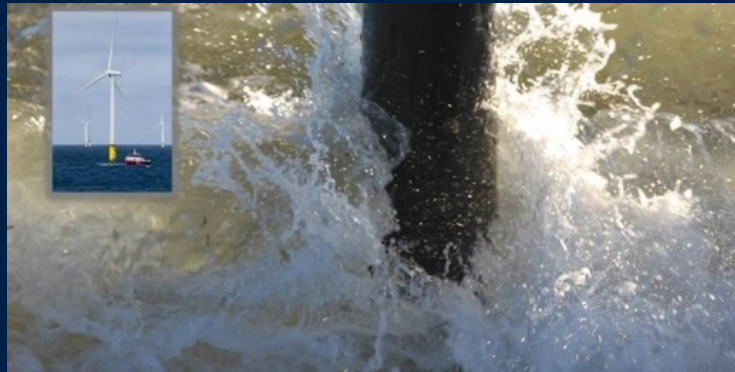


DEPARTMENT OF ENGINEERING SCIENCE

EXTREME WIND AND WAVE LOADS ON THE NEXT GENERATION OF OFFSHORE WIND TURBINES

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With thanks to: Tim Tang, Dylan Barratt, Anela Bajrić-Hodžić, Mark McAllister, Wentao Xu, Xingya Feng, Amin Ghadirian, Dripta Sarkar, *et al.*

Projects in this talk

- De-Risk project (2015-19)
 - Collaboration between DTU, DHI, Oxford, Stravanger and industry
 - PI — Henrik Bredmose (DTU)
 - CI — Harry Bingham; Torben Larsen, et al. (DTU); Paul Taylor (now UWA); Tom Adcock (Oxford)
 - Funded by Innovation Fund Denmark
- China project (2017-2019)
 - Collaboration between Oxford, Shanghai Jiao Tong and Edinburgh
 - PI — Tom Adcock (Oxford)/Ye Li (Shanghai)
 - CI — Shijun Liao, Zhiliang Lin (Shanghai); Ross McAdam, Richard Willden, Ton van den Bremer (Oxford); Alistair Borthwick (Edinburgh)
 - Funded by EPSRC, NERC and NSFC



Problem we are tackling



Improving understanding of wave loading \longrightarrow More efficient design

Technical work packages

- Wave environment
 - Understanding the physics and statistics of waves in severe sea-states
 - Kinematics for use in wave loading
- Wave forces
 - Improved understanding of wave loads on offshore wind turbines
 - Experimental, numerical and theoretical modelling
- Implementation into design

