

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?



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

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

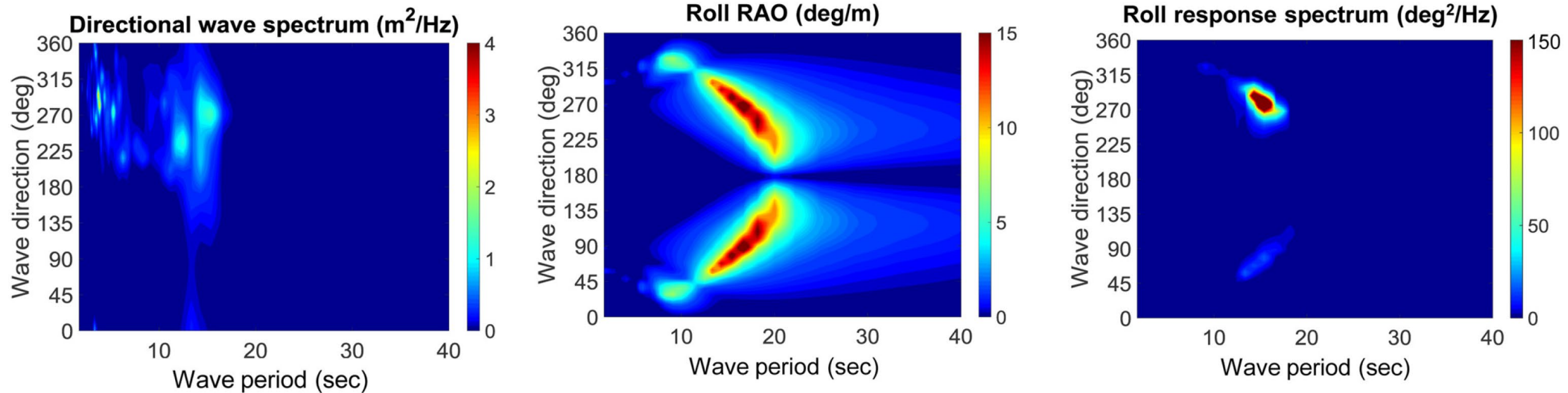
A_{jk}	Hydrodynamic added mass matrix
B_{jk}	Hydrodynamic damping matrix
C_{jk}	Hydrostatic restoring coefficient matrix
M_{jk}	Mass matrix
X_j	Wave load complex amplitude
ω_0	Wave frequency (<u>rad</u> /s)

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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.



