Comparison of WAMIT with measured wave-induced motions of container ships and bulk carriers, using an adjustment for ship speed

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Incentive

- Calculating wave-induced motions of a large number of ships
- WAMIT is well-suited to batch-processing ship motions at zero speed
- Consider adjusting WAMIT to be able to batch-process ship motions at forward speed
- For example: world shipping fleet contains around 25000 ships over 150 m, in the following classes:
    - Dry bulk carriers
    - Liquid bulk carriers
    - Container ships
    - Car carriers
    - LNG carriers
    - Cruise ships
- Can we calculate wave-induced motion RAOs of all of these?

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What about other software?

- **Rankine-source seakeeping codes (GL Rankine from TUHH, SEACAL from Marin, WASIM from DNV)**
  - **good accuracy but computationally intensive (time-domain)**
  - **stability issues with waterline panels, transom sterns, short wavelengths**
  - **difficult to batch-process**
- **CFD codes (FINE/Marine from Numeca, Star-CCM+ from Siemens)**
  - **similar benefits and drawbacks to Rankine-source**
- **Strip theory codes (PDStrip from TUHH, SEAWAY from TU Delft)**
  - **may not be accurate across all ship types**
  - **difficult to batch process.**
- **Other zero-speed Green function codes (HydroSTAR from BV, Nemoh/Capytaine from ECN et al., ShipMo3D from ProteusDS, VERES3D from SINTEF)**
  - **may also be good, but I'm more experienced with WAMIT.**

WAMIT software

- **Zero-speed only! Forward-speed Green's function version (TIMIT) is no longer publicly available**
- **Very efficient solver, uses hull symmetry, quickly calculates wave loads and hydrodynamic coefficients for a 5000-panel hull**
- **Robust solver, irregular frequencies are well handled**
- **Easily parallelizable for multi-core machines**
- **Can be batch-processed using MATLAB or Python scripting**
- **Zero-speed motion RAOs extensively validated in OMAE (2015), MASHCON (2019) and other articles**
- **Zero-speed wave loads and hydrodynamic coefficients extensively validated for moored ships at wave-exposed berths (in combination with MoorMotions)**
- **Used by Curtin University and Perth Hydro for a wide variety of hull shapes over many years.**

Relevance to MASHCON

- **Ship UKC in shallow water**
- **Fills gaps in the MASHCON 2019 ship motion code benchmarking paper: DTC wave-induced motions**
- **Compile shallow-water validation cases for this and other codes.**

Gaps in MASHCON 2019 paper

Wave-induced motions of the Duisburg Test Case container ship in shallow water

- **Cases CW2 and CW5 were "blind", with no model test data available to compare the codes with. CW2 and CW5 model test results have now been post-processed by Flanders Hydraulics and University of Ghent (thanks Guillaume…) and are included in this MASHCON 2025 paper.**
- **Forward-speed results were given for HydroSTAR (using zero-speed Green's functions), but not WAMIT. WAMIT forward-speed data has now been calculated for forward-speed cases and included in this paper.**

The method

- The ship is assumed to oscillate at the wave *encounter frequency*
- Added mass and damping are calculated by WAMIT at the encounter frequency
- Wave loads are calculated by WAMIT at the correct *wave frequency*
- Added mass, damping and wave load coefficients are read into MATLAB
- Additional viscous roll coefficients due to bilge keels, eddy damping, hull lift and forward speed effect are calculated in MATLAB
- Additional roll moments due to fin stabilizers (for cruise ships) are calculated in MATLAB. These are assumed nonlinear with wave height, but sinusoidal in time
- The resulting coupled 6-DoF equation of motion is solved for the 6-DoF motion amplitudes and phases.

The rationale

- **Large ocean-going ships tend to operate at low Froude numbers (typically 0.1 to 0.2). This means that ship-generated waves are small compared to the medium-to-large ocean waves that are of most interest in deep water. In shallow water, it is nice to be able to (artificially) de-couple squat and wave-induced motions.**
- **Wave loads are sensitive to wavelength, with humps and hollows according to the wavelength/shiplength ratio. It is important to use the correct wavelength.**
- **The principal component of wave loads on ships is the Froude-Kriloff component, found by integrating the pressure field of the *undisturbed* wave pattern over the surface of the ship. This component is unaffected by ship speed.**

