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Full-Scale Dynamic Motion Validation of Moored Container Ships at the Port of Napier

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Executive Summary

A set of full-scale measurements has been undertaken on three container ships moored at Napier No. 6 Wharf with ships' lines and ShoreTension units. Motions in six degrees of freedom were accurately measured using survey GNSS equipment recording at 1 Hz.

Motions of the three ships have been compared with modified PIANC guidelines for loading containers from mobile harbour cranes. The first ship, Capitaine Baret, was found to have the largest motions of the three ships tested. Her motions were on the threshold at which container loading efficiency is predicted to drop below 95% of calm-water loading rates.

For this ship, a detailed validation was undertaken using the WAMIT+MoorMotions method developed for modelling ship motions at this berth. Simulations were done using the ship in its tested condition, and measured wave data at the time of the trials.

It was found that the method used for developing long wave thresholds in previous studies agreed quite well with the measured results. Opportunities exist for refining the wave directionality in the method. It is intended to use the data in continuous improvement of ship dynamic mooring analysis at Napier.

CONTENTS

NOMENCLATURE

DoF	Degrees of freedom
GM	Transverse metacentric height above centre of gravity
Hs	Significant wave height
KG	Centre of gravity height above keel
LBP	Length between perpendiculars
LCG	Longitudinal centre of gravity
LOA	Length overall
LPW	Long period wave
MBL	Minimum breaking load
NZDT	New Zealand daylight time (UTC+13)
PIANC	Permanent International Association of Navigational Congresses
RMS	Root-mean-square
SSA	Single-significant amplitude = 2 x RMS
STU	ShoreTension unit
TEU	Twenty-foot equivalent units
Tp	Peak wave period
Ts	Significant wave period
UTC	Coordinated universal time
VCG	Vertical centre of gravity

1. Ship motion measurements

Details of the moored ship measurements are shown in Table 1.

Moored ship measurements			
	Capitaine Baret	*Kota Lumba*	*NYK Futago*
LOA	210.00 m	260.00 m	266.65 m
LBP	198.80 m	246.04 m	250.00 m
Breadth moulded	30.10 m	32.25 m	35.40 m
Capacity	2700 TEU	4250 TEU	4500 TEU
Depth moulded	16.70 m	19.30 m	19.50 m
Design draft	11.50 m	11.00 m	10.80 m
Scantling draft	11.50 m	12.60 m	12.70 m
GNSS start, NZDT	2025-02-10, 07:26	2025-02-11, 08:55	2025-02-12, 16:57
Touch fender, NZDT	2025-02-10, 07:54	2025-02-11, 09:23	2025-02-12, 18:02
All lines fast, NZDT	2025-02-10, 08:50	2025-02-11, 10:20	2025-02-12, 18:40
GNSS end, NZDT	2025-02-10, 13:45	2025-02-12, 09:31	2025-02-13, 15:28
Side to berth	Starboard	Starboard	Starboard
Arrival drafts (aft/fwd)	9.00 m / 9.00 m	8.80 m / 8.30 m	9.95 m / 8.70 m
Arrival displacement	32,577 tonnes	N/A	44,704 tonnes
Arrival KG	10.92 m	N/A	12.86 m
Arrival GM	2.44 m	N/A	3.76 m
Departure drafts	9.40 m / 9.90 m	N/A	11.60 m / 8.80 m
Departure displ.	35,780 tonnes	N/A	51,208 tonnes
Departure KG	11.76 m	N/A	13.88 m
Departure GM	1.73 m	N/A	3.00 m
ShoreTension units	NPO-005 aft breast NPO-006 fwd breast	NPO-005 aft breast NPO-006 fwd breast	NPO-005 aft breast NPO-006 fwd breast NPO-003 aft spring NPO-004 fwd spring
Ship's lines	4 stern lines on winches 2 stern lines on bitts 4 head lines on winches 1 head line on bitts	4 stern lines on winches 1 stern line on bitts 5 head lines on winches	4 stern lines on winches 2 aft spring lines on winches 2 forward spring lines on winches 4 head lines on winches

Table 1: Details of moored ship measurements

2. PIANC motion limits

For gantry cranes, PIANC motion limits are shown in Table 2. These are based on motion single significant amplitude (SSA) away from the mean position. Different motion limits are given for 85%, 90% or 95% container loading efficiency (PIANC 2023, Table 6-3).

