Some Recent Developments in Dynamic Mooring Analysis for Ships

Presented to Royal Institution of Naval Architects, Western Australian Branch

by

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Talk overview

1. Moored ship at open trestle berth

The simple case?

2. Moored ship in harbour

Oceanography meets naval architecture

3. Two ships moored side-by-side

11 degrees-of-freedom too many

4. Long-term simulations

Has anyone got a supercomputer?

Limitations

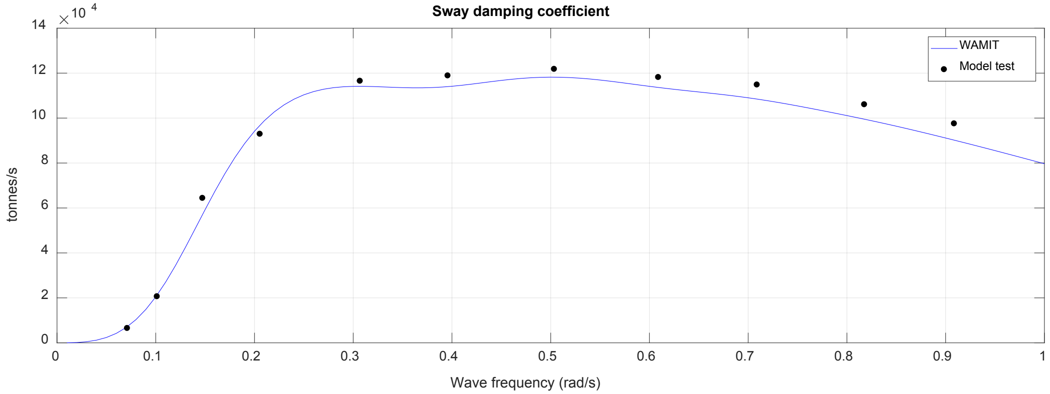
- **This talk will focus on waves, which are the dominant forcing on moored ships in most WA ports.**
- **Wind loads also become critical for cruise ships (at all ports) and container ships (at Fremantle).**
- **Current loads become important for high-current ports such as Port Hedland.**

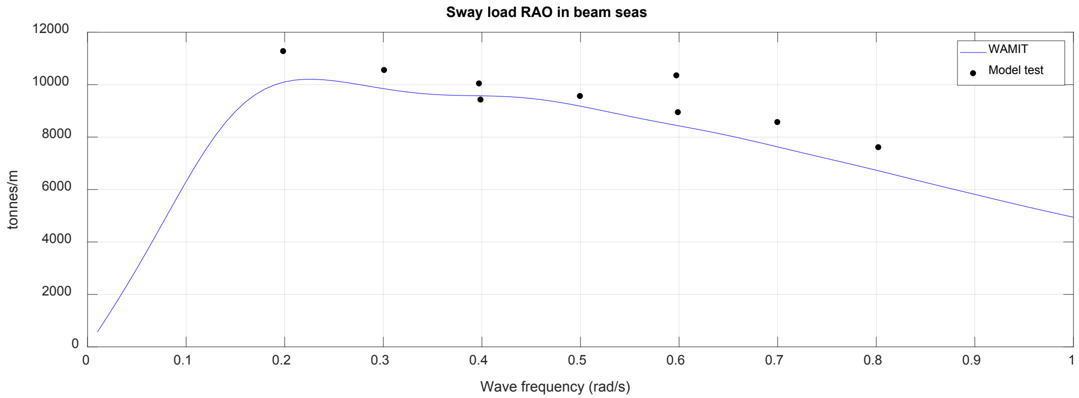
Introduction

Geraldton, Panamax bulk carrier, 32x real-time

1. Moored ship at open trestle berth

- **Typically operational up to 1.5 – 2.5 m Hs**
- **WA examples: North-west LNG terminals**
- **Classic test case: van Oortmerssen 1973, 200,000 DWT tanker**





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Moored ship at open trestle berth - findings

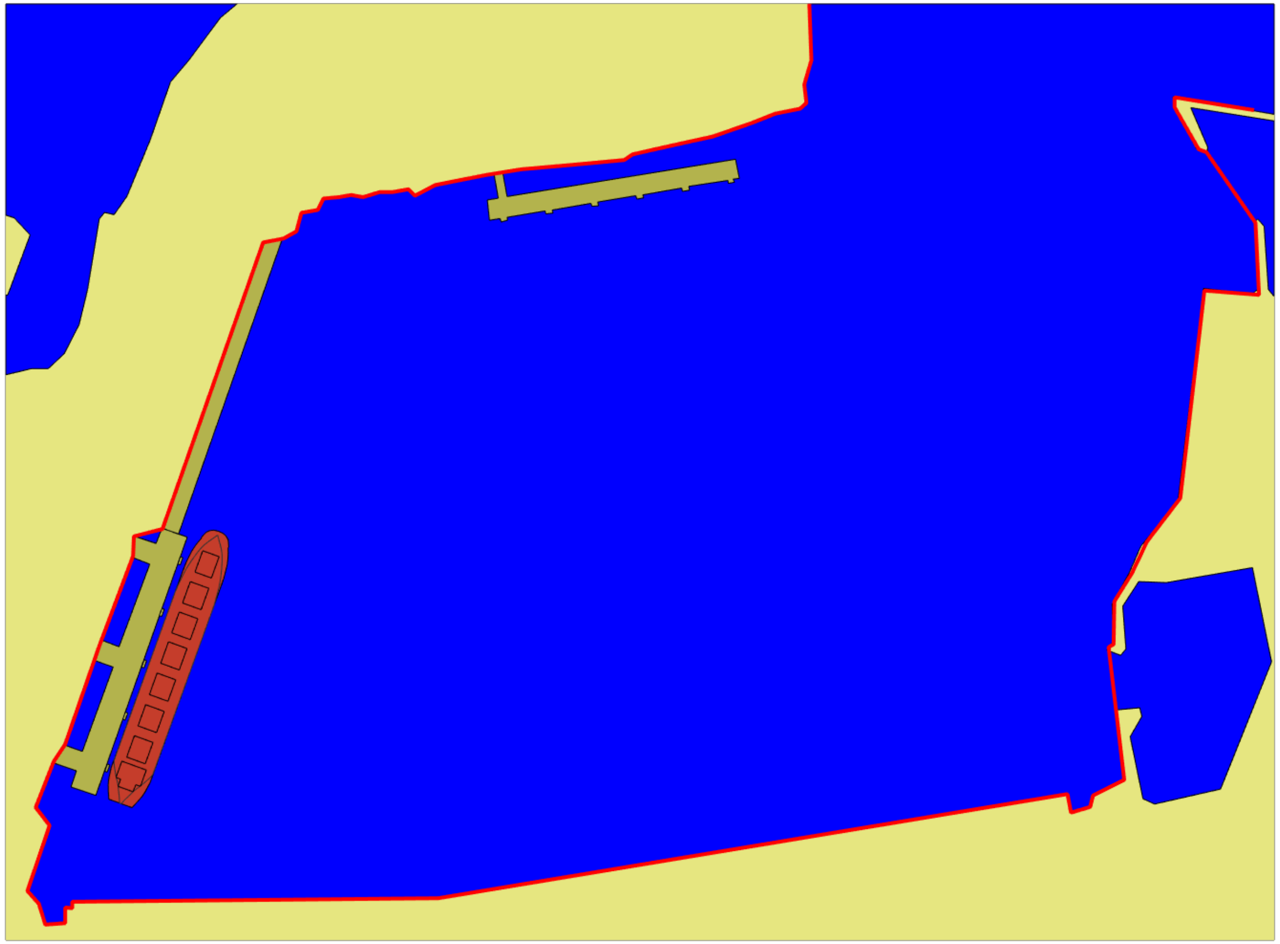
- **Natural surge, sway and yaw periods are 1-3 minutes.**
- **Moored ship motions are not sine waves. Frequency-domain modelling (as used for seakeeping) can't be used.**
- **Use of a Runge-Kutta time-domain solver opens new possibilities. Any external loads can be modelled.**
- **WAMIT gives accurate wave loads, added mass & damping.**
- **MoorMotions gives accurate time-domain motions and loads.**
- **Unlike floating offshore structures, moored ships with fenders have considerable mechanical damping.**
- **Swell and shallow-water long waves are important.**
- **Short-period seas can be important, due to second-order wave loads.**

