OC5 Project Phase Ib: Validation of Hydrodynamic Loading on a Fixed, Flexible Cylinder for Offshore Wind Applications

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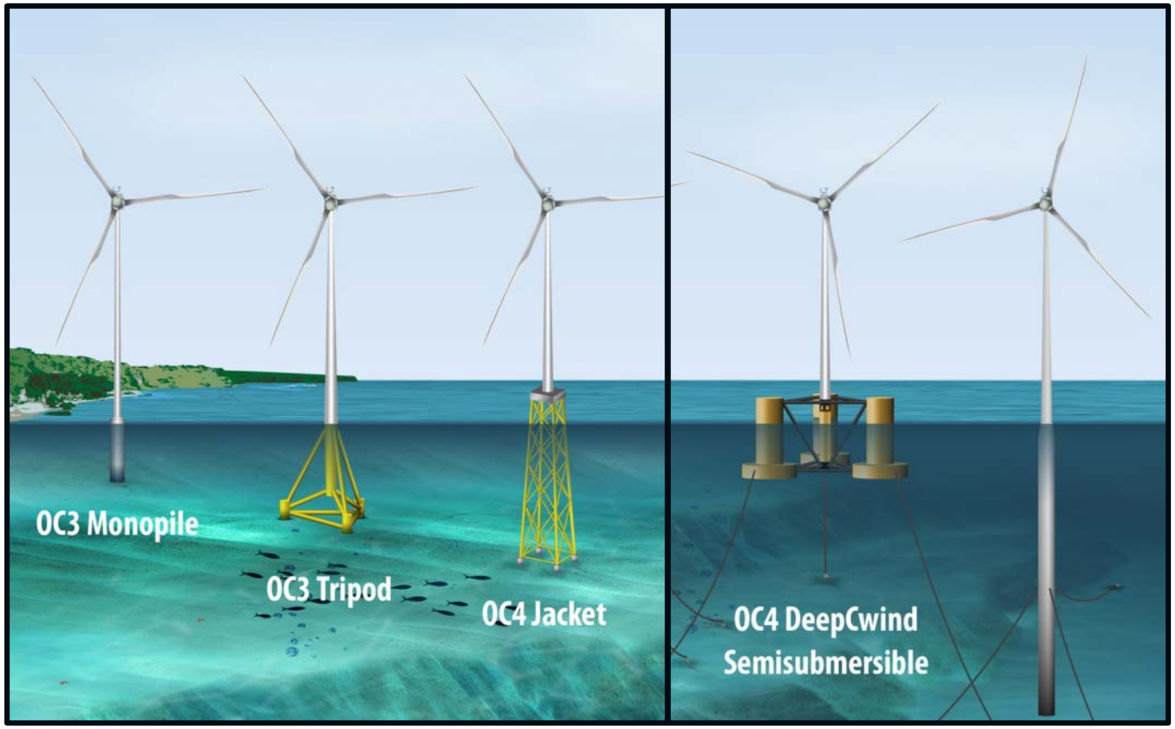
IEA Wind Tasks 23 and 30 (OC3/OC4/OC5)

- Verification and validation of offshore wind modeling tools are need to ensure their accuracy, and give confidence in their usefulness to users.
- Three research projects were initiated under IEA Wind to address this need:



OC3 = Offshore Code Comparison Collaboration (2005-2009)

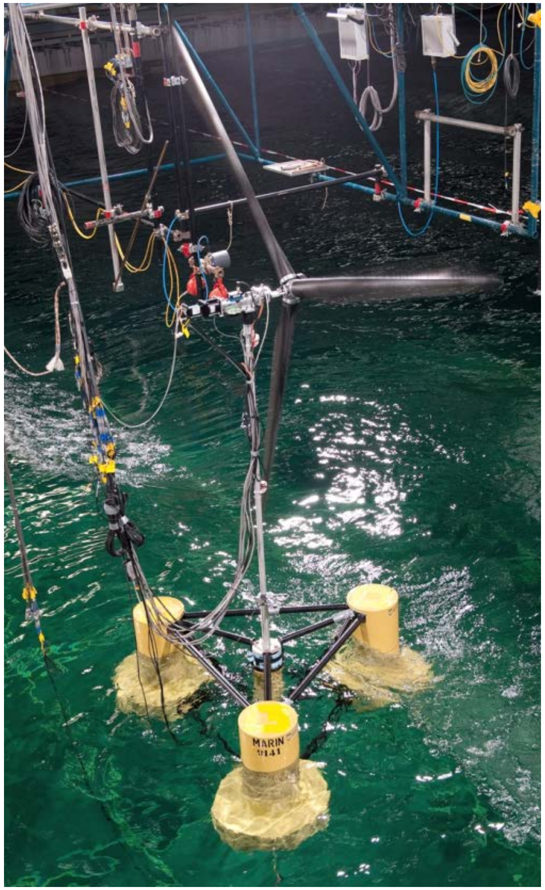
OC4 = Offshore Code Comparison Collaboration, Continuation (2010-2013)

OC5 = Offshore Code Comparison Collaboration, Continuation, with Correlation (2014-2017)

OC5 Project Phases

- OC3 and OC4 focused on ***verifying*** tools (tool-to-tool comparisons)
- OC5 focuses on ***validating*** tools (code-to-data comparisons)

