Observations from hydrodynamic testing of a flexible, large-diameter monopile in irregular waves

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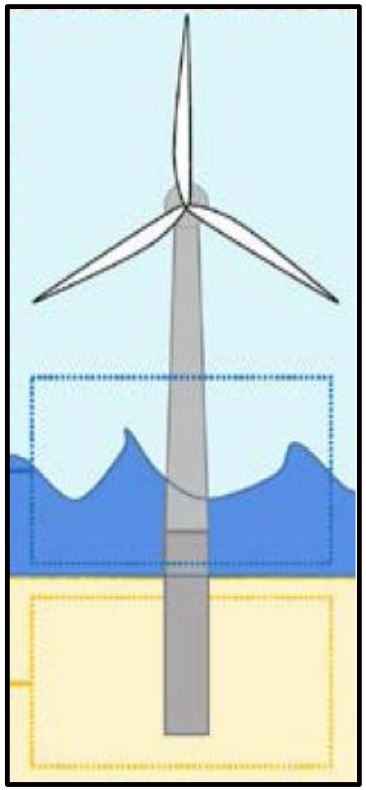


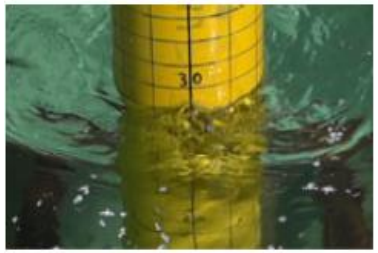
https://www.sintef.no/projectweb/was-xl

Norwegian University of Science and Technology

Background

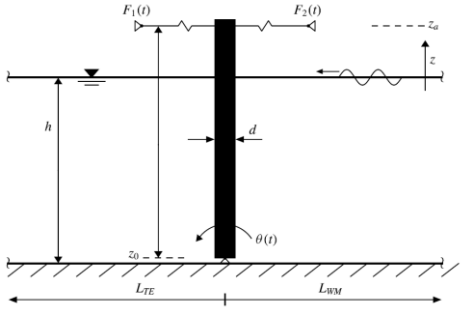
- Larger wind turbines, deeper water, larger monopiles
  - Concerns about dynamic responses to severe waves (ULS)
- Need for validation of numerical models
  - Experimental campaigns

Rigid model



Kristiansen and Faltinsen, 2017

Pitching model

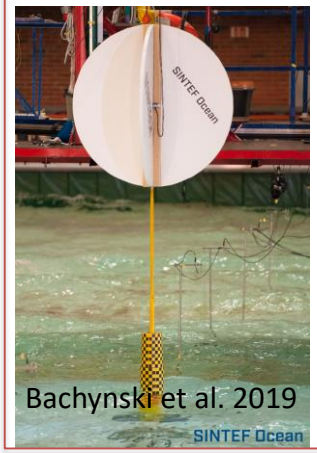


Riise et al., 2018

Bachynski et al. 2017

Flexible model

de Ridder et al., 2011



Bachynski et al. 2019

Bredmose et al., 2013

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What's new?

- Larger diameter, larger top mass
- More realizations
- More repetitions
- Measurements of both base shear and bending moment
- Variations in damping level (1.14% and 1.7%)

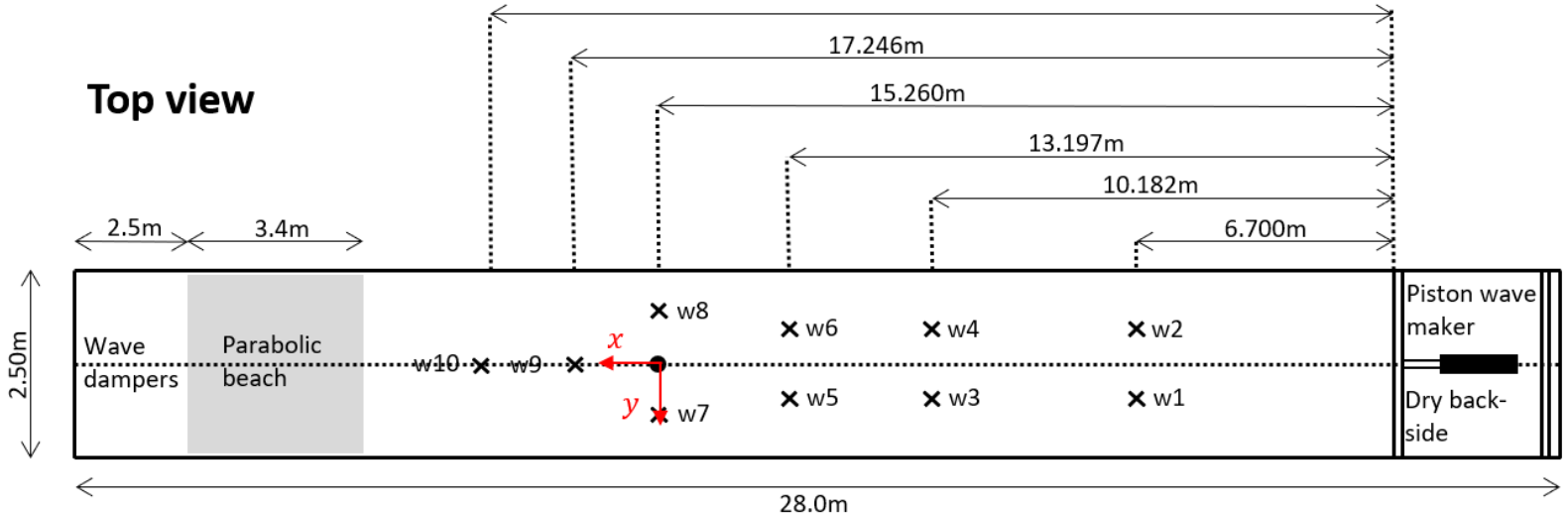
	Scale	h (m)	D (m)	f_1 (Hz)	f_2 (Hz)	ξ_1 (%)	ξ_2(%)
WiFi[1]	1:30	30	5.8-7.0	0.29	1.21	1.1	1.1
WaveLoads[2]	1:80	20.8-40.8	6.0	0.28	2.0	1.7	1.7
NOWITECH[3]	1:40	30	7.0	0.22	0.85	0.5	-
WAS-XL Phase II	1:50	27	9.0	0.25	1.58	1.1	0.4

