	0.002	0.001					0.336
7-8								0.001	0.012	0.027	0.037	0.010	0.006	0.003	0.003					0.099
8-9									0.001	0.004	0.009	0.005	0.005	0.001	0.001					0.025
10-11												0.001	0.001							0.002
11-12											0.001									0.001
Sum	0.114	2.455	10.179	15.786	18.141	16.271	13.030	9.512	6.340	3.918	2.275	1.125	0.498	0.243	0.081	0.021	0.010	0.001	0.001	100.000



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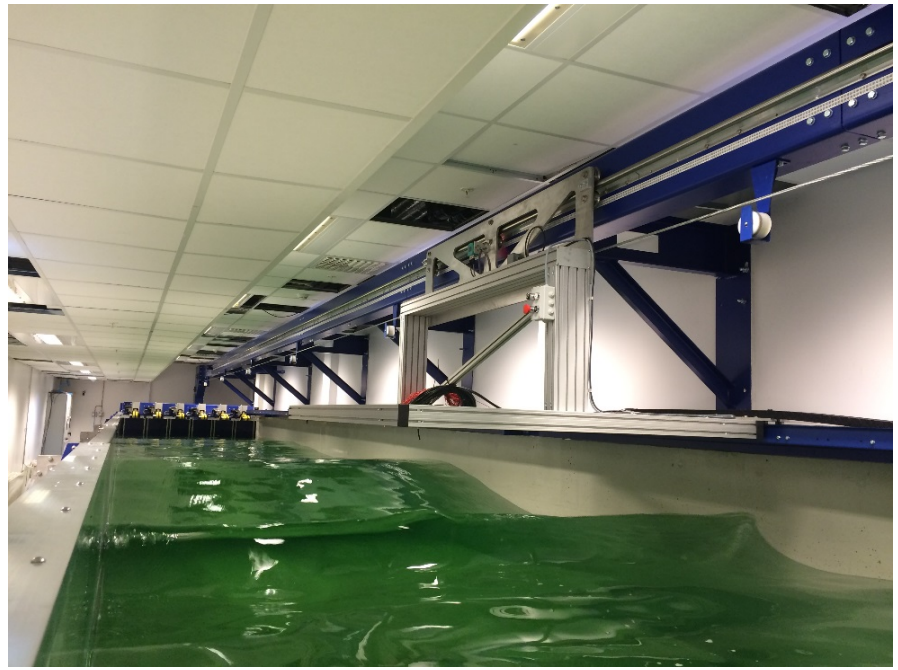
MarinLab towing tank

50m x 3m x 2.2m
EDesigns 6 flap-type wavemaker
H_{max}=0.5 m, T=0.5-3 s
Carriage – U=5m/s, $\dot{U}$=1.2m/s^2



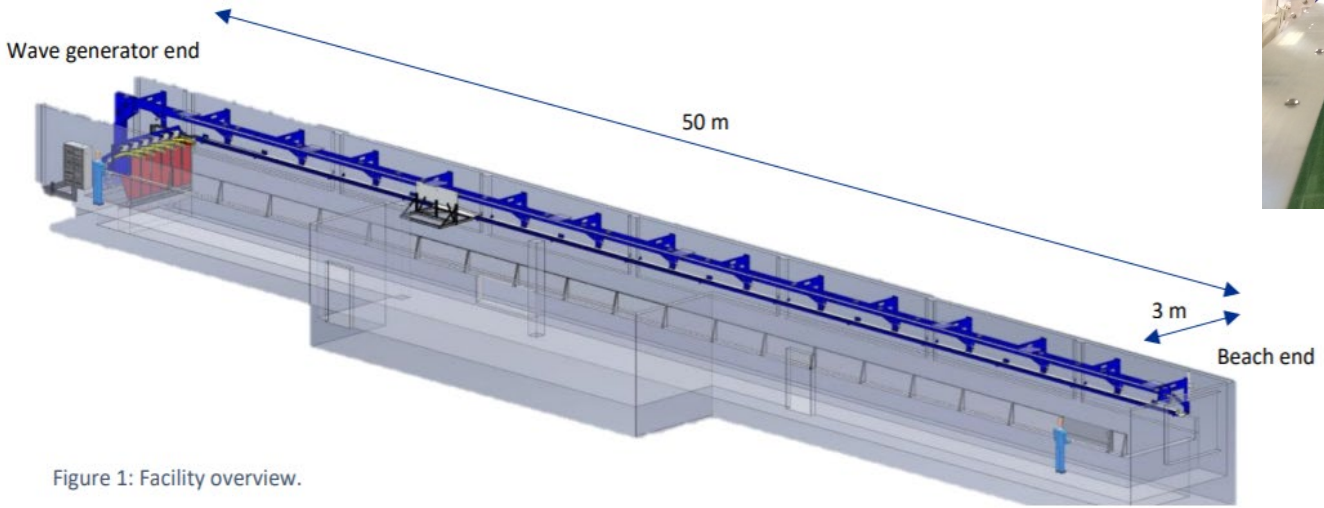
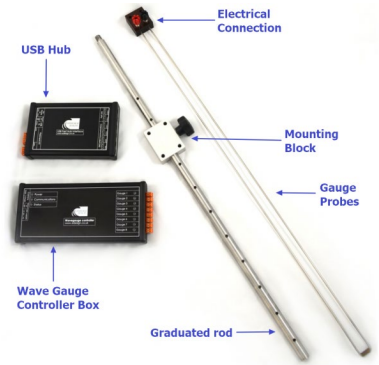