Motion criteria for container loading from gantry cranes			
Parameter	*Loading efficiency*		
	95%	*90%*	*85%*
Ship roll SSA	1.0°	1.5°	2.0°
Ship surge SSA	0.3 m	0.6 m	0.8 m
Ship sway SSA at container being loaded	0.5 m	0.8 m	1.0 m

Table 2: PIANC motion criteria for loading container ships from gantry cranes

Napier presently uses mobile harbour cranes for loading container ships at Nos. 5 & 6 Wharf. The port also has its own mobile harbour crane simulator, as shown in Figure 1.

Figure 1: (Left) Napier's mobile harbour crane simulator. (Right) Loading containers at No. 5 Wharf.

Advice was sought from an experienced Napier Port crane operator on whether the PIANC gantry crane limits are appropriate for mobile harbour cranes. It was suggested that the PIANC sway and roll limits are approximately in accordance with crane operator experience, but that surge amplitudes of 1 – 2 m are possible when loading with mobile harbour cranes. Mobile harbour cranes can slew to follow the surge motions of the ship, which gantry cranes cannot do. Ship surge is relatively slow, and visibility of surge motions is good, meaning that ship surge motions can be followed relatively easily.

Modified PIANC motion limits for loading containers from mobile harbour cranes are shown in Table 3.

Motion criteria for container loading from mobile harbour cranes			
Parameter	*Loading efficiency*		
	95%	*90%*	*85%*
Ship roll SSA	1.0°	1.5°	2.0°
Ship surge SSA	0.6 m	1.2 m	1.6 m
Ship sway SSA at container being loaded	0.5 m	0.8 m	1.0 m

Table 3: Modified PIANC motion criteria for loading container ships from mobile harbour cranes

3. GNSS data

Dual-frequency GNSS data, from all available satellites, were measured at 1-second intervals, at 3 receivers on each vessel. Javad Triumph-2 receivers were used for the measurements, as shown in Appendix A.

The GNSS data was post-processed, together with data from the shore base station (also shown in Appendix A), to give accurate GNSS time-stamped (latitude, longitude, altitude) of each receiver. Justin3 software was used for the processing. Expected RMS error was also output by the software; any points with expected RMS error > 0.015 m were rejected. Percentage data availability for each measurement is shown in Table 4.

GNSS data availability			
	Capitaine Baret	*Kota Lumba*	*NYK Futago*
Port receiver	99%	93%	99%
Starboard receiver	98%	93%	99%
Bow receiver	95%	95%	99%

Table 4: Percentage GNSS data availability for each ship measurement

Factors affecting data availability were:

- *Shielding*: The bridge wings and forecastle each had surrounding steelwork that gave the receivers an incomplete view of the sky.
- *Time of day*: Data dropouts occurred at the same time on subsequent days, due to insufficient visible satellites.

Multipath issues were also present with the steelwork surrounding each ship receiver. The Justin3 software was generally able to resolve the multipath issues, provided sufficient satellites were available.

Once accurate 1-second fixes of (latitude, longitude, altitude) were calculated for each receiver, rigid-body dynamics were used to calculate relevant ship motion parameters, as follows:

- Only time values when all receivers had data availability were used.
- Since port and starboard receivers were symmetric about the ship centreline, the altitude difference, and constant measured distance between these, were used to calculate absolute roll angle.
- Port and starboard receiver positions were averaged to give (latitude, longitude, altitude) at the bridge height, on the ship centreline.
- The berth orientation was used to transform latitude and longitude into surge and sway of the ship, at the bridge centreline and bow positions.
- Because roll motions contribute to sway motions, depending on the height above the centre of gravity, we transform the sway motions to a chosen height by allowing for the roll motion. The PIANC sway limits (Table 3) are to be applied at the container being loaded. The critical locations are the top stack on the forwardmost bay, and the top stack on the aftmost bay. We shall calculate sway motions at these points, using the ship General Arrangements. Note that there were not always containers present in the top stack during the measurements, but the same location is used throughout.

- Roll and ShoreTension ram displacements are given as absolute values. Heave is given relative to the initial position. Surge and sway motions are mean-subtracted.
- For single significant amplitude (SSA) calculations, motions are de-trended over 15-minute intervals to remove heel effects, then the SSA is found as twice the RMS value. The SSA approximately corresponds to average of the highest 1/3 motion amplitudes.

This report uses the WAMIT and MoorMotions sign conventions for ship motions, as shown in Table 5.