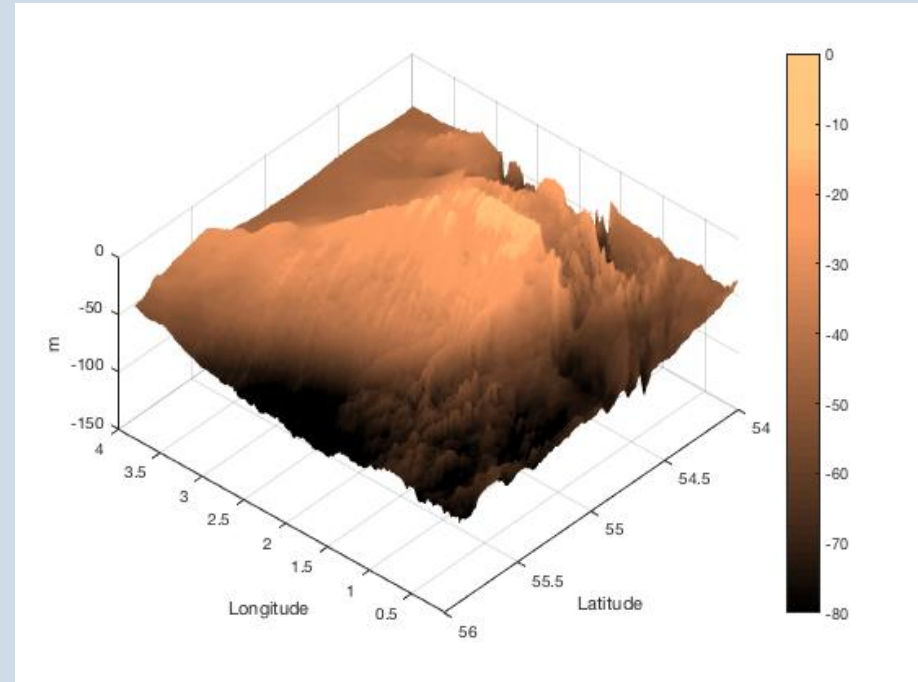


Next generation of wave prediction



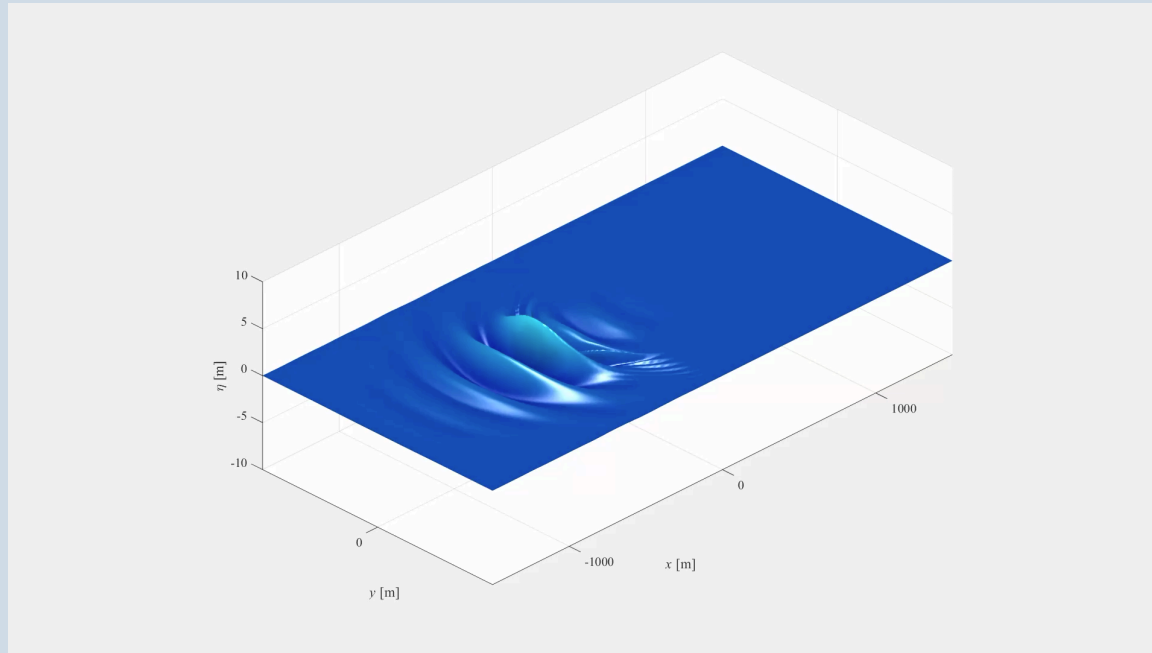
Wave modelling — beyond phase averaged models

- Designers need accurate short-term and long-term wave elevation and kinematics
- For offshore wind many areas have rapidly varying bathymetry which is too complex for phase averaged models
- Most models for short-term statistics are questionable for steep waves



Oceanwave3D

- Fully non-linear potential flow solver developed at DTU
- Capable of simulating flow over varying bathymetry
- Explicitly solves for kinematics within the fluid
- Being developed for GPU architecture — huge computational potential!



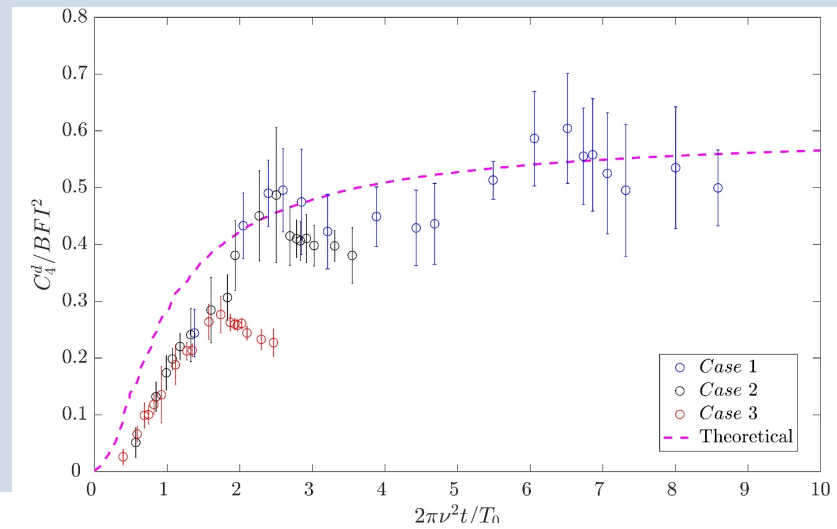
Other numerical models

- We are working on a number of other phase resolved numerical models
 - (Higher order) non-linear Schrödinger models
 - Boussinesq
- Experimental data
 - Tests in DHI in Denmark
 - Towing tank in Shanghai



