

Launch of Sea-Swallows Engineering Tool, 23 June 2025, Bath, UK

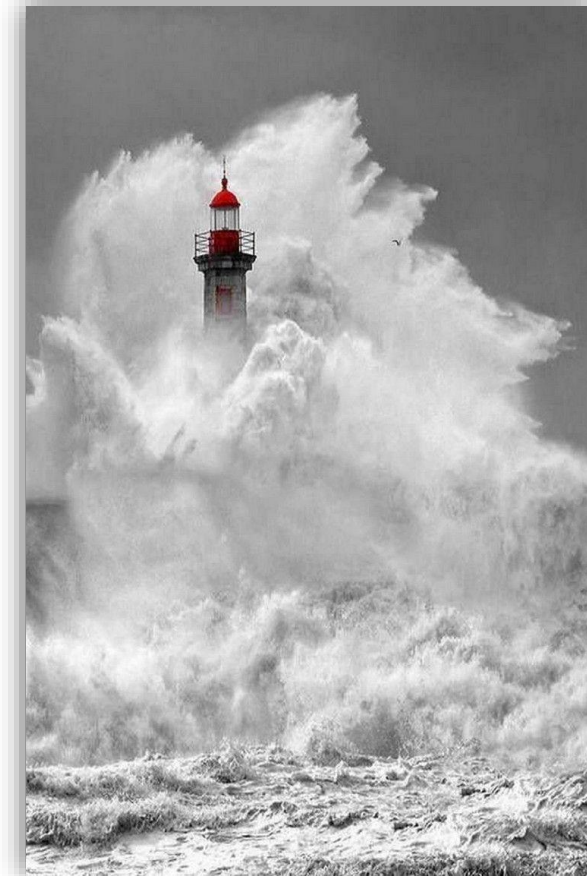
# Overview of the Sea-Swallows Project and the Development of Sea-Swallows Engineering Tool

Professor Jun Zang, University of Bath, UK

A lighthouse hit by a **giant wave**

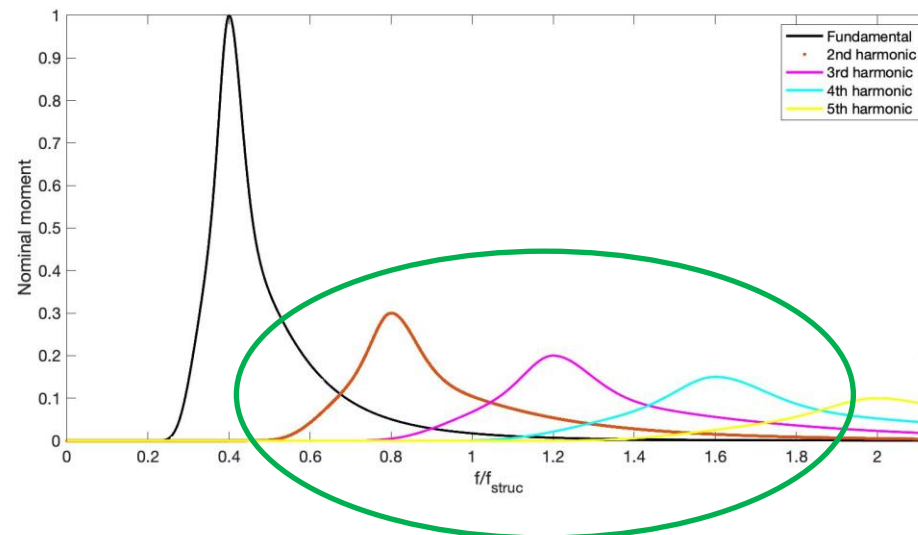


A **moderate** storm in the North Sea in the winter



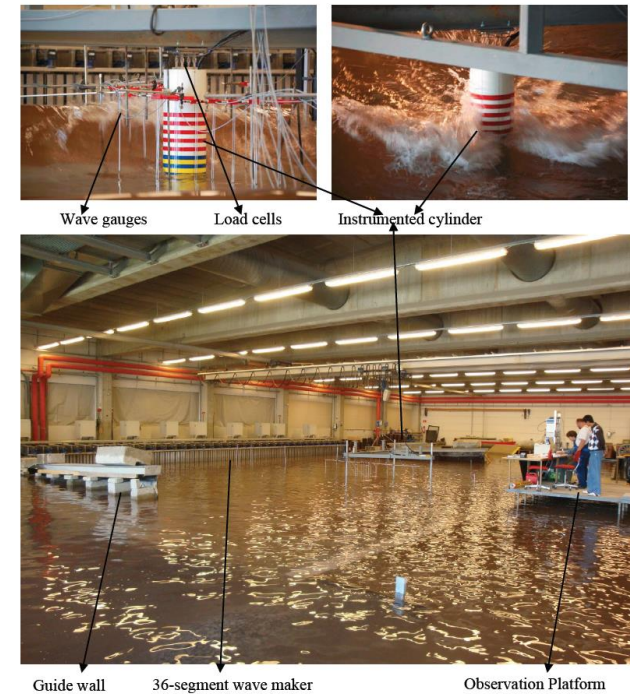
# Fixed offshore wind turbine foundations

- Wave loads are a key design driver for the design
- Monopile structures are dynamic with resonances two to three times the dominant wave frequencies are typically designed using linear wave models
- However, higher harmonics of the fundamental loading coincide with natural frequency so need to be included



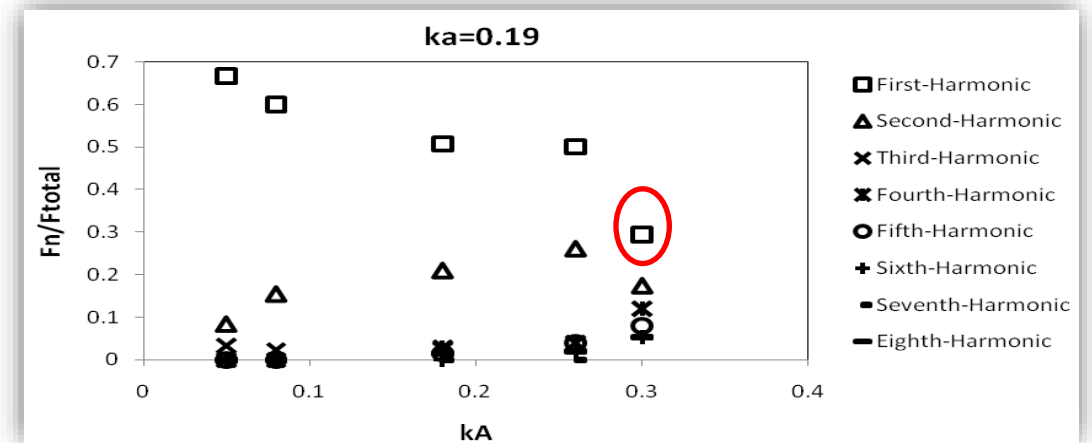
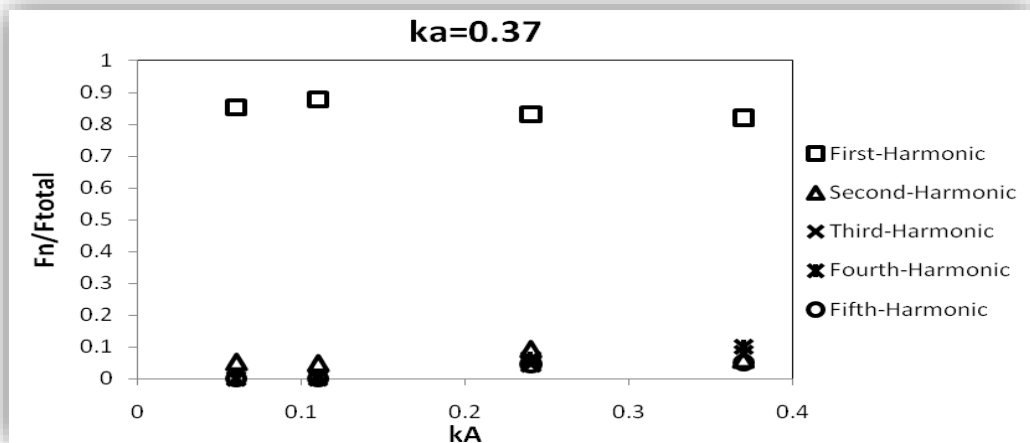
# Our DHI Experiments (performed in Denmark, funded by EU)