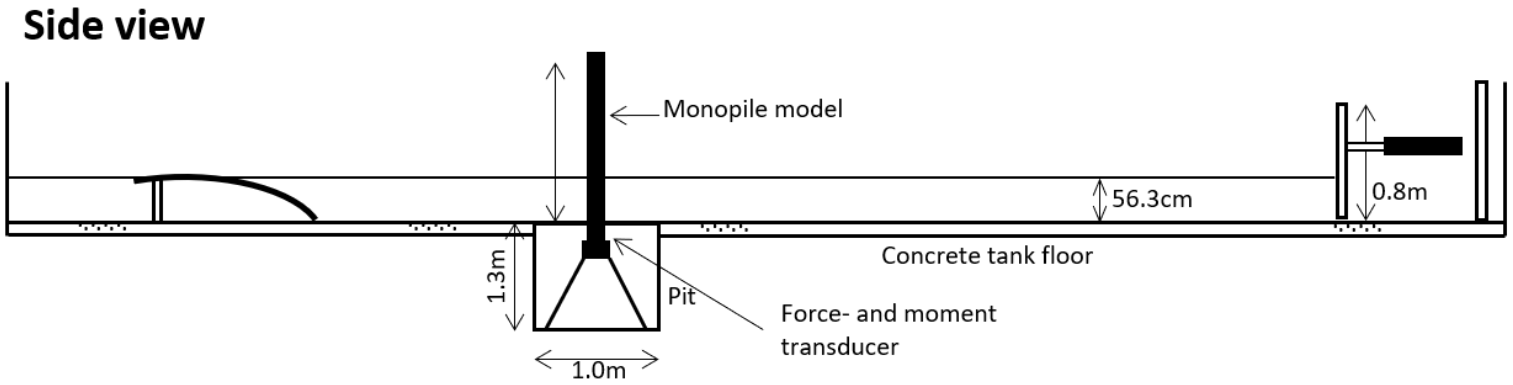
1. Suja-Thauvin et al. 2017, de Ridder et al. 2011, de Ridder et al. 2017
2. Nielsen et al. 2012, Bredmose et al. 2013, Hansen et al. 2012
3. Bachynski et al. 2019

Outline

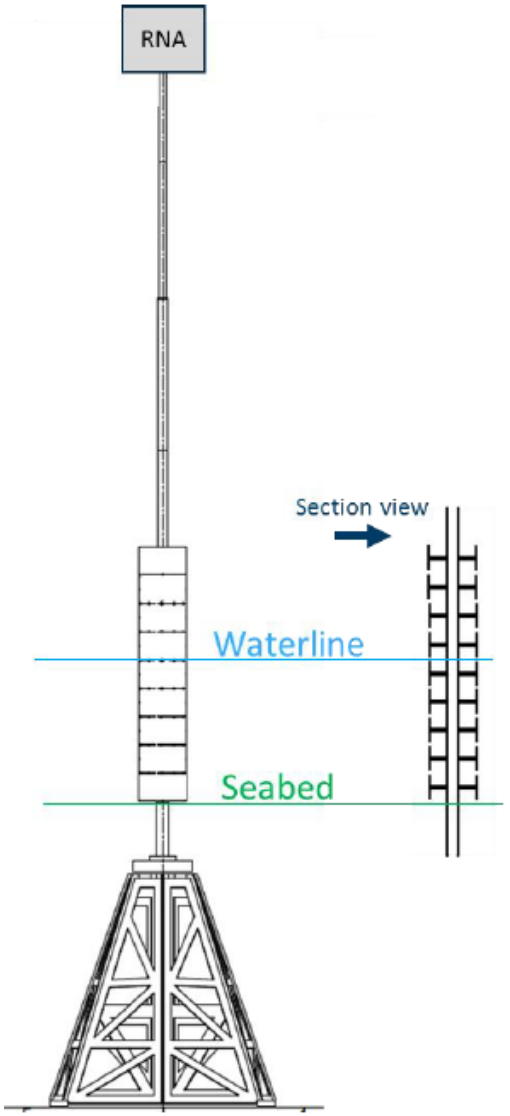
- Experimental design
- Decay tests
- Irregular wave test results
  - Distributions of extreme responses
  - Frequency content of extreme responses
  - Repeatability