Sign convention	
Surge	Positive forwards
Sway	Positive to port
Heave	Positive upwards
Roll	Positive starboard side down
Pitch	Positive bow-down
Yaw	Positive bow-to-port

Table 5: Sign convention for ship motions, as used in this report

Start and end times for the plotted ship motions are shown in Table 6.

Plotted ship motion data			
	Capitaine Baret	*Kota Lumba*	*NYK Futago*
Start time, NZDT	2025-02-10, 08:50	2025-02-11, 10:20	2025-02-12, 18:40
End time, NZDT	2025-02-10, 13:01	2025-02-12, 08:06	2025-02-13, 15:28

Table 6: Start and end times of plotted ship motion data

4. Environmental conditions during ship motion measurements

Following the ship motion measurements, raw wave data was supplied by Napier Port from the following wave gauges:

- Offshore TriAxys wave buoy
- No. 6 Wharf East (chainage -25 m), VegaPuls C21 radar unit “T6E”
- No. 6 Wharf (chainage 65 m), RBR Solo pressure sensor
- No. 6 Wharf Mid (chainage 157 m), VegaPuls C21 radar unit “T6M”
- No. 6 Wharf (chainage 220 m), RBR Solo pressure sensor
- No. 6 Wharf West (chainage 300 m), VegaPuls C21 radar unit “T6W”

Locations of the wave gauges are shown in Figure 30.

The raw wave data was processed by Oceanum to determine wave timeseries and statistics. Measured wave data at No. 6 Wharf during the times of the ship motion trials is shown in Figure 2.