- Violent wave impact on offshore wind turbine foundations

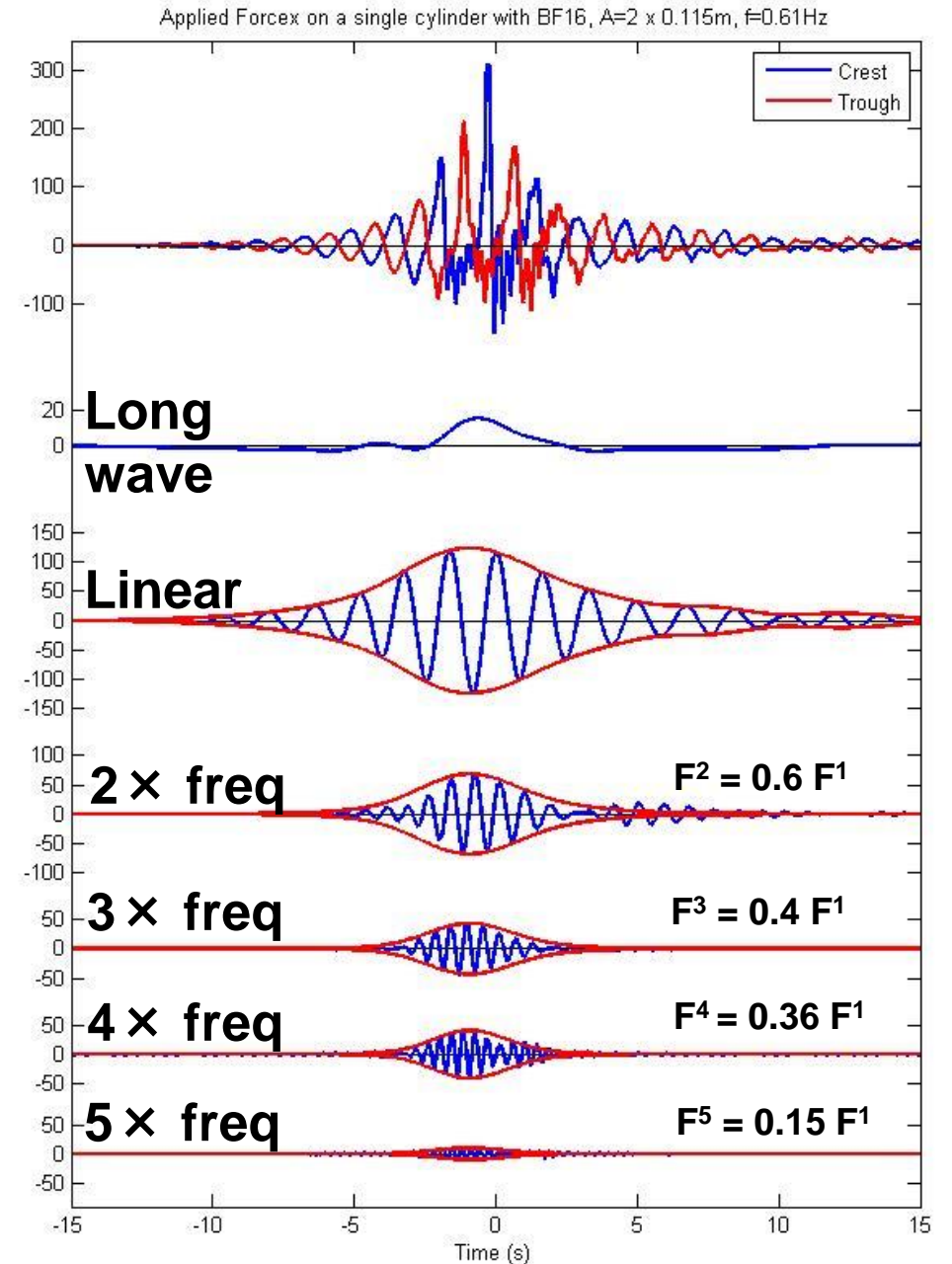


# We have discovered

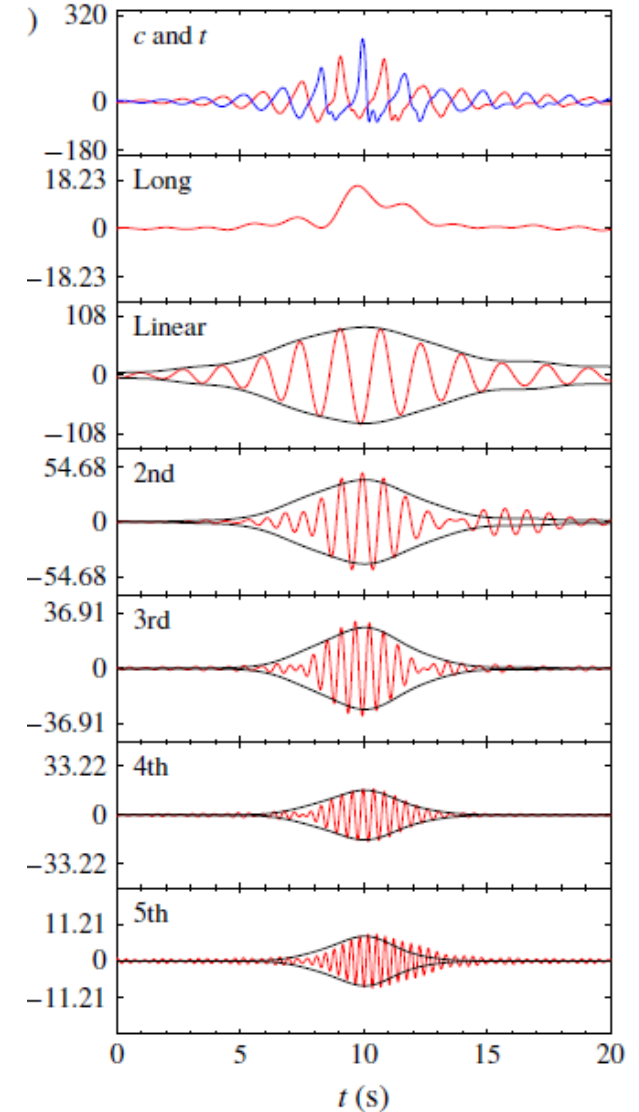
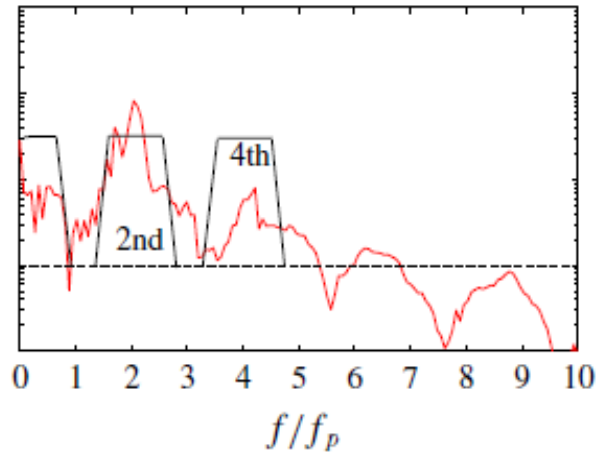
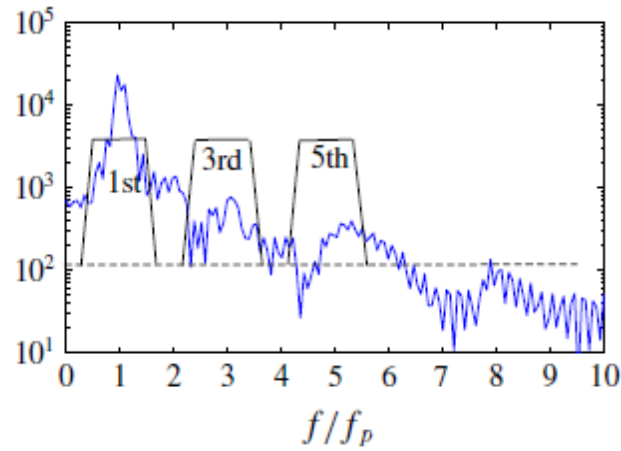
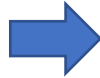
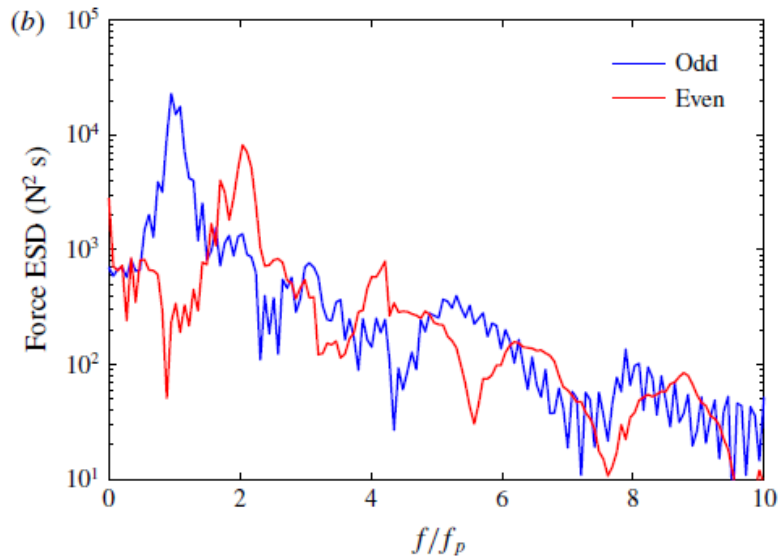
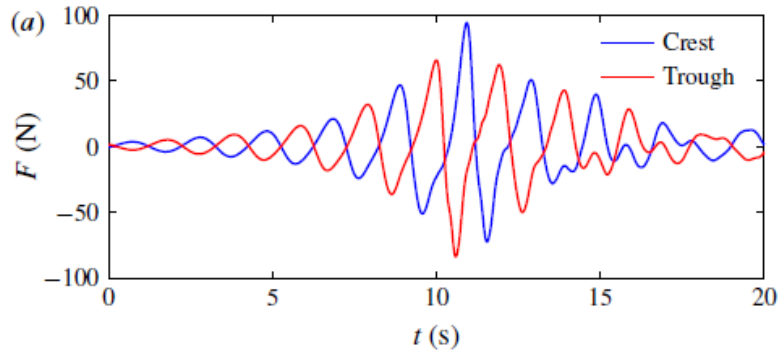
- Importance of high-order wave loading