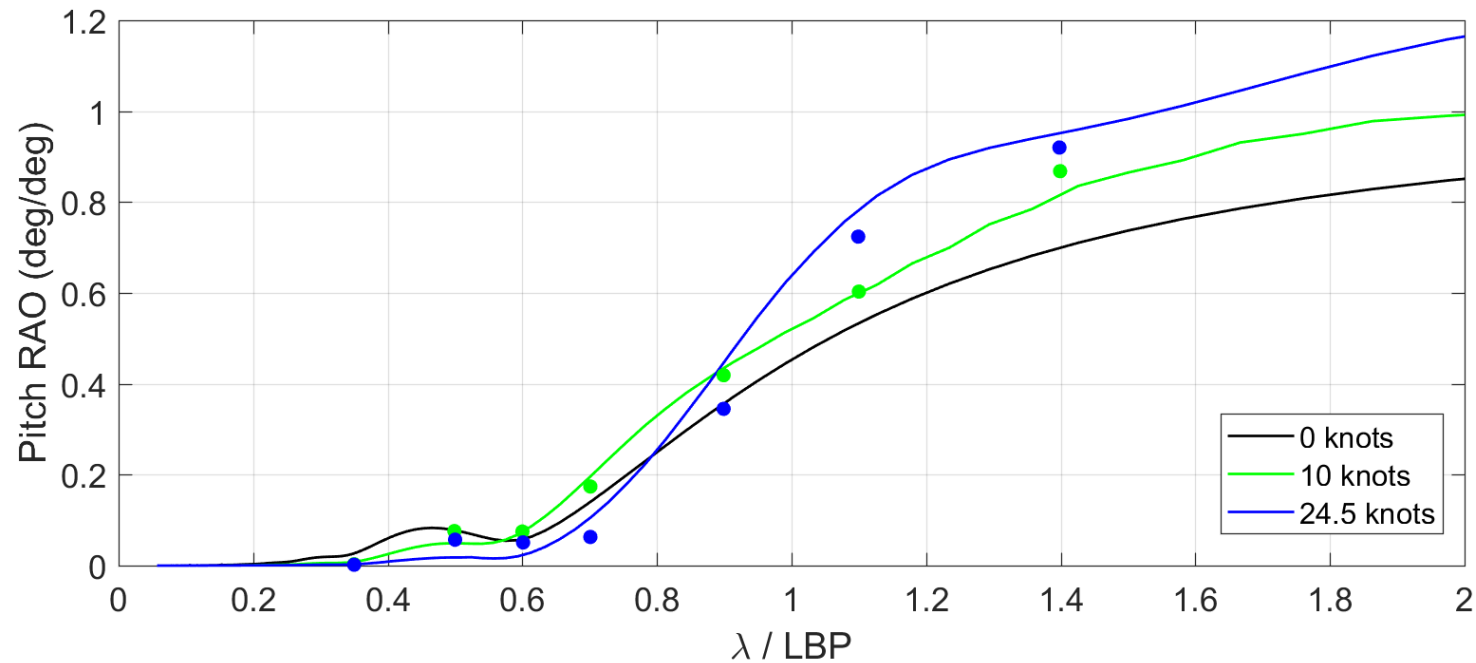