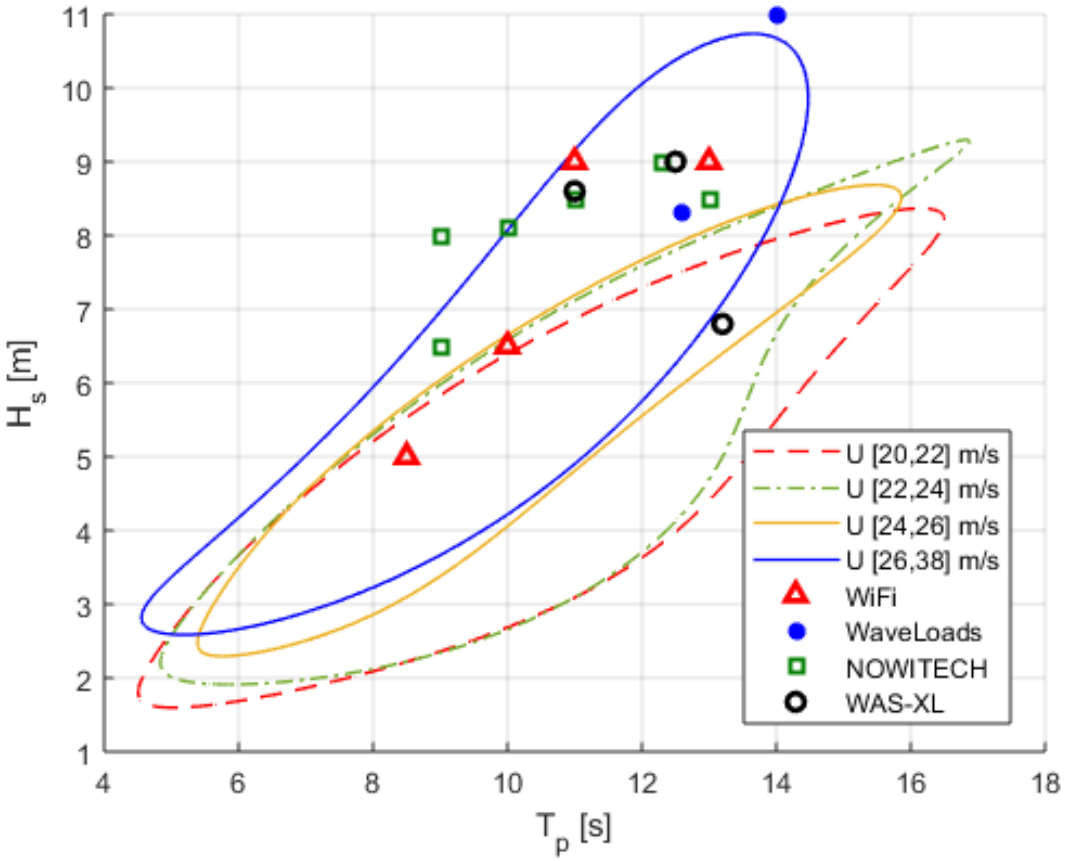
Experimental design



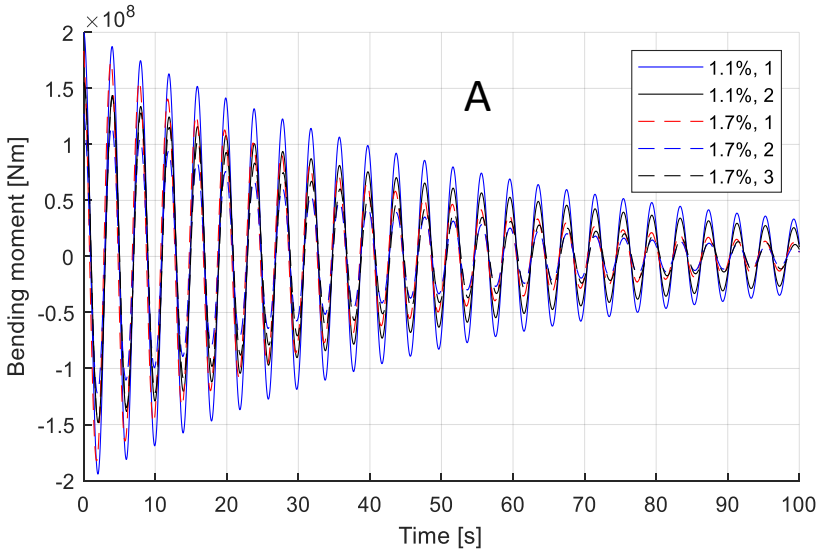


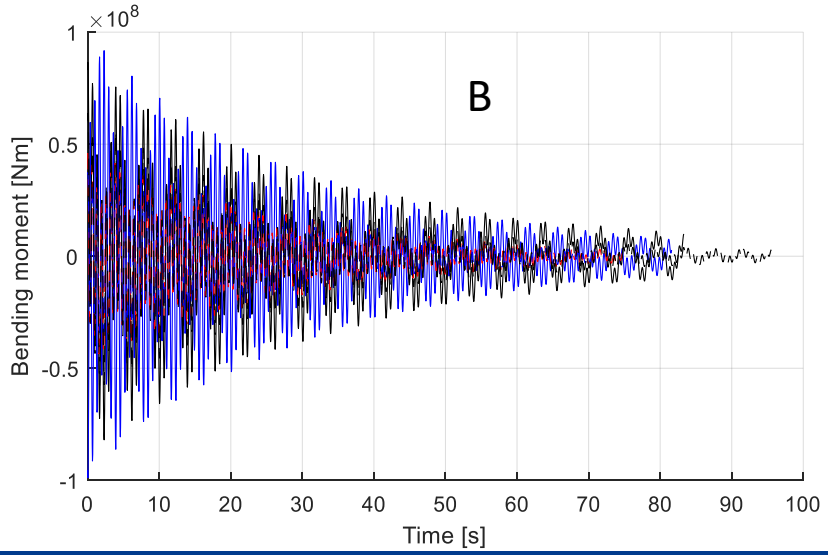
Experimental design

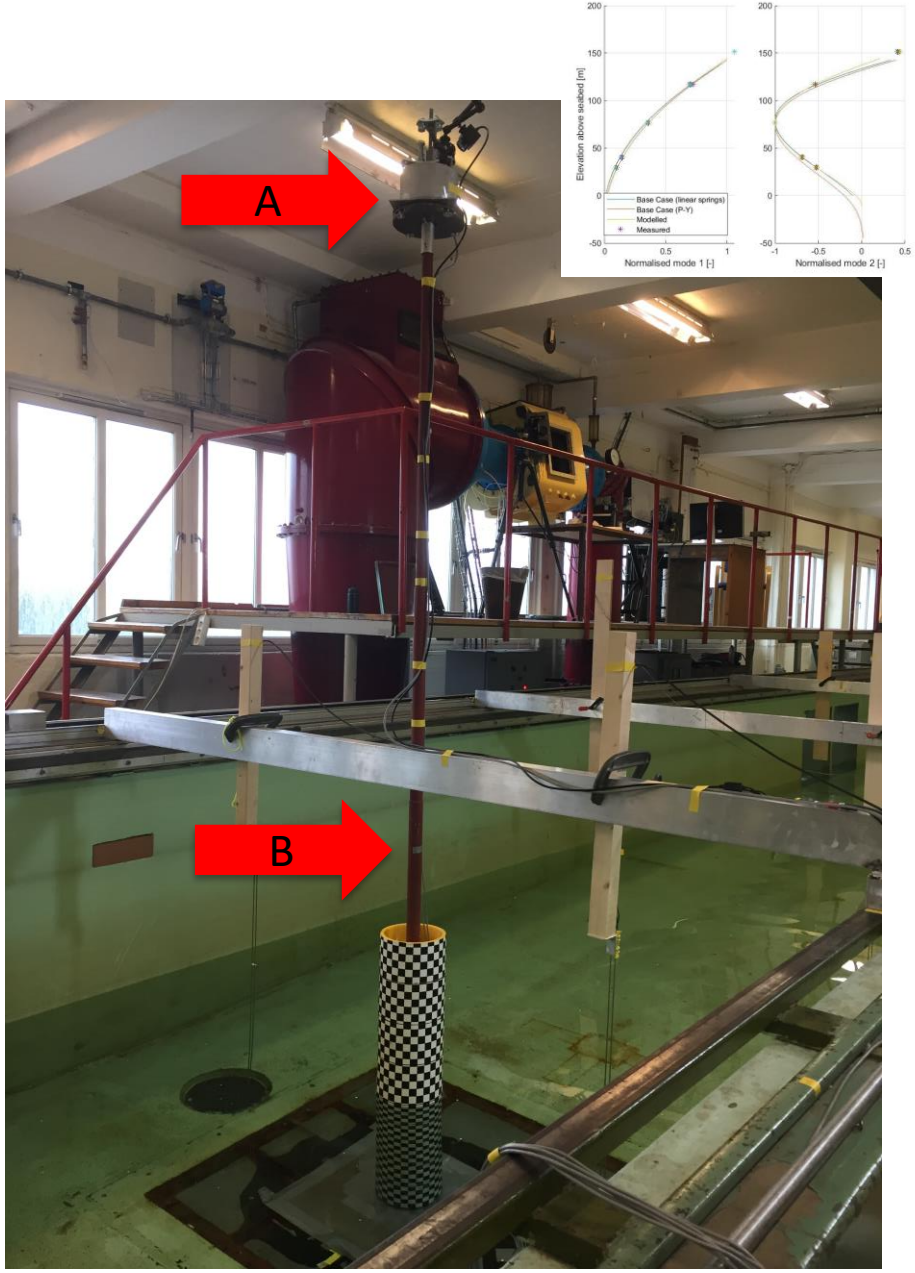




Decay tests







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