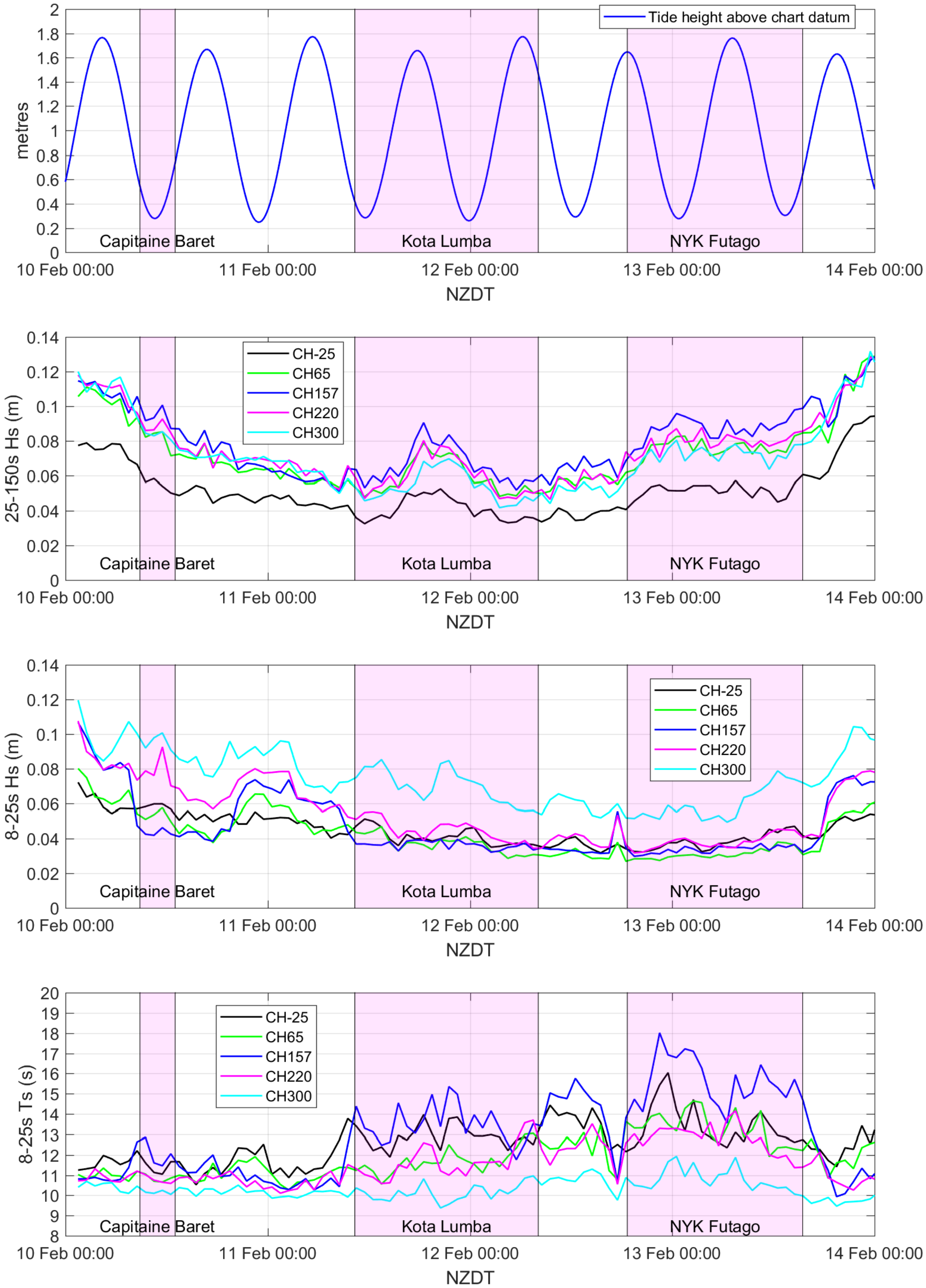

Figure 2: Forecast tide and measured wave data at 6 Wharf. The times of plotted ship motion data from Table 6 are overlaid.

Some comments on Figure 2 are:

- CH-25 long wave data is considerably smaller than at the other four wave gauges on the berth.
- CH157 swell data is affected by the presence of a ship on the berth. A decrease in CH157 swell height, and increase in CH157 swell period, is observed each time a ship is on the berth.

Available measured wave data at the offshore wave buoy is shown in Figure 3.