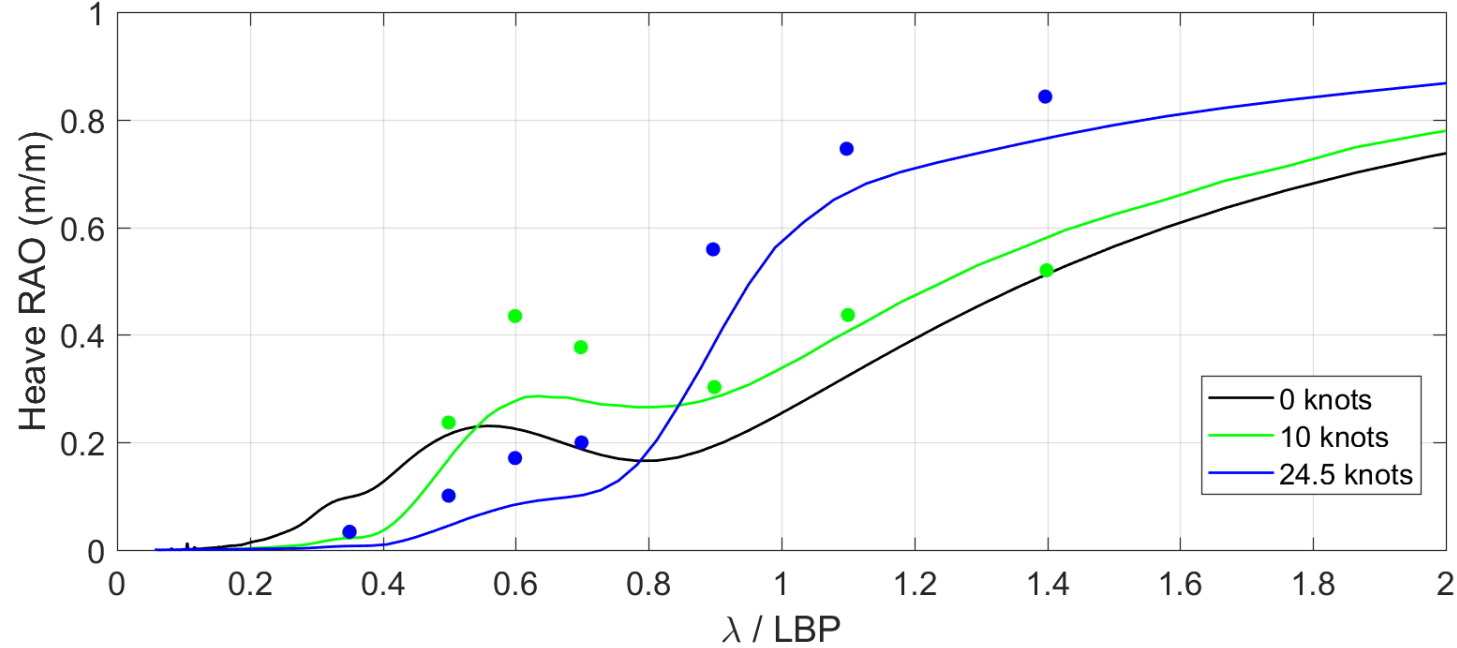
Validation cases