Preliminary experiments in China

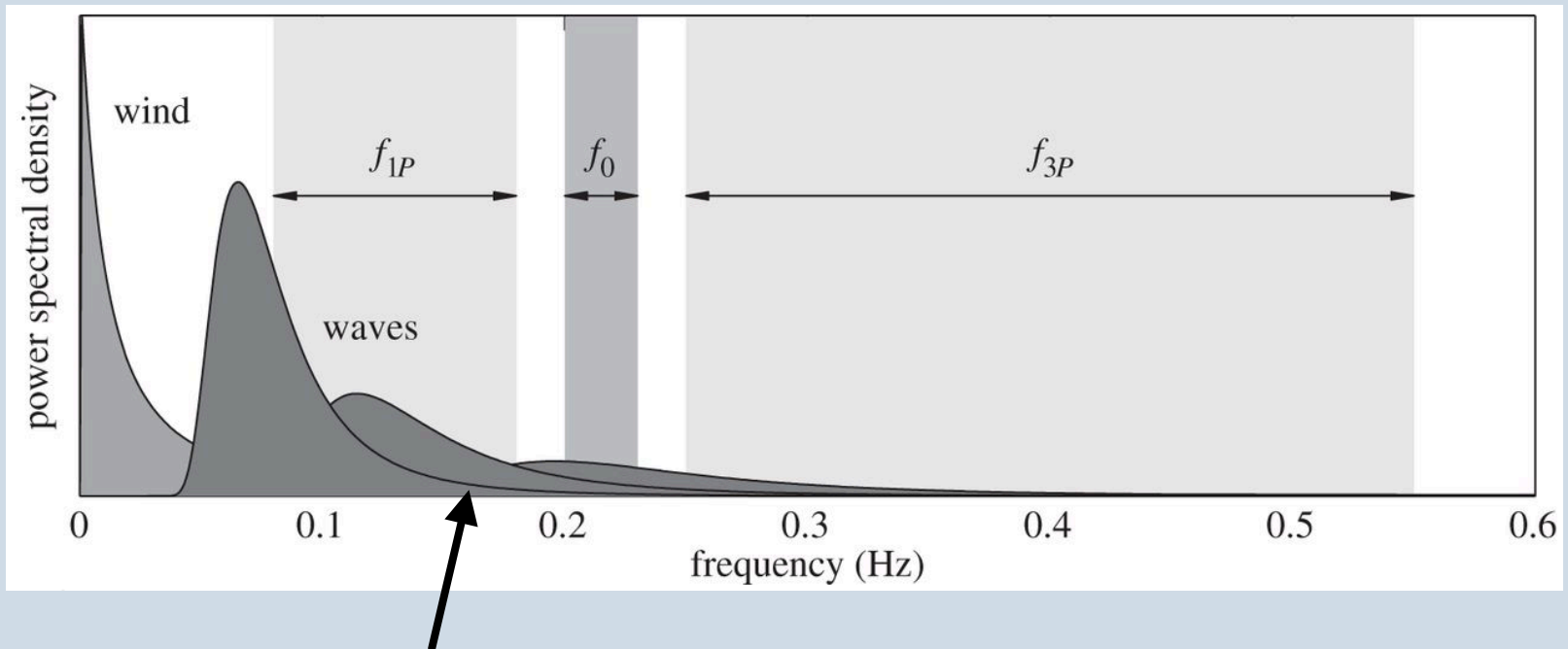
- 300 m towing tank
- 4 phase control to allow us to identify different harmonics of the waves
- A range of sea-states tested
- Studying sea-state statistics focussing on non-linear instabilities