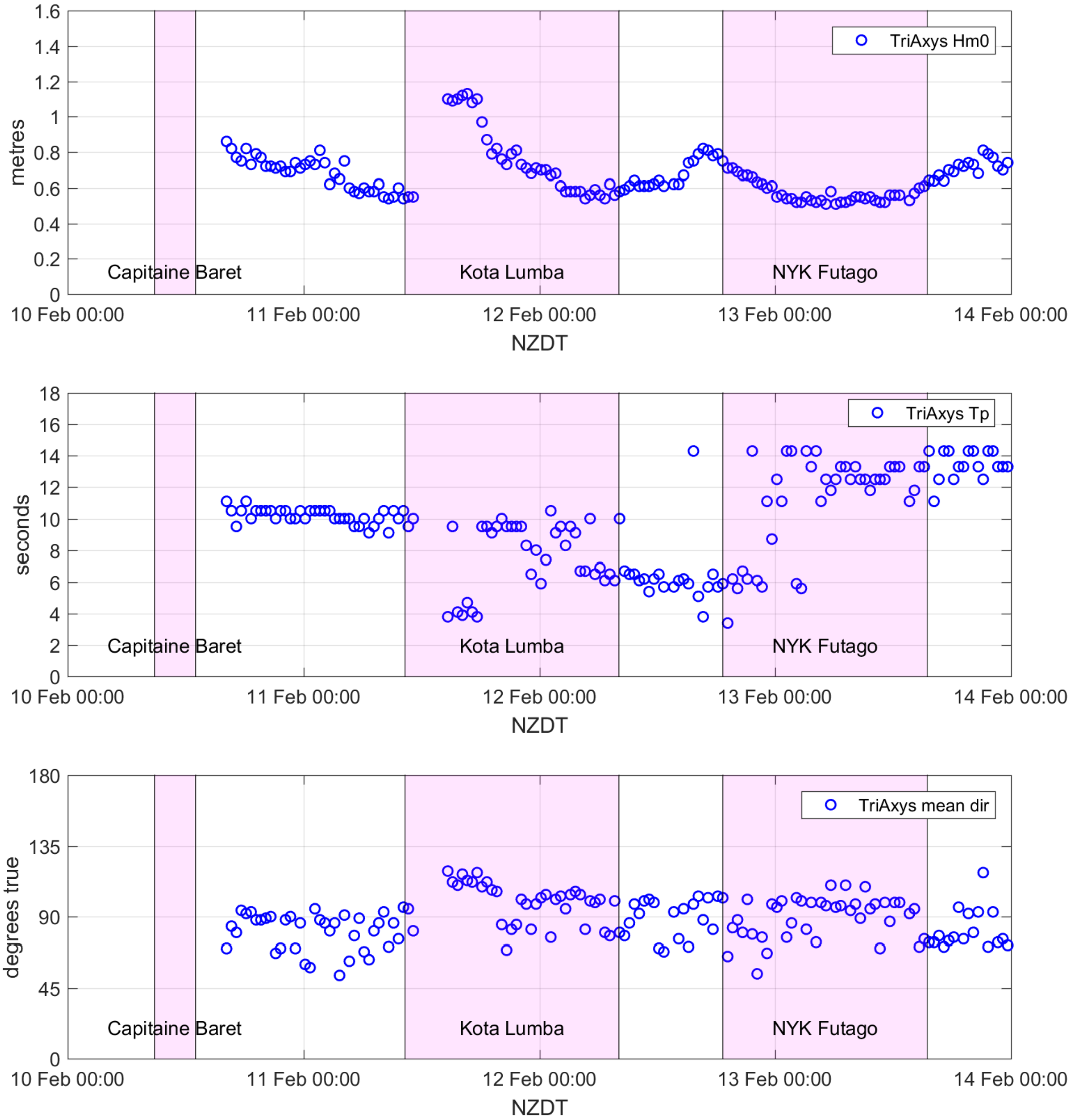

Figure 3: Measured wave data from TriAxys offshore wave buoy during the trials

Wind conditions were either calm or light wind during the Capitaine Baret, Kota Lumba and NYK Futago measurements.