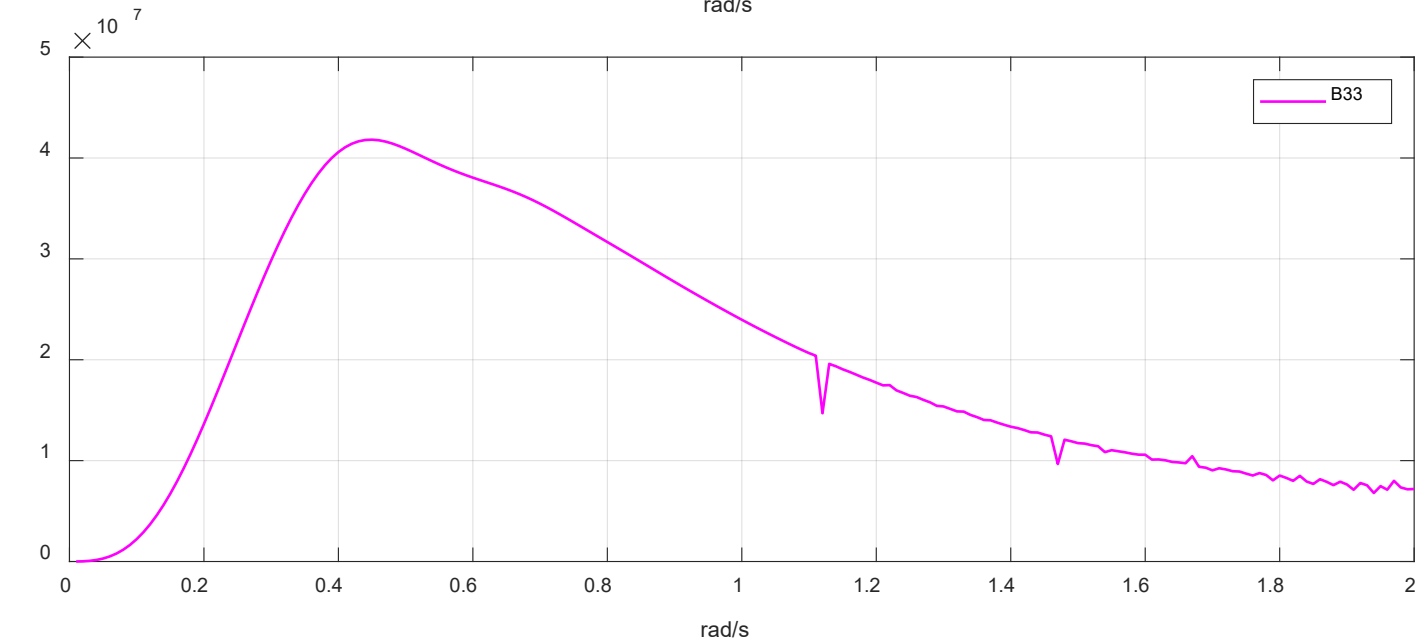
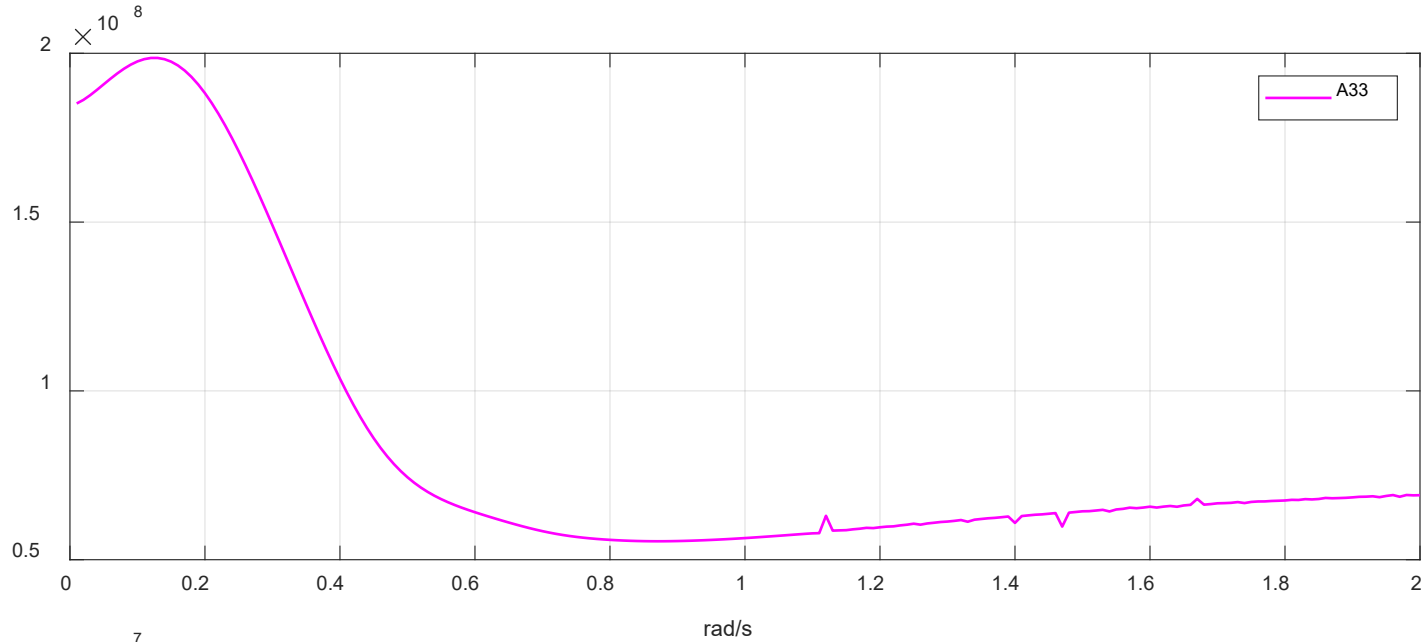
Validation cases presented in the paper include:

- **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



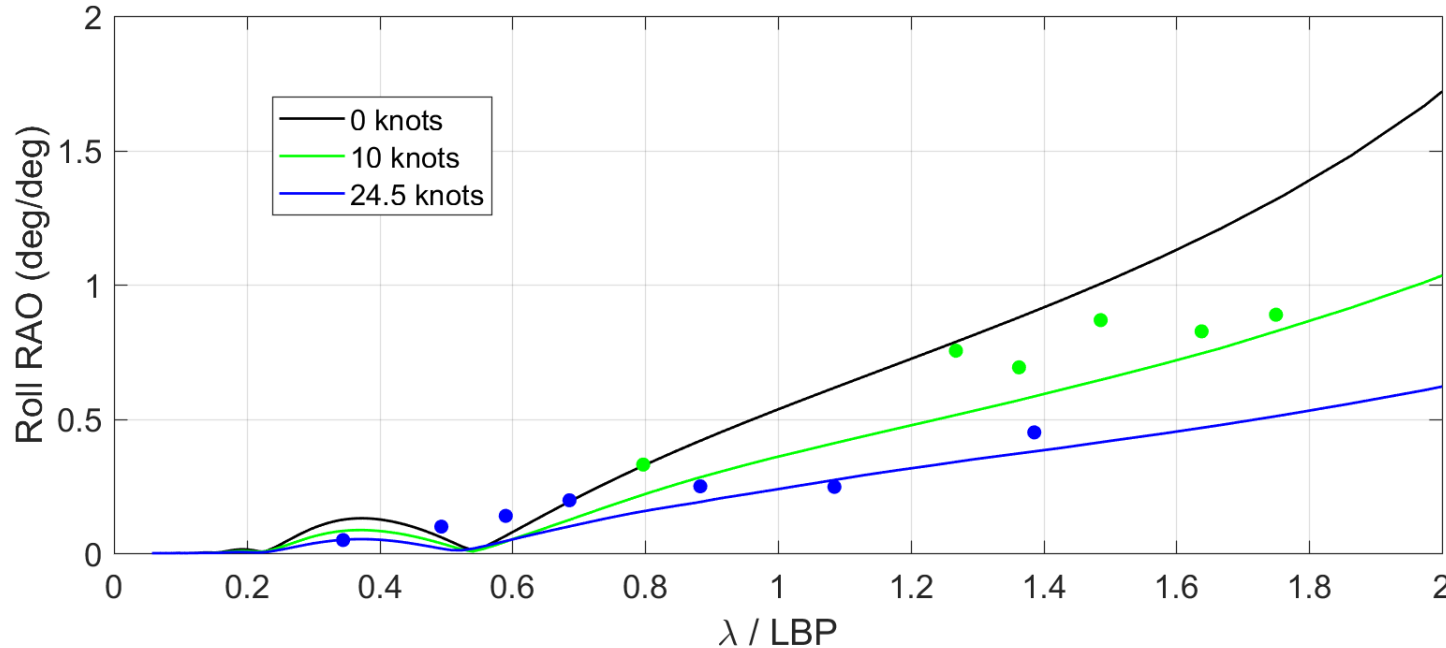


Effect of ship speed

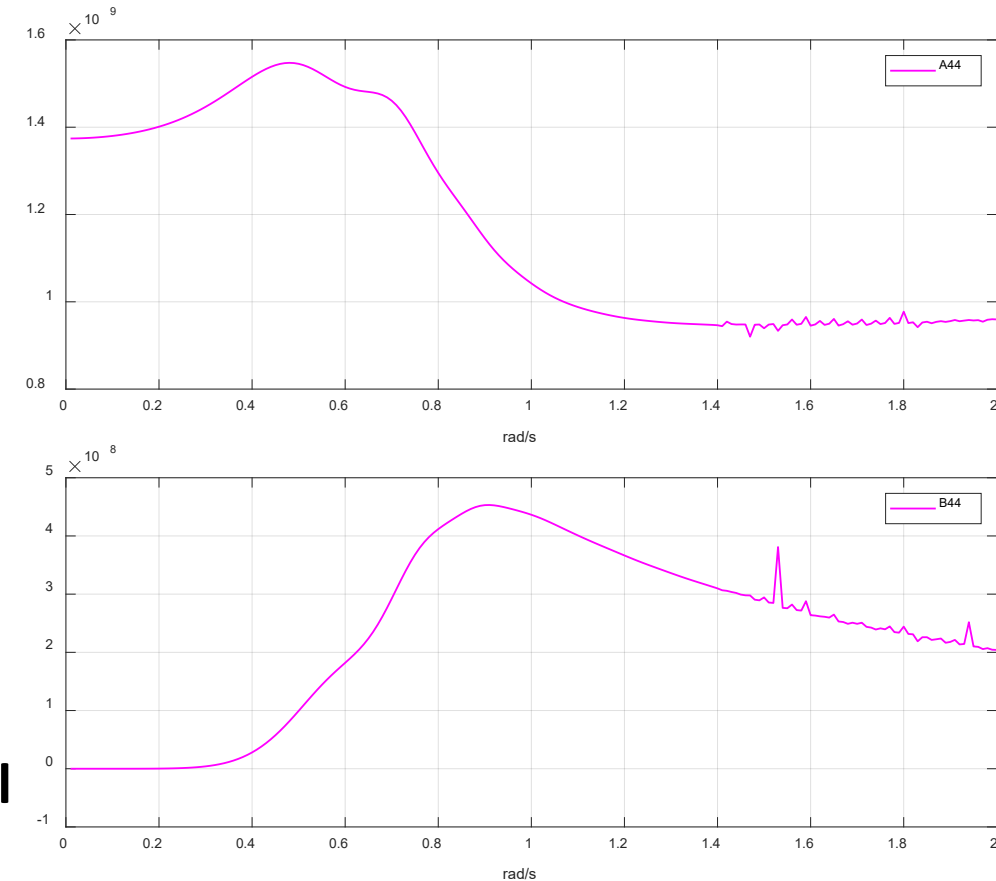
- At $\lambda / \text{LBP} = 1.4$, wave frequency = 0.4 rad/s, speed increases encounter frequency, decreases heave damping and increases motions.
- At $\lambda / \text{LBP} = 0.4$, wave frequency = 0.8 rad/s, speed increases heave added mass and decreases motions. Added mass important at high frequency.