**Note: Size of 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, and 5<sup>th</sup>  
force harmonics**



# Separation of force harmonics

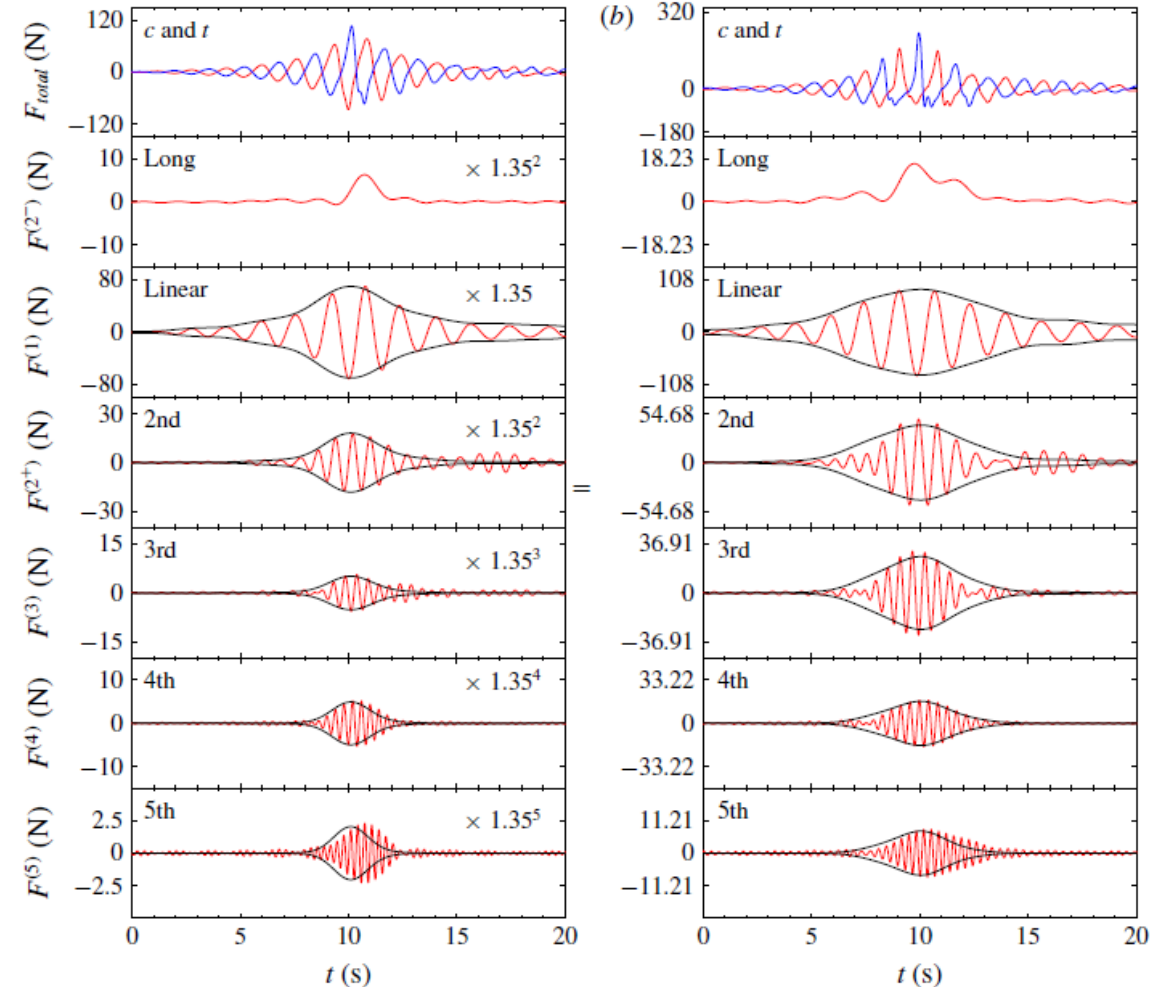


## We have also found

- Relationship between high-order and linear wave loading
- A new fast method for predicting the complex non-linear high-order wave loading on monopiles.