2. Moored ship in harbour

- **Typically operational up to 0.15 m longwaves**
- **WA example: Geraldton**
- **Waves vary in size and direction throughout the harbour**
- **Development of coupled ship and harbour method in 2017**

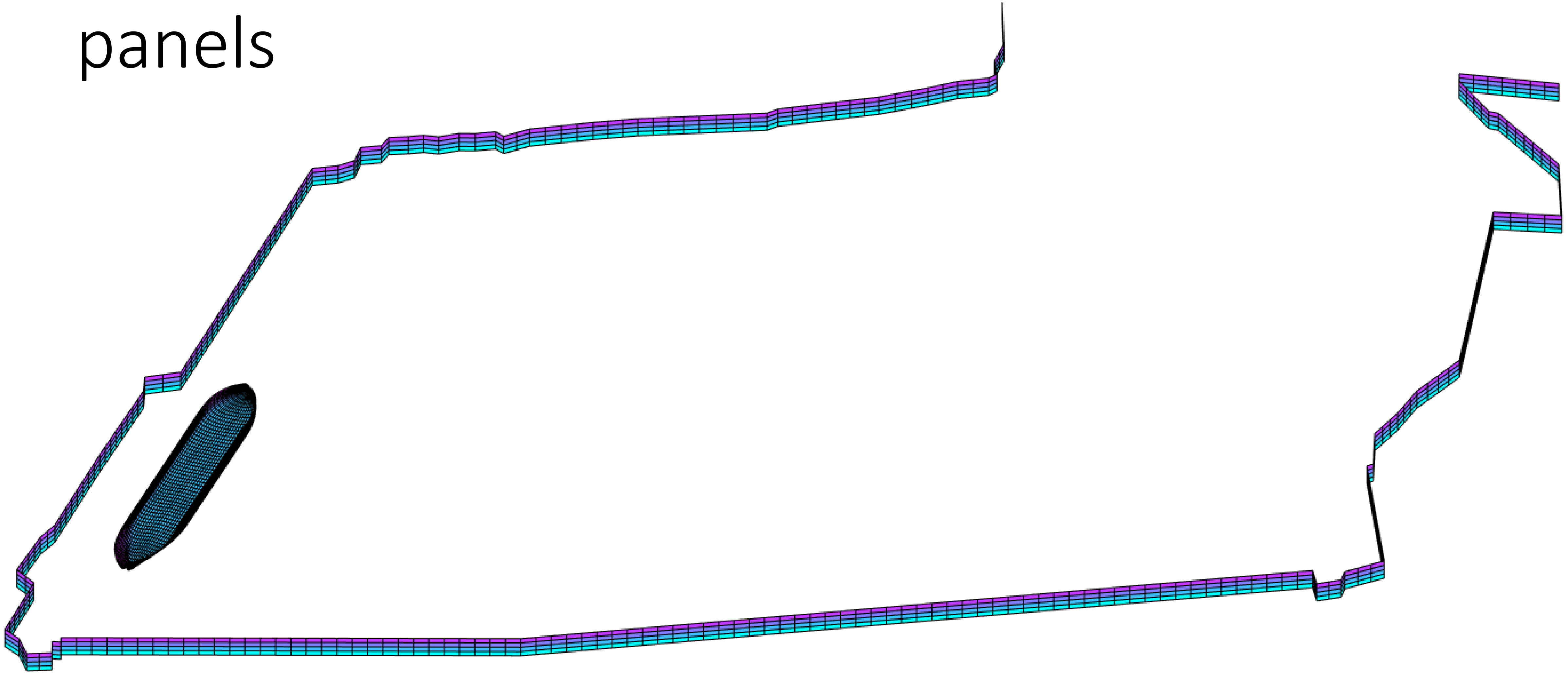
Image © MWPA

Coupled ship and harbour method

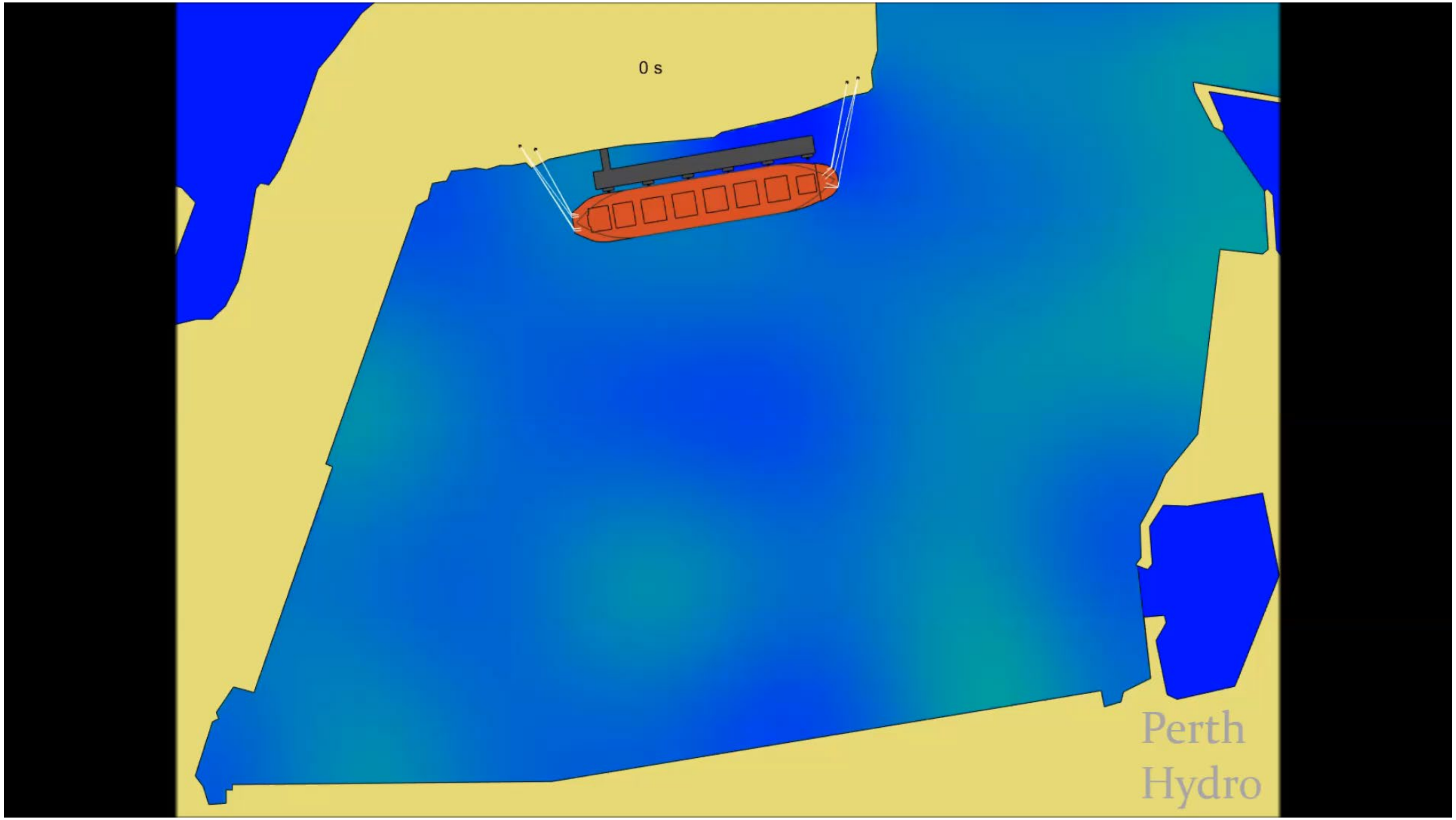


- **Wave amplitude RAOs in harbour calculated using WAMIT and used to calculate input wave spectrum**
- **First- and second-order wave loads on ship (and harbour) calculated using WAMIT**