Phase I:
Monopile - Tank Testing

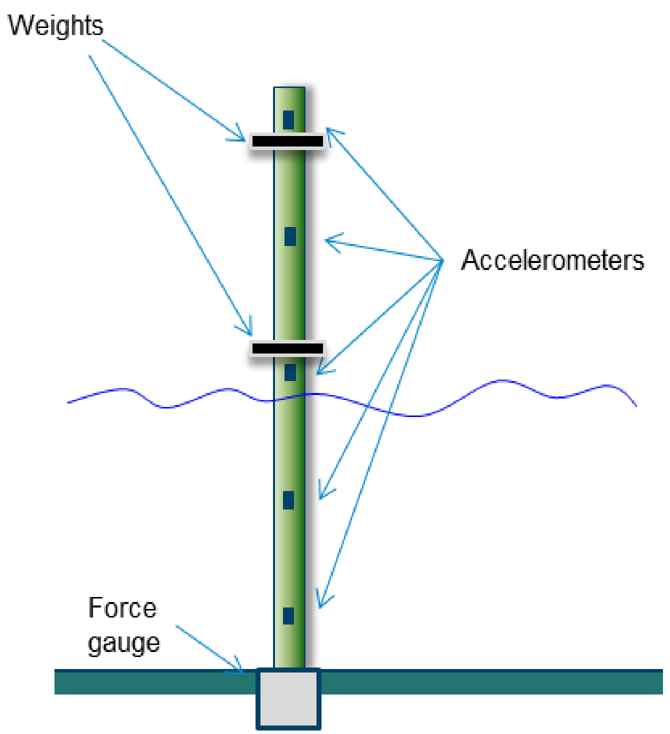


Phase II:
Semi - Tank Testing

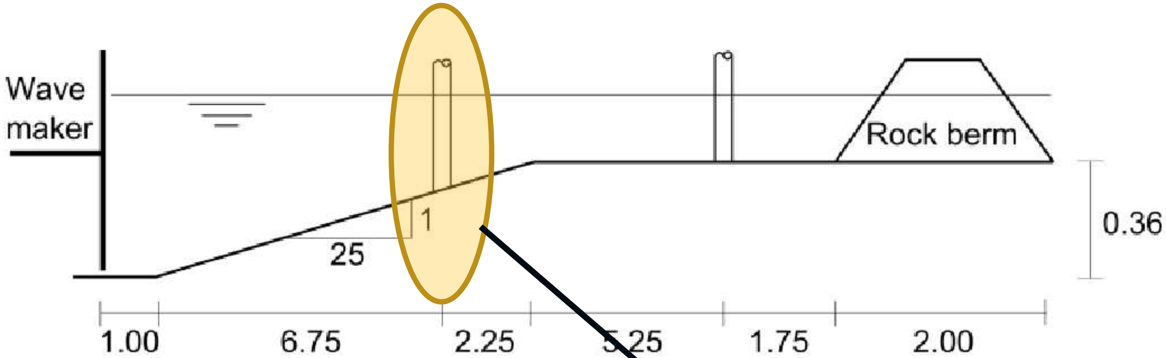
Phase III:
Jacket/Tripod – Open Ocean

OC5 Phase Ib

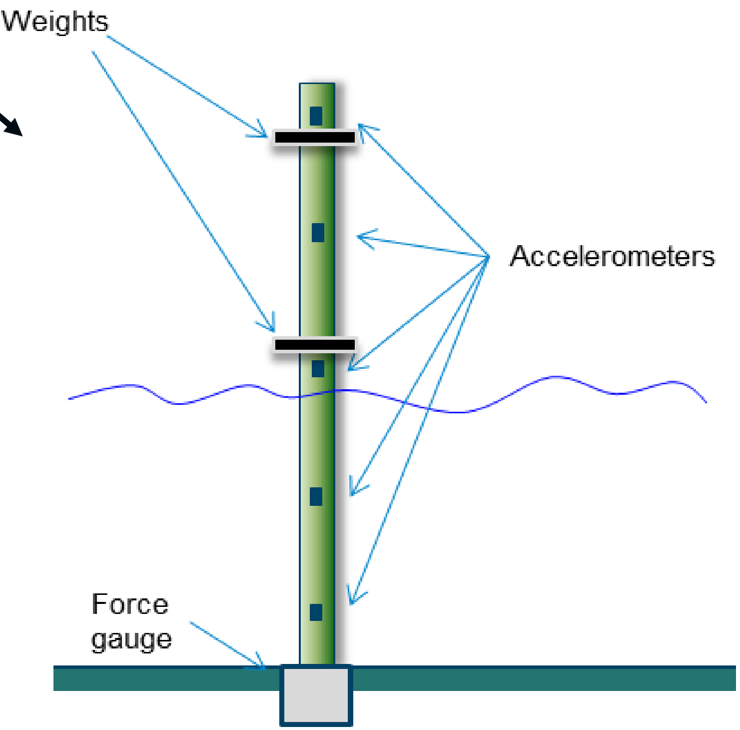
- **Objective**: validate hydrodynamic loads and acceleration response for a fixed, flexible cylinder
- Test Data from **Wave Loads Project:**
  - 3-year project with goal of improving numerical models for wave loads on offshore wind turbines
  - Carried out collaboratively by DTU Wind Energy, DTU Mechanical Engineering, and DHI
  - Performed at shallow-water basin at DHI
  - **Thank you to:** Ole Petersen at DHI and Henrik Bredmose and Michael Borg at DTU for graciously supplying the data and information needed for this phase of the OC5 project.



Test Set-Up



- 1:80 scale, flexible cylinder
- On slope – to create steep waves
- Tests done at two water depths:
  0.51 m and 0.26 m
  (40 and 20 m full scale)
- Measurements used:
  - Wave elevation
  - Acceleration at top mass of cylinder
  - Total hydrodynamic force on cylinder



Tests Simulated

Test #	Wave Type	Water Depth (m)	H/Hs (m)	T/Tp (s)	Gamma	C_A	C_D
1	Regular	0.51	0.090	1.5655		1.22	1.0
2	Regular	0.51	0.118	1.5655		1.22	1.0
3	Irregular	0.51	0.104	1.40	3.3	1.0	1.0
4	Irregular	0.51	0.140	1.55	3.3	1.0	1.0
5	Regular	0.26	0.086	1.565		1.22	1.0
6	Regular	0.26	0.121	1.565		1.22	1.0
7	Irregular	0.26	0.133	1.560	3.3	1.0	1.0

- **7 Datasets were examined:**
  - 4 regular cases
    - 2 water depths
    - 2 wave heights
  - 3 irregular cases
    - 2 water depths
    - 2 wave heights
- **First regular wave case used for calibration**

