Dynamic Mooring Analysis for Cruise Ships at the Port of Napier

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Abstract
Dynamic mooring analysis is done for a 347 m cruise ship moored at Napier's recently-built No. 6 Wharf, which is semi-exposed to sea, swell and long-period waves.

New PIANC guidelines (Report of Working Group 212) set strict motion limits for safe passenger transfers to and from cruise ships. At a semi-exposed berth, wave limits must be set to ensure that ship motions are within these limits. Other "safe mooring" limits must be checked for dynamic mooring line and fender loads.

For a cruise ship moored with standard ship's lines, against fenders with low-friction facing, motion damping is minimal, and ship motions can easily exceed PIANC limits. ShoreTension units provide hydraulic damping through each motion cycle, which can greatly reduce horizontal ship motions.

In this study, we use dynamic mooring analysis to assess the largest visiting cruise ship *Ovation of the Seas* at No. 6 Wharf. Wave propagation, from the open ocean into the harbour, is modelled using FUNWAVE software and tuned using wave measurements. Wave loads on the ship are modelled using WAMIT software, with a coupled ship-and-harbour method. Nonlinear time-domain ship motions and mooring loads are modelled using MOORMOTIONS software. ShoreTension unit dynamic characteristics are built into the time-domain modelling in cooperation with ShoreTension BV.

The analysis shows that long-period waves are the most important wave component for dynamic motions and loads of large cruise ships at No. 6 Wharf. Long-period waves at Napier are generated by various processes, including wave transformation in shoaling bathymetry, wave groups passing the entrance, and reflections off the downstream coast.

Dynamic mooring analysis showed that large cruise ships at Number 6 Wharf may be safely moored with four ShoreTension units in long-period wave heights of up to 20 cm. This gives excellent operability during the summer and autumn period when cruise ships visit.

Keywords: dynamic mooring analysis, cruise ships.

1. Nomenclature

DoF	Degrees of freedom
FCS	Fincantieri cruise ship
GNSS	Global navigation satellite system
HMPE	High modulus polyethylene
H_S	Significant wave height
LDBF	Line design break force
LPW	Long period wave
MBL	Minimum breaking load
RAO	Response amplitude operator
SDMBL	Ship design MBL
STU	ShoreTension unit
SWL	Safe working load
T_P	Peak wave period

2. Cruise ships in Napier Port

Napier Port has been increasing the number of cruise vessel calls over the past 10 years and currently has about 90 vessel visits each season. There are two berths that are useable for the largest of cruise ships, Higgins Wharf (No.2) and Te Whiti (No.6).

Despite facing challenges with large ships in a small harbour, the port has developed a reputation for collaborating with ship crews to maintain high safety standards through knowledge and communication.

Large cruise vessels present several challenges for Napier Port, including navigation, passenger infrastructure, operational impacts, and safe mooring in a deep-water swell environment. The new "Te Whiti" wharf has reduced the operational impact on the inner harbour, but the vessels have an increased exposure to most wave frequencies.

Ovation of the Seas first berthed at No.6 wharf on 29th November 2023. Being the first and largest vessel to use the berth, it was an obvious subject for dynamic mooring analysis. It remains the largest vessel to visit Napier Port to this day.

The use of wave modelling and dynamic mooring modelling to establish safe operating parameters on 6 wharf enabled a rapid transition to full operational capacity. The modelling demonstrated that the use of STUs was the most effective mooring method for cruise ships on Te Whiti wharf. The findings from motion modelling have been combined with the Pilot and Mooring teams' experience, to determine the safe operating limits. Since implementation, the limits have been found to be very accurate. Traditionally, the port would have started with conservative limits and increased these with experience, inevitably cancelling some vessel calls while working up to maximum realistic operating parameters. The use of dynamic mooring analysis has minimised the missed opportunities as we gain experience in different weather and wave climates.

Figure 1 Extract from chart NZ5612, showing Napier harbour

3. Ship modelling

In this report, we show example calculations for the cruise ship *Ovation of the Seas*, shown in Figure 2.

Figure 2 *Ovation of the Seas* taking on pilots to enter the Port of Napier, 14th February 2025

Principal dimensions of the ship are shown in Table 1.