Figure 1: Facility overview.



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Model overview

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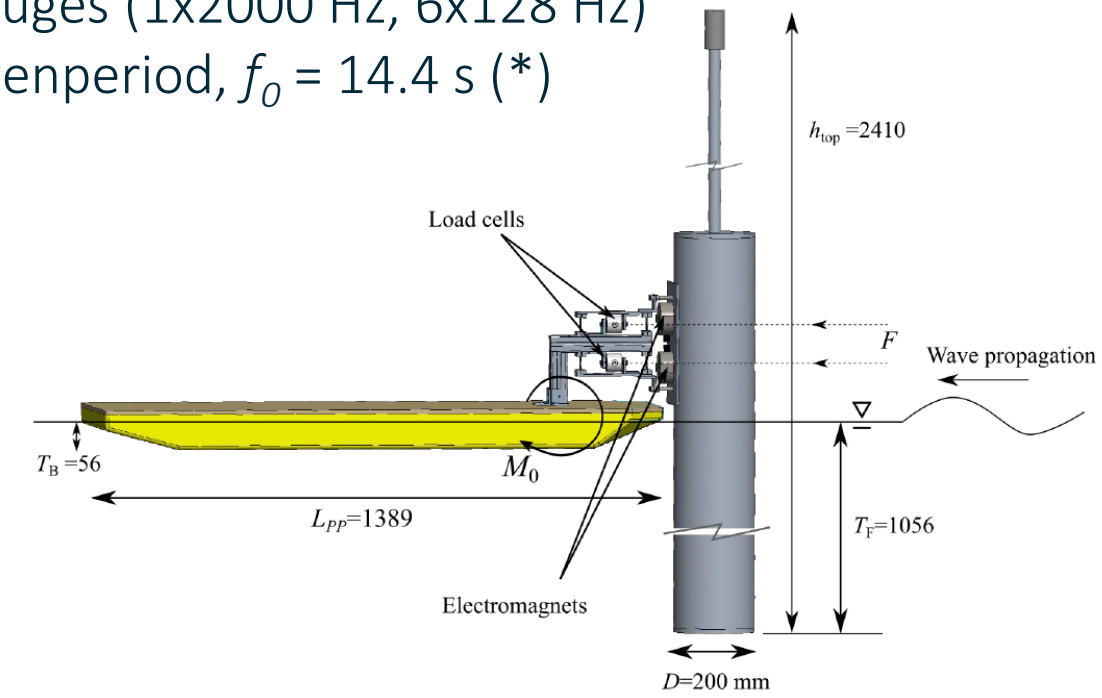
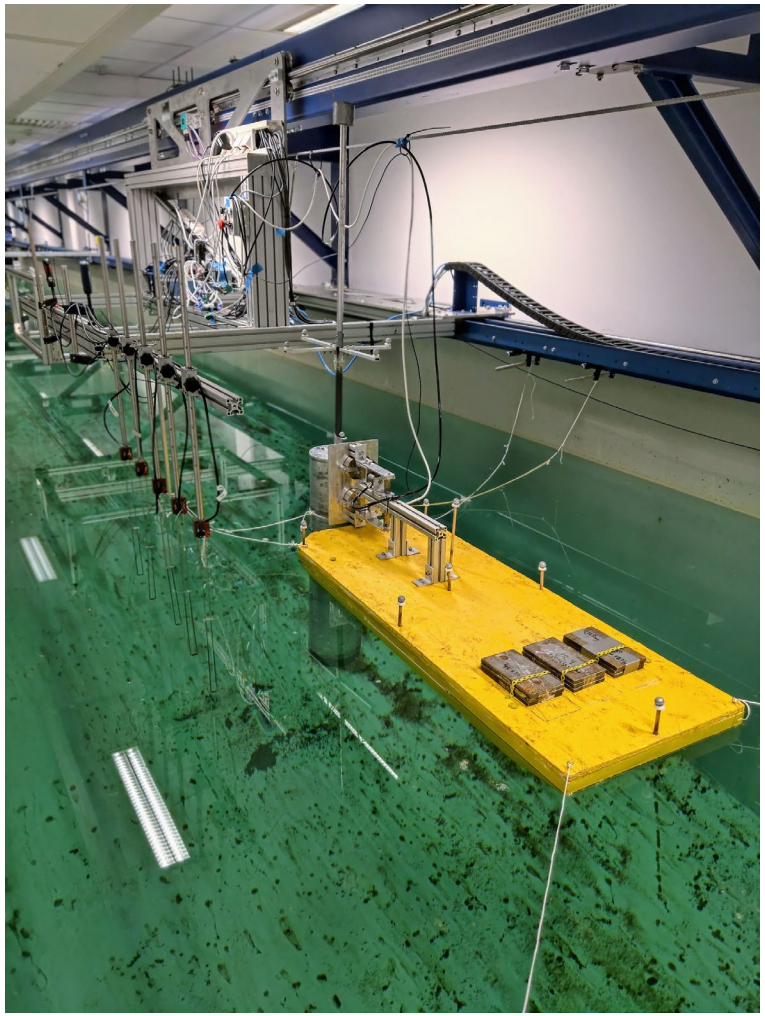
1/72 scale
Barge allows 18% draught reduction of FWT
Qualysis motion capture (150 Hz)
Load cells (2000 Hz)
Wave gauges (1x2000 Hz, 6x128 Hz)
Pitch eigenperiod, f_0 = 14.4 s (*)