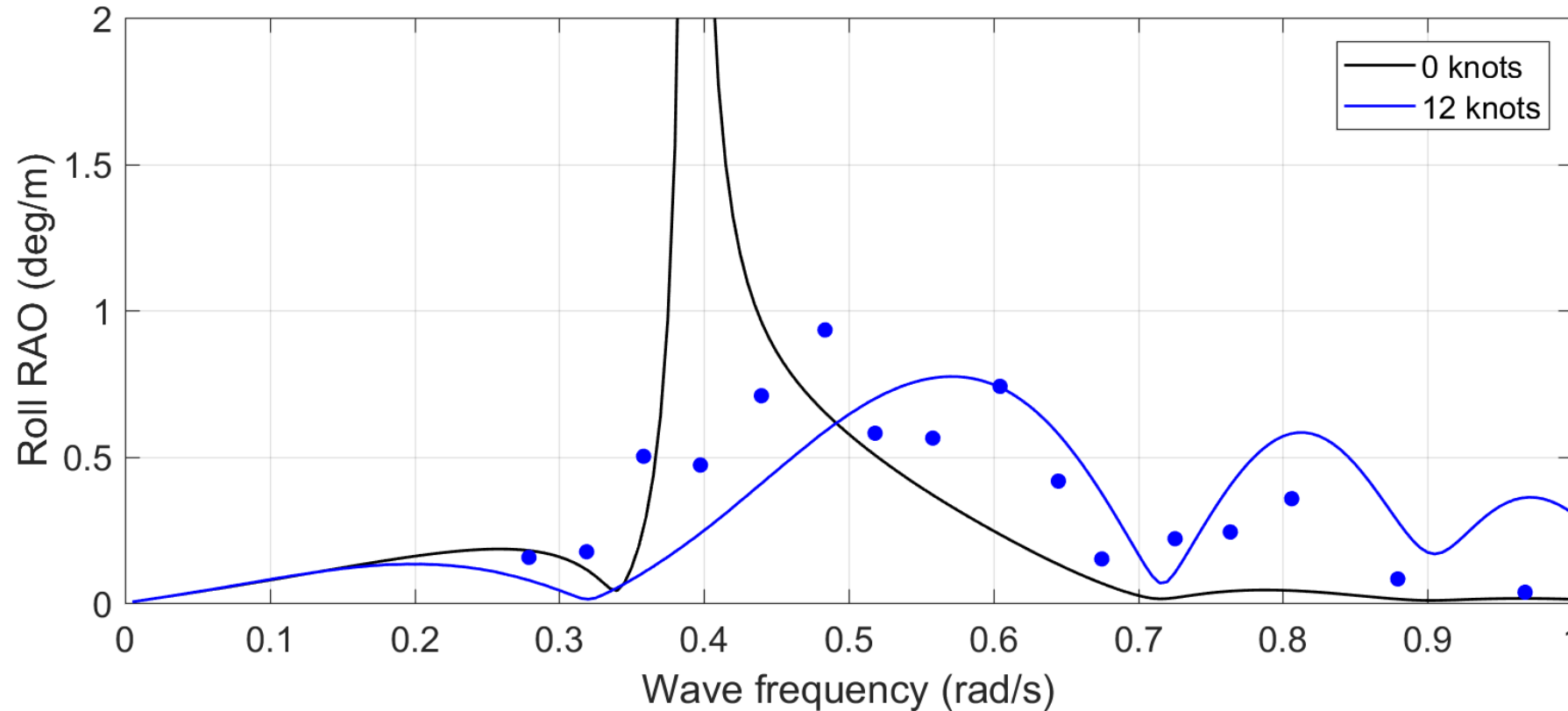
284 m container ship, bow-quartering seas, roll motions



- At $\lambda / LBP = 1.4$, 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.