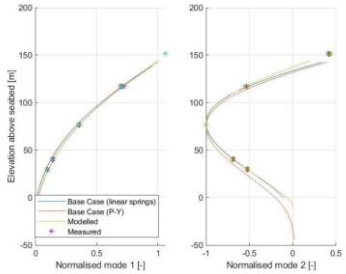
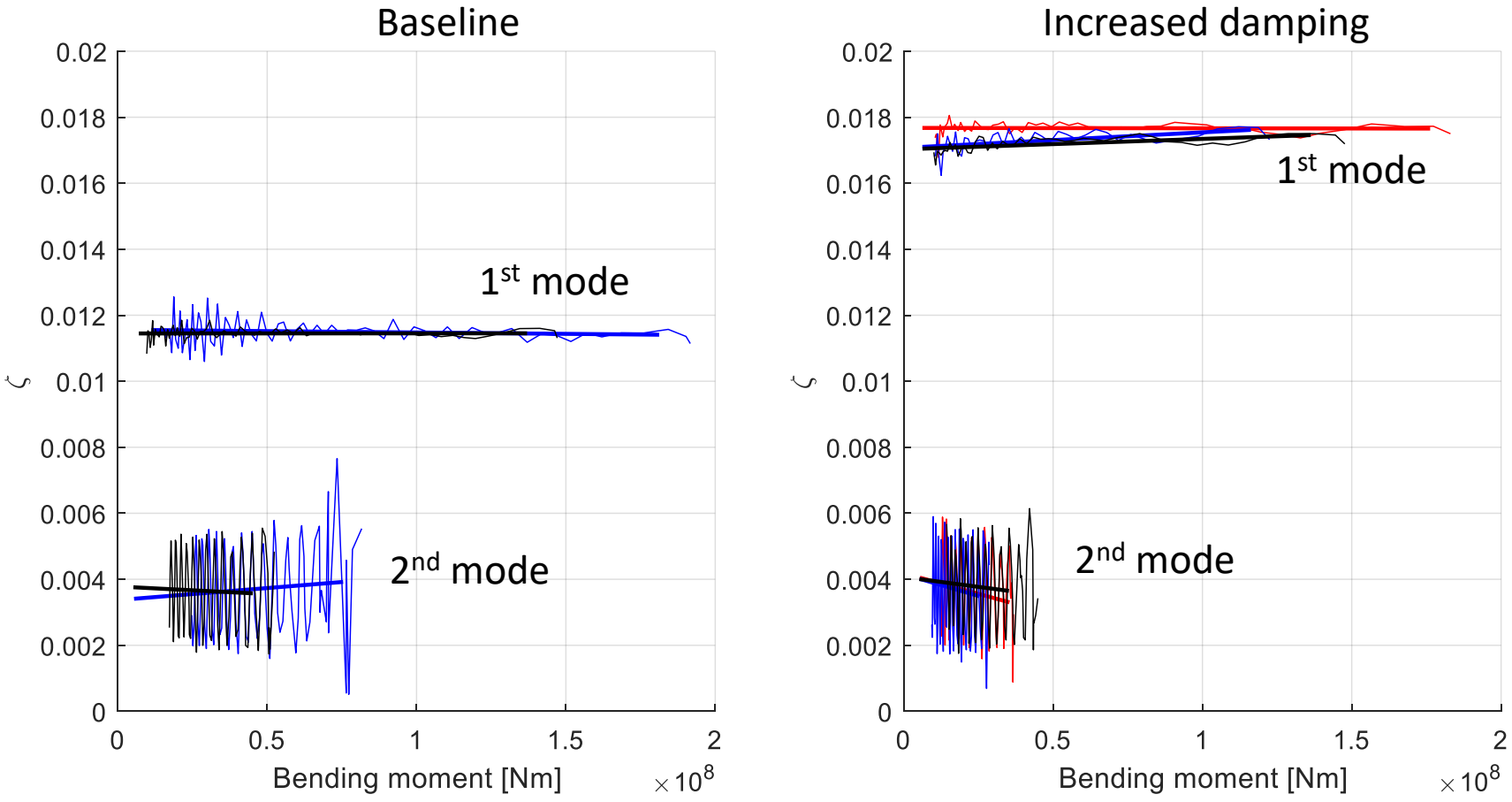
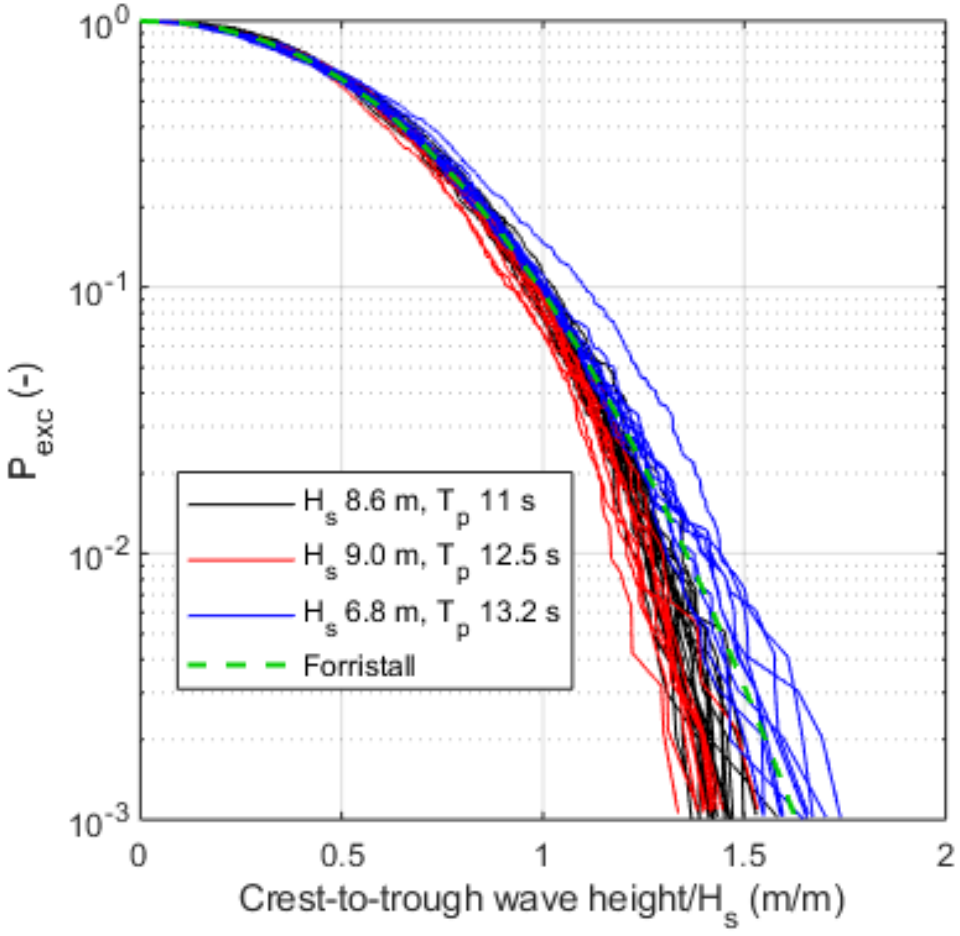
Damping


Elevation above seabed [m]
Base Case (linear springs)
Base Case (P-Y)
Modelled
Measured
Normalised mode 1 [-]
Normalised mode 2 [-]