Table 1 Ship dimensions

Ovation of the Seas	
Length overall	347.1 m
Length between perpendiculars	320.1 m
Waterline beam	41.40 m
Summer draft	9.0 m
Design draft	8.5 m

The modelled loading condition is taken from typical stability data for this vessel and is shown in Table 2. Roll gyradius is a typical value for cruise ships, as described in Gourlay (2023). Displacement, centre of gravity and roll period are calculated in WAMIT, using the modelled hull mesh.

Table 2 Modelled loading condition for *Ovation of the Seas*

Modelled loading condition	
Draft aft	8.5 m
Draft forward	8.5 m
Displacement	73,400 tonnes
Longitudinal centre of gravity	164.7 m from aft extremity
Vertical centre of gravity	20.9 m above keel
Metacentric height above centre of gravity	4.0 m
Roll radius of gyration	43% waterline beam
Pitch radius of gyration	25% length overall
Yaw radius of gyration	25% length overall
Natural roll period	17 seconds
Profile area above waterline	14660 m^2
Profile centroid above waterline	22.9 m

The modelled hull mesh is developed from the Fincantieri cruise ship (FCS) hull, shown in Figure 3 and Figure 4.

Figure 3 FCS standard cruise ship hull model (IMO 2004, p.22)

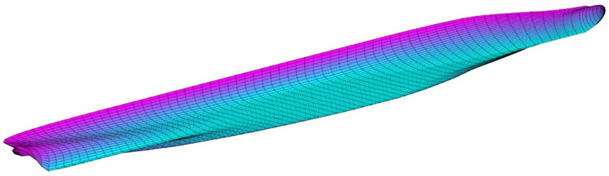

Figure 4 3780-panel surface mesh for FCS parent hull

4. Modelled mooring arrangement

The ship is modelled with 20 ship's lines, as follows:

- 6 stern lines
- 4 aft spring lines
- 4 forward spring lines
- 6 head lines

Figure 5 shows example ship's lines on *Ovation of the Seas*.

Figure 5 Head lines on *Ovation of the Seas* at Napier No. 6 Wharf, 14th Feb 2025

Ship mooring lines are modelled as shown in Table 3.

Table 3 Mooring lines for *Ovation of the Seas*

Ovation - mooring lines		
	HMPE line	*Stretcher*
Make	Timm Acera Amundsen 12-strand	Timm Signal Master Ringtail
Material	HMPE	Signal B5 yarn and polyester
Diameter	44 mm	76 mm
Length	200 m	11 m
MBL (unspliced)	148.9 tonnes	202.4 tonnes
LDBF (spliced)	134.0 tonnes	182.2 tonnes
Elongation	2% @ MBL	13% @ MBL

Ship's lines are modelled using their nonlinear tension-extension curves. Pre-tension is set at 15 tonnes for all ship's lines.

Four ShoreTension units are used when mooring *Ovation of the Seas* at No. 6 Wharf, as follows:

- Forward breast line
- Forward spring line
- Aft spring line
- Aft breast line

An example ShoreTension unit is shown in Figure 6.

Figure 6 *Ovation of the Seas* at Napier No. 6 Wharf, 14th Feb 2025, showing aft breast ShoreTension unit

ShoreTension lines and hydraulic damping units are modelled using their specific characteristics, as supplied by ShoreTension BV. The user-set pay-out tension is modelled at 40 tonnes.

Fenders (Supercone 1400mm F1.6) are modelled using their nonlinear reaction-compression curves.

5. Wave measurements

An observation program supported the study, involving 5 wave gauges spaced along Berth 6. Three were the permanent wave radar sensors, supplemented by two temporary RBR-solo pressure sensors. All data were recorded continuously at 1 or 2 Hz, and band-pass filtering created spectral partitions of sea surface elevations as sea (<7s) swell (7-25s) and LPW (25-150s) bands. Zero crossing analysis at hourly intervals allowed the derivation of integrated wave parameters for each band.

6. Wave modelling

Wave propagation modelling from the open ocean into the harbour was undertaken using FUNWAVE software for varying offshore wave conditions. An example is shown in Figure 7.