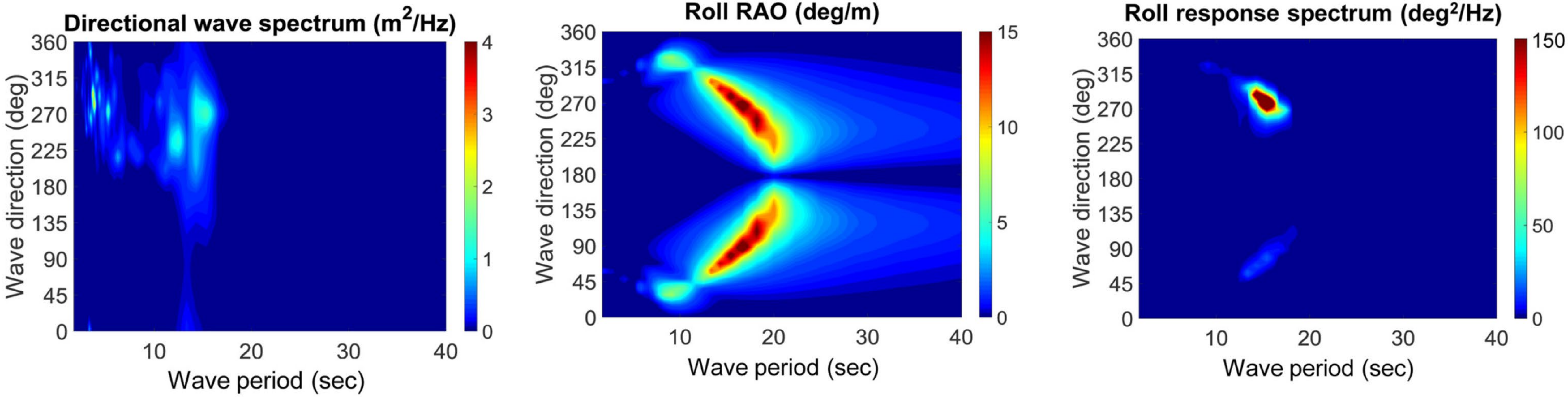
The maths

$$\sum_{k=1}^{6}\left[M_{jk}+A_{jk}\right]\ddot{x}_k+\sum_{k=1}^{6}B_{jk}\dot{x}_k+\sum_{k=1}^{6}C_{jk}x_k=Re\left\{X_j e^{i\omega_0 t}\right\}\ ;\ j=1..6$$

A_{jk}	Hydrodynamic added mass matrix
B_{jk}	Hydrodynamic damping matrix
C_{jk}	Hydrostatic restoring coefficient matrix
M_{jk}	Mass matrix
X_j	Wave load complex amplitude
ω_0	Wave frequency (rad/s)

Including viscous roll damping

Full-scale trials on container ships and offshore vessels were used to validate and tune Ikeda's viscous roll damping components. The resulting MATLAB code has been used in this study.



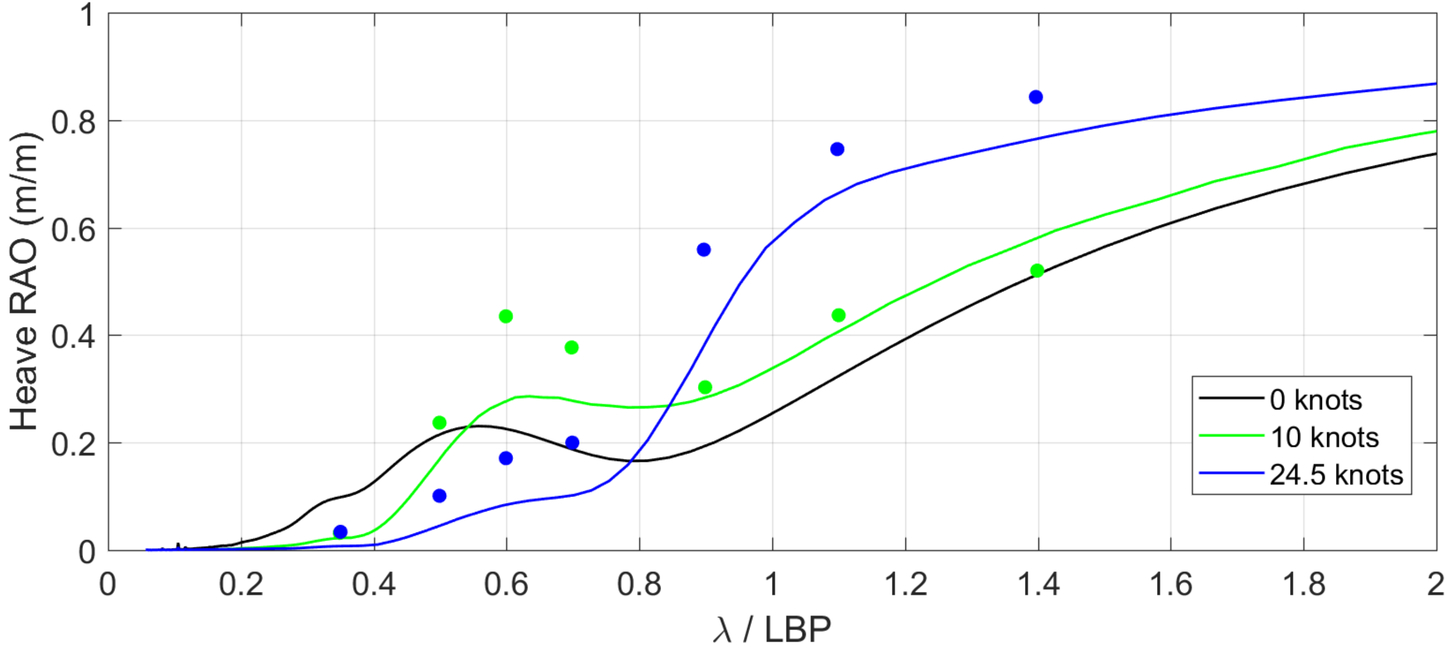
From *Ha, J.-H., Gourlay, T.P. (2018) Full-scale measurements and method validation of container ship wave-induced motions at the Port of Fremantle, JWPCOE*.