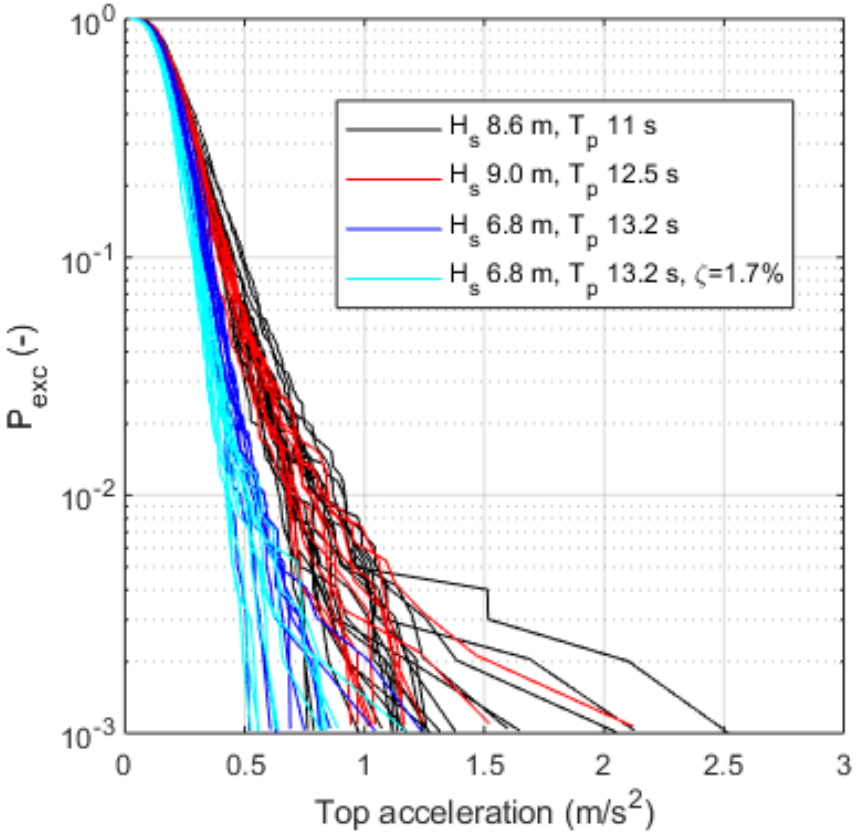

Baseline
Increased damping
1st mode
2nd mode
ζ
Bending moment [Nm]
×10^8

Probability of exceedance: crest-to-trough wave height



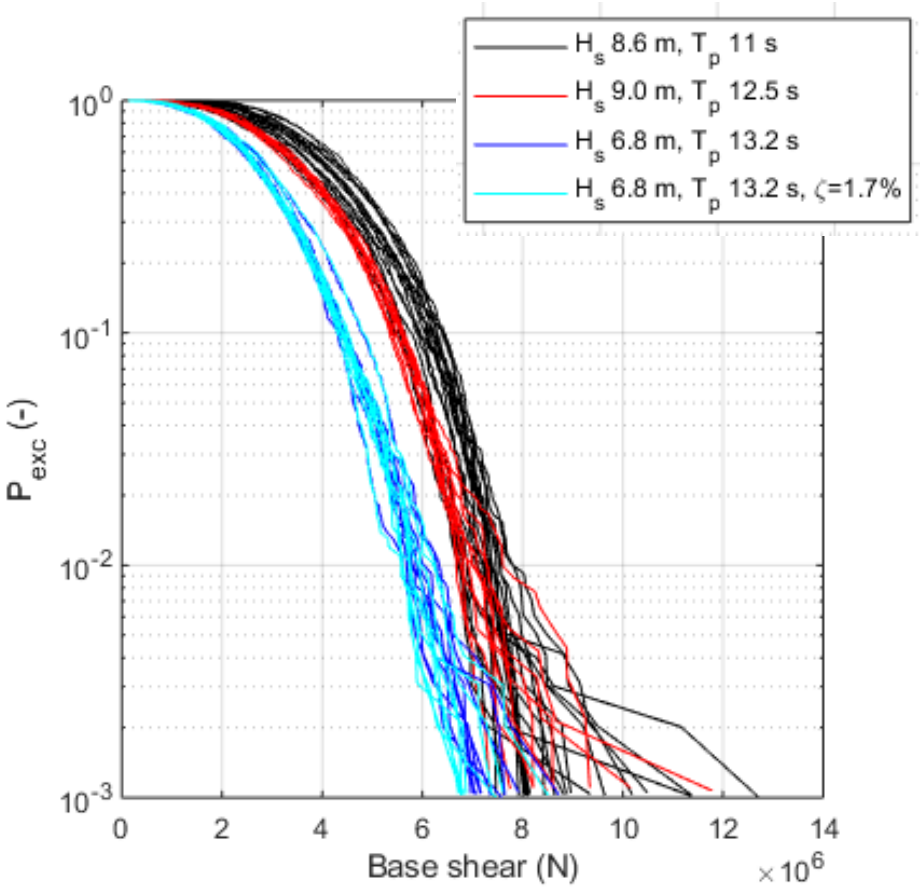
(Compare to Hansen et al. 2012)

Probability of exceedance: accelerations



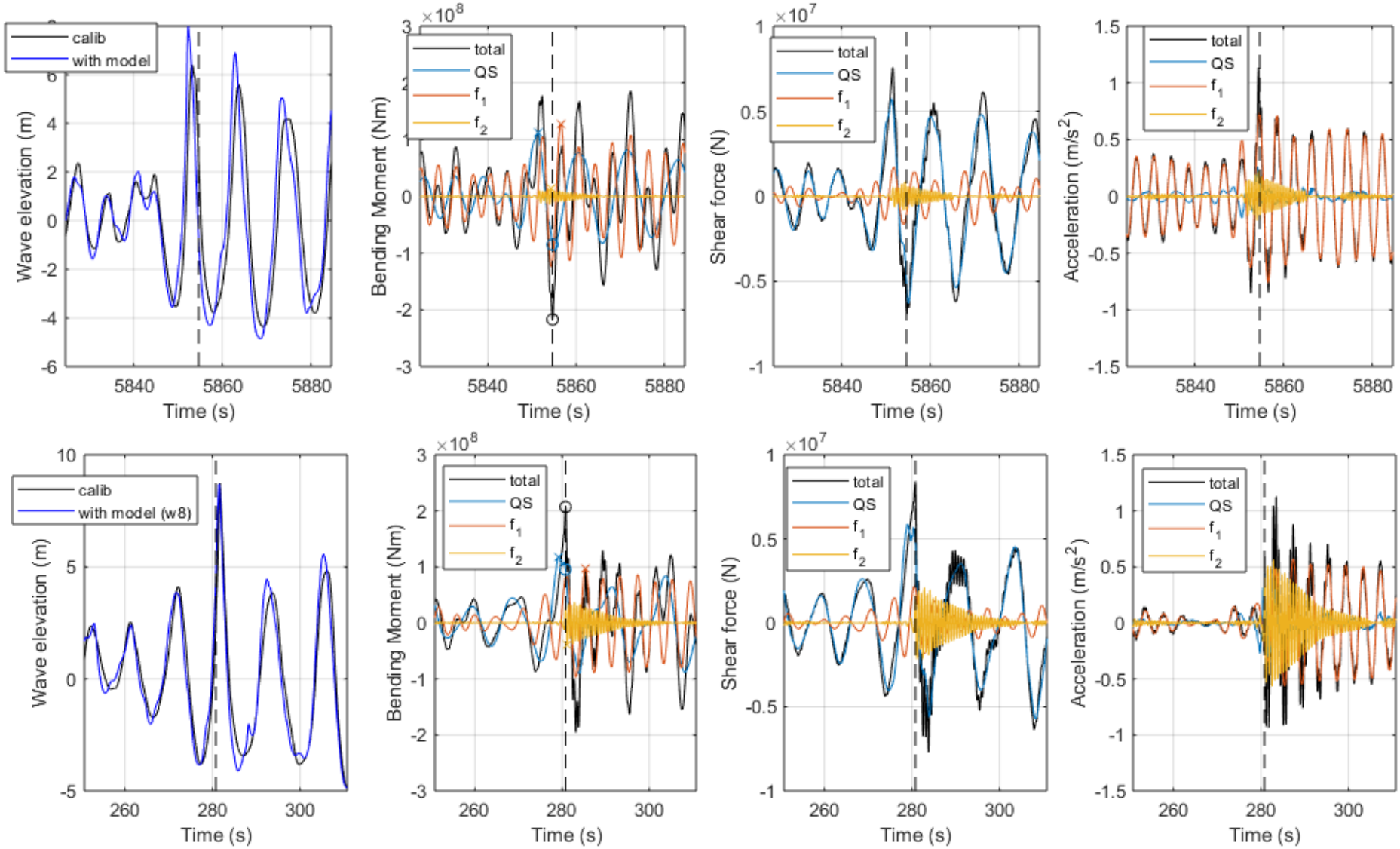
(Compare to Bredmose et al., 2013)