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Testing

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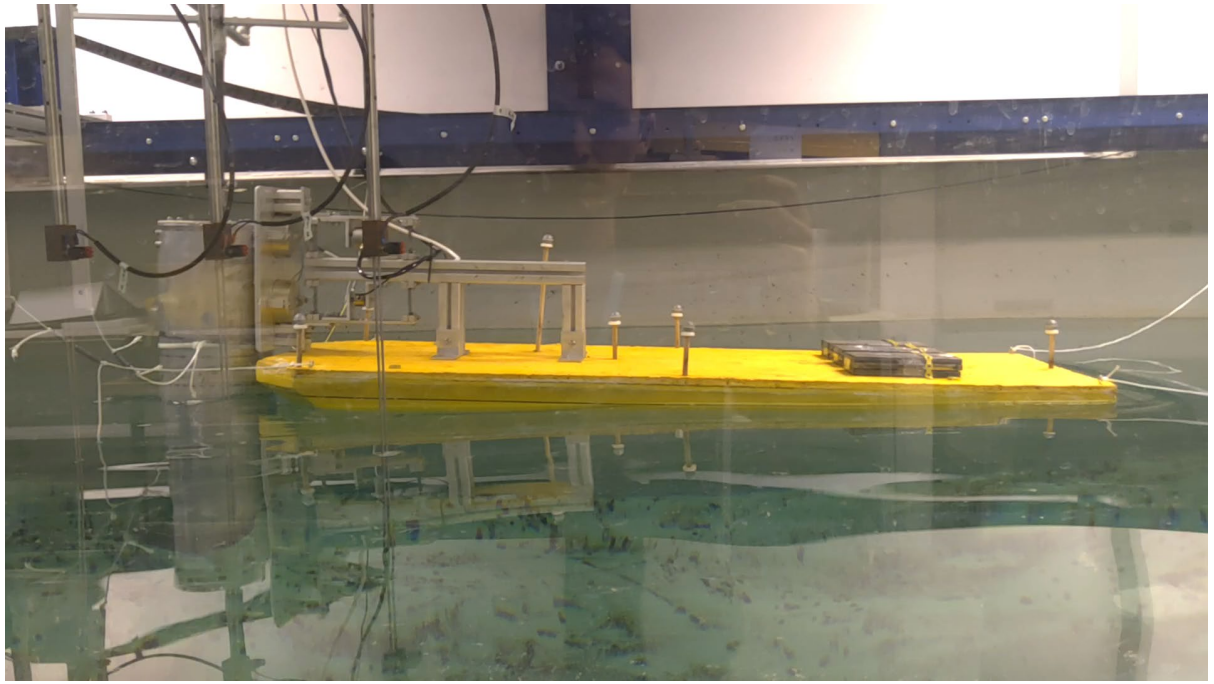
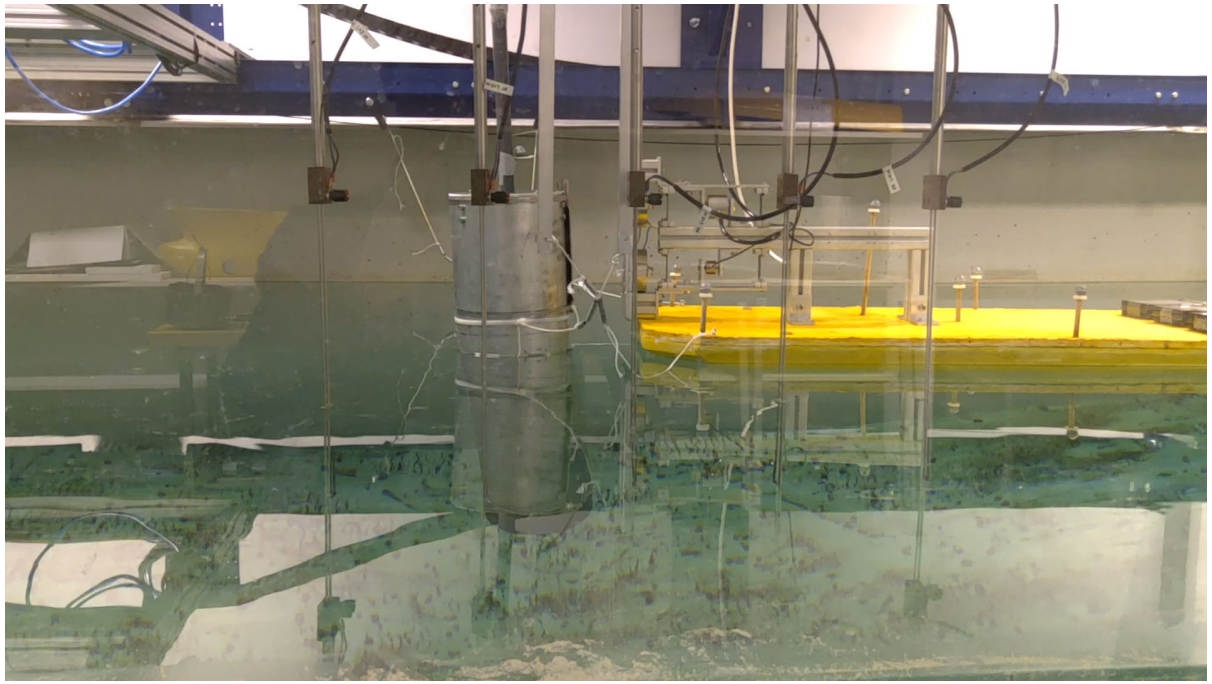
Overturning moments