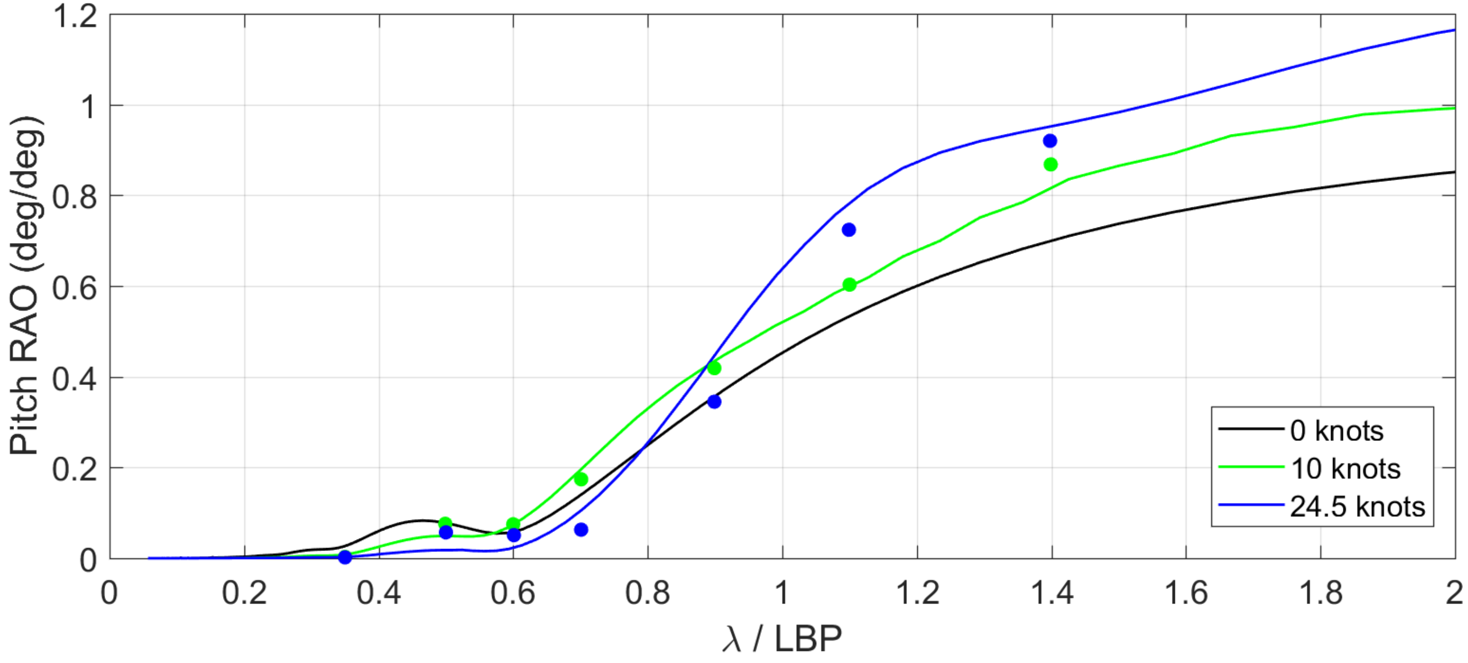
Validation cases

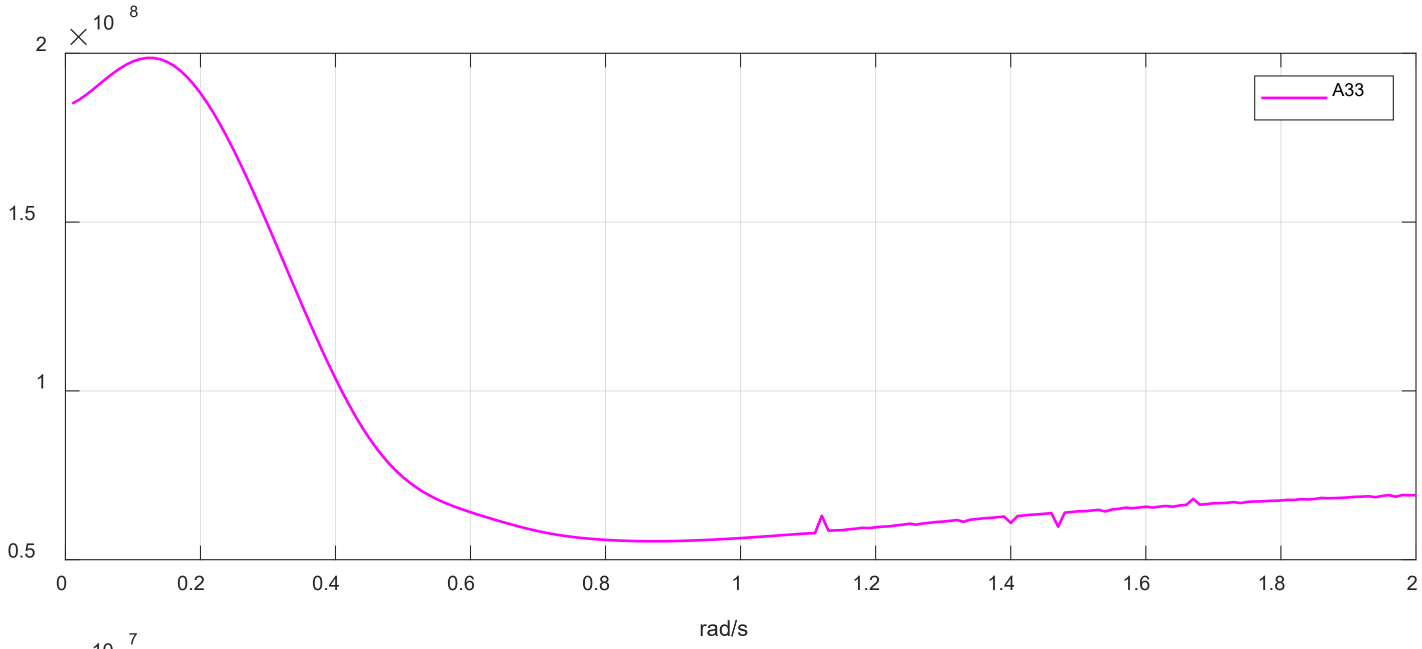
Validation cases presented in the paper include:

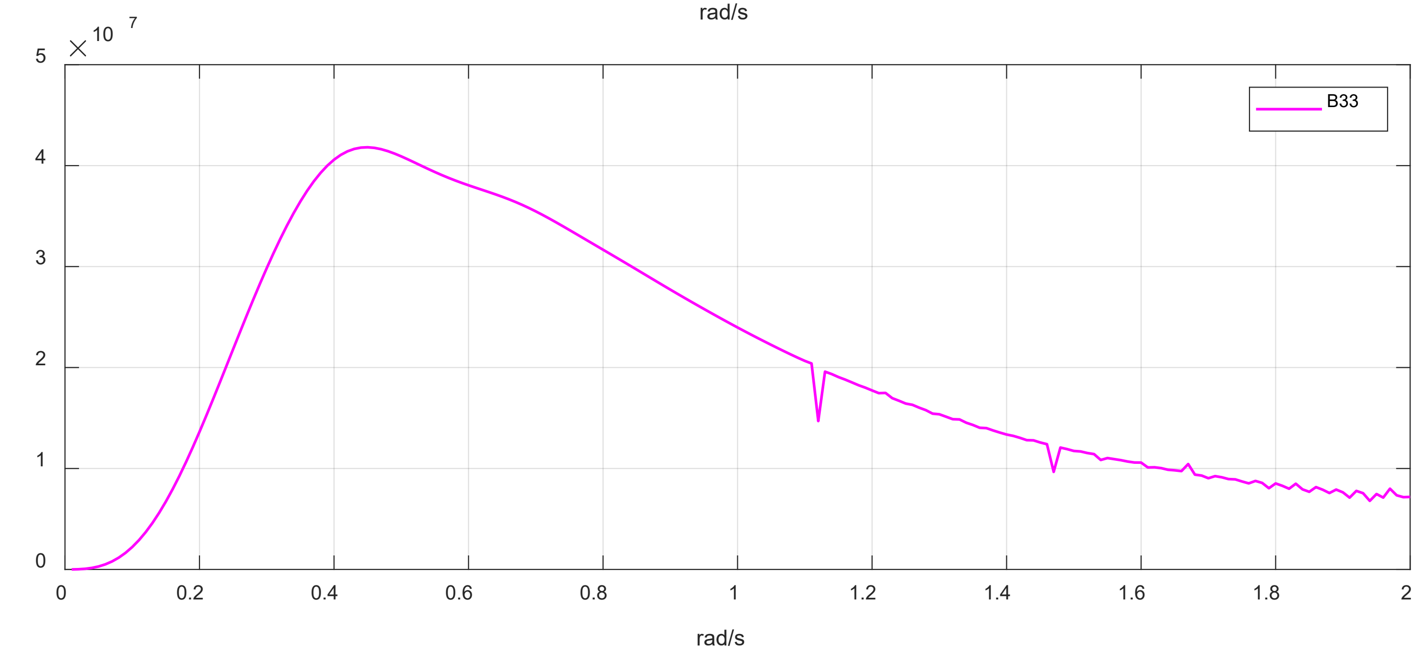
- **190 m LOA bulk carrier "Ship G", tested in shallow water at Flanders Hydraulics**
- **200 m LOA container ship "Ship F", tested in shallow water at Flanders Hydraulics**
- **284 m LOA container ship "Flokstra 1974", tested in deep water at Marin**
- **300 m LOA container ship "Ship D", tested in shallow water at Flanders Hydraulics**
- **373 m LOA container ship "DTC", tested in shallow water at Flanders Hydraulics**