Given linear wave force only, predict high order wave forces

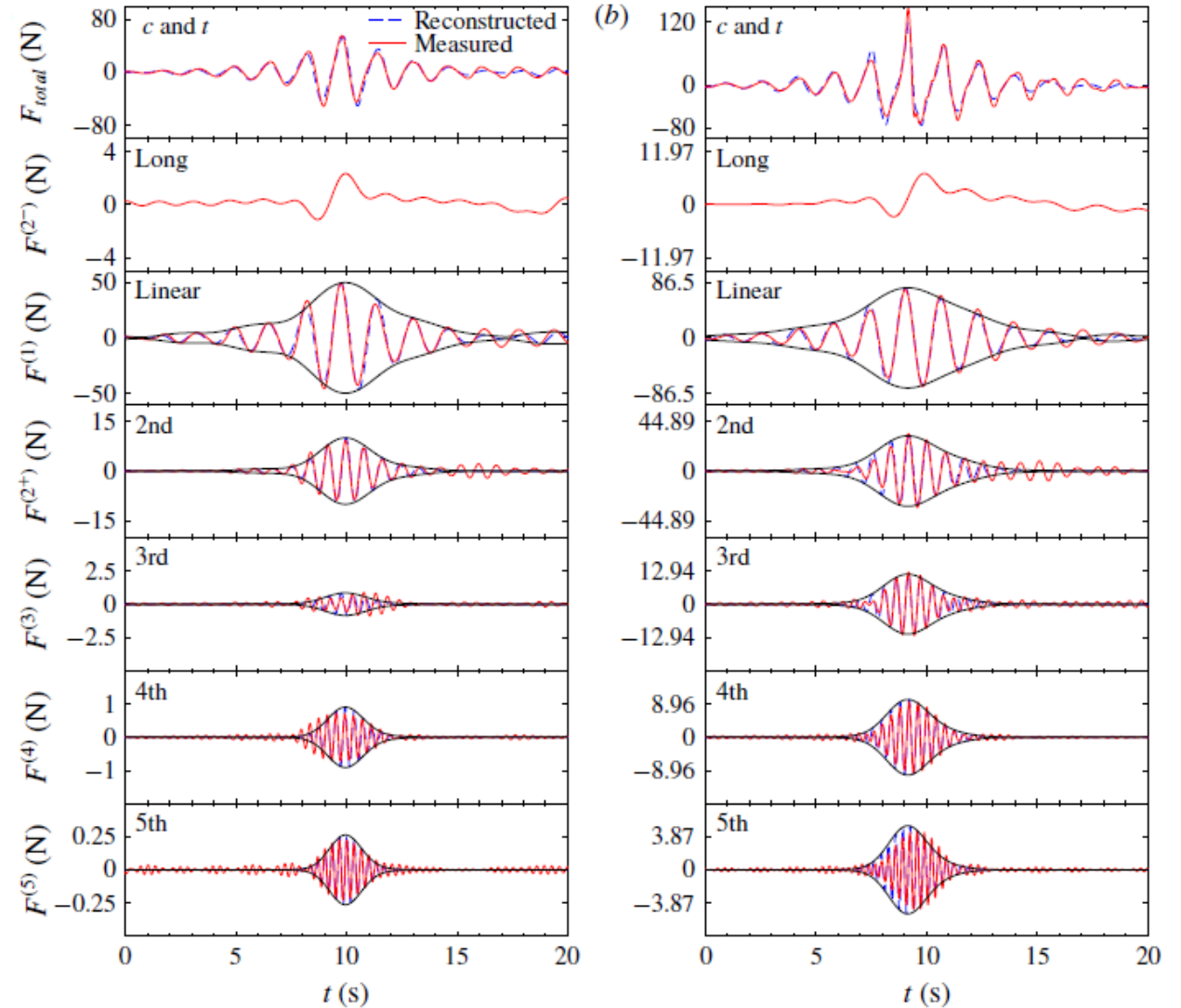
$$\frac{F}{\rho g R^3} = \frac{\mathcal{F}_1}{\rho g R^3} [f_1] + S_{FF2} \left( \frac{\mathcal{F}_1}{\rho g R^3} \right)^2 [\alpha_{FF2}(f_1^2 - f_{1H}^2) + \beta_{FF2}(2f_1 f_{1H})] + S_{FF3} \left( \frac{\mathcal{F}_1}{\rho g R^3} \right)^3 [\alpha_{FF3} f_1 (f_1^2 - 2f_{1H}^2) + \beta_{FF3} (f_{1H} (3f_1^2 - f_{1H}^2))] + \dots$$



# Reconstruct wave loading using the new approach

Chen, L.F., Zang, J., Taylor, P.H., Sun, L., Morgan, G.C.J., Grice, J., Orszaghova, J. and Tello Ruiz, M. (2018)  
 An experimental decomposition of nonlinear forces on a surface-piercing column: Stokes-type expansions of the force harmonics.

*Journal of Fluid Mechanics*



# Access to the DHI experimental data

Some of the selected experimental data from our experiments on focused wave interaction with a circular cylinder have been made openly accessible.

Below is the link to download the data, which is included in the CCP-WSI webpage.

[https://www.ccp-wsi.ac.uk/data\\_repository/test\\_cases/test\\_case\\_008](https://www.ccp-wsi.ac.uk/data_repository/test_cases/test_case_008)

# EPSRC Project: SEA-SWALLOWS

(1 Oct 2021- 30 Sept 2025)

## Severe Storm Wave Loads on Offshore Wind Turbine Foundations

University of Bath,

University of Oxford

University of Strathclyde

in collaboration with Dalian University of Technology

To develop an **Open-access engineering tool** for calculating violent wave loading on offshore wind turbine foundations

## We have conducted

- high-quality wave tank measurements in two laboratories - 3 phases
- high-quality numerical simulations - using both OpenFOAM and PIC model
- novel machine learning Gaussian Process model predictions
- **development of an open-access accurate & efficient engineering tool – launched today.**

covering a wide range of sea-states, based on  $kR$ ,  $kA$ ,  $kd$ , ...

Additional research achievements (beyond the original objectives) include

- T-FNV method was developed
- Secondary load cycle was investigated

# Project Team

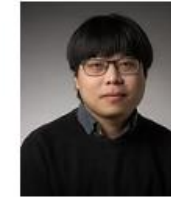
- Jun Zang – PI, University of Bath
- Thomas Adcock – Co-I, University of Oxford
- Saishuai Dai – Co-I, University of Strathclyde
- Xi Chen – Co-I, University of Bath
- Cormac Reale – Co-I, University of Bath
- Haoyu Ding – Post-Doctoral RA, Bath
- Thobani Hlope – Post-doctoral RA, Bath
- Tianning Tang – Post-Doctoral RA, now Lecturer, Manchester
- Sandy Day – Retired
- Paul Taylor – Chair of Advisory Board

Project webpage <https://www.sea-swallows.org/>

## University of Bath



Prof. Jun Zang



Dr. Haoyu Ding



Dr. Xi Chen



Dr. Cormac Reale

## University of Oxford



Prof. Thomas Adcock



Dr. Tianning Tang

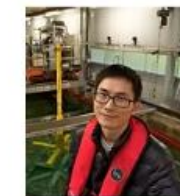


Dr. Thobani Hlope

## University of Strathclyde



Prof. Sandy Day



Dr. Saishuai Dai

## University of Western Australia



Prof. Paul Taylor

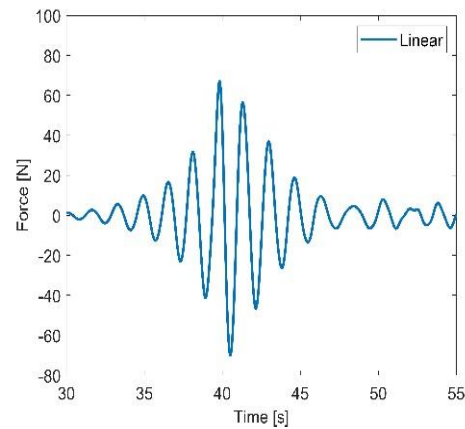
Visiting  
Professor of  
University of  
Oxford

# Stokes' type force model:

$$F_t(t) \approx F_1 + F_2 + F_3 + F_4 + F_5 + \dots$$

$$F_n = \Gamma_n \hat{\mathcal{F}}_1^n \cos(n\phi - \psi_n)$$

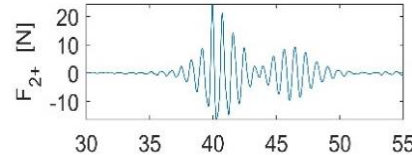
$\Gamma_n$ : amplitude coefficient  
 $\psi_n$ : phase angle