Hs=1.5 m, Tp=14 s

Collision loads



Hs=1.5 m, T=16 s

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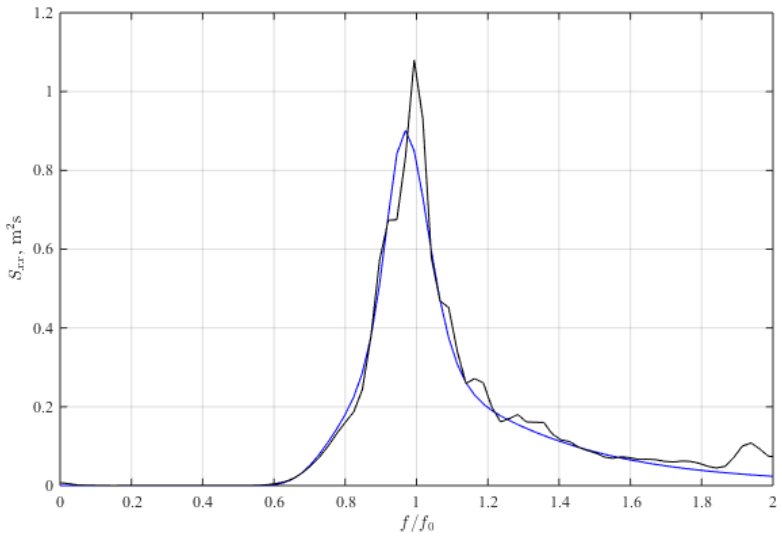
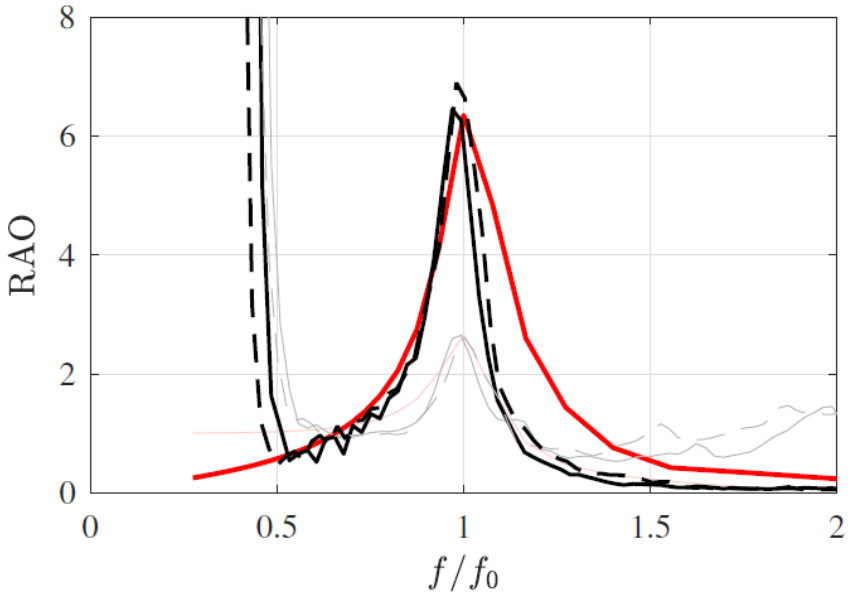
Vessel response