Wave loads on columns

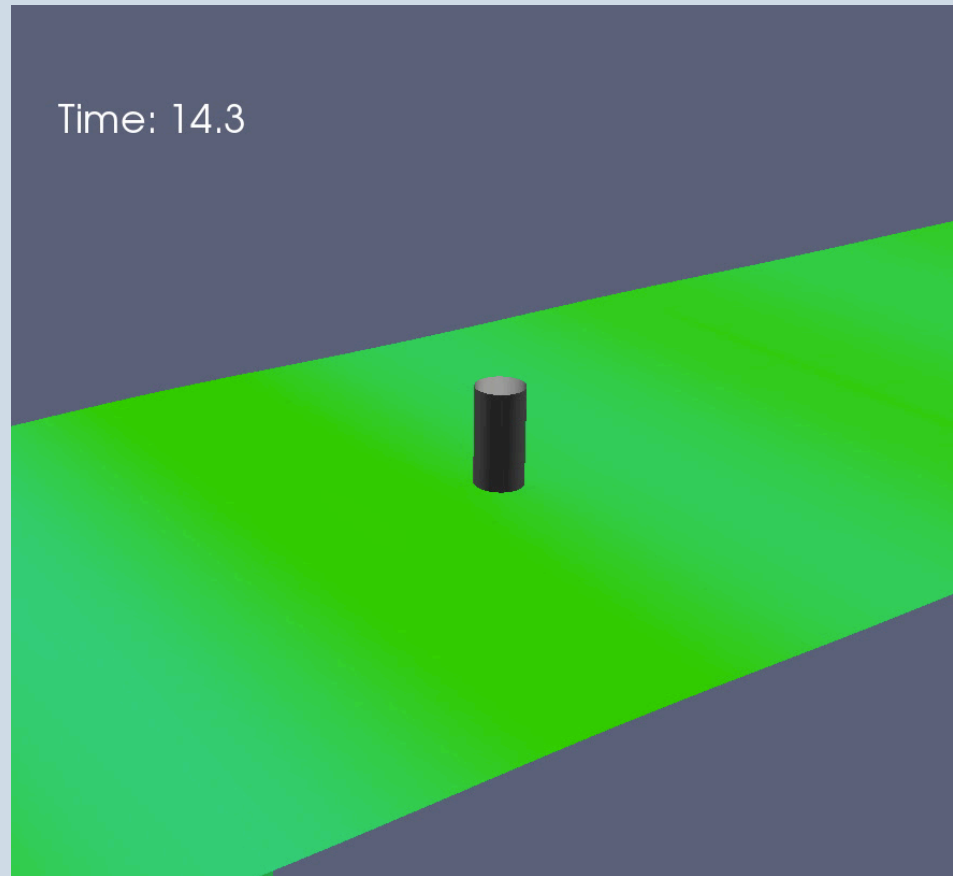


Loads

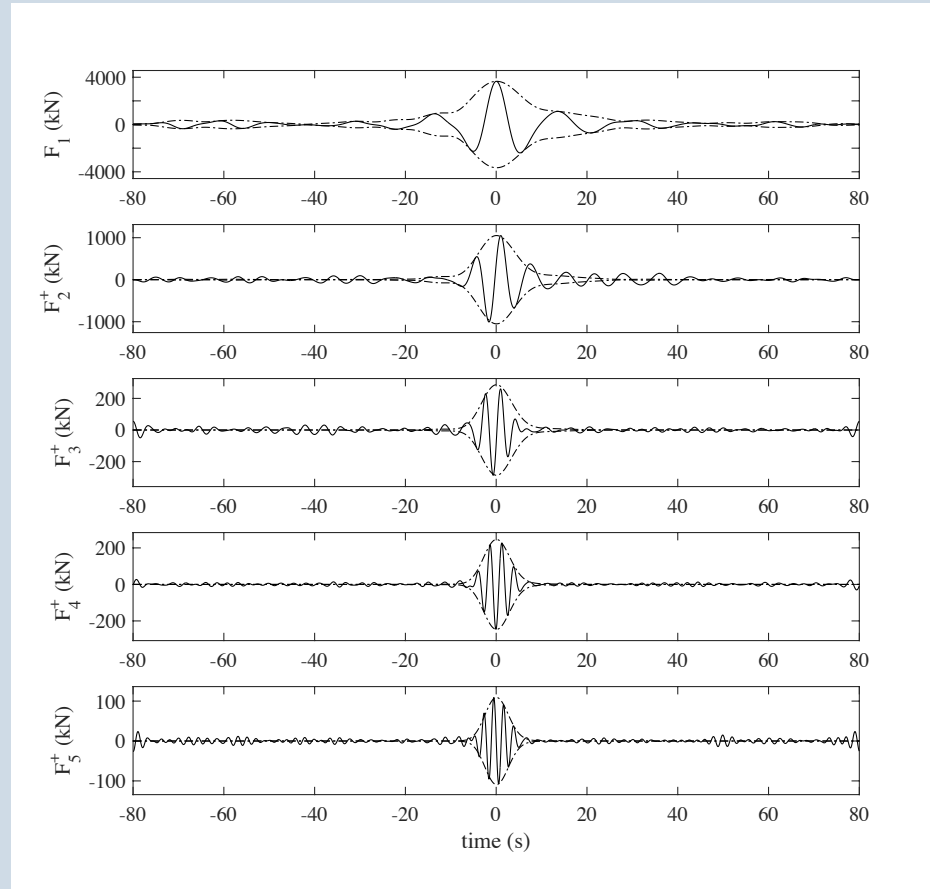


Different spectra for wave loading

Waves interacting with a monopile have higher harmonics