Probability of exceedance: base shear



Compare to Bredmose et al., 2013

Frequency content of extreme responses



Compare to Suja-Thauvin et al. 2018

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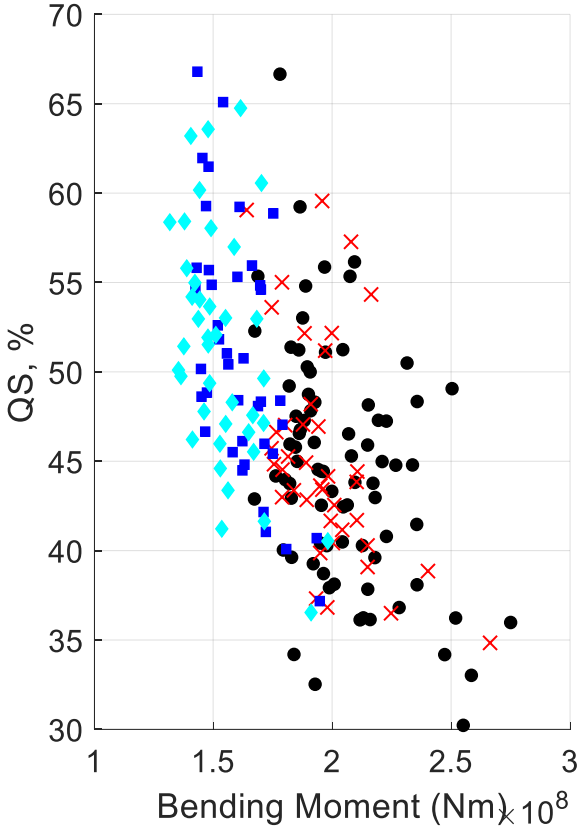
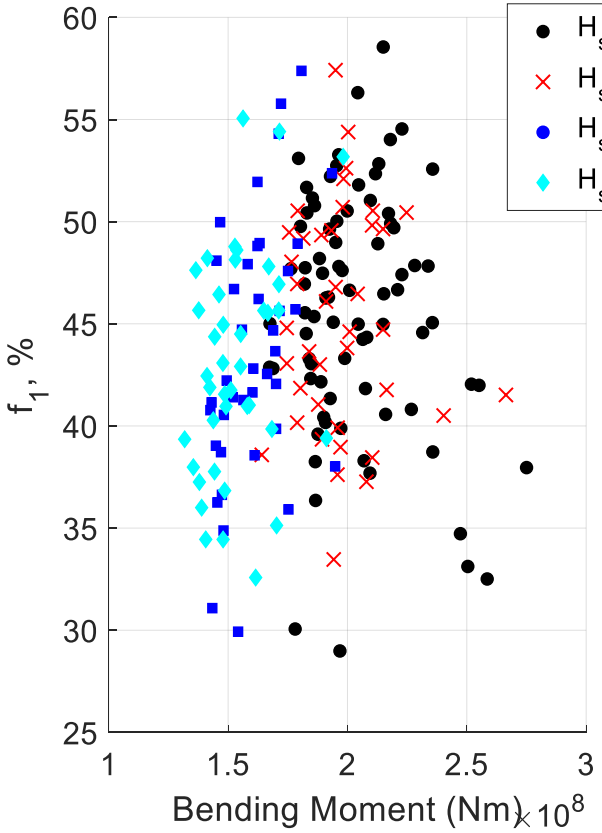
Frequency content of extreme responses