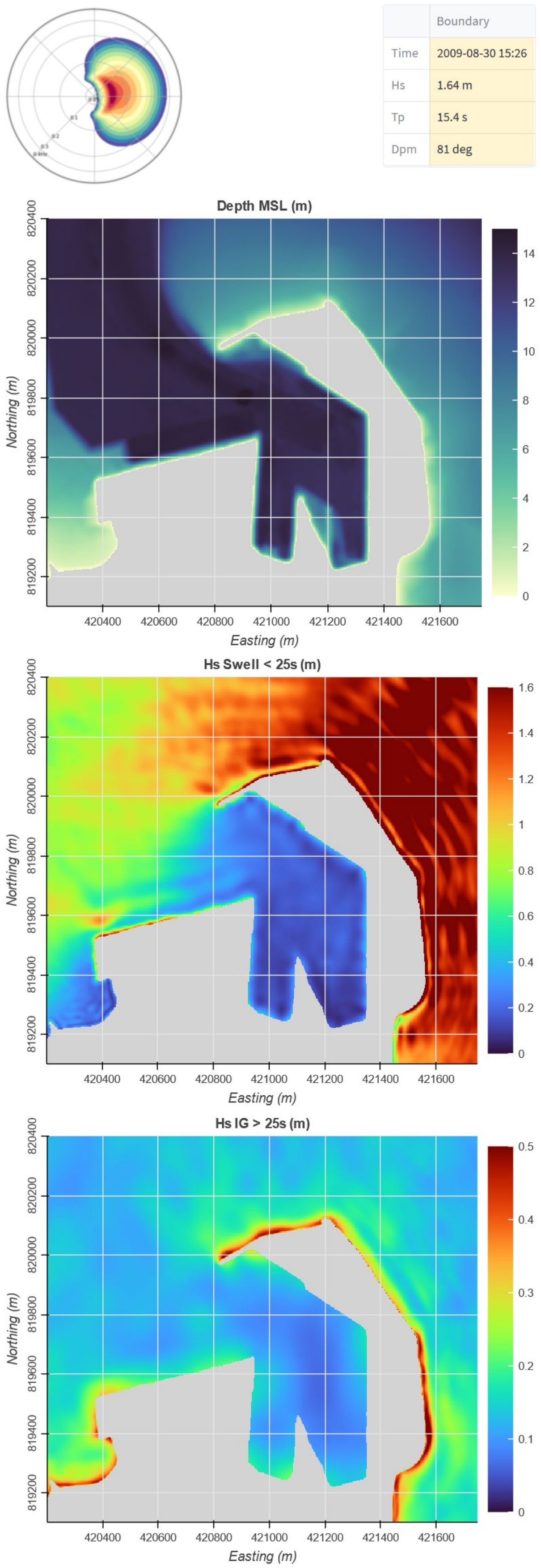

Figure 7 Screenshots from Oceanum's Datamesh app, showing swell and LPW for example offshore wave conditions.

Combined with wave measurements, wave modelling provided information on wave attenuation/amplification and changing wave directionality for sea/swell/LPW components, from the open ocean into the harbour.

7. Coupled ship and harbour method for wave loads

Wave load RAOs are calculated using a coupled ship-and-harbour method. This treats the ship and harbour as a coupled system, so can replicate the flow patterns around a ship in a harbour with complex shape. The general method is described in Gourlay (2019).

A dipole mesh is firstly developed for the harbour walls, as shown in Figure 8.

Figure 8 WAMIT harbour mesh (shown in red) for coupled ship-and-harbour method. Wave gauges at No. 6 Wharf shown in green. "Harbour entrance" modelling point shown in pink.

The coupled ship-and-harbour problem is modelled in WAMIT (www.wamit.com) by adding the ship mesh to the harbour mesh shown in Figure 8.

WAMIT settings used for calculating wave loads with the coupled ship-and-harbour model are shown in Table 4.