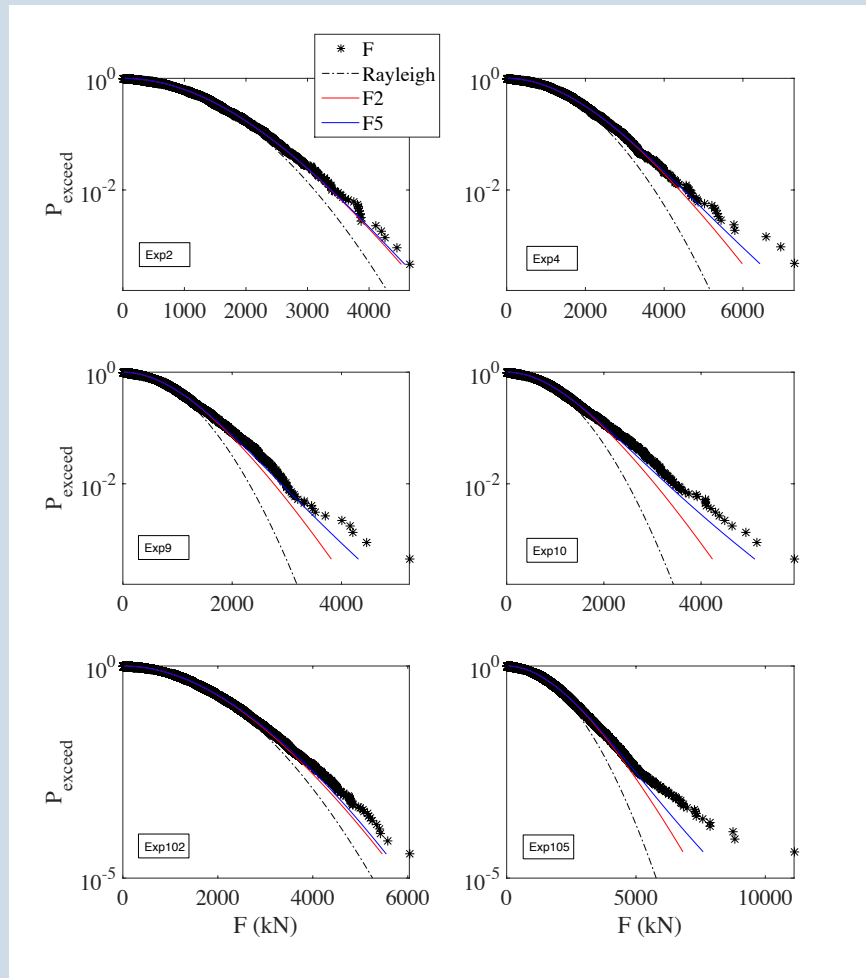


Higher harmonics of wave loads

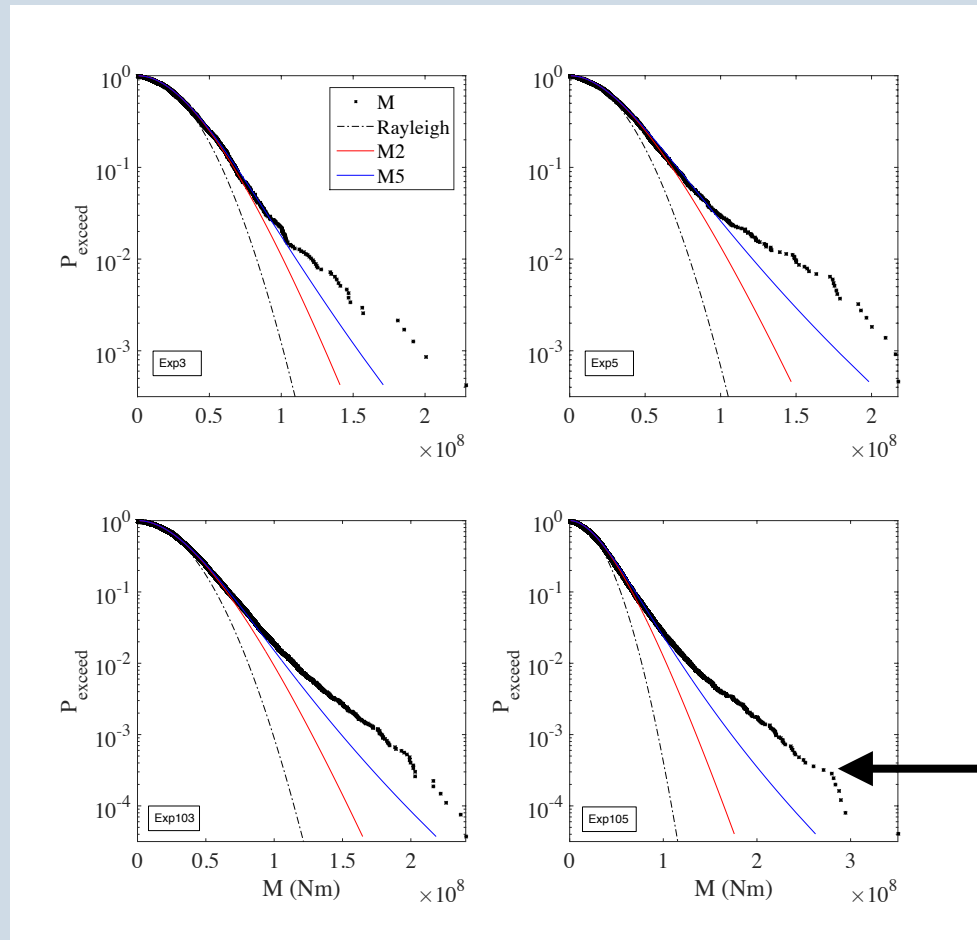


Moment is more non-linear still

Impact of higher harmonics on force statistics



And moment statistics



Very high moments
probably due to
breaking waves
— probably not
such a significant
issue for design

Investigating harmonic structure of wave loads

- Experimentally
 - DHI
 - Kelvin tank in Strathclyde
 - Plans for large scale tests in Shanghai