284 m container ship, head sea heave and pitch





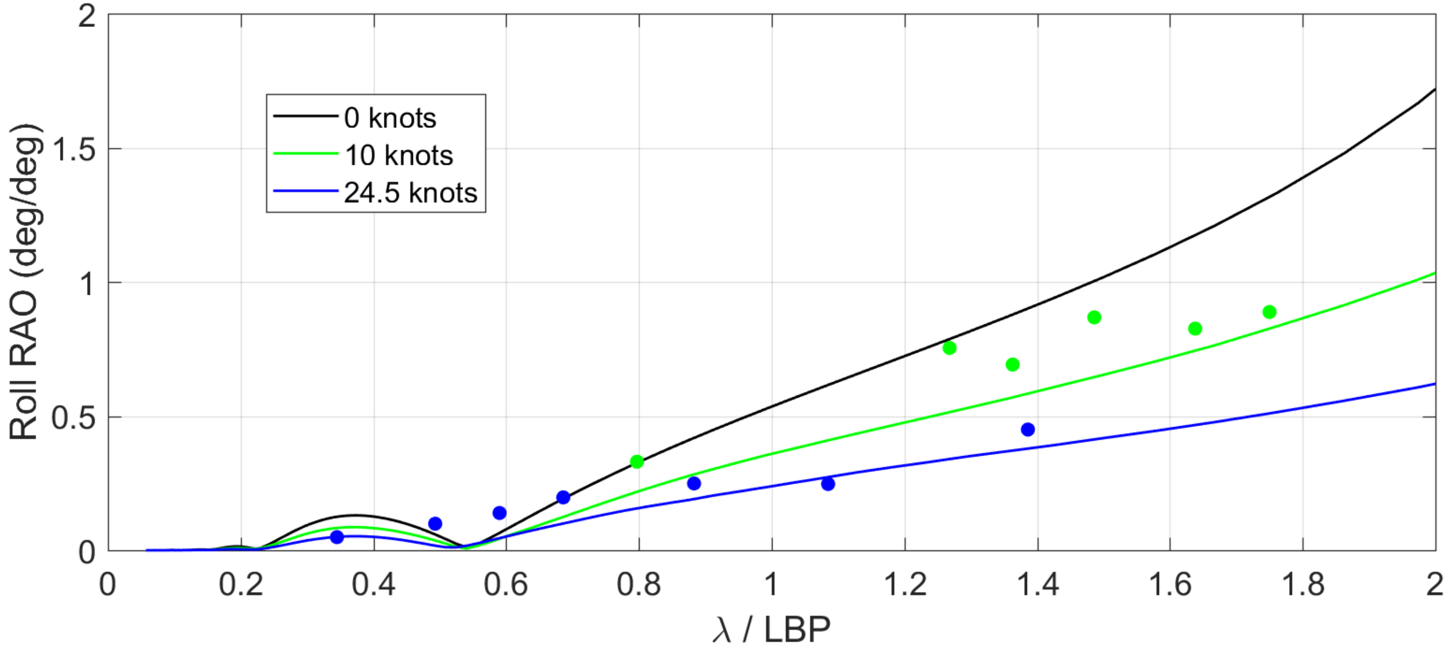


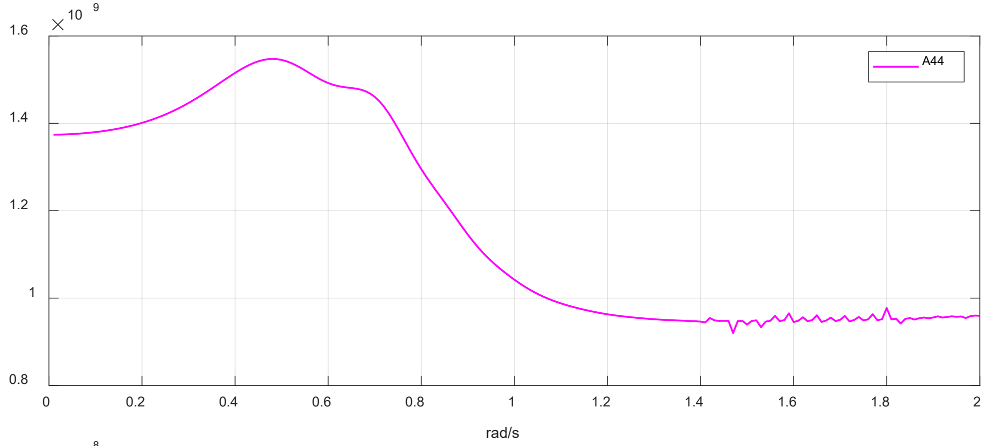


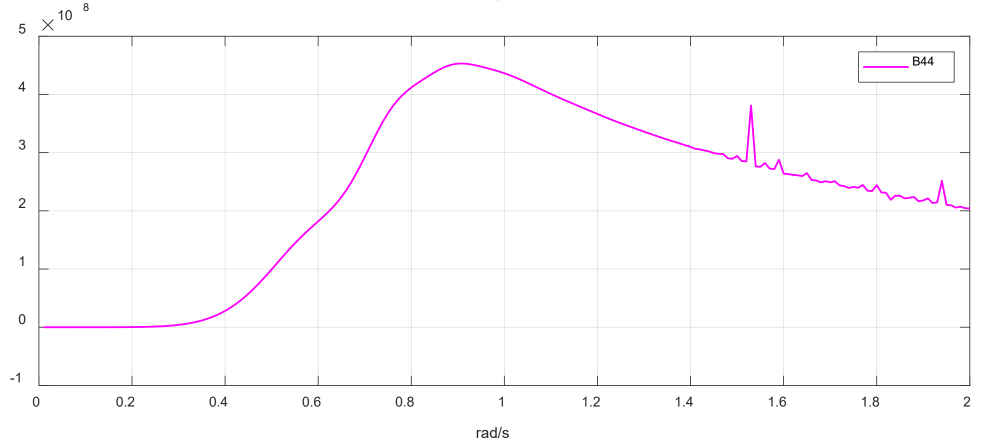
Effect of ship speed

- **At λ / LBP = 1.4, wave frequency = 0.4 rad/s, speed increases encounter frequency, decreases heave damping and increases motions.**
- **At λ / LBP = 0.4, wave frequency = 0.8 rad/s, speed increases heave added mass and decreases motions. Added mass important at high frequency.**