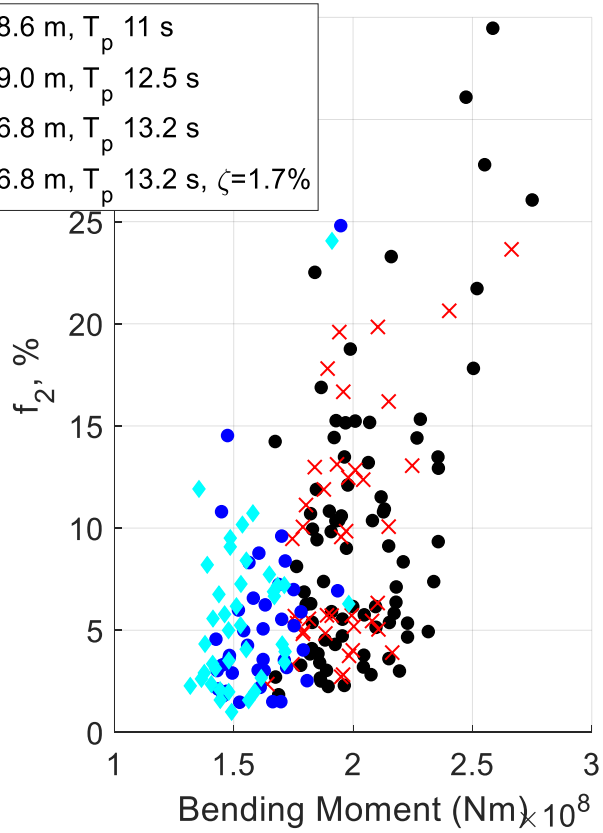
Quasi-static



First natural frequency



Second natural frequency



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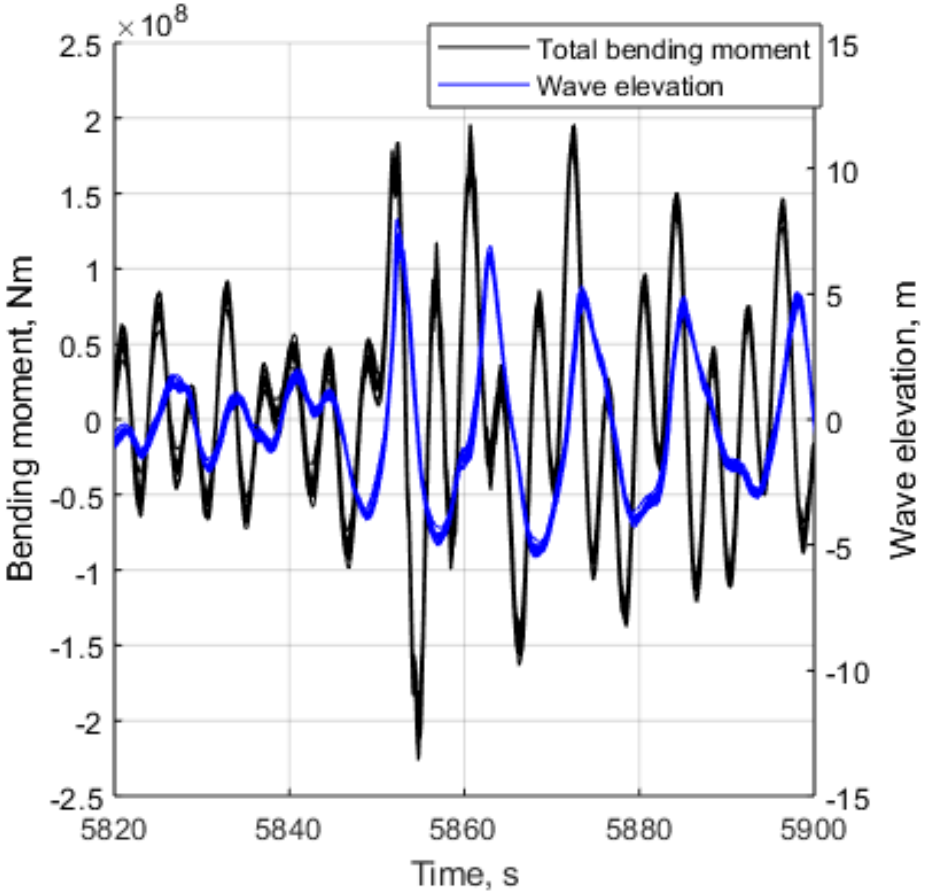
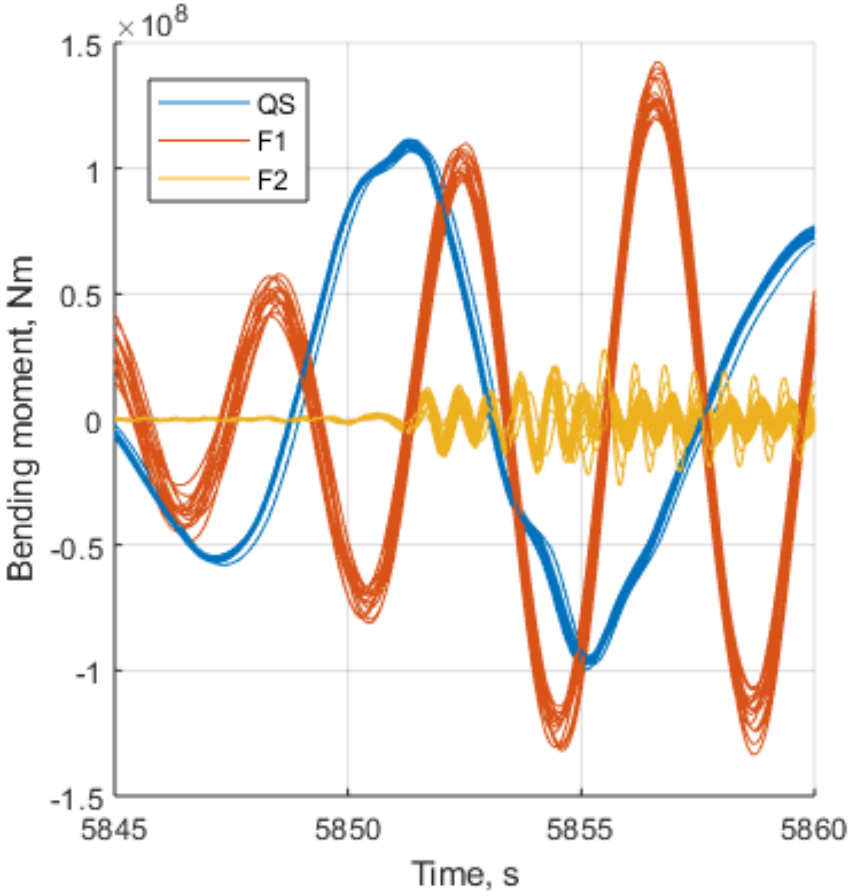
Repeatability: example 1