Table 4 WAMIT settings for coupled ship-and-harbour modelling

WAMIT settings, coupled ship and harbour	
WAMIT solver	Direct solver, standard velocity potential formulation
Representative water depth	14.0 m, including tide
Wave frequencies	0.03 : 0.01 : 1.58 rad/s (156 off)
WAMIT wave headings	0˚ : 15˚ : 360˚ (25 off)
Output	6-DoF wave load RAOs on the ship

8. Tuning the coupled ship and harbour method

The WAMIT coupled ship-and-harbour method takes as input the "open-water" wave conditions outside the harbour.

The input wave spectrum is back-calculated to give the correct measured wave conditions at No. 6 Wharf. This is done by first running the model with no ship present, to find the predicted wave conditions at No. 6 Wharf in terms of the outside wave conditions. This "harbour-only" modelling is done using the settings shown in Table 5.

Table 5 WAMIT settings for harbour-only modelling

WAMIT settings, harbour only	
WAMIT solver	Direct solver, standard velocity potential formulation
Representative water depth	14.0 m, including tide
Wave frequencies	0.03 : 0.01 : 1.58 rad/s (156 off)
WAMIT wave headings	0˚ : 15˚ : 360˚ (25 off)
Output	Wave amplitude RAO at No. 6 Wharf wave gauge locations

The input wave spectrum to the coupled ship-and-harbour model is chosen as shown in Table 6.

Table 6 Method for specifying input wave conditions for ship wave loads

Input wave conditions for calculating ship wave loads	
H_S of (sea, swell, LPW)	Back-calculated to give correct measured H_S of (sea, swell, LPW) at No. 6 Wharf
Wave spectral shape	Incoming LPW frequency spectrum tuned to give correct LPW frequency spectrum at the berth. Bretschneider standard wave spectrum used for sea and swell components, with T_P as measured at No. 6 Wharf.
Wave directionality	Incoming LPW evenly spread over directions 270˚T to 045˚T. Peak incoming sea and swell direction set to 035˚T (most common peak wave direction at harbour entrance) with cosine-squared wave spreading to ±45˚

Note that the presence of a ship attenuates the sea and swell components as measured at the berth, so the correct ratios must be taken from measurements done without a ship present.

9. WAMIT modelling – impulse response functions

Hydrodynamic added mass and damping are calculated for the cruise ship using WAMIT software. These are then converted into "impulse response functions" (time-domain added mass and damping) by Filon quadrature (Perth Hydro 2021) in WAMIT. Settings used are as shown in Table 7.

Table 7 WAMIT settings for impulse response functions

WAMIT settings, impulse response functions	
WAMIT solver	Direct solver, standard velocity potential formulation
Representative water depth	14.0 m, including tide
Wave frequencies	0.005 : 0.005 : 2.500 rad/s (500 off), plus zero frequency and infinite frequency
Degrees of freedom	Coupled 6-DoF (surge, sway, heave, roll, pitch, yaw)
Frequency-dependent added mass and damping method	Radiation potential
Impulse response function method	WAMIT f2t utility, coupled 6-DoF, time step 0.1 seconds, length 300 seconds

10. Dynamic mooring analysis method

Dynamic moored ship motions and loads are calculated using MoorMotions software (www.moormotions.com). MoorMotions is a nonlinear time-domain solver developed at Perth Hydro. It uses a fourth-order Runge-Kutta solver, with 6-DoF motion coupling for a moored ship. The software and its validation are described in Gourlay et al. (2024, 2023, 2019) and Perth Hydro (2019).

11. Dynamic mooring operability criteria

Operability criteria for mooring safety of cruise ships are shown in Table 8 and Table 9.

Table 8 Operability criteria for safe mooring of cruise ships

Operability criteria – safe mooring		
Parameter	*Limit*	*Source*
Mooring line tension	55% MBL = 81.9 tonnes	PIANC (2019, Table 8.4) for avoiding line breakage.
Mooring line tension	50% SDMBL = 81.3 tonnes	OCIMF (2018, Fig. 1.4) before winch renders.
Mooring line tension	50% shore bollard SWL = 75.0 tonnes	Shore bollard SWL 150 t, two lines on each
STU ram motion amplitude	1.65 m	Red zone 0.50 m from end stops, 4.30 m stroke
Fender compression	1.01 m	Rated compression 72% x 1.400 m

Table 9 Operability criteria for safe passenger transfers to/from cruise ships

Operability criteria – safe passenger transfers		
Parameter	*Limit*	*Source*
Ship surge amplitude	0.3 m	PIANC (2023, Table 8-2) for cruise ship with fixed gangway
Ship sway amplitude at gangway	0.5 m	
Ship roll amplitude	2°	

Ship sway motions are modelled at the midships gangway (42% LOA from aft extremity) and forward gangway (72% LOA from aft extremity), as used at No. 6 Wharf on 14th February 2025, and shown in Figure 9.