- **Ship Impulse Response Functions calculated using WAMIT**
- **Nonlinear fender and mooring line force/displacement curves**
- **Coupled 6-DoF ship motions and loads calculated using MoorMotions time-domain solver**

Ship and harbour mesh – source and dipole panels



Coupled ship and harbour modelling, Berth 7



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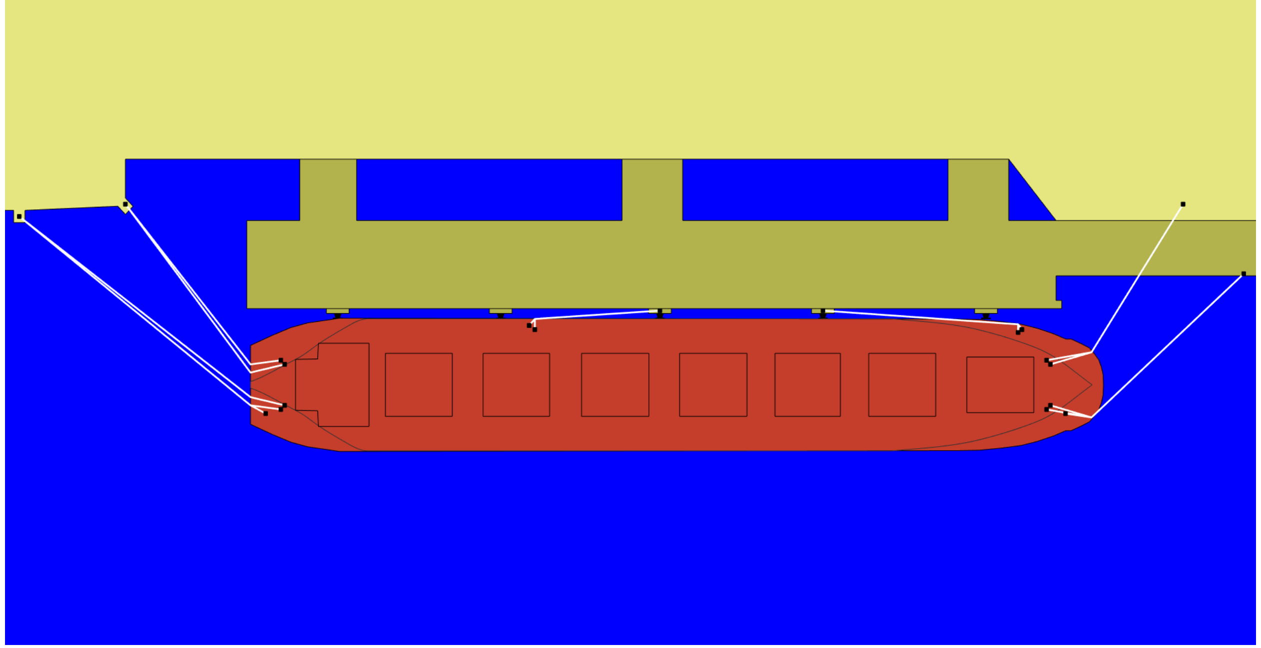
Coupled ship and harbour modelling, Berth 5 validation