- Wave spectra



- Wave gauge 10 m in front of model (▬) compared to JONSWAP (▬)

- Vessel RAO (/m)



- Reduced draft (---) has slightly greater pitch response than full draft (▬)
- Reasonable agreement to HydroD full-draft model (▬)

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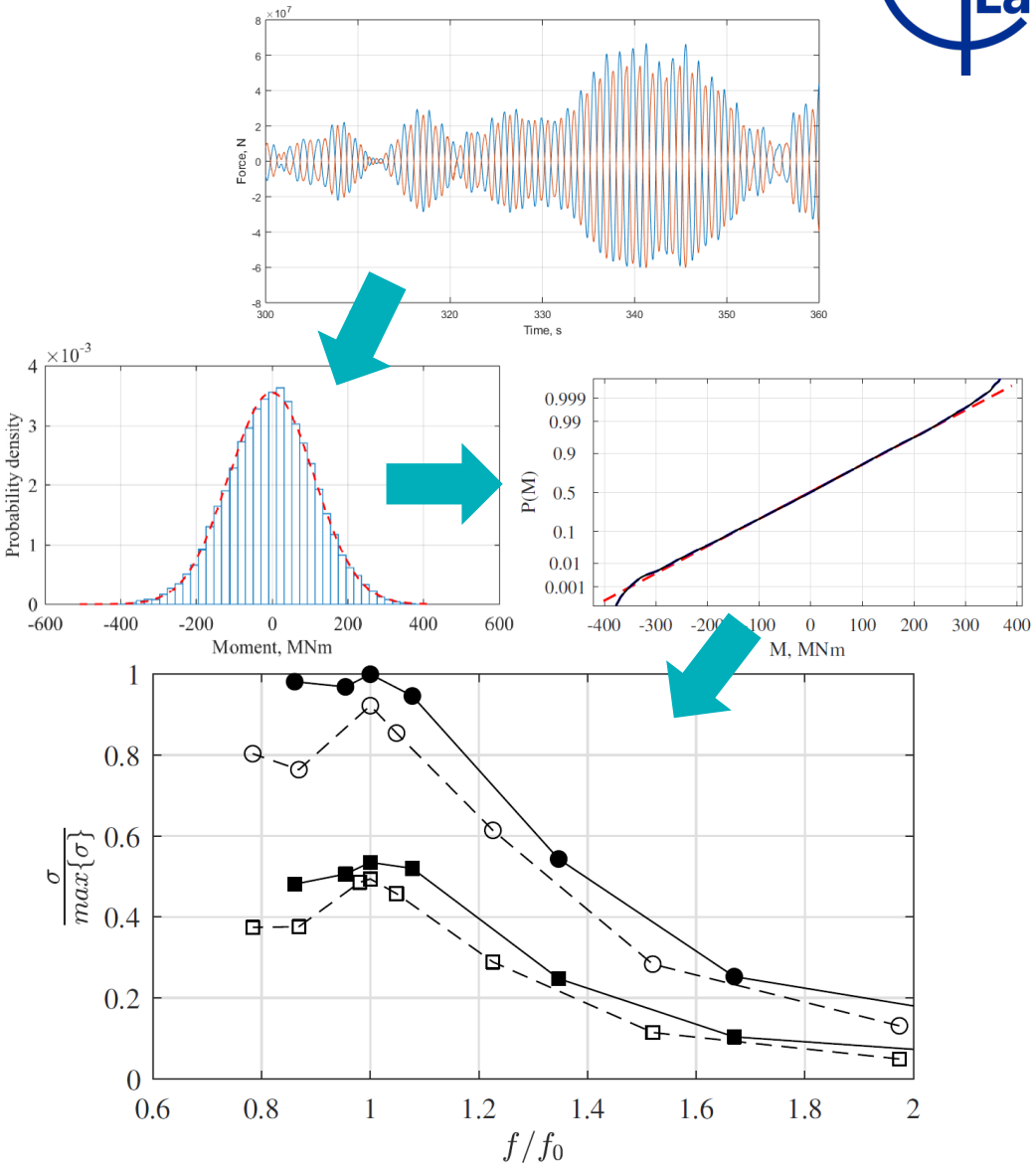
Overturning moments