Figure 9 Midships gangway on *Ovation of the Seas* at No. 6 Wharf

12. Example results in large wave conditions

Separate calculations in large sea, swell or LPW conditions show that LPW height is the most important wave parameter governing dynamic ship motions and loads of large ships at No. 6 Wharf. Swell height is of secondary importance, while short-period sea is of little importance. Here we calculate example dynamic motions and loads for *Ovation of the Seas* moored in 0.20 m LPW height, which is an extreme condition at the 96.5th percentile of measured wave data at this berth.

Wave conditions at the berth are shown in Table 10. Note that sea and swell waves are attenuated by the presence of the ship, so average (H_S, T_P) values were adopted for this LPW height.

Table 10 Modelled wave conditions at central wave gauge on No. 6 Wharf

Measured wave conditions at centre of berth	
LPW (25-150 s)	H_S = 0.20 m, frequency spectrum matched to measured spectrum at berth
Swell (7-25s)	H_S = 0.22 m, Bretschneider spectrum with average T_P = 10.9 s
Sea (<7s)	H_S = 0.13 m, Bretschneider spectrum with average T_P = 4.5 s
Total	H_S = 0.32 m

Dynamic mooring analysis results are shown in Table 11, for an example 3-hour simulation.

Table 11 Dynamic mooring results for *Ovation of the Seas* with wave conditions in Table 10

Peak values over 3-hour simulation		
Parameter	*Limit*	*Value*
Surge amplitude	0.30 m	0.27 m
Midships gangway sway ampl.	0.50 m	0.17 m
Forward gangway sway ampl.	0.50 m	0.22 m
Roll amplitude	2.00°	0.60°
Outer stern lines tension	75.0 t	36.0 t
Middle stern lines tension	75.0 t	37.6 t
Inner stern lines tension	75.0 t	39.4 t
Aft outer springs tension	75.0 t	37.9 t
Aft inner springs tension	75.0 t	36.6 t
Fwd inner springs tension	75.0 t	23.5 t
Fwd outer springs tension	75.0 t	20.4 t
Inner head lines tension	75.0 t	31.4 t
Middle head lines tension	75.0 t	31.2 t
Outer head lines tension	75.0 t	30.9 t
Aft breast STU ram amplitude	1.65 m	0.43 m
Aft spring STU ram amplitude	1.65 m	0.23 m
Fwd spring STU ram amplitude	1.65 m	0.38 m
Fwd breast STU ram amplitude	1.65 m	0.58 m
Maximum fender compression	1.01 m	0.20 m

We see that the combination of 20 ship's lines and 4 ShoreTension units allows safe mooring and safe passenger transfers in the extreme wave conditions of 0.20 m LPW height.

13. Conclusions and outlook

This article describes wave modelling and dynamic mooring analysis for cruise ships moored at Napier's newest berth, No. 6 Wharf. The results demonstrate safe mooring and passenger transfers up to 0.20 m LPW height at the berth. The results are broadly in agreement with experience, however detailed validation of the wave modelling and dynamic motions and loads is desirable. To this end, a recent set of GNSS measurements has been undertaken on *Ovation of the Seas* in large wave conditions. These measurements will be analyzed and compared with predictions in a subsequent article. Already-completed validation for container ships (Perth Hydro 2025) showed good agreement with predictions.

Figure 10 Capt. Robbie Jensen with starboard stern GNSS receiver on validation trials for *Ovation of the Seas*, 14th Feb 2025. Similar receivers on the port side and bow allow survey-accuracy 6-DoF ship motions to be measured at 1 Hz.

Relevant UN sustainable development goals

8, 9, 11, 17. (https://sdgs.un.org/goals)

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