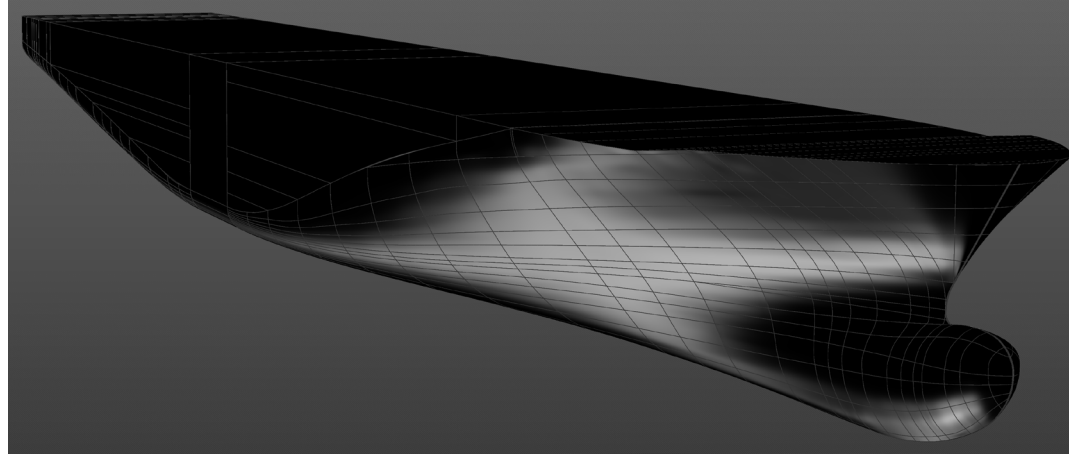
300 m container ship, waves 10° off-stern, roll



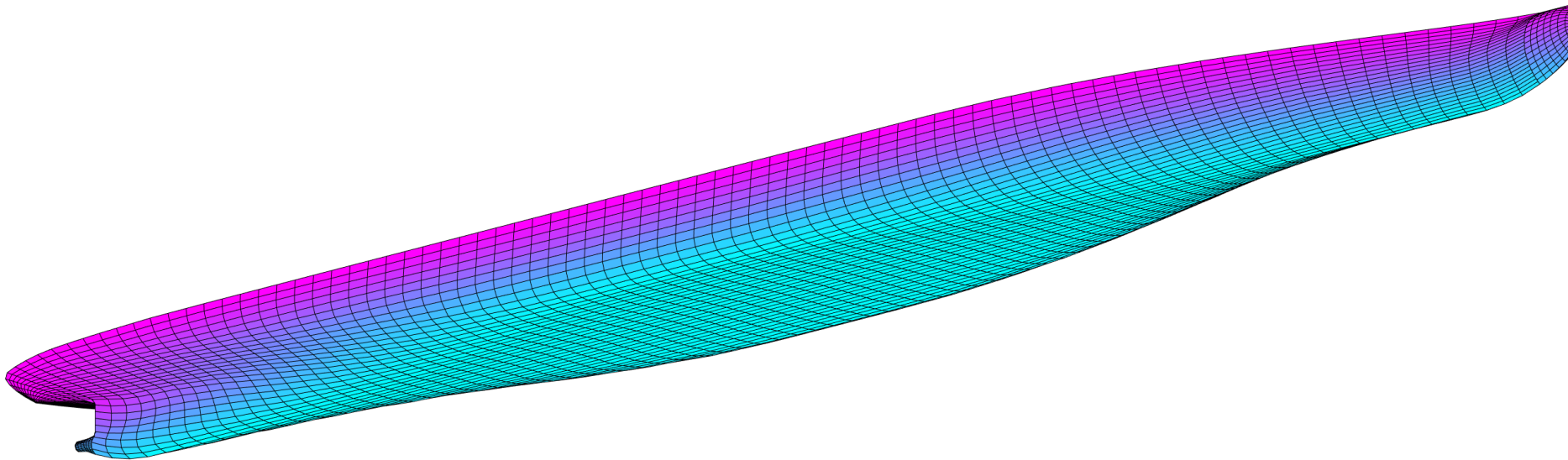
- **Speed effect very important for inviscid and viscous damping, and encounter frequencies in following seas**