- Loads are normally distributed
- Peak load aligns with pitch eigenfrequency of combined vessel-FWT
- Doubling Hs, doubles load
- 18% reduction in draft gives 10-20% reduction in loads



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Design loads

Max. wave overturning moment: 1.49 GNm

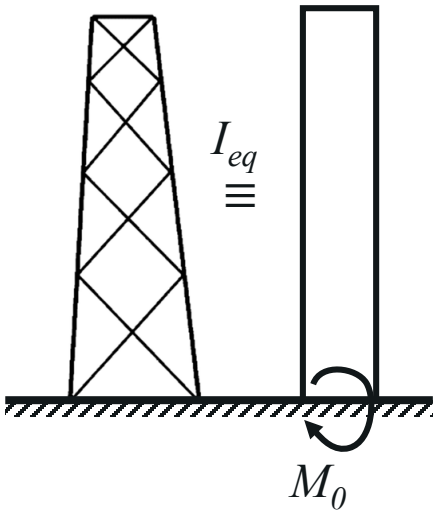
Wind-induced moment:

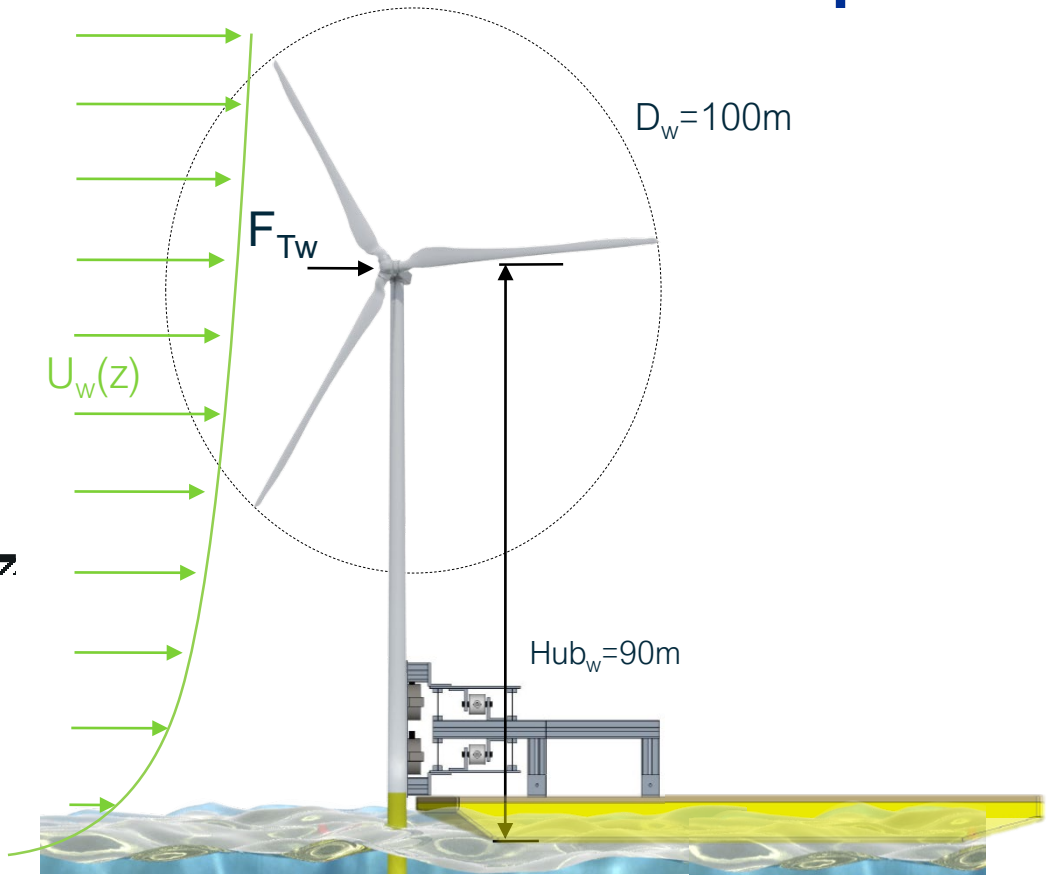
U=8m/s, α=0.14, NTM (I=7.7%)