5. Measured ship motions – Capitaine Baret

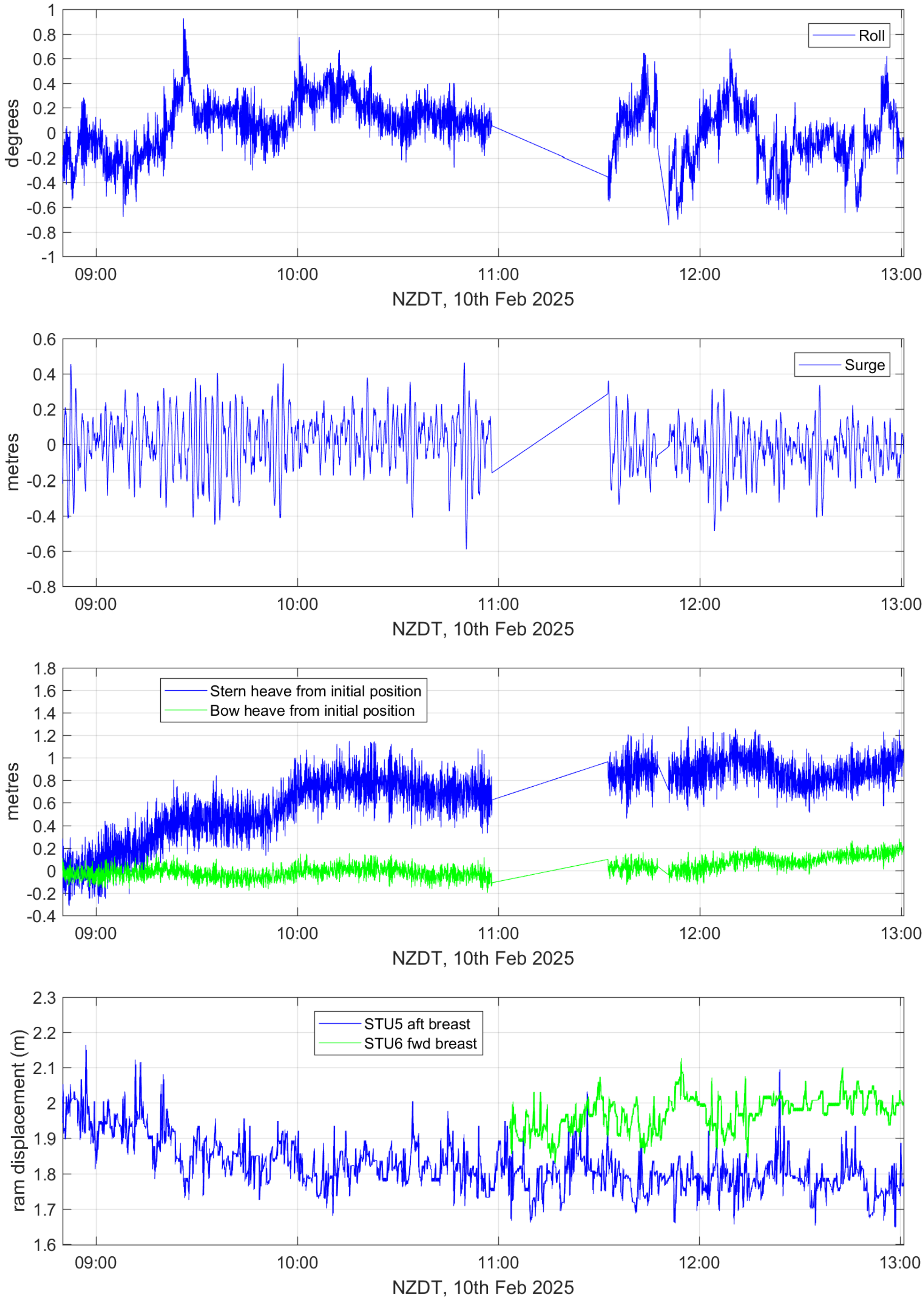

Figure 4: Measured roll, surge, heave and ram displacements for Capitaine Baret. Straight lines indicate missing motions data. STU6 data was unavailable for the first half of the measurements.