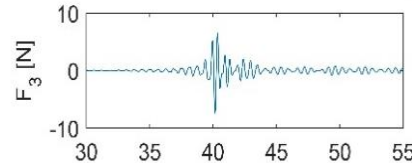
Linear force

+

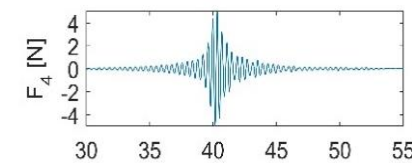
$$\Gamma_2, \psi_2$$



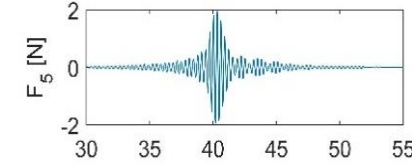
$$\Gamma_3, \psi_3$$



$$\Gamma_4, \psi_4$$

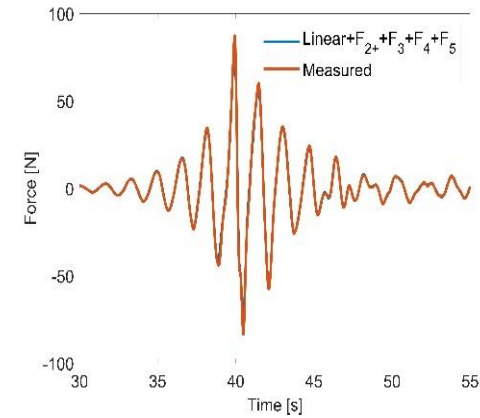


$$\Gamma_5, \psi_5$$



Higher order harmonics

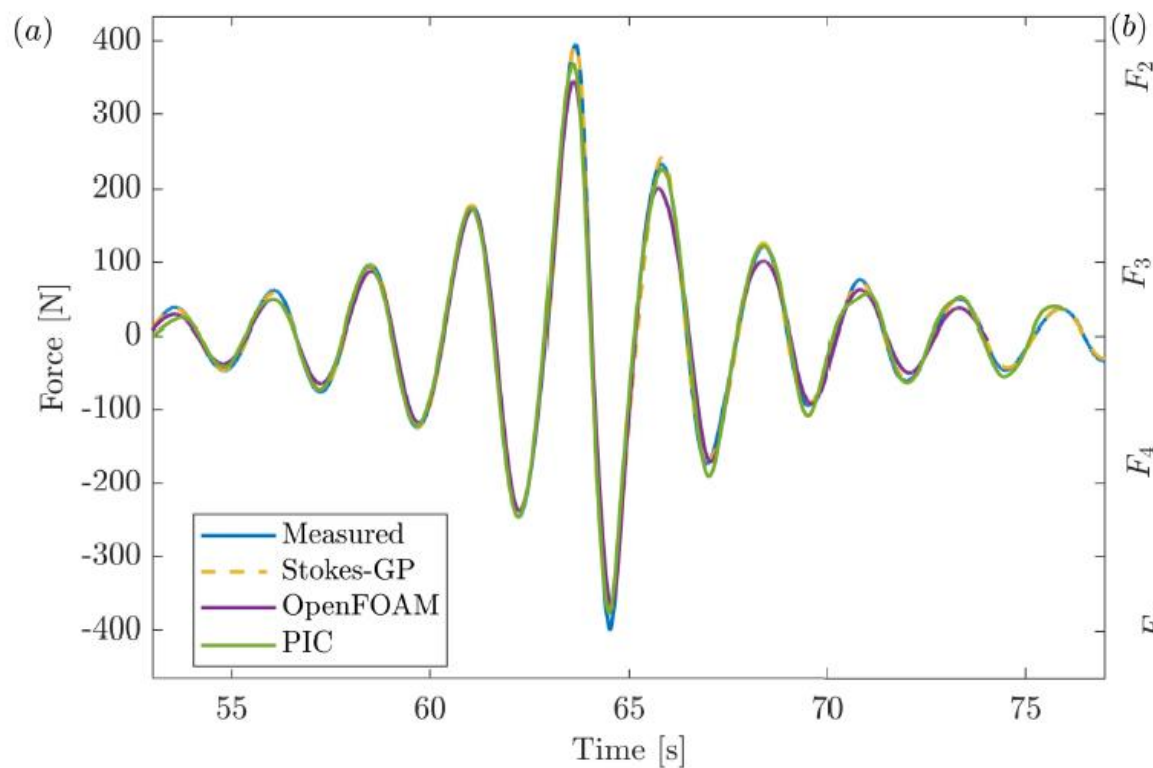
≈



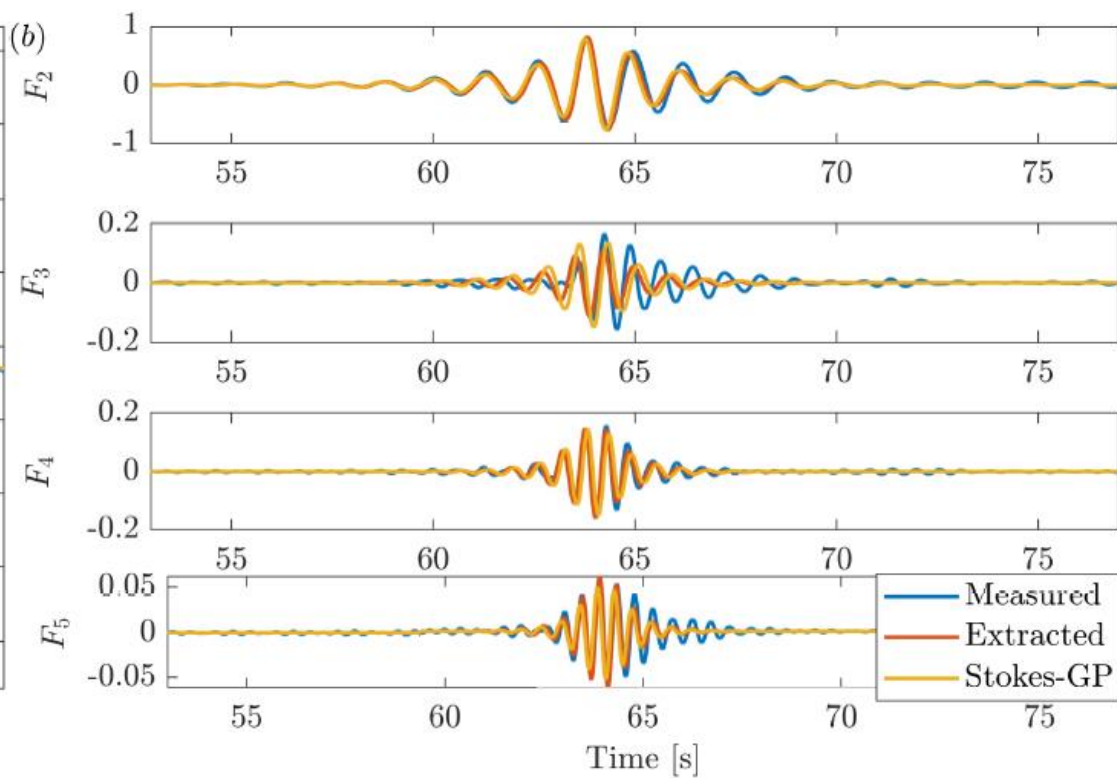
Nonlinear force

# Stokes' type model predictions of nonlinear forces

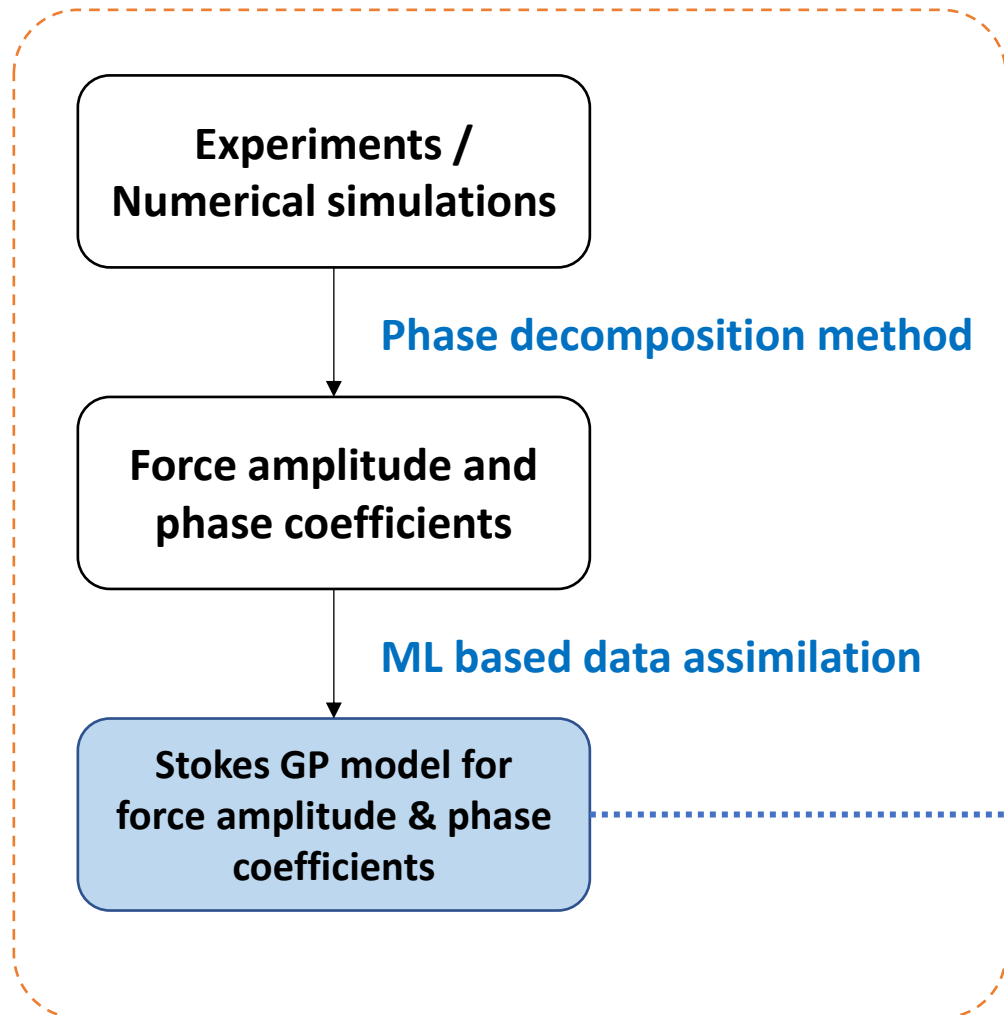
(a): total inline forces



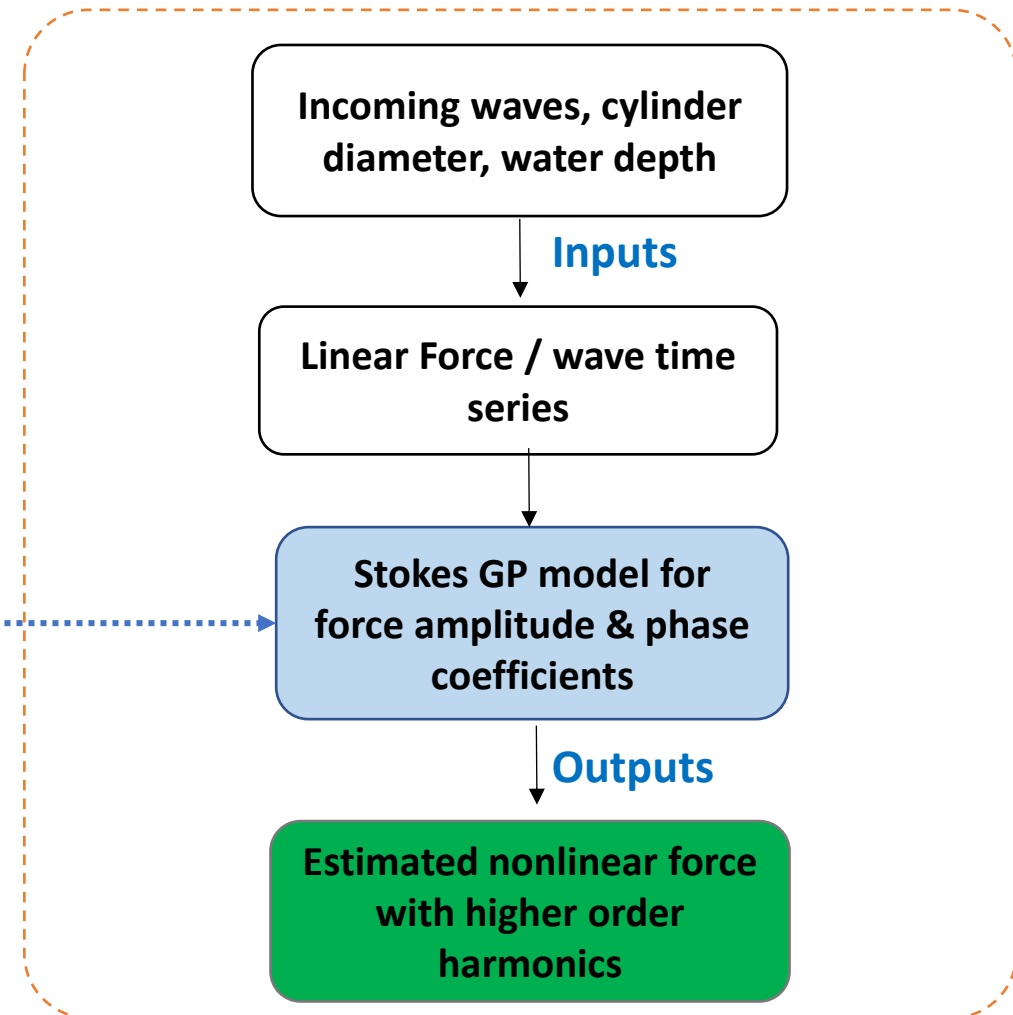