Summary of Tools and Modeling Approach

Participant	Code	Wave Model (Reg/Irr)	Wave Elevation	Hydro Model	Structural Model	Number DOFs
4Subsea	OrcaFlex	FNPF kinematics	FNPF kinematics	ME	FE, RDS	160 elements 960 DOFs
GE	SAMCEF Wind Turbines (S4WT)	5th Order Stokes/ Linear Airy	Stretching	ME	FE (TS), RD	13 elements 84 DOF
DNV GL-ME	Bladed 4.6	6th and 8th Order SF/ Linear Airy	Measured	ME	FE (TS), MD	8 (CB)
DNV GL-PF	Bladed 4.6	Linear Airy	Measured	1st Order PF	Rigid	N/A
DTU-HAWC2	HAWC2	6th and 8th Order SF/L. Airy & FNPF kinematics	Stretching & FNPF kin.	ME	FE (TS), RDS	20 elements, 126 DOF
DTU-HAWC2-PF	HAWC2	6th and 8th Order SF/L. Airy	Stretching	1st Order PF	FE (TS), RDS	31 elements, 192 DOF
DTU-BEAM	OceanWave3D	FNPF kinematics	FNPF kinematics	ME+Rainey	FE (EB), RD	160 DOFs
IFE	3Dfloat	FNPF kinematics	FNPF kinematics	ME	FE (EB), RDS	62 elements, 378 DOF
IFE-CFD	STAR CCM	CFD	CFD-derived	CFD	Rigid	N/A
IFP-PRI	DeeplinesWind	3rd Ord. SF/ Linear Airy	Measured	ME	FE	200 elements
UC-IHC	IH2VOF	FNPF kinematics	FNPF kinematics	ME	Rigid	N/A
MARINTEK	RIFLEX	2nd Order Stokes & FNPF kinematics	Measured & FNPF kin.	ME	FE(E-B), RDS, FS	167 elements, 1002 DOF
NREL-ME	FAST	2nd Order Stokes & FNPF kinematics	Measured & FNPF kin.	ME	FE (TS), MD	4 (CB)
NREL-PF	FAST	2nd Order Stokes	Measured	2nd Order PF	Rigid	N/A
NTNU-Lin	FEDEM 7.1	Linear Airy	None	ME	FE (EB), RD	13 elements, 84 DOF
NTNU-Stokes5	FEDEM 7.1	5th Order Stokes	None	ME	FE (EB), RD	13 elements, 84 DOF
NTNU-Stream	FEDEM 7.1	Stream Function	None	ME	FE (EB), RD	13 elements, 84 DOF
PoliMi	POLI-HydroWind	2nd Order Stokes	None	ME	FE (EB), RD	23 elements, 69 DOF
SWE	SIMPACK +HydroDyn	2nd Order Stokes	None	ME	FE (TS), MD	50
UOU	UOU + FAST	2nd Order Stokes	None	ME	Rigid	N/A
WavEC	Wavec2Wire	2nd Order Stokes /Linear Airy	Measured	2nd/1st Order PF	Rigid	N/A
WMC	FOCUS6 (PHATAS)	FNPF kinematics	FNPF kinematics	ME	FE (TS), MD	12 (CB)

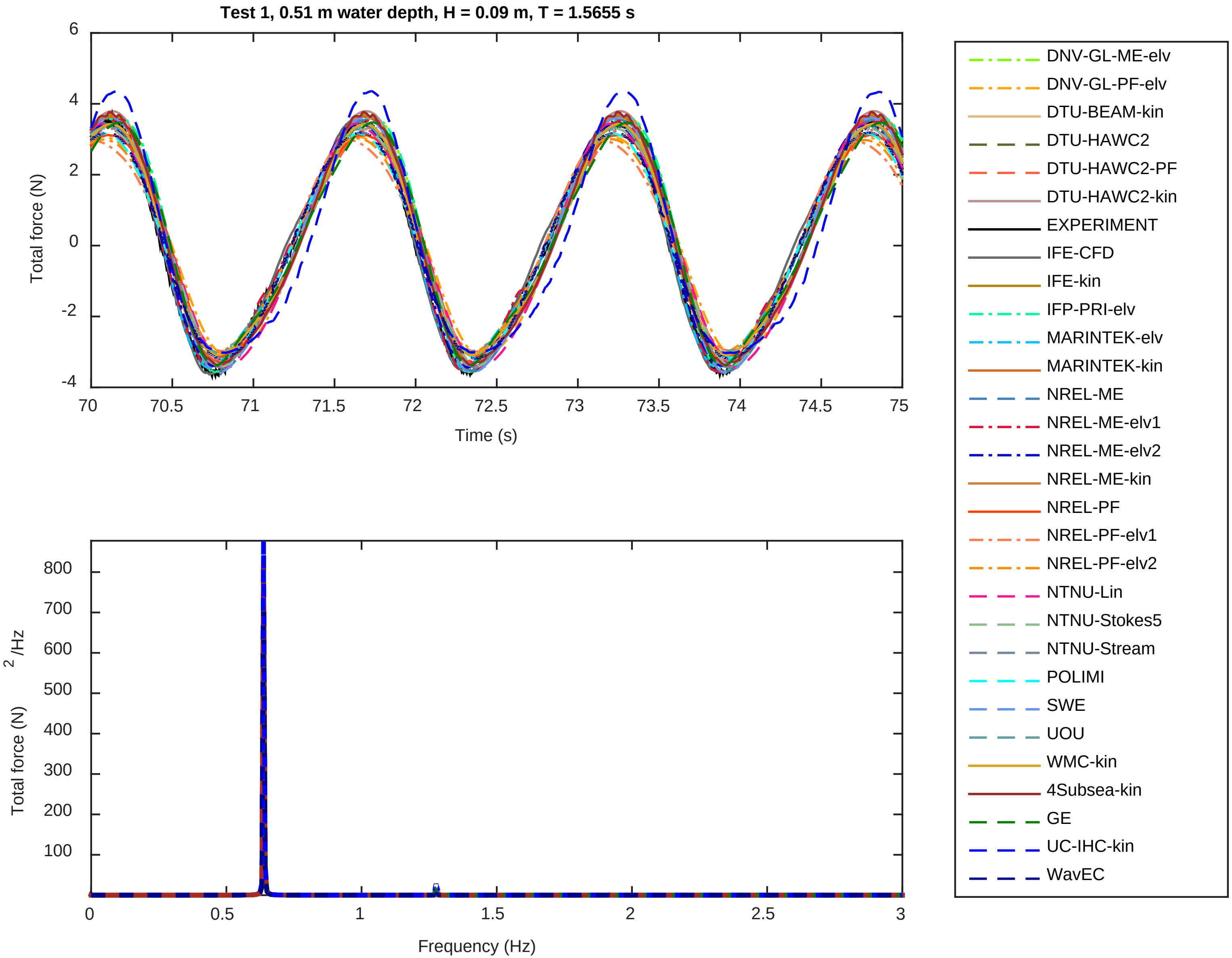
Calibration

- **Group calibrated C_A and C_D coefficients based on Test 1, to get appropriate levels of force**
  - All participants used same values to have consistency in model parameters – to better see differences in modeling approach
- **A C_A value of 1.22 was required, which is larger than expected**
  - Suspect the higher measured loads might be due to reflected waves that were not modeled in the simulation