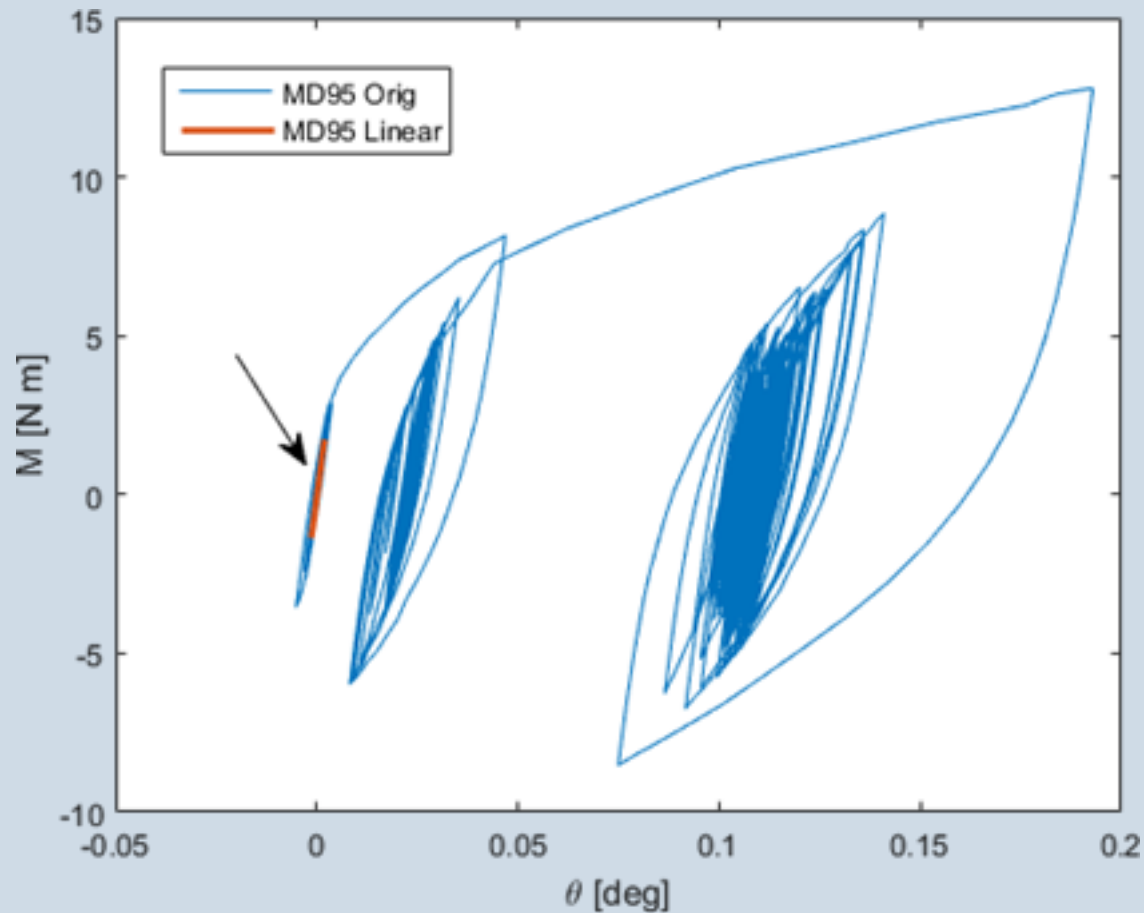


Investigating harmonic structure of wave loads

- Numerical
 - Potential flow calculations based on OxPOT
 - CFD simulations in OpenFOAM
- Key development is the quasi-analytical analysis technique!



Impact of higher harmonics on fatigue in foundations



Is this what happens at sea?

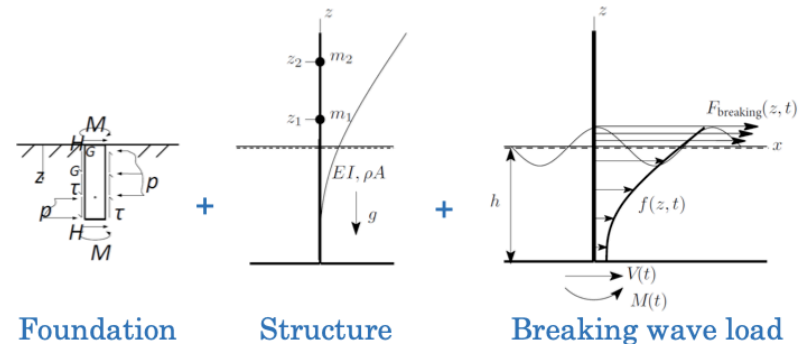


First steps toward field validation

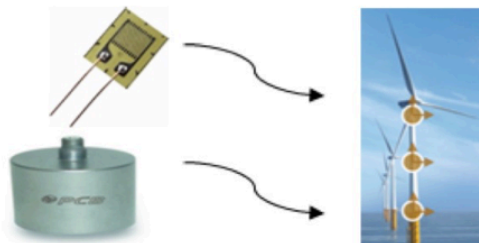
ID method

Time domain identification algorithm:

- Soil-structure model parameters
- Breaking wave load time history
- Valid for wave loads in the field



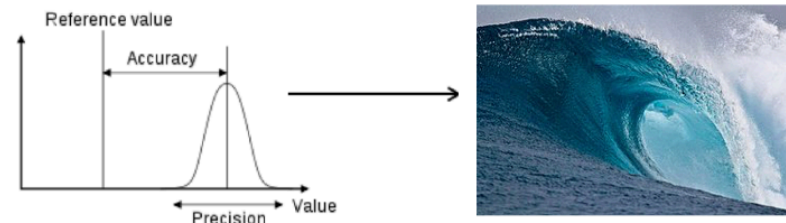
Sensor layout



- Observability of frequency components of breaking wave loads
- Limitations of sensor layout imposed on wave load monitoring

Accuracy

- Quantification of the accuracy of breaking wave load predictions
- Model selection and classification



Summary

- Working towards improved understanding of
 - Wave evolution
 - Wave statistics
 - Wave loads