284 m container ship, bow-quartering seas, roll motions







- **At λ / LBP = 1.4, wave frequency = 0.4 rad/s, speed increases encounter frequency and increases inviscid roll damping**
- **Speed also increases viscous roll damping**
- **Roll motions are reduced.**

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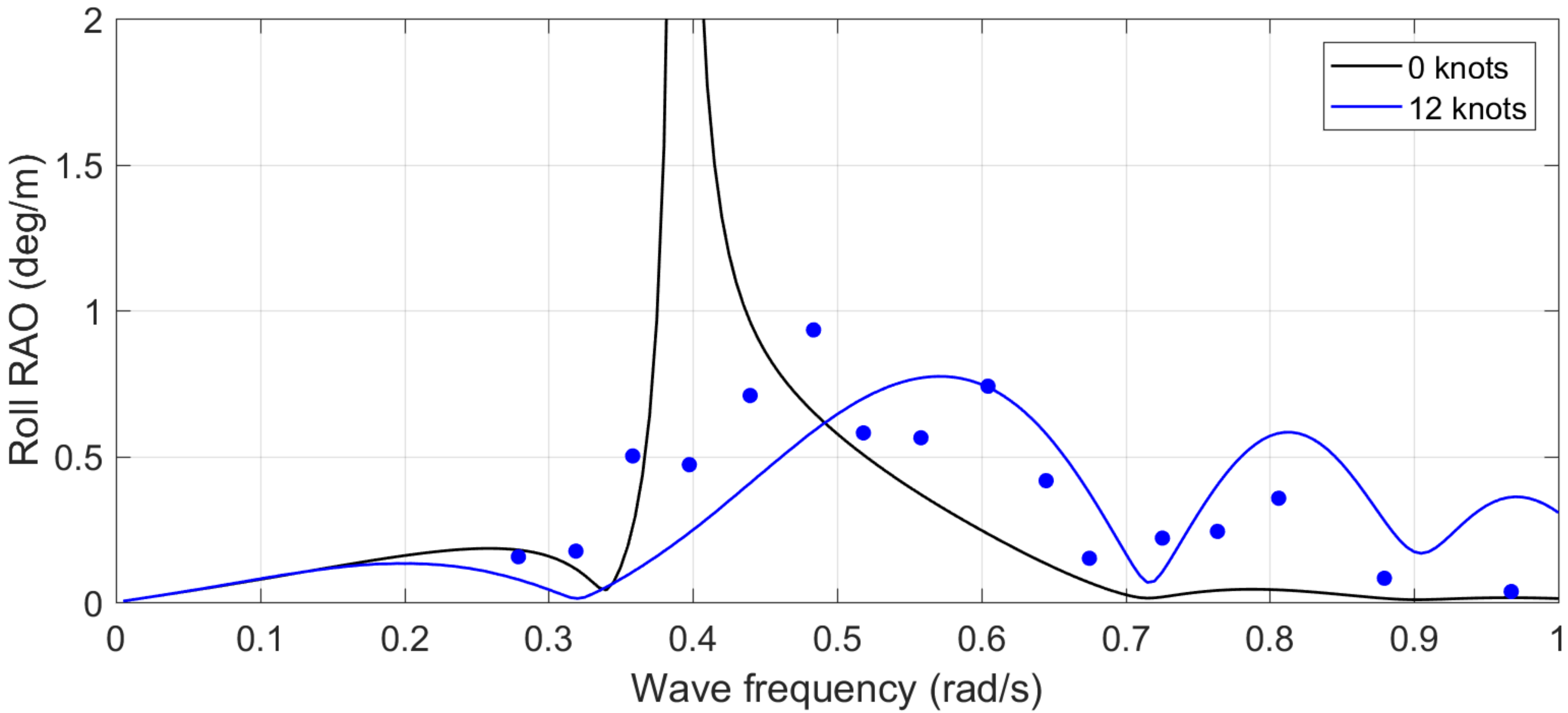
300 m container ship, waves 10° off-stern, roll