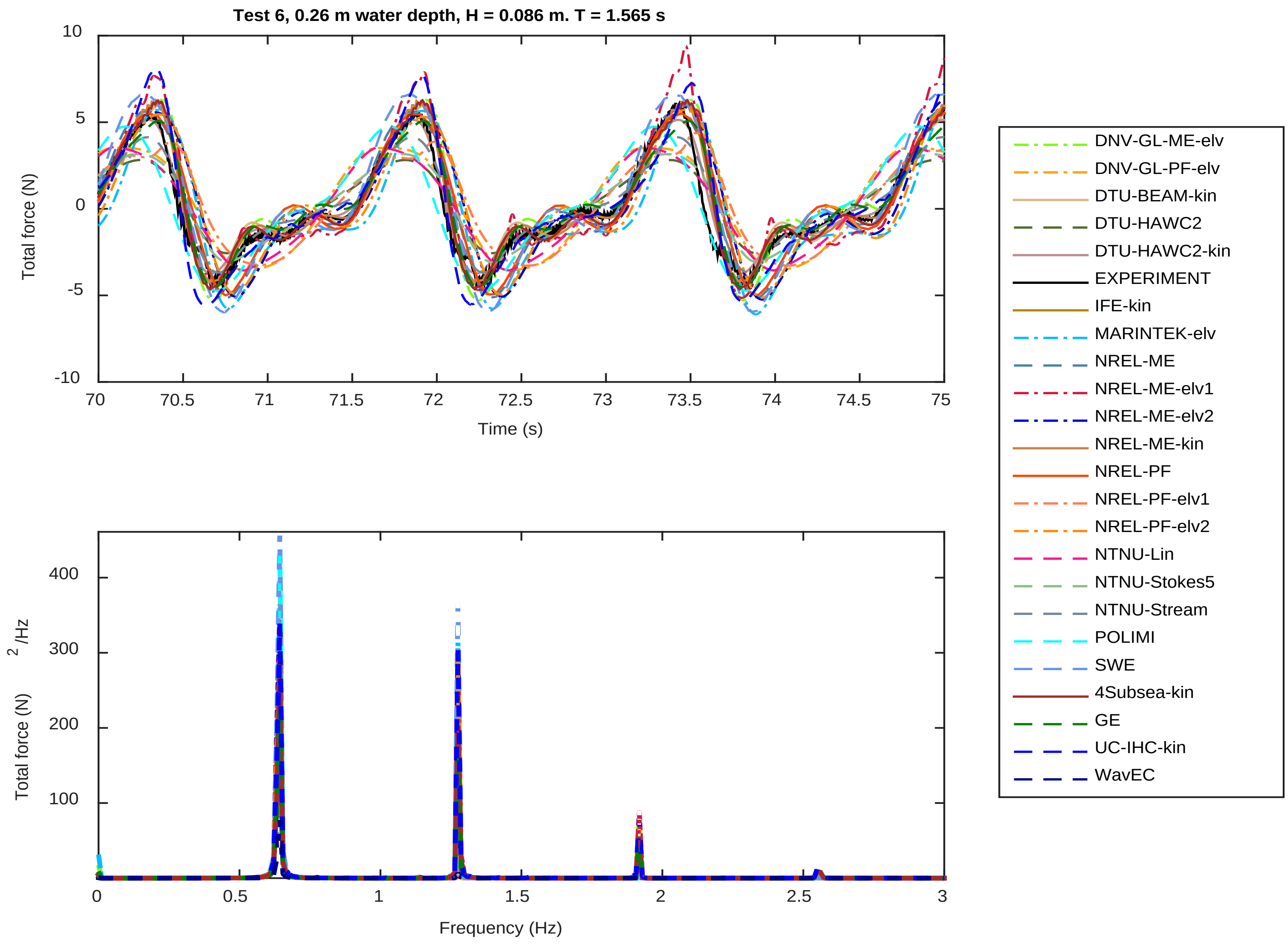
$$F = \frac{1}{2} C_D \rho D u |u| + C_M \rho \frac{\pi D^2}{4} \dot{u}$$