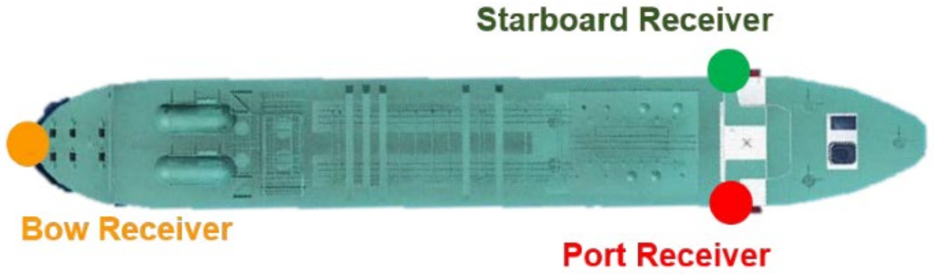


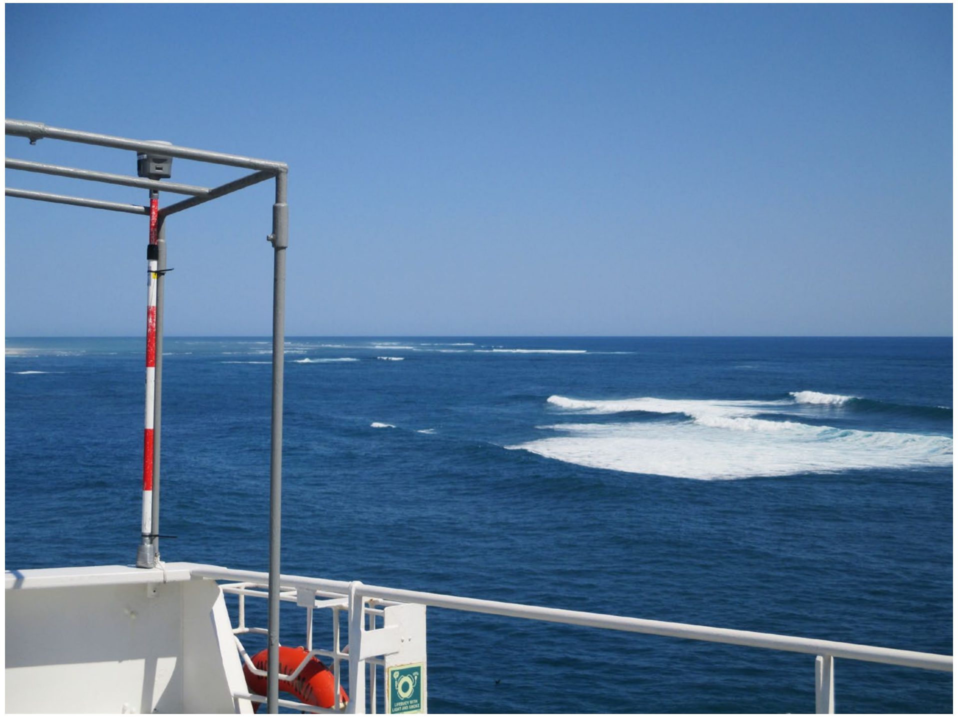
Measured wave conditions during validation trial

- **Waves measured at Berth 3/4 wave gauge**
- **1-hour time period chosen for analysis, 0840-0940 WST, 2nd Oct 2015**
- **13 cm significant long wave height (25-120s)**
- **14 cm significant swell height (8-25s)**

Measured ship motions during validation trial

- **Trimble R10 GNSS receivers on ship**
- **GNSS base station on shore**
- **=> high-accuracy 6-DoF ship motions**
- **Note: no measured mooring line loads**





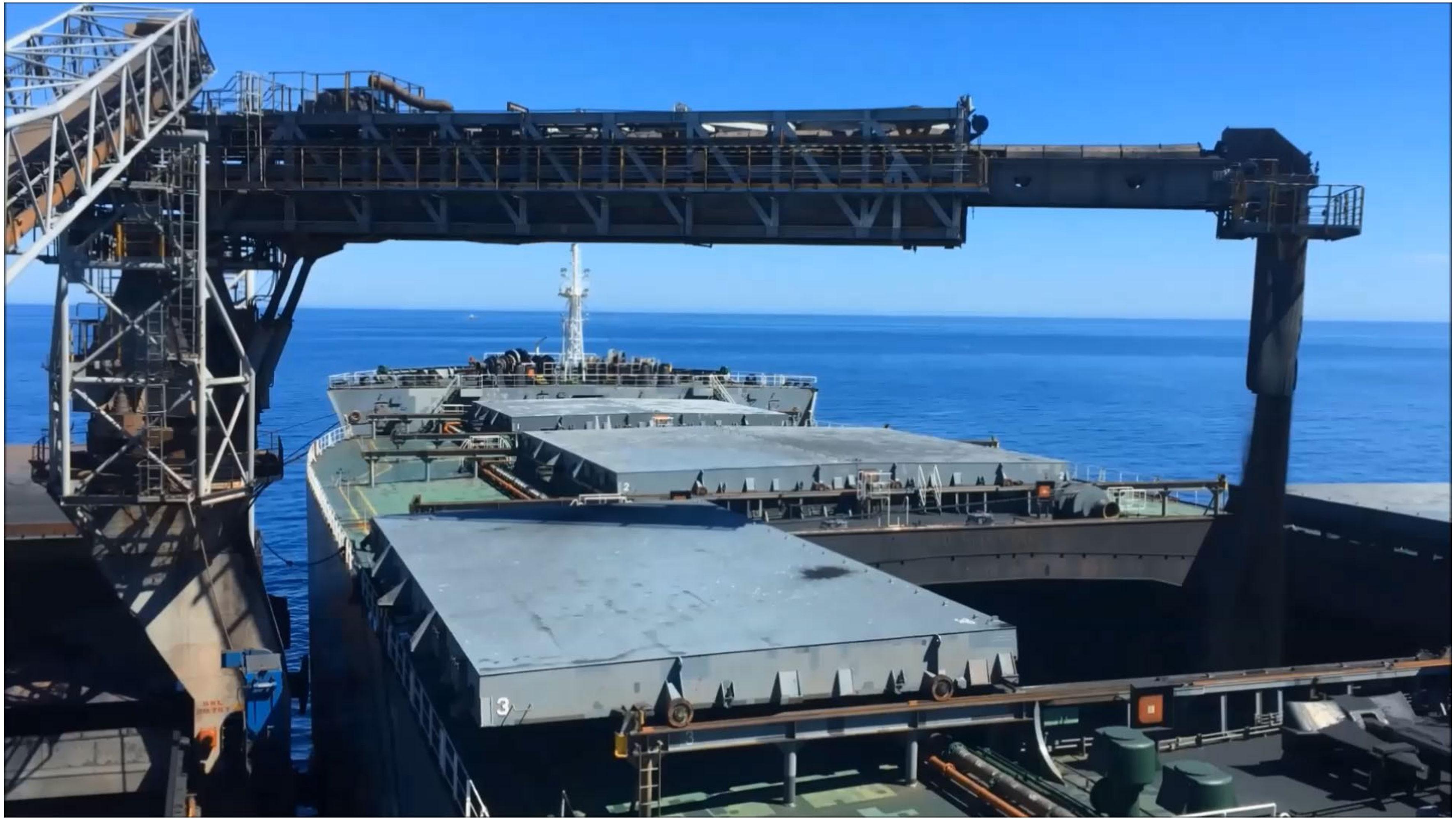
Peak-to-peak ship motion results

	Time-domain, 0.5 t pre-tension	Time-domain, 5.0 t pre-tension	Frequency domain	GNSS measurements
Surge	2.71 m	1.77 m	-	1.88 m
Sway	1.41 m	1.15 m	-	1.17 m
Heave	0.20 m	0.20 m	0.25 m	0.19 m
Roll	0.35°	0.34°	0.51°	0.52°
Pitch	0.14°	0.14°	0.14°	0.15°
Yaw	1.13°	0.66°	-	1.44°

Peak mooring line loads (modelled)