- **Speed effect very important for inviscid and viscous damping, and encounter frequencies in following seas**

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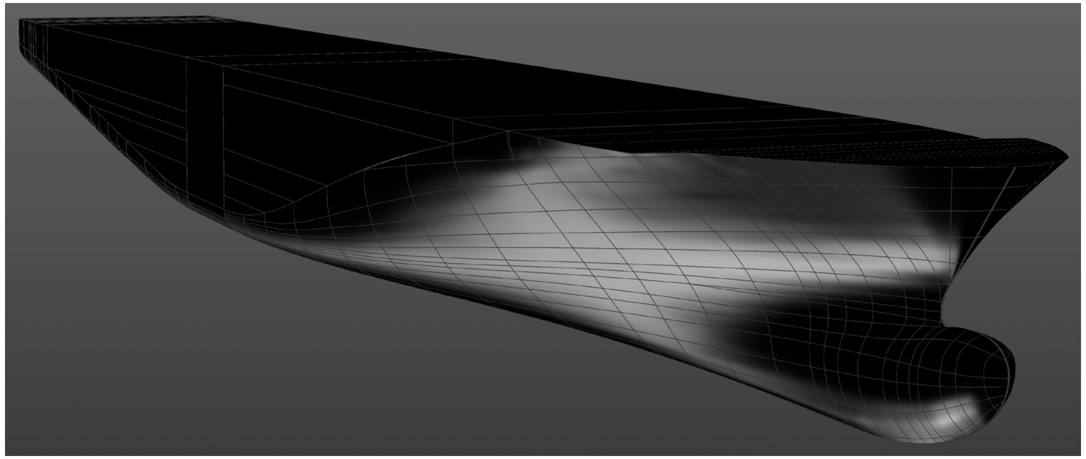
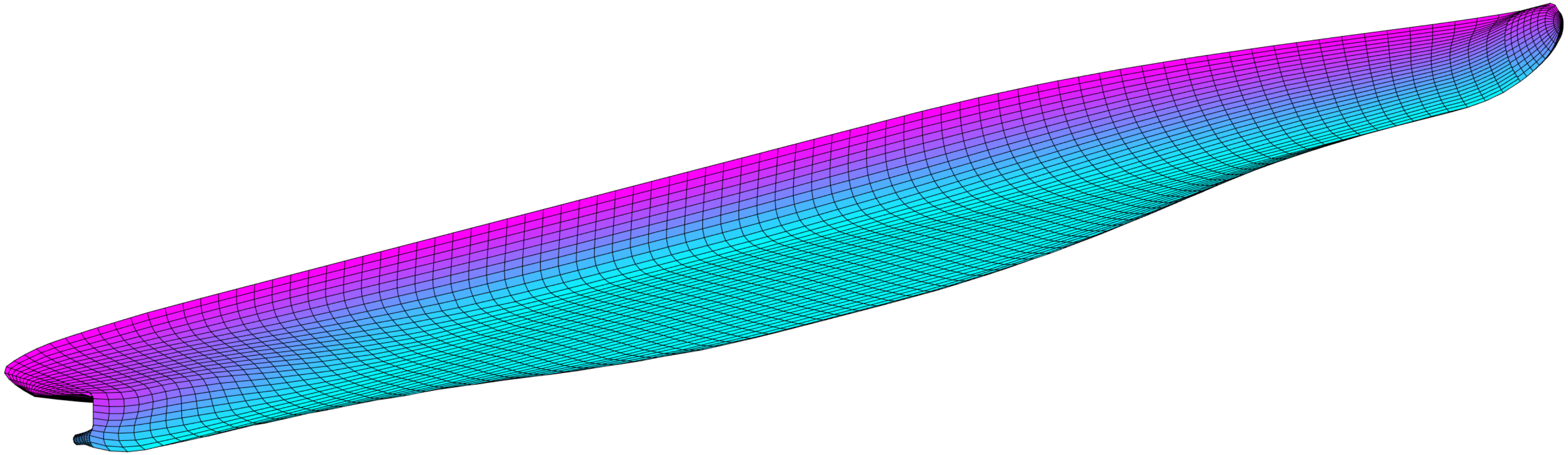
Duisburg Test Case, MASHCON 2019