4.24 GNm

Truss modelled as equivalent Euler-Bernoulli beam

Required footprint area=7m^2





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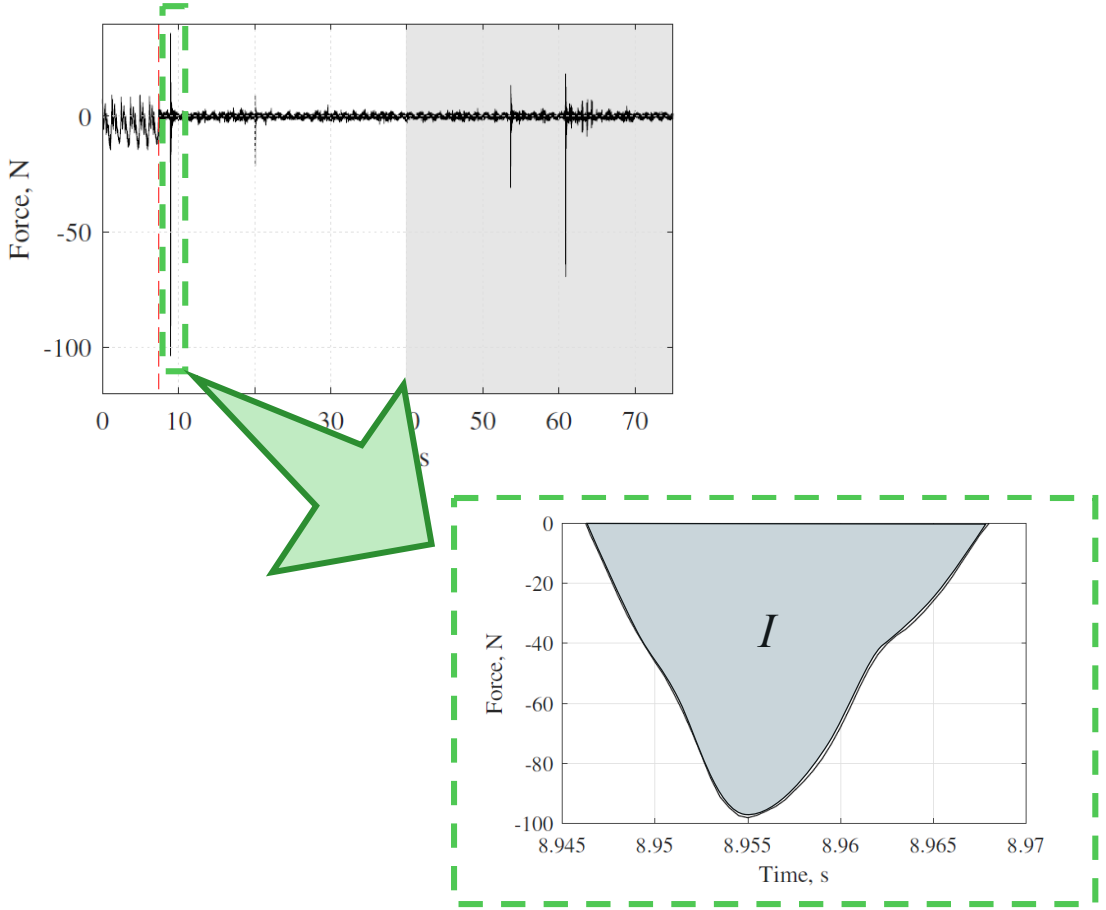
Collisions – full draught

- Electromagnet release time relative to wave phase made no difference.
- Collisions were repeatable.
- Collisions beyond surge period ignored
- Impulse calculated for each collision