b): higher order harmonics



## Model Training



## Model Prediction

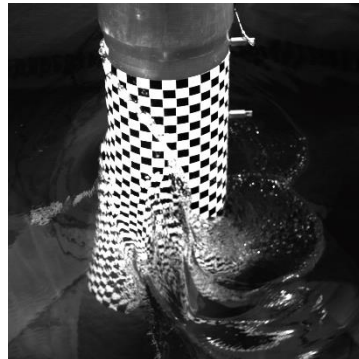


# Physical experiments

## Uni-directional focused wave tests

We performed a new set of experiments in the large flume (76m x 4.6m x 1.8m) at Kelvin Hydrodynamics Laboratory, the University of Strathclyde.

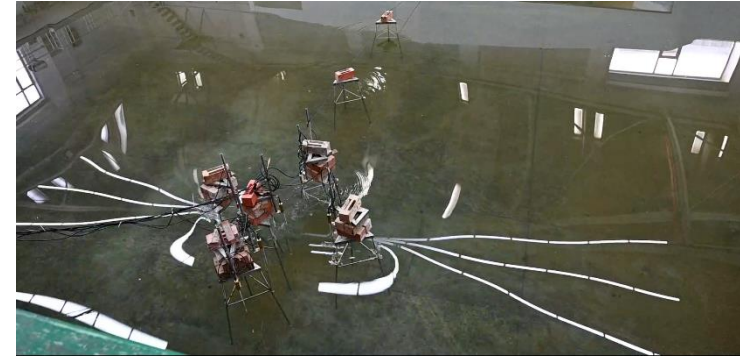
A single fixed surface-piercing vertical cylinder with a radius ( $R$ ) of 0.2 m was placed 35.3 m away from the wavemaker. Ranges of uni-directional focused wave groups and random waves are generated.