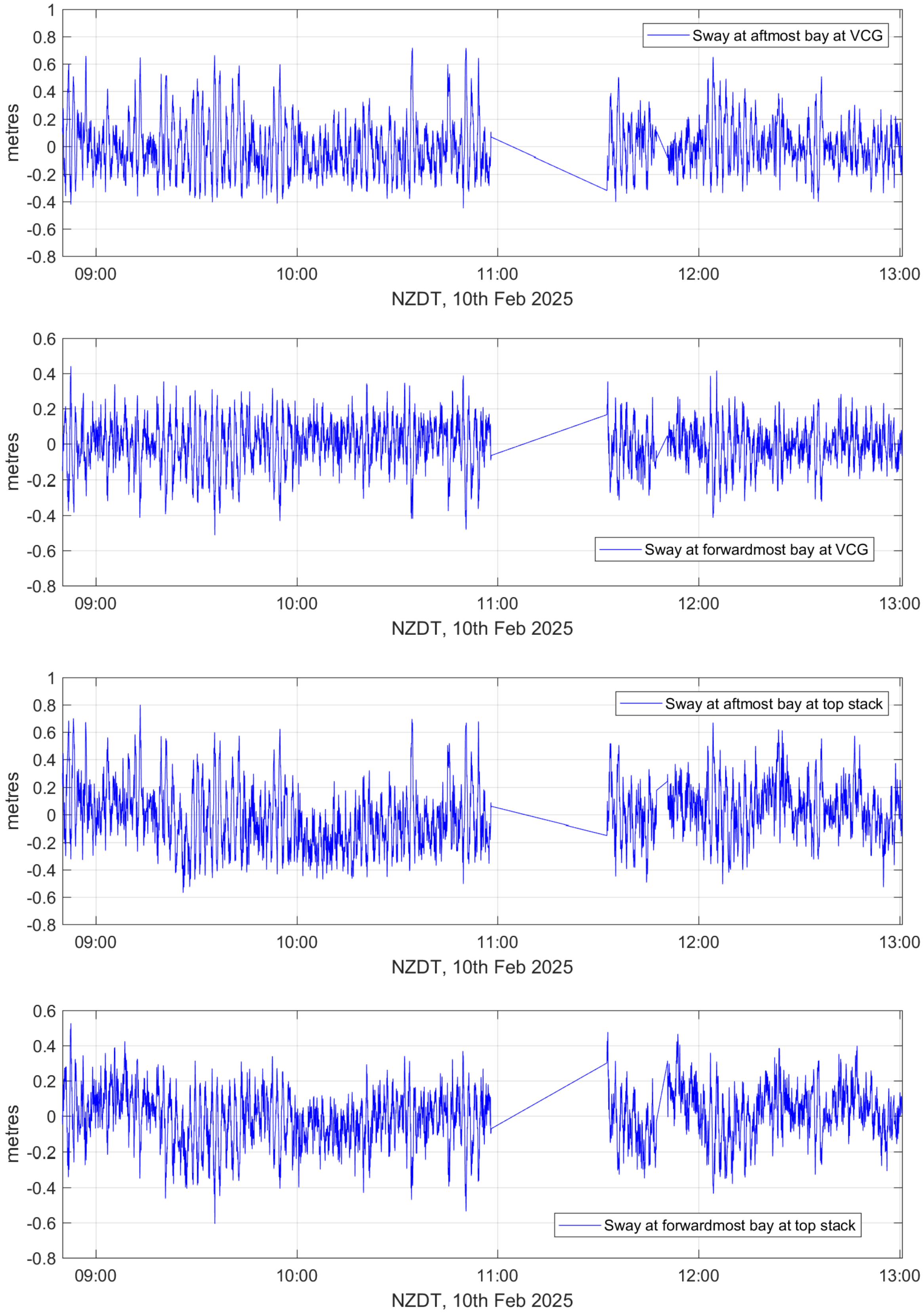

Figure 5: Measured sway motions for Capitaine Baret

6. Measured ship motions – Kota Lumba

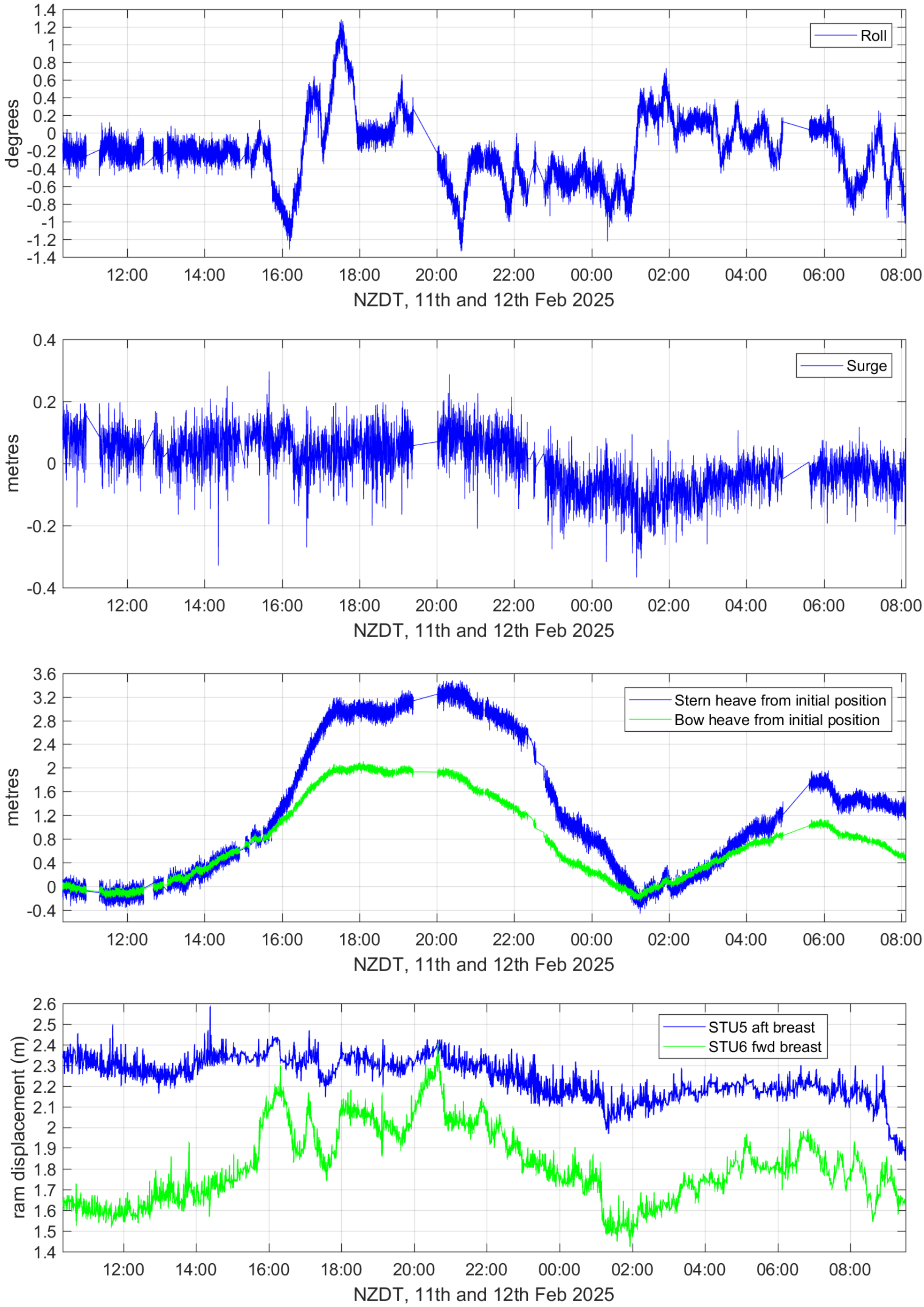