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Collision impulse

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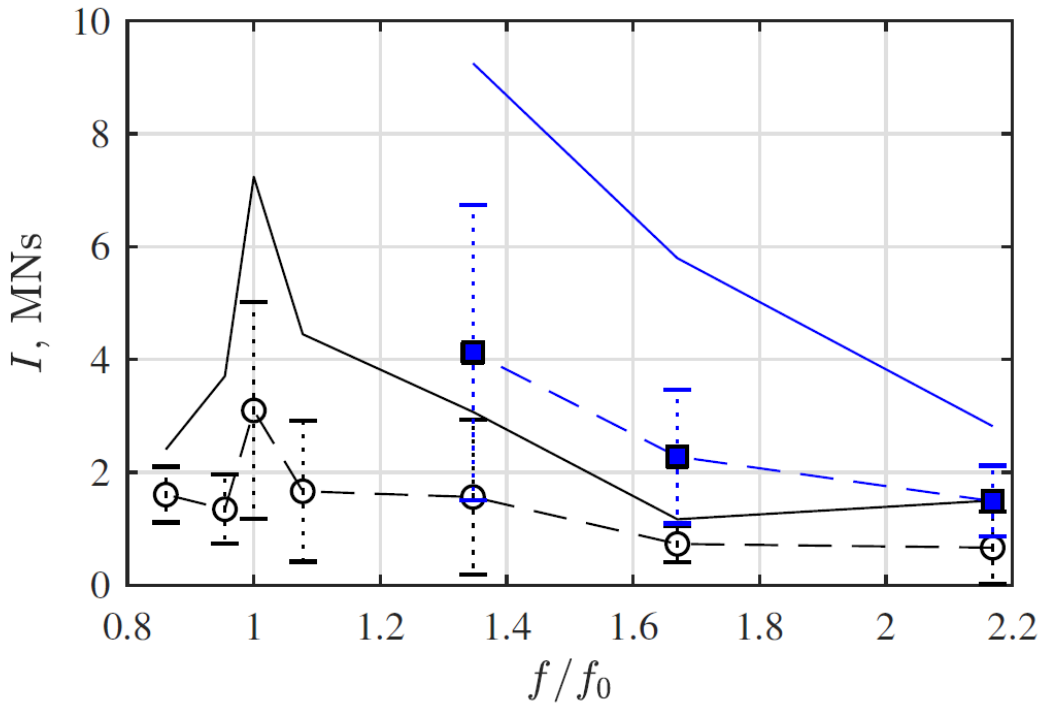
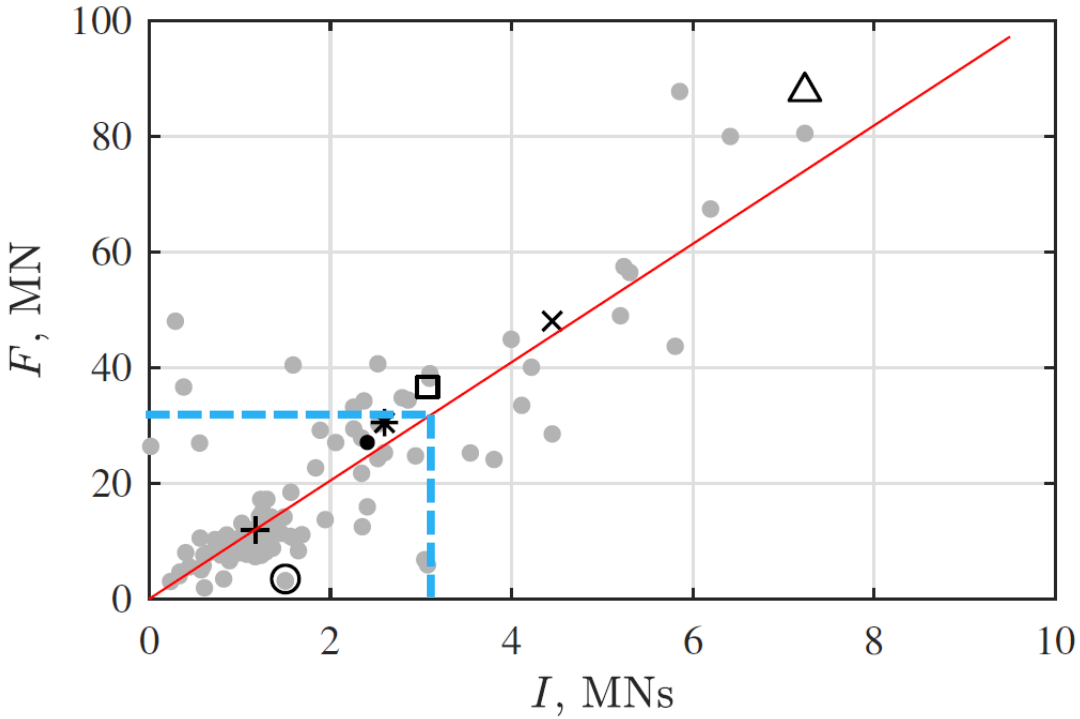
Standard: $F_{DNV} = 2.5\Delta$ = 32.5 MN



- Peak impulse is at f_0
- Large spread of loads – cannot confirm normal distribution



- Doubling Δt, halves impulse and therefore F within DNV standard

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Conclusions & future work

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- Loads from waves and wind can be accommodated
- Vessel with lower eigenfrequency improves operational range of Tp (Hs<2.9 m necessary).
- Use of spring-damper to reduce impulse

- Assess loads on nacelle
- Comparison to collision models
- Test new vessel in wider range of wave headings

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Thank you & questions?

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Thank you to Equinor ASA for support in building the model

References:

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