DELFTship render of DTC



4680-panel hull mesh for WAMIT

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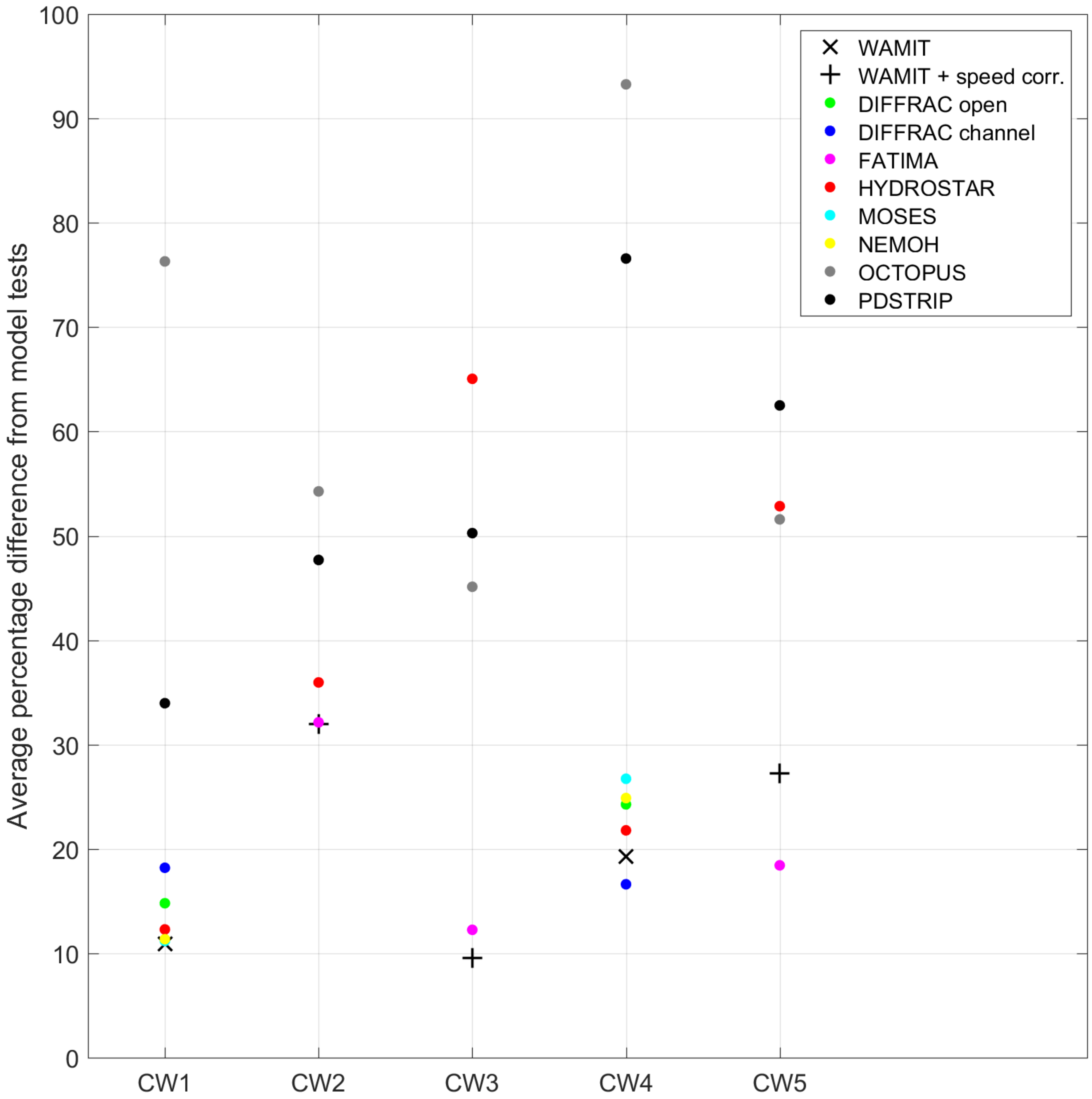
DTC container ship, head seas

Test case	Static UKC (% draft)	Speed (full-scale)	Wave height (full-scale)	Wave period (full-scale)
CW1	100%	0 knots	4.86 m	13.0 s
CW2	100%	6 knots	5.55 m	13.0 s
CW3	100%	16 knots	5.56 m	13.0 s
CW4	20%	0 knots	1.98 m	15.7 s
CW5	20%	6 knots	1.90 m	15.7 s

DTC container ship, head seas



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Thank you for your attention

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