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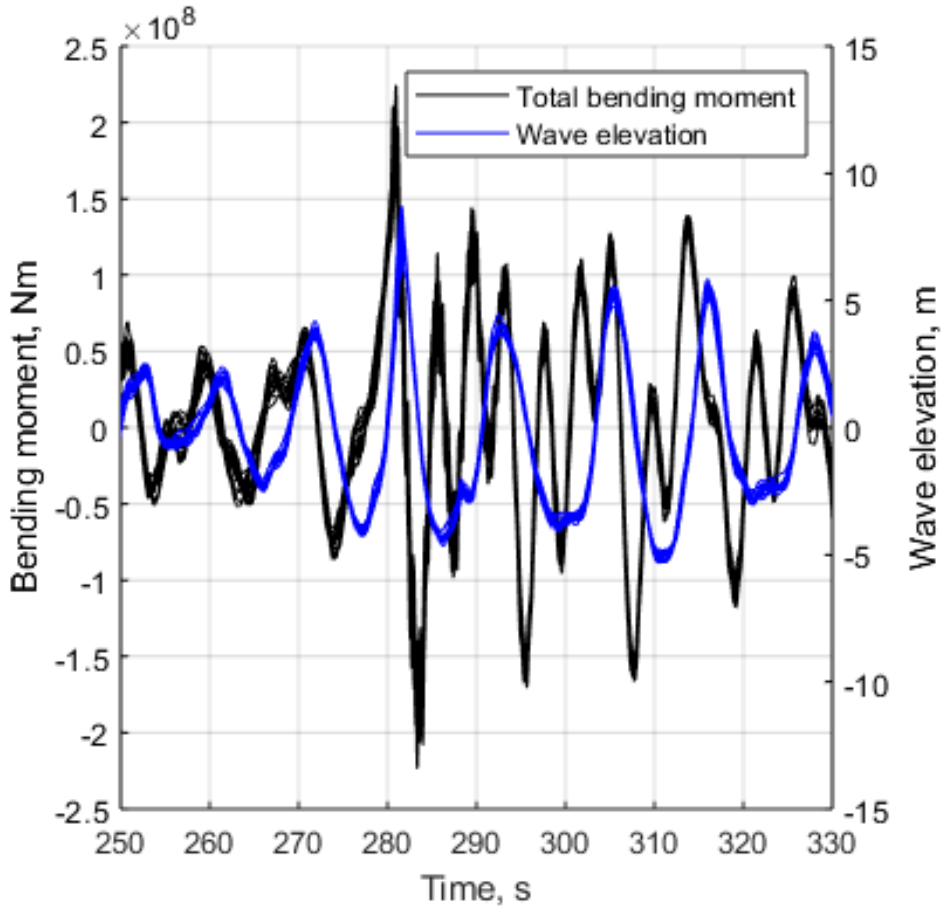
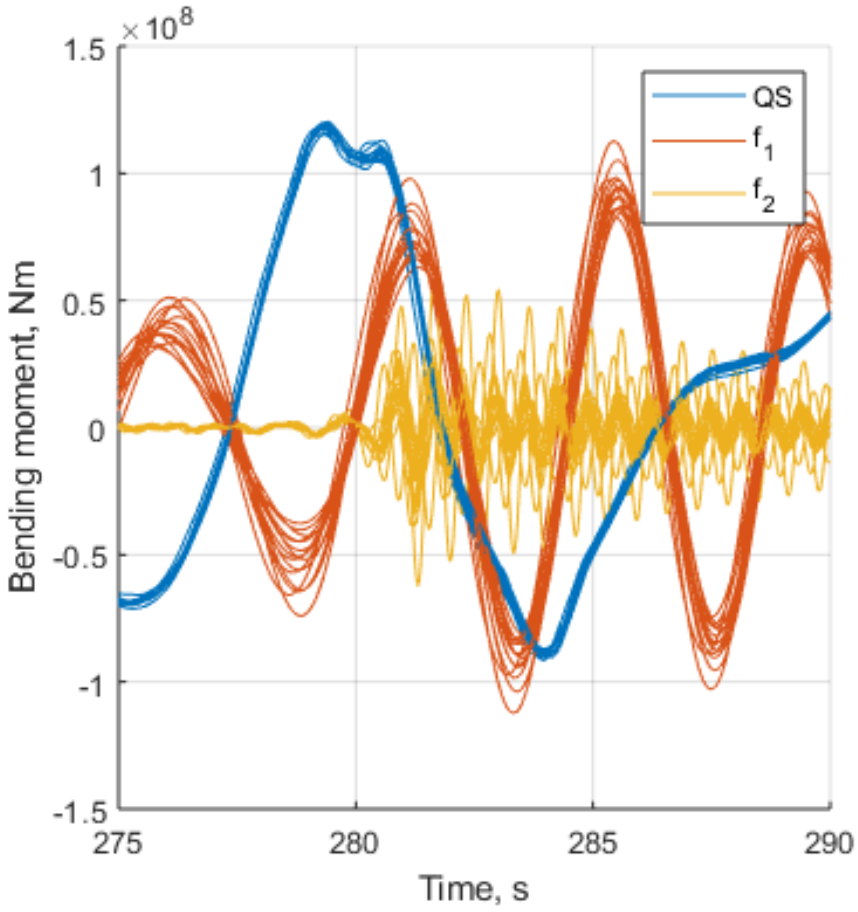
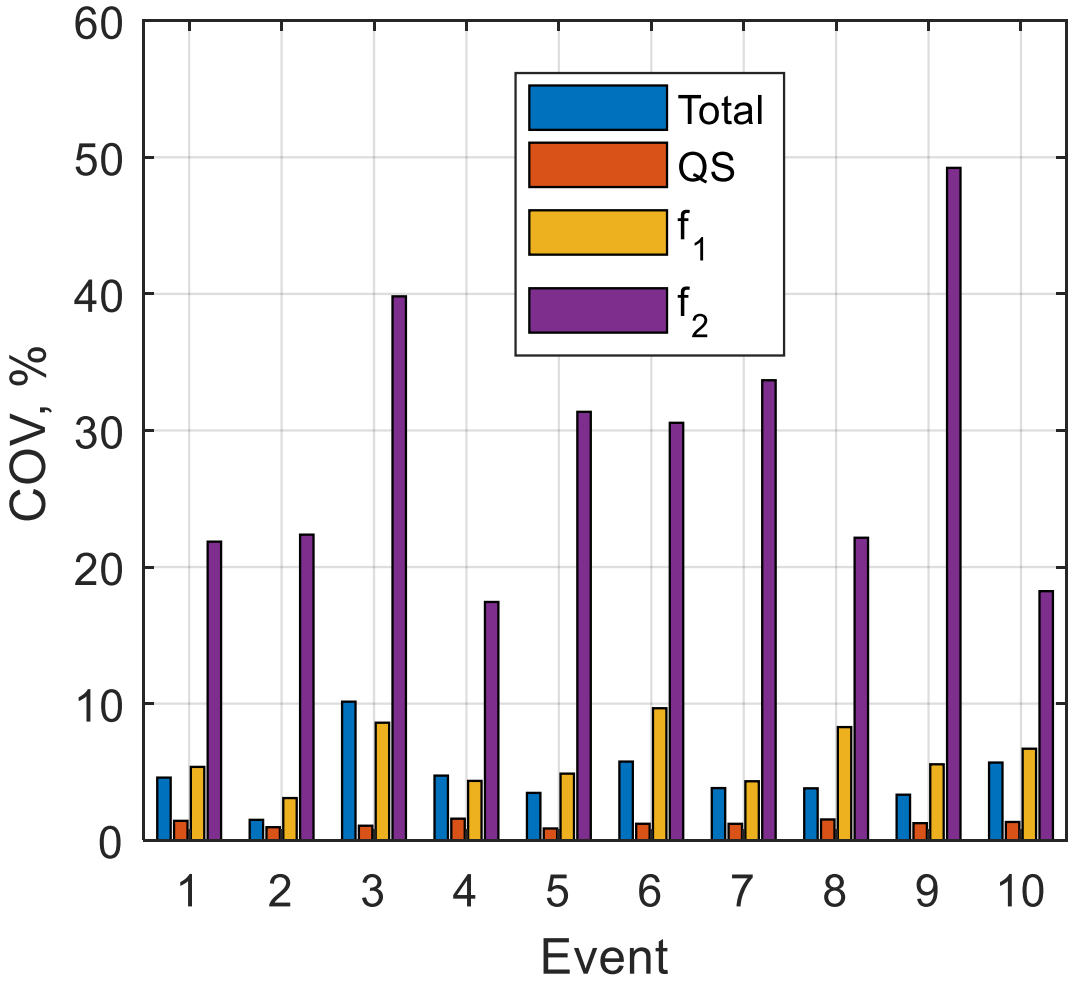
Repeatability: example 2





Repeatability: 10 events, 15 repetitions



Summary

- Experimental campaign with a flexible monopile in severe waves
  - Larger diameter, larger top mass
  - More realizations and repetitions
  - Measurements of both base shear and bending moment
  - Variations in damping level (1.14% and 1.7%)
- Compared to previous experiments
  - Differences in distributions of responses
  - Similar relative contributions from different frequency bands
  - Larger damping appears to give better repeatability, but higher modes are less repeatable
  - (Not shown) more observations of large accelerations far from wave breaking limit
  - Additional results in the paper!

Acknowledgments

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https://www.sintef.no/projectweb/was-xl

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