Morison's Equation

Test 1 – Regular Wave – Deeper Water - Force Results

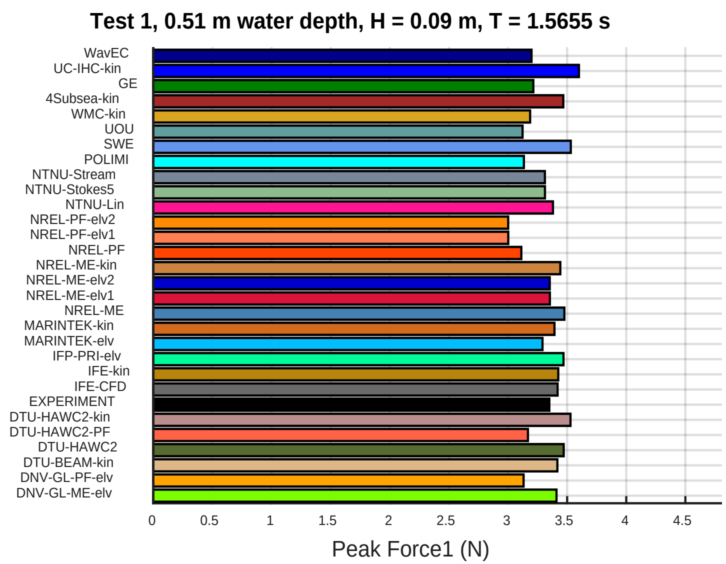


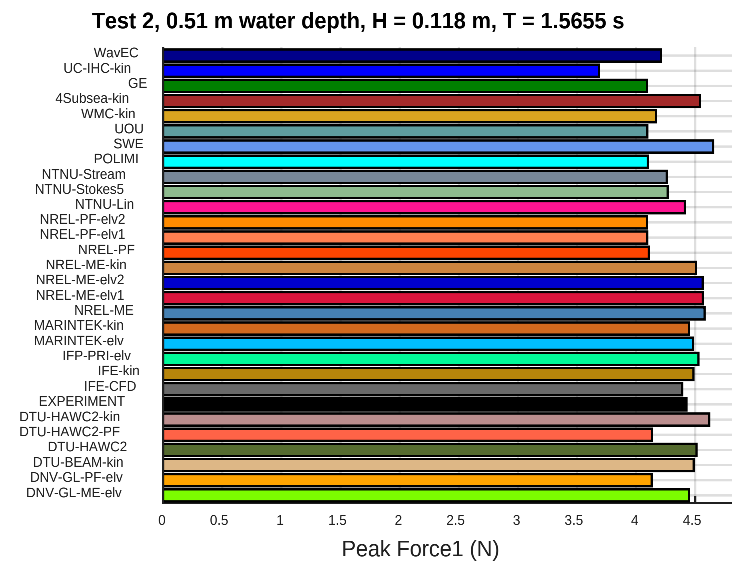
Test 6 – Regular Wave – Shallower Water - Force Results