Duisburg Test Case, MASHCON 2019



**DELFTship
render of DTC**



**4680-panel hull
mesh for WAMIT**

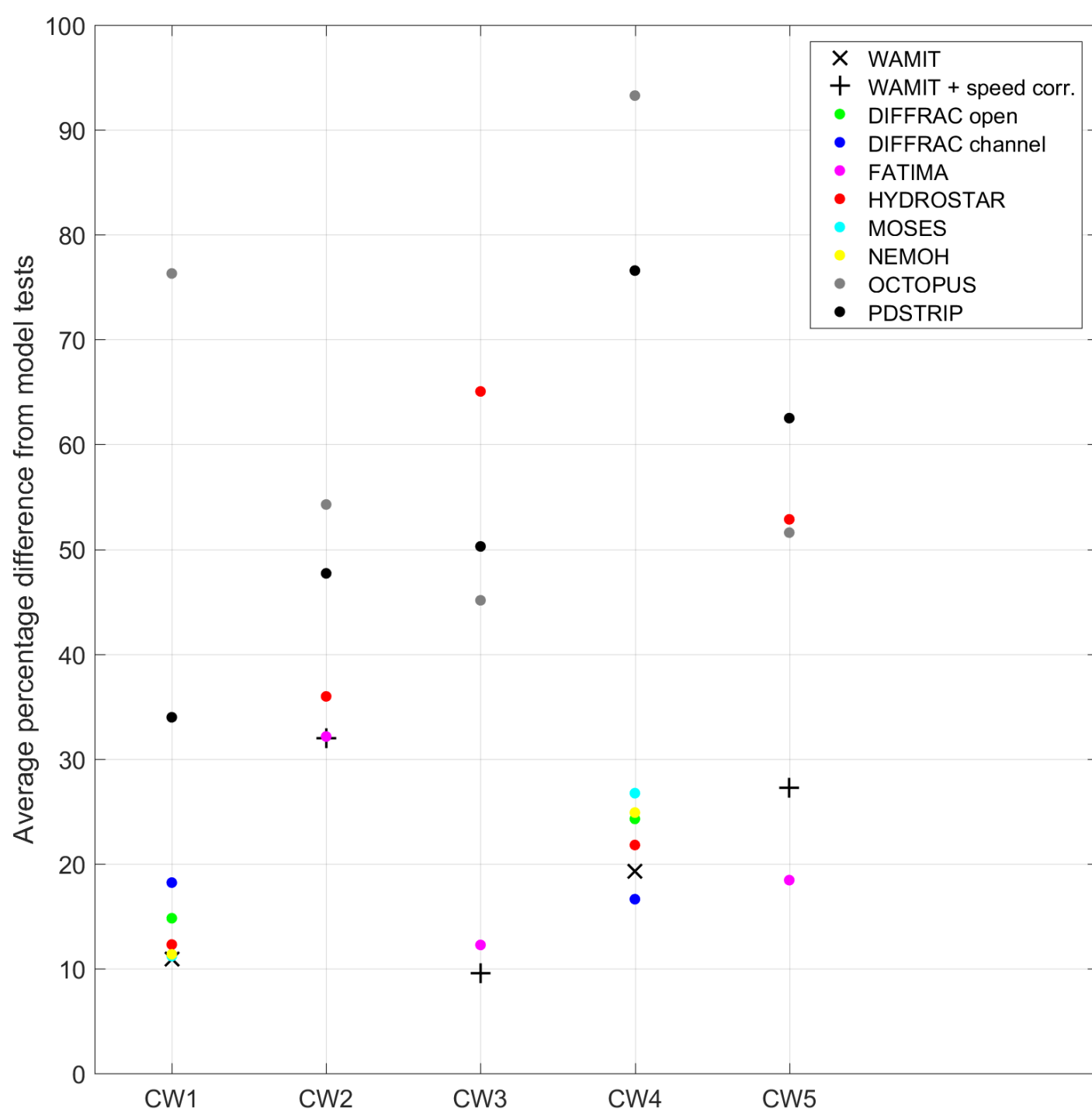


DTC container ship, head seas

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



Thank you for your attention