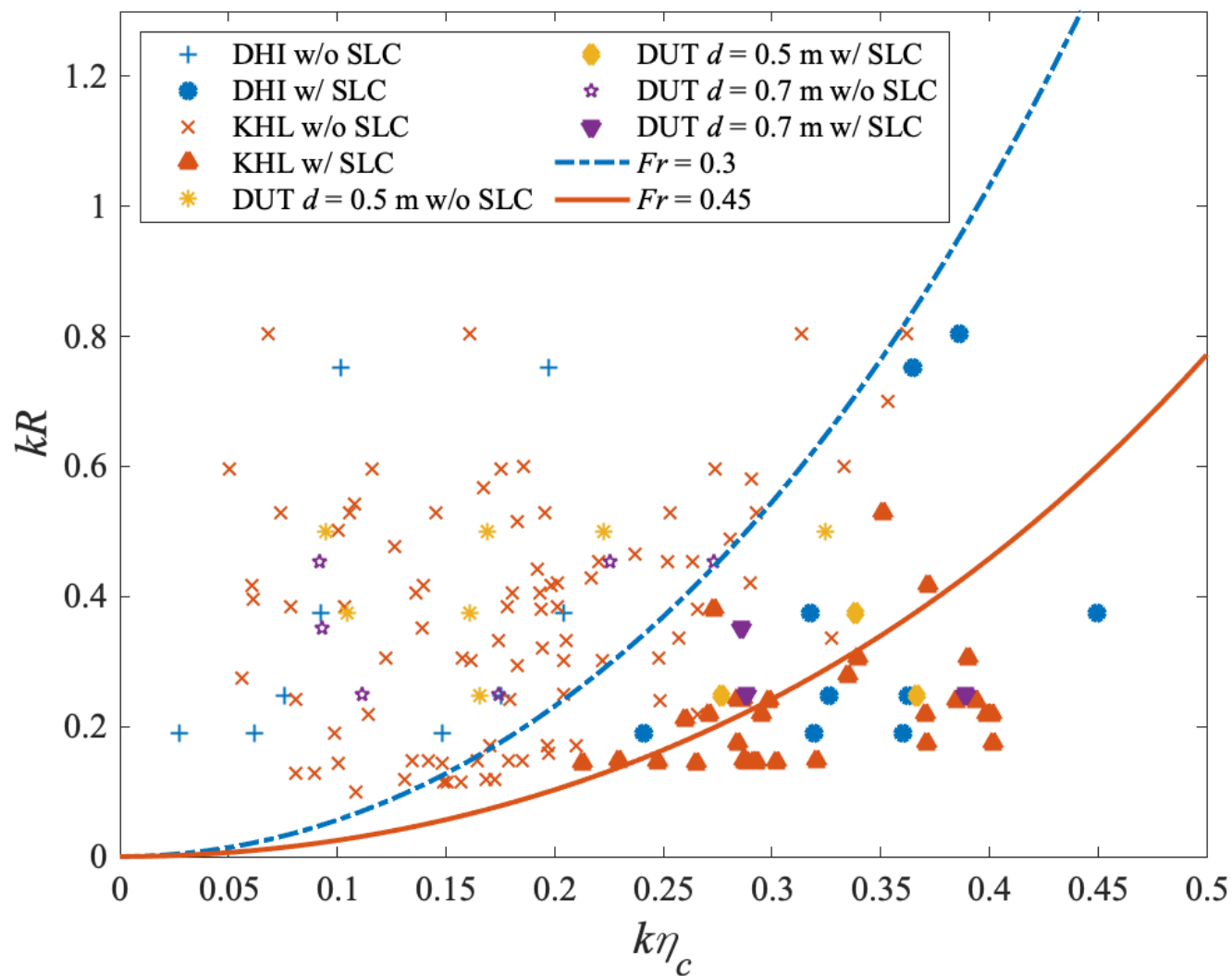
## Uni and directionally spread focused wave tests

This experiment was carried out in the multi-functional tank (54m x 34m x 1.3m) of the State Key Laboratory of Coastal and Offshore Engineering of Dalian University of Technology.

A single fixed surface-piercing vertical cylinder with a radius ( $R$ ) of 0.125 m was placed 10 m away from the wavemaker. Ranges of Focused wave groups and directionally spread waves are generated, and various wave spreading conditions are investigated.



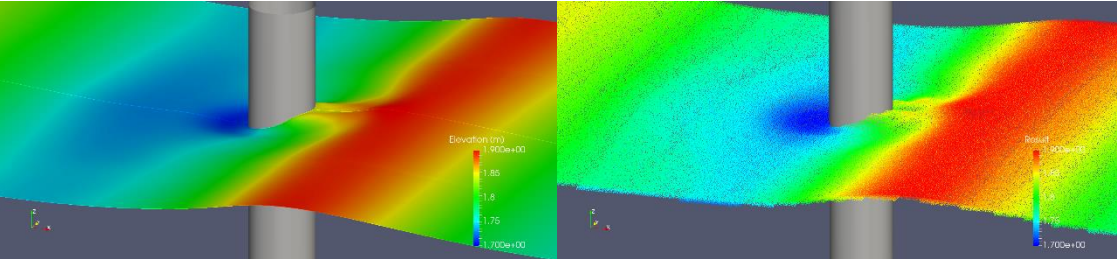
# Physical experiments



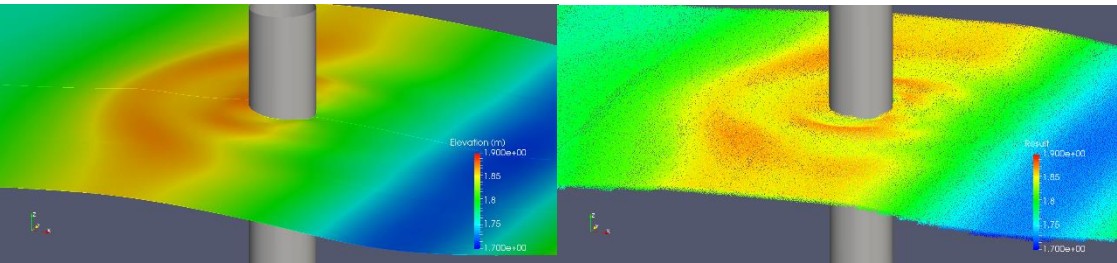
# Numerical simulations provide more training data