	Time-domain, 0.5 t pre-tension	Time-domain, 5.0 t pre-tension
Stern lines	5.1 t	7.5 t
Aft breast lines	12.7 t	10.8 t
Aft spring lines	16.5 t	17.8 t
Fwd spring lines	8.9 t	9.8 t
Fwd breast lines	12.0 t	14.4 t
Head lines	5.6 t	9.7 t

3. Two ships moored side-by-side



8x real-time

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Examples of side-by-side ship mooring in open water

- **Bulk transhipment (e.g. Whyalla iron ore, Cape Preston iron ore, Balla Balla iron ore, Mardie Salt)**
- **Floating LNG production (e.g. Prelude to LNG carrier)**
- **Crude oil transfer (lightering)**
- **LNG bunkering**

Side-by-side operability limits

- **Mooring line loads: 50% MBL**
- **Fender rated compression (solid rubber or pneumatic)**
- **3 degree roll amplitude on both ships (dry bulk or LNG)**
- **Relative motion limits at LNG manifolds (hoses)**
- **20-25 knot wind limit**

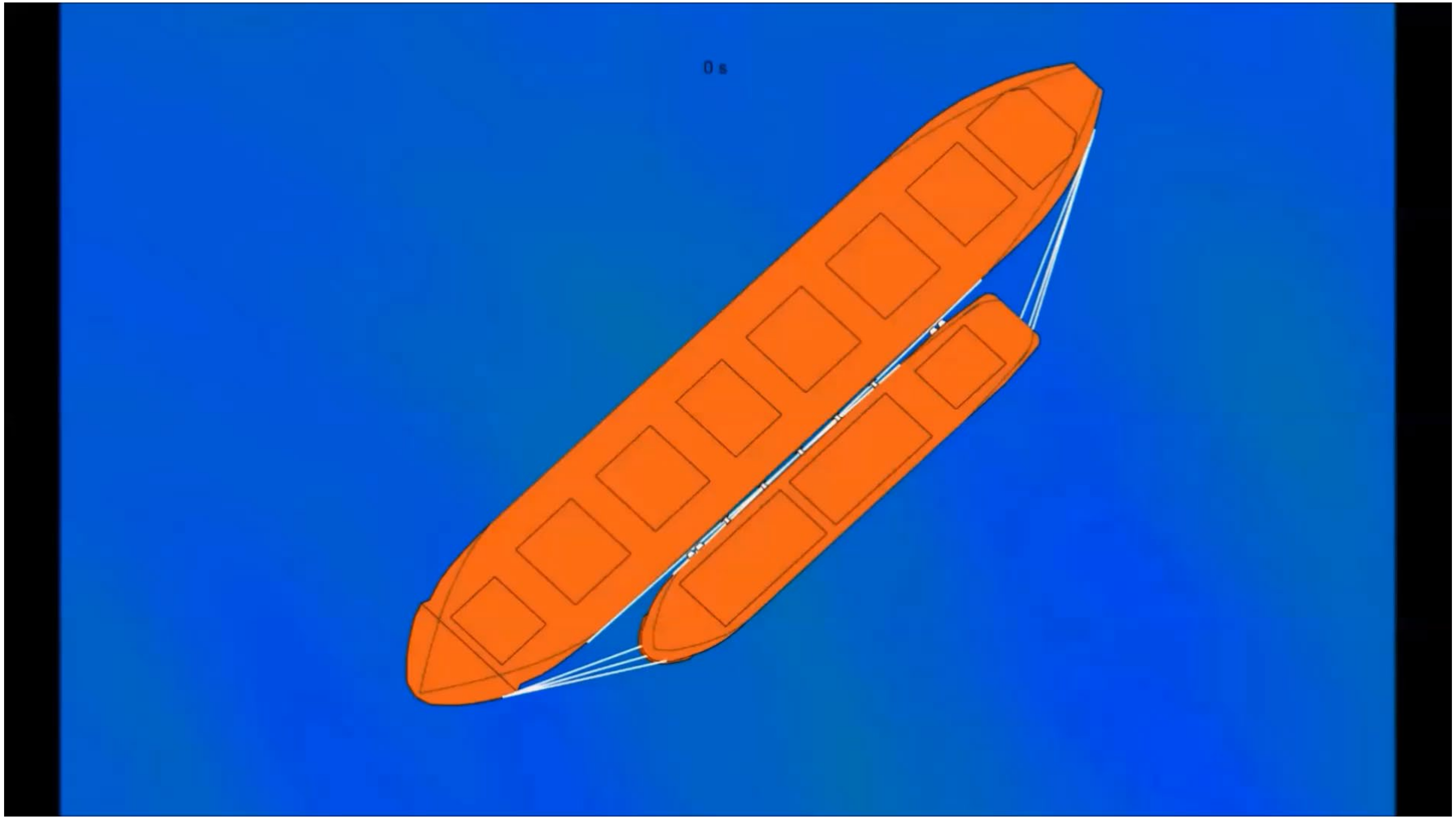
Options:

- **Anchored, turret moored or slow steaming**
- **Mooring lines or dynamic positioning**
- **Side-by-side or bow-to-stern (tandem)**

General calculation method – side-by-side ships

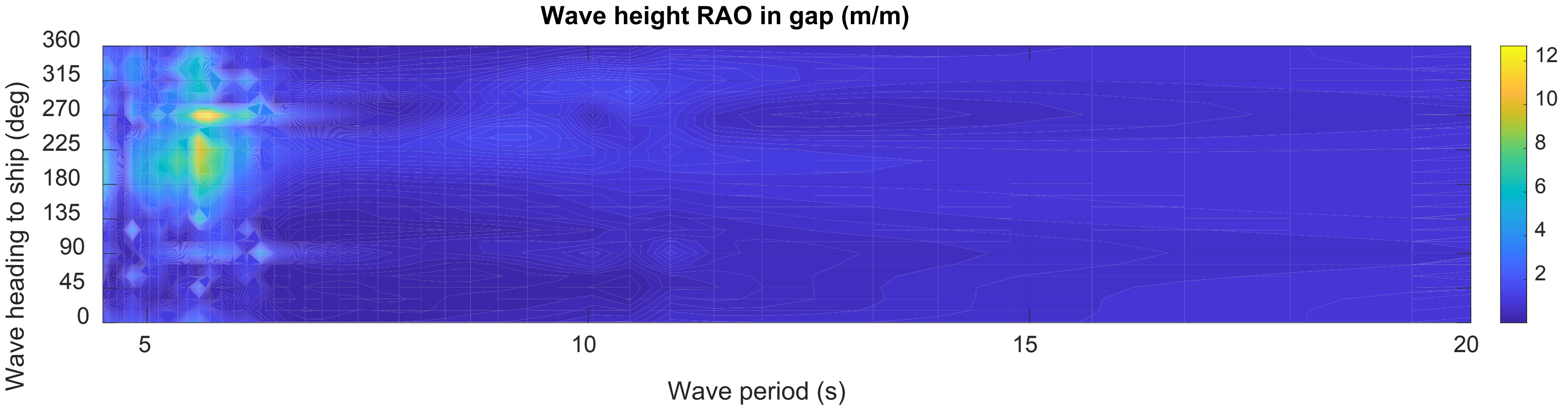
- **12-DoF coupled system**
- **First- and second-order wave loads on coupled system from WAMIT**
- **12-DoF coupled impulse response functions from WAMIT**
- **Gap resonance analysis**
- **Directional wave spectrum for wave loading**
- **Heading timeseries**
- **Nonlinear fender and mooring line curves**
- **MoorMotions time-domain solver, coupled 12-DoF**