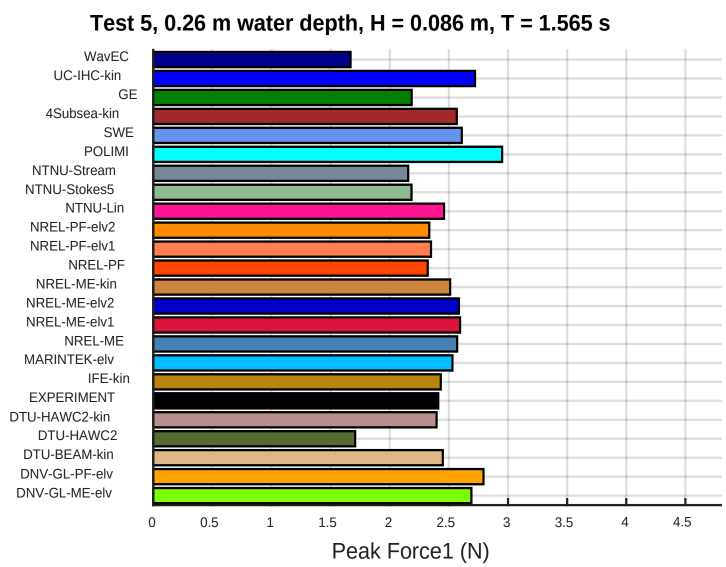
1st Peak Force Component

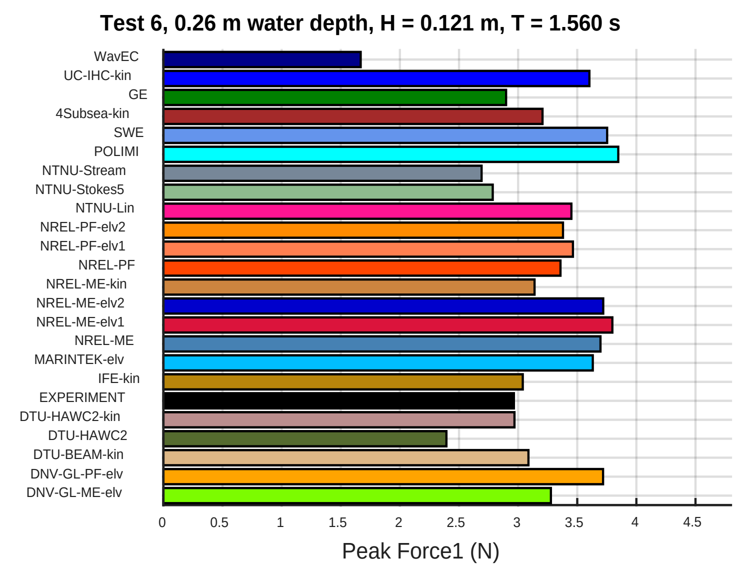
Deeper Water Depth





Shallower Water Depth

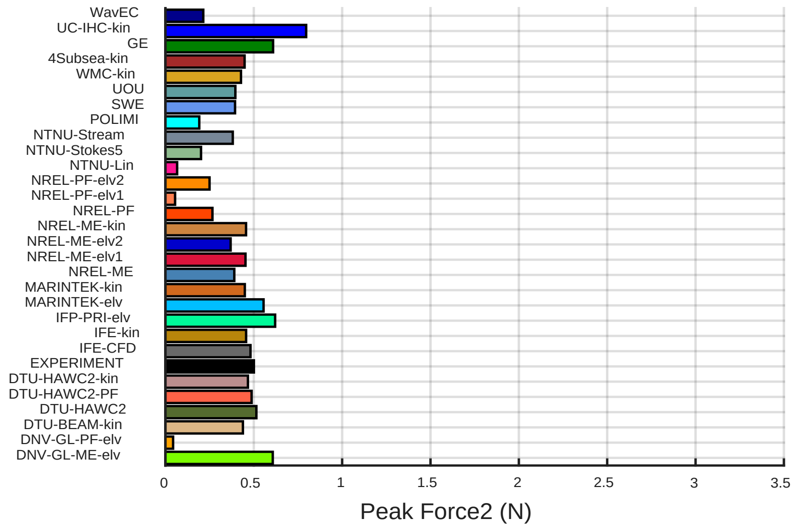




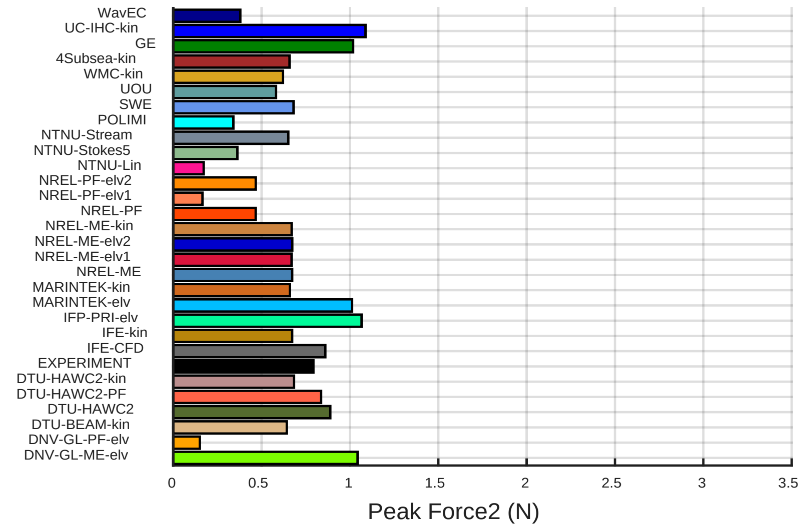
2nd Peak Force Component

Deeper Water Depth

Test 1, 0.51 m water depth, H = 0.09 m, T = 1.5655 s

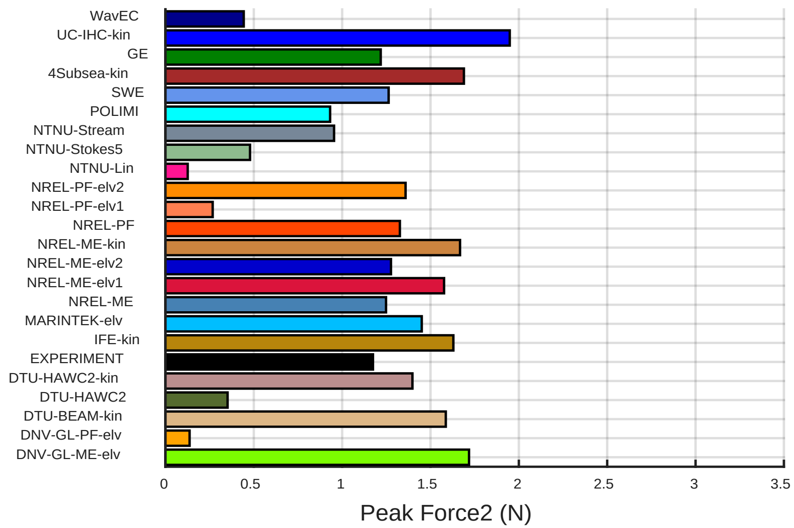


Test 2, 0.51 m water depth, H = 0.118 m, T = 1.5655 s

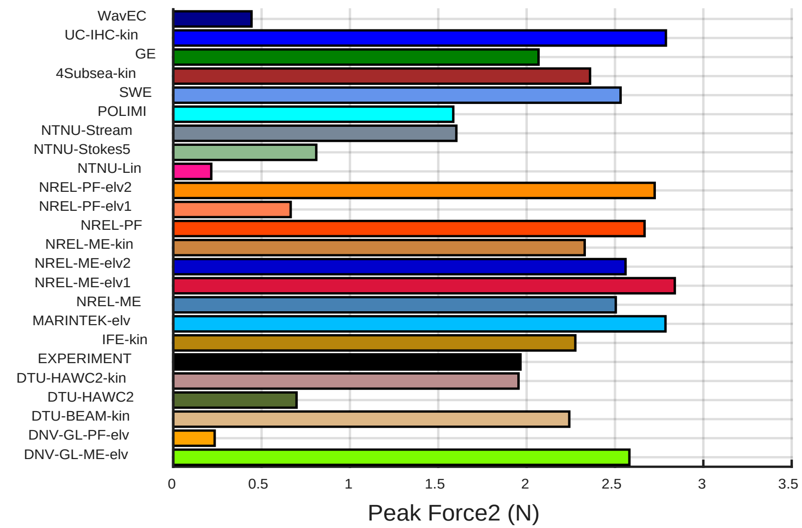


Shallower Water Depth

Test 5, 0.26 m water depth, H = 0.086 m, T = 1.565 s



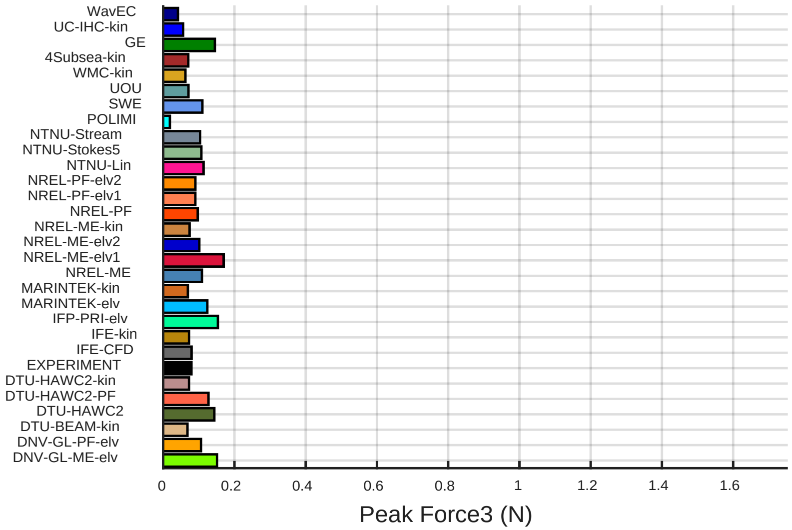
Test 6, 0.26 m water depth, H = 0.121 m, T = 1.560 s