OpenFOAM

PIC model

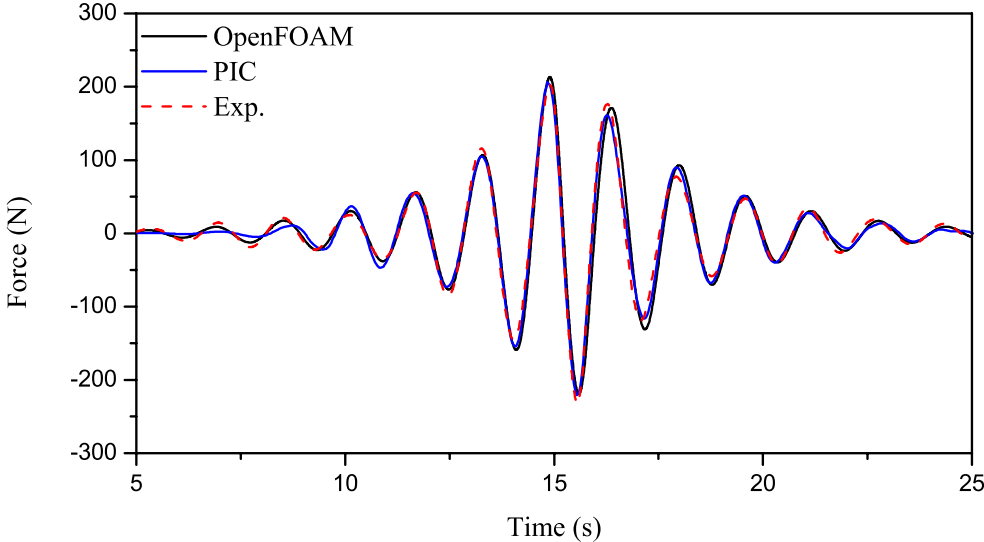


The main crest passes the cylinder



The first crest after the main crest passes

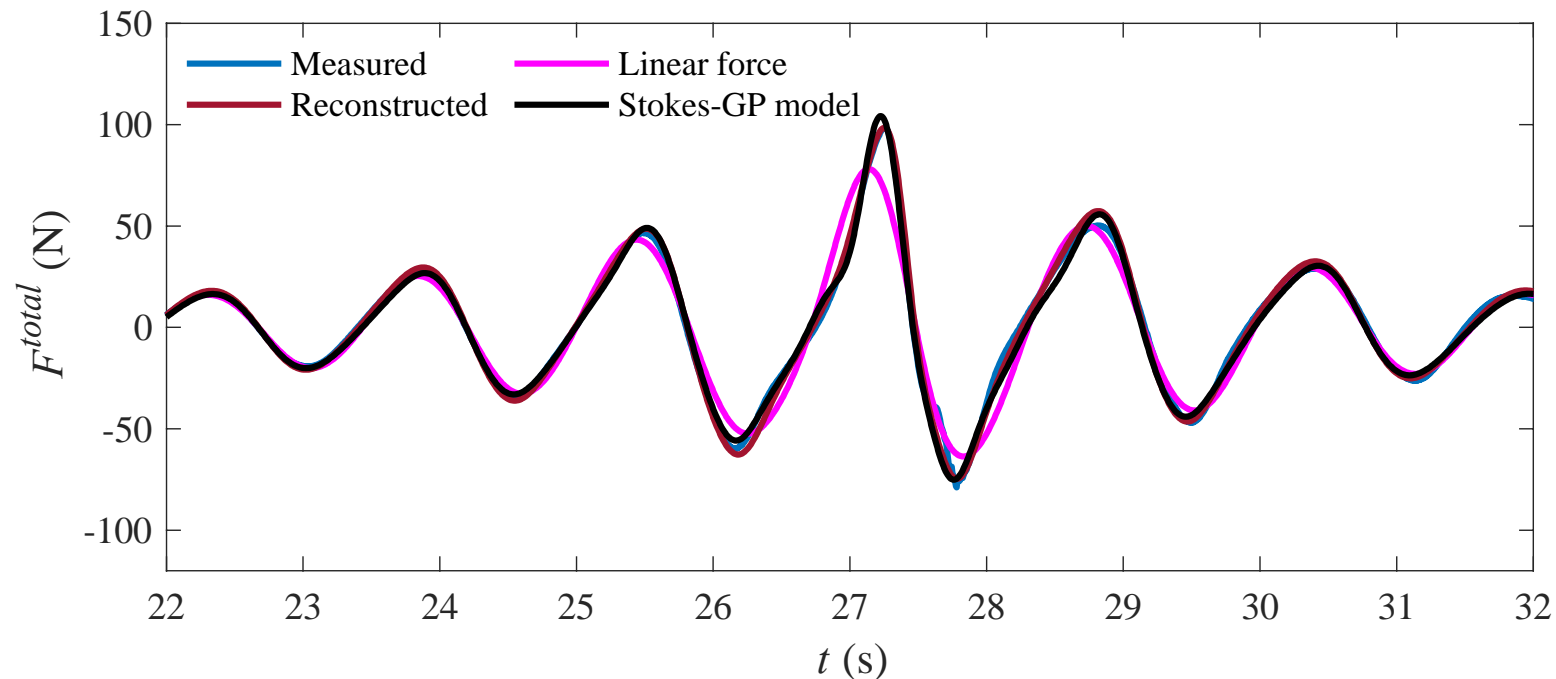
$$kA = 0.16, kR = 0.32, kd = 2.88$$



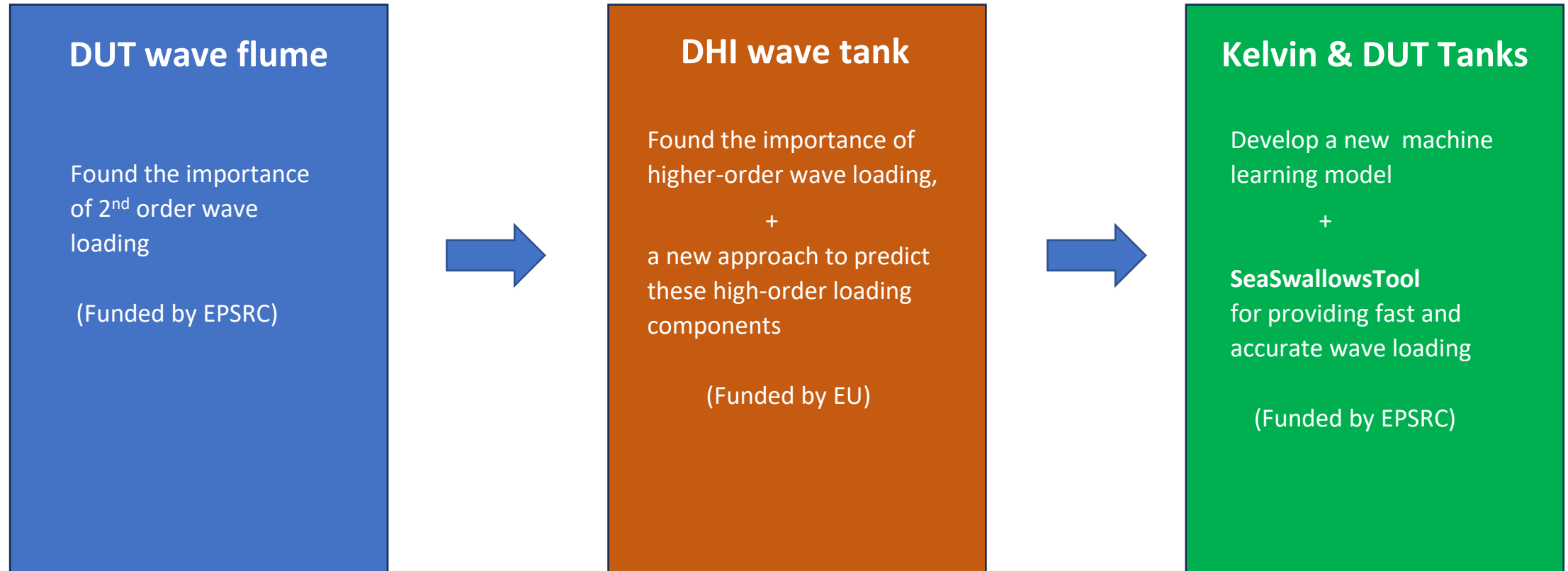
## SeaSwallowsTool: predictions of nonlinear forces

The nonlinear wave forces on a monopile predicted by the new SeaSwallowsTool show excellent agreement with experiments.

Comparisons are presented for the test case:  $kA = 0.22$ ,  $kR = 0.25$ ;  $kd = 0.99$



# Our journey ...



# What is to come?

- Wider range of wave inputs:  
user defined time-series
  1. linear elevation
  2. fully nonlinear time series (such as from a fixed wave gauge)
- Treatment of directionally spread waves
- Addition of T-FNV force model, to take elevation -> force / moment output

**Your feedback is greatly appreciated!**



***Thank you!***

Prof. Jun Zang [J.Zang@bath.ac.uk](mailto:J.Zang@bath.ac.uk)

Sea-Swallows project webpage: <https://www.sea-swallows.org/>

SeaSwallowsTool download page: <https://www.sea-swallows.org/download>