Side-by-side example: iron ore transhipment

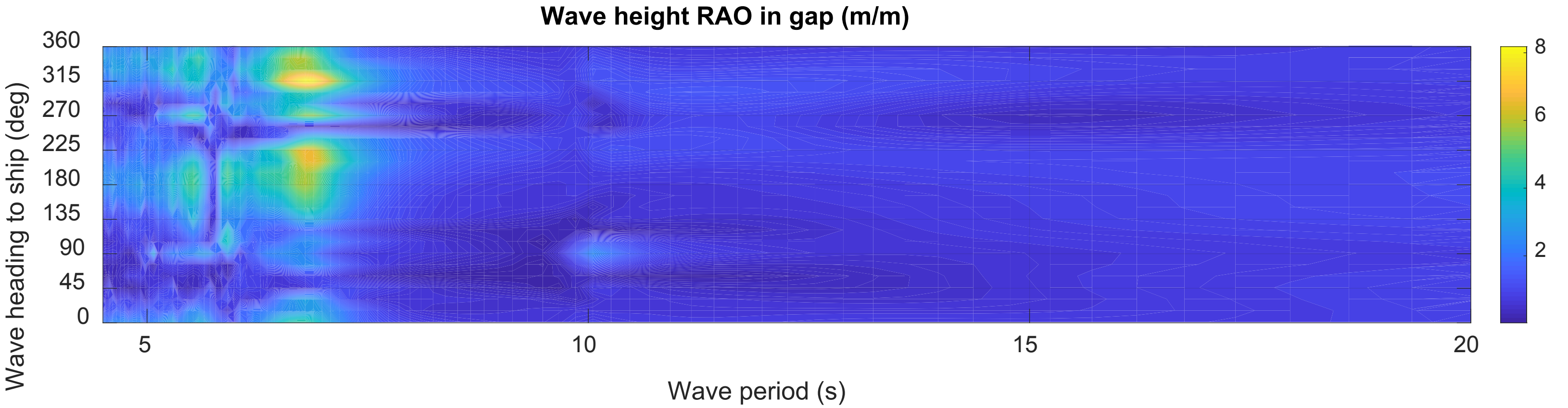


Gap resonance

2 metre gap



4 metre gap



Option to use "gap lid" to damp wave motions in gap

Relative sway damping

- **Buchner 2001 "*Numerical multiple-body simulations of side-by-side mooring to an FPSO*": free decay sway tests showed linear sway damping insufficient; corrected with linear viscous damping coefficient**
- **Perth Hydro alternative method: quadratic sway damping based on jet outflow from gap between vessels**
- **Relative sway motions cause high-speed jet outflow/inflow from between vessels**
- **Mass conservation and Bernoulli's theorem give hydrodynamic pressure between hulls due to jet**
- **Pressure times area gives relative sway damping force**

Stability of time-domain solver

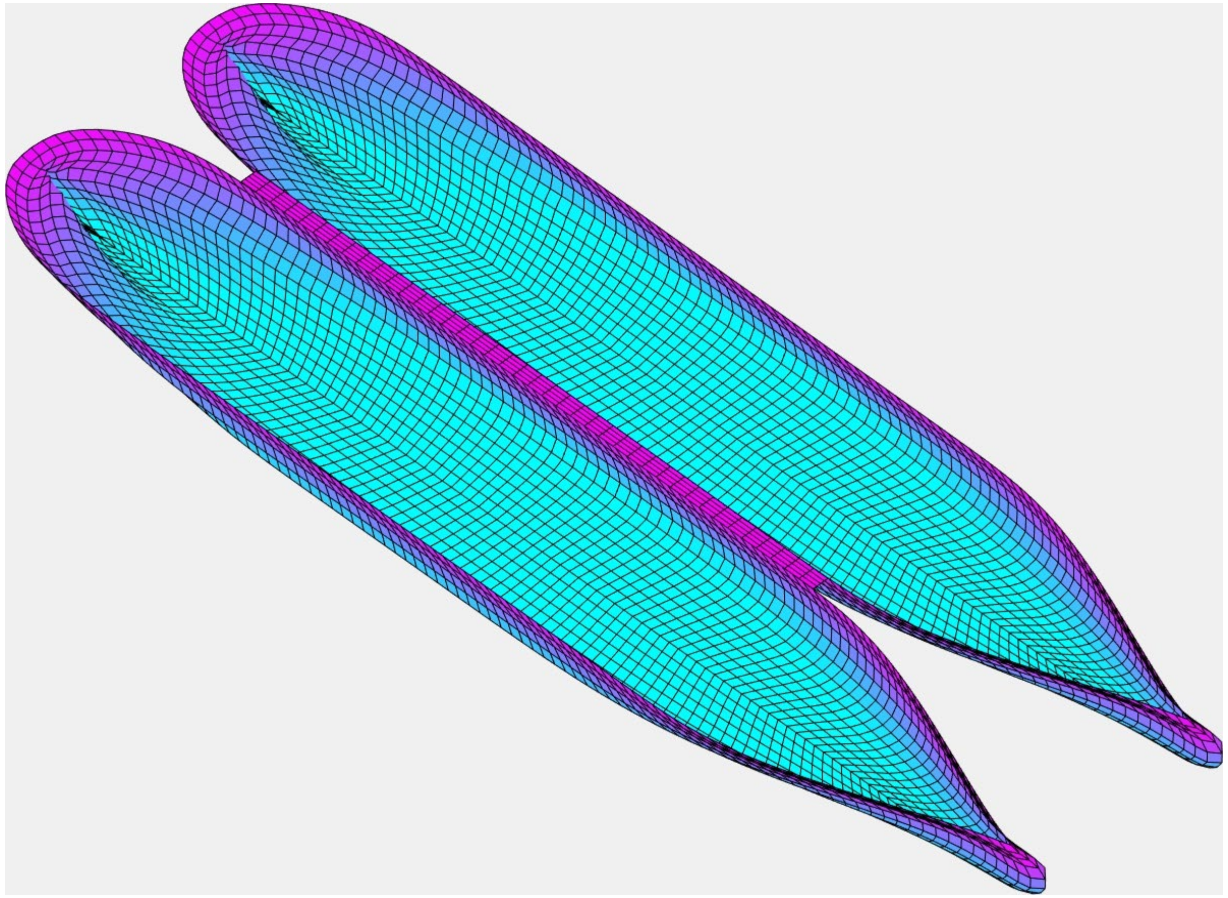
- **Can be difficult to achieve numerical stability of fully-coupled 12-DoF system of equations when using time-domain solver**