3rd Peak Force Component

Deeper Water Depth

Test 1, 0.51 m water depth, H = 0.09 m, T = 1.5655 s



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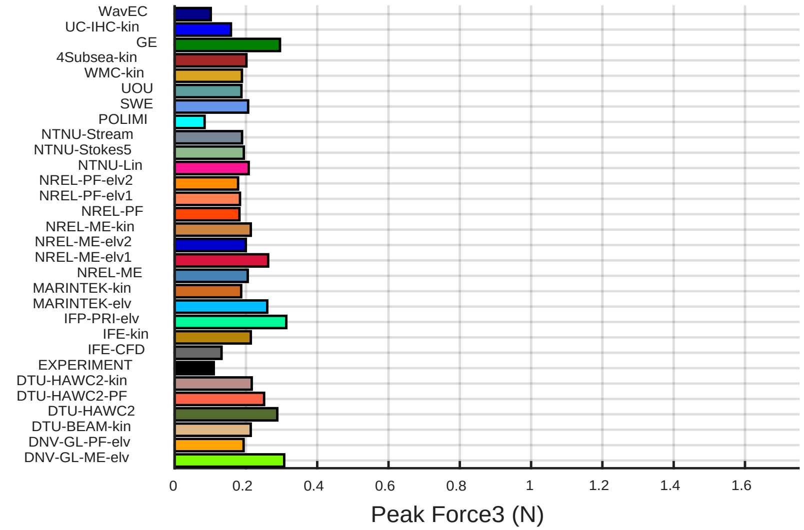

Shallower Water Depth

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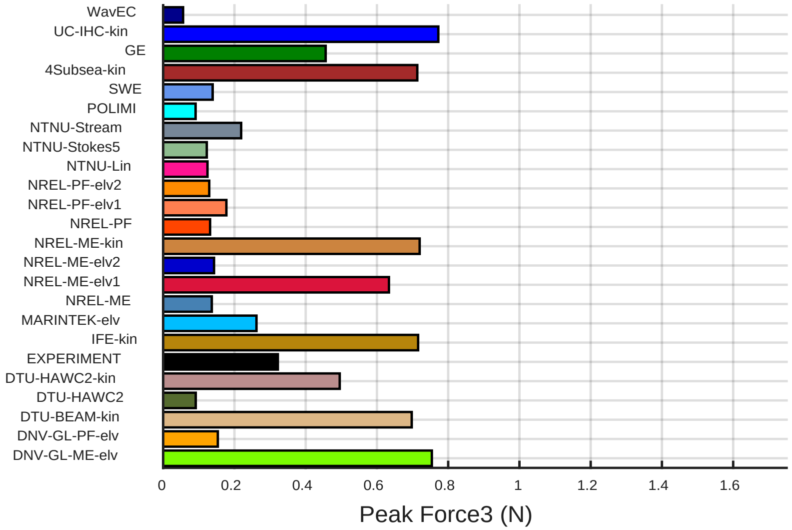