Important factors affecting numerical stability:

- **Short time step (0.1-0.2 s)**
- **Long timespan to ensure IRFs decay to zero (100-300 s)**
- **May need to remove cross-coupling terms in hydrostatic restoring matrix C_{35}, C_{45} etc.**
- **Large difference in displacement: may need to de-couple x_9**
- **Fender and line energy dissipation can produce spurious modes**

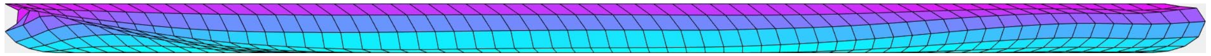
Validation of motions and loads for side-by-side (SBS) LNG carriers

- **Marin model tests on side-by-side LNG carriers in head seas**
- **Model tests used single LNGC adjacent to wall. 2 m gap to wall, equivalent to 4 m gap between LNGCs**
- **Validation of WAMIT v7.3, with or without damping lid**

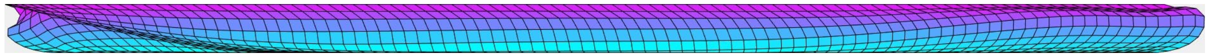


SBS mesh dependency

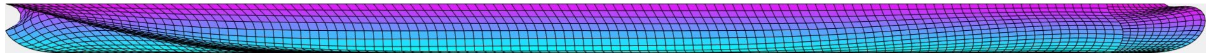
1040-panel mesh

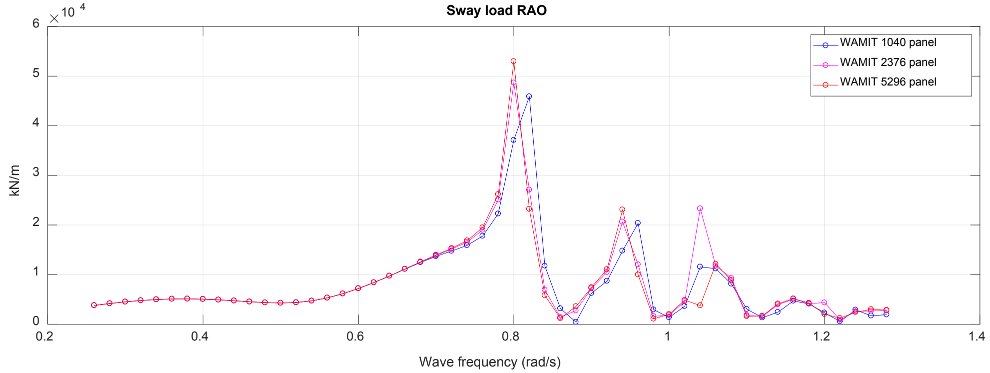


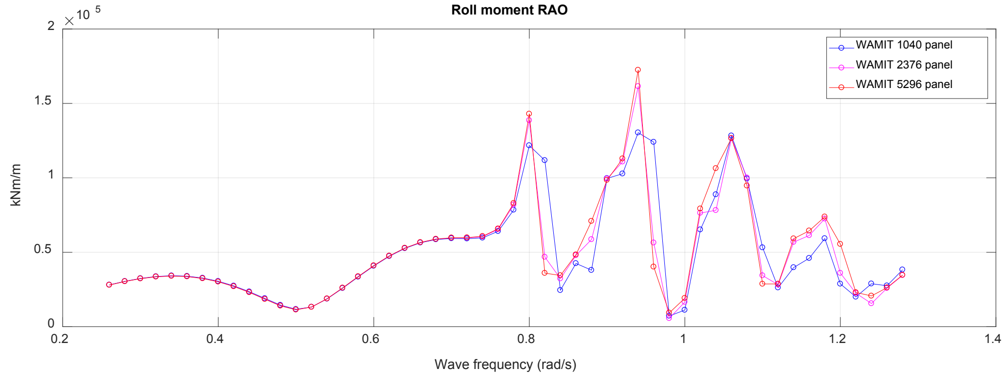
2376-panel mesh

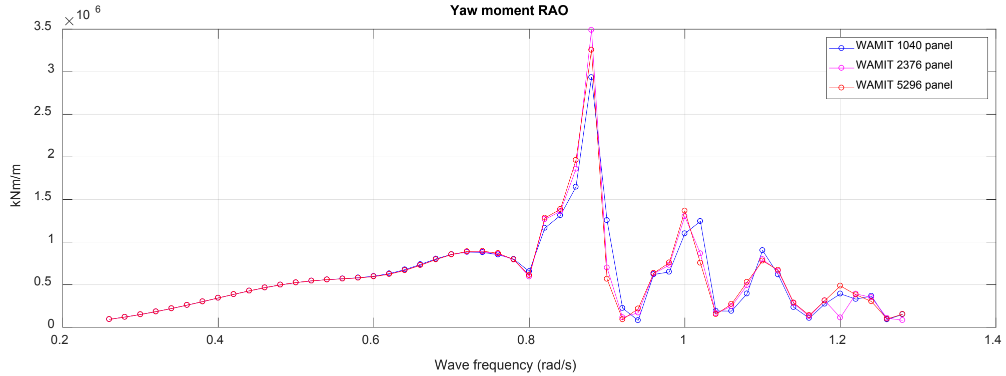


5296-panel mesh









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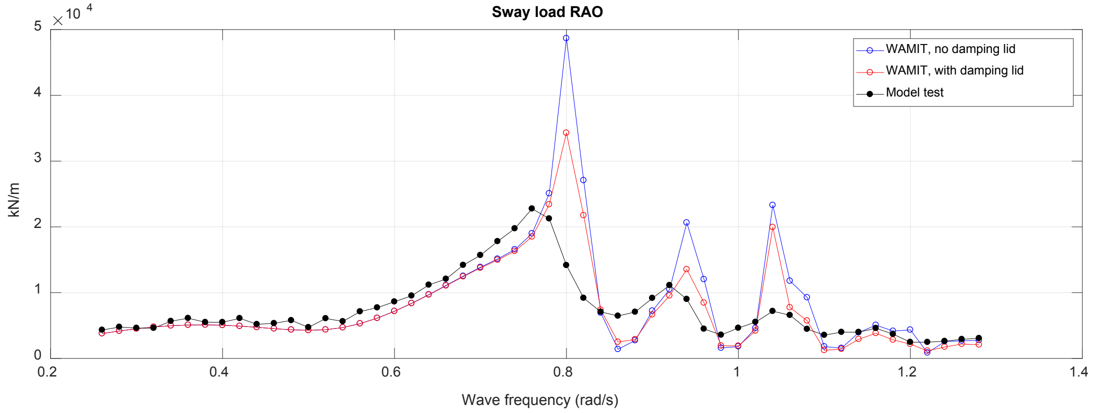
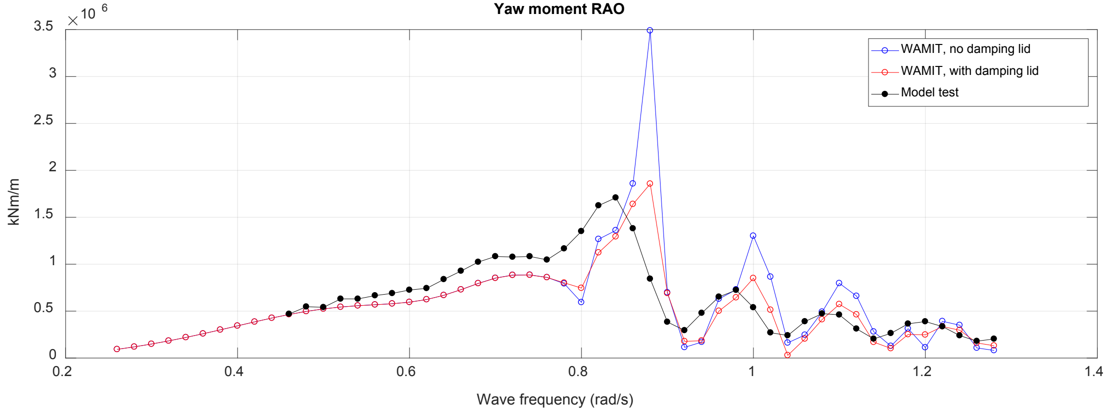
SBS wave load validation

- **Damping lid has no effect at wave frequencies up to 0.8 rad/s (wave period > 8 s)**
- **Damping lid important at gap resonance frequencies**
- **Generally good agreement with model tests**





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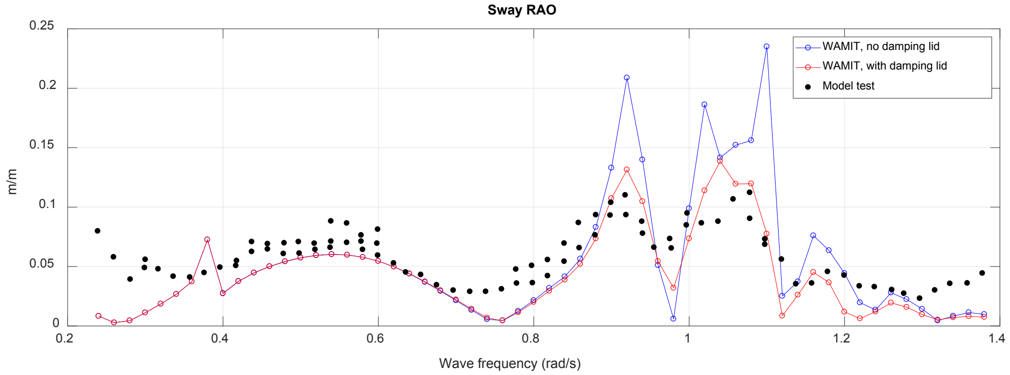
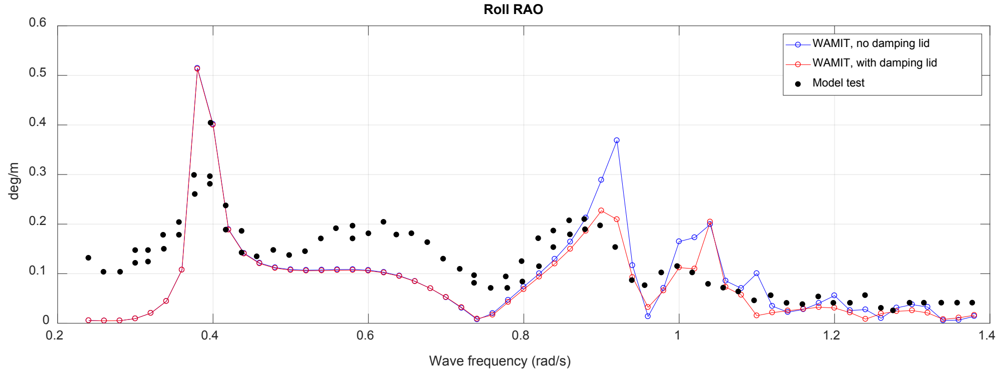
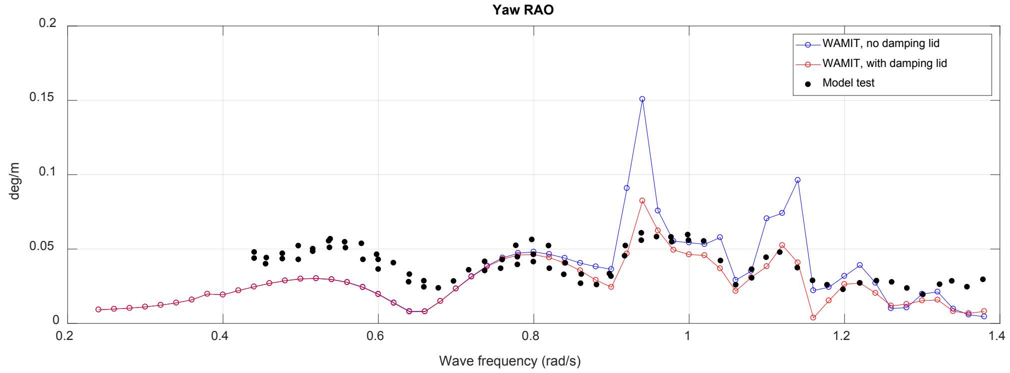
SBS wave-induced motions validation

- **Generally good agreement with model tests**
- **Damping lid only required for wave periods < 8 s**







4. Long-term simulations

Example hourly, 5-year hindcast of side-by-side ship motions and loads:

- **43,824 sets of wind/wave/current hourly data**
- **2 loading conditions of smaller vessel**
- **87,648 independent 1-hour simulations**
- **3600 s simulation takes ~400 s on single core**
- **Total 10,000 core-hours per site**
- **May be multiple sites**

Pawsey Supercomputing Centre, Perth

For the above project:

- **8 nodes, each of 28 cores, made available on the Zeus cluster**
- **Original Matlab code compiled in Octave to run on Zeus**
- **Total 40 hours of computation time**

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Further information

- **Perth Hydro Research Report R2019-09, Comparison of WAMIT and MoorMotions with model tests for a tanker moored at an open berth.**
- **Gourlay, T.P. 2019 A coupled ship and harbour model for dynamic mooring analysis in Geraldton Harbour, Proc. Coasts and Ports 2019.**
- **Perth Hydro Research Report R2019-08, Comparison of WAMIT v7.3 with Marin model tests for side-by-side LNG carriers in waves.**

All available at www.perthhydro.com/archive.html

Q&A

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