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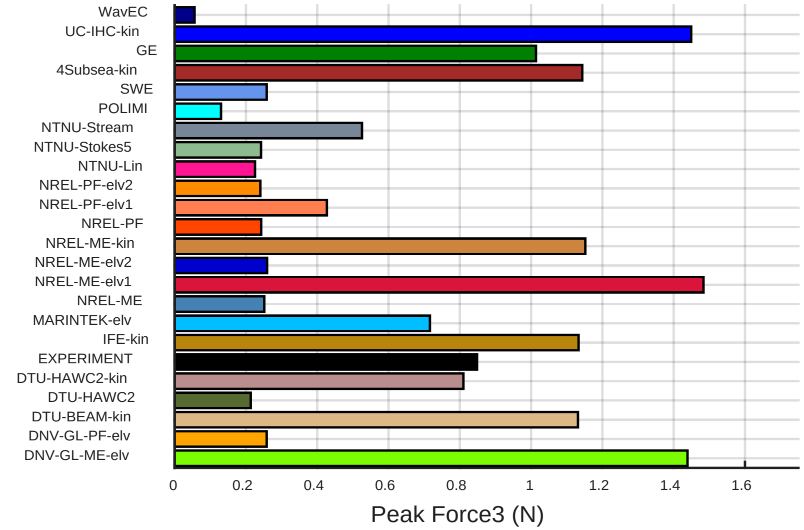
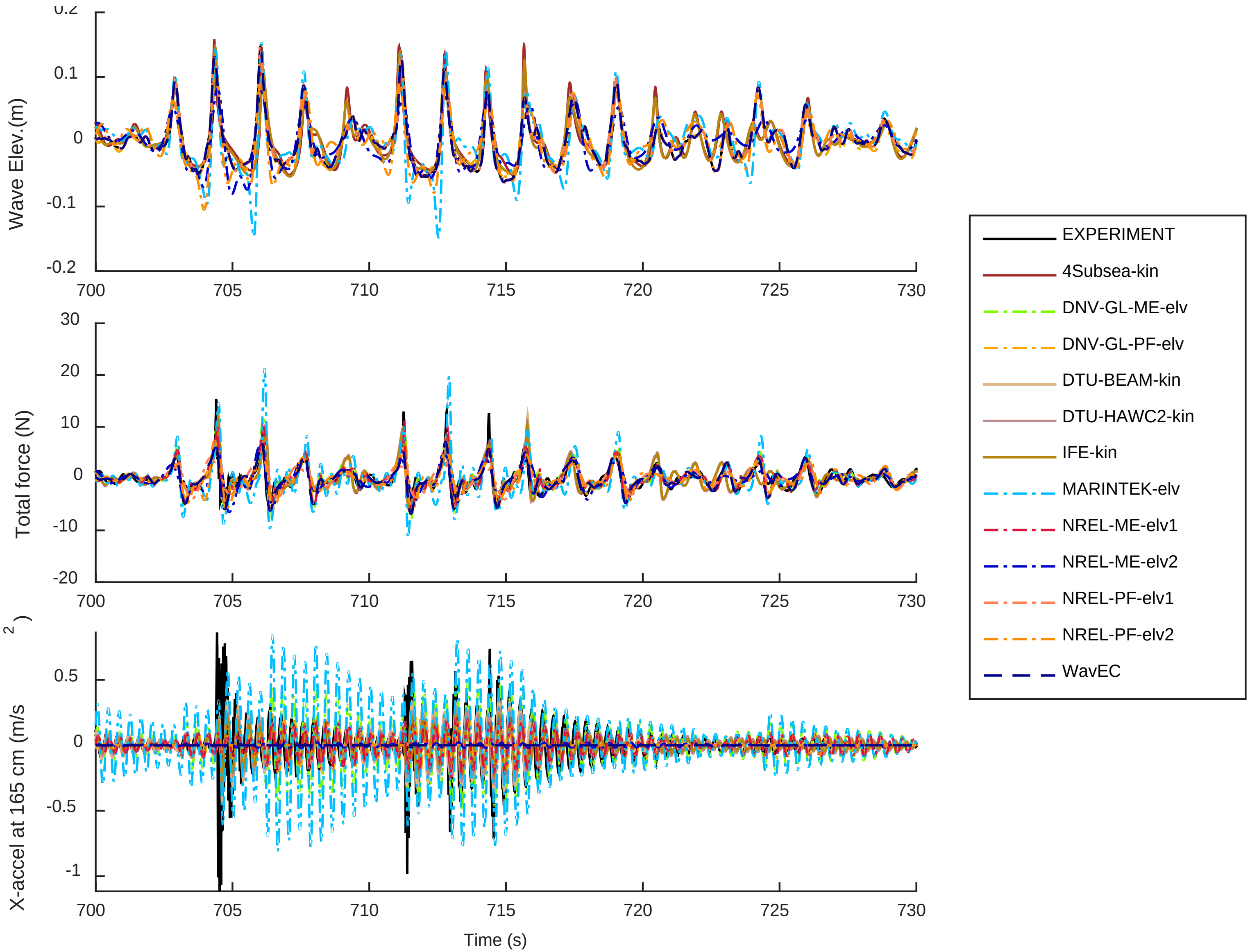
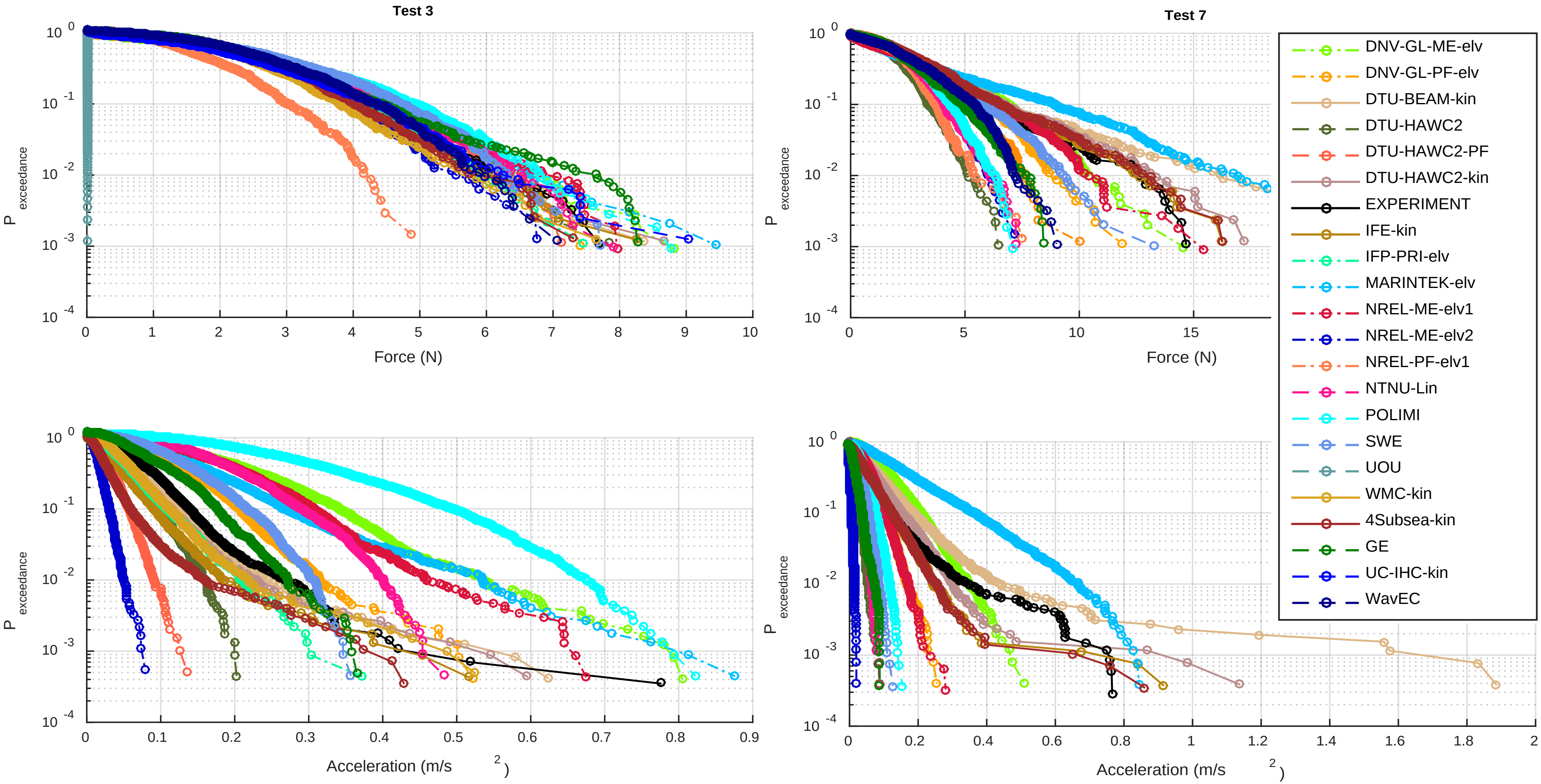


Test 7 – Irregular Wave – Shallower Water



Irregular Waves – Exceedance Probability Plots



Conclusions

- **Higher-order wave theory important in capturing higher-order components of hydrodynamic force**
  - Extreme loads
  - Excitation of structural frequencies
  - Most important in shallow water

- **Sloped seabed creates complex wave kinematics**
  - Standard wave theories cannot account for slope
  - CFD-type analysis might be needed to create wave kinematics for non-flat seabed conditions

- **Majority of offshore wind modeling tools do not presently address breaking waves**
  - Complex wave theories and CFD can accurately model steep waves that will break
  - Need to model the impulsive load that a breaking wave will impart on the structure
  - Some codes are seeking to include this

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Thank You!

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