Figure 6: Measured roll, surge, heave and ram displacements for Kota Lumba

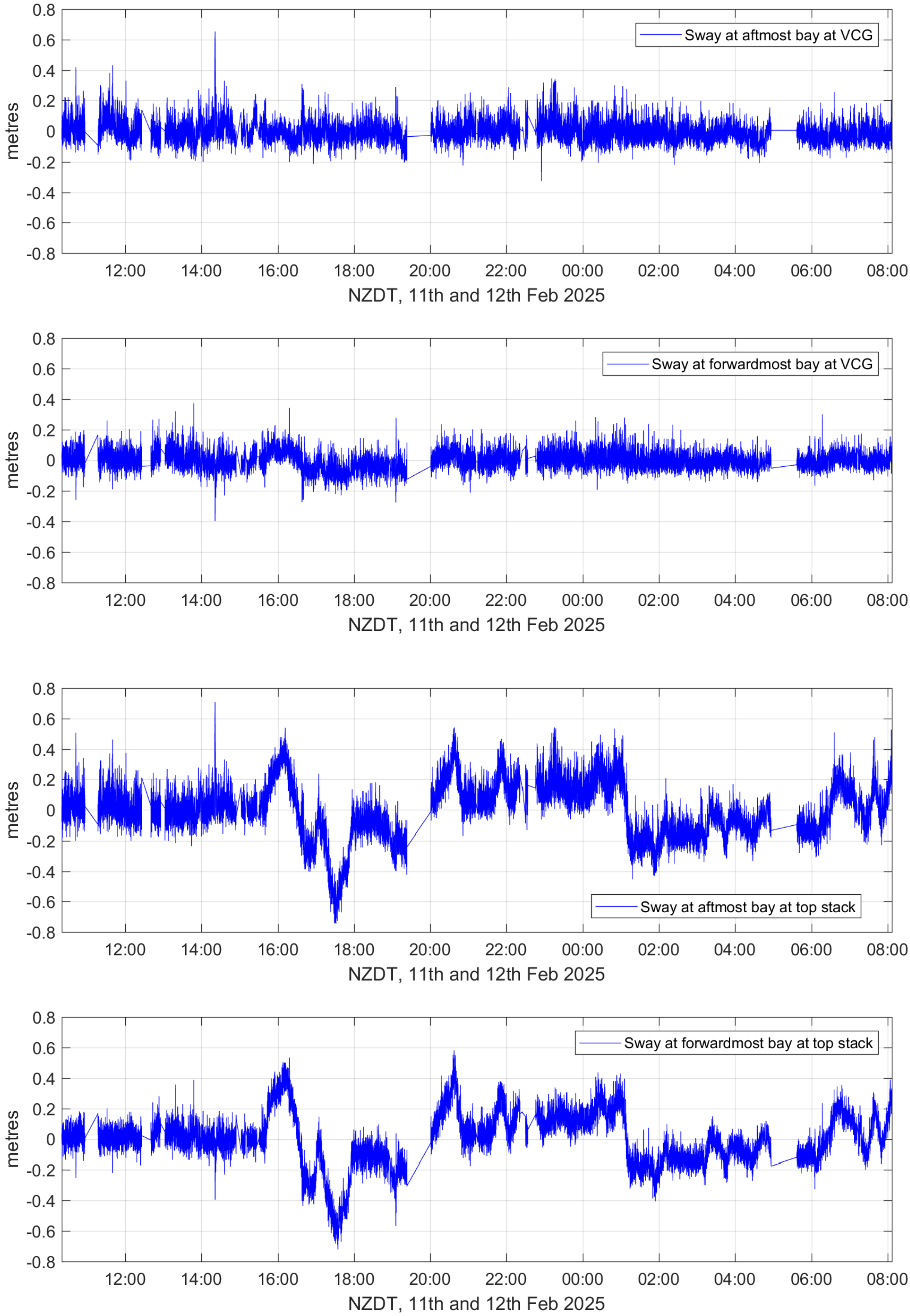

Figure 7: Measured sway motions for Kota Lumba

7. Measured ship motions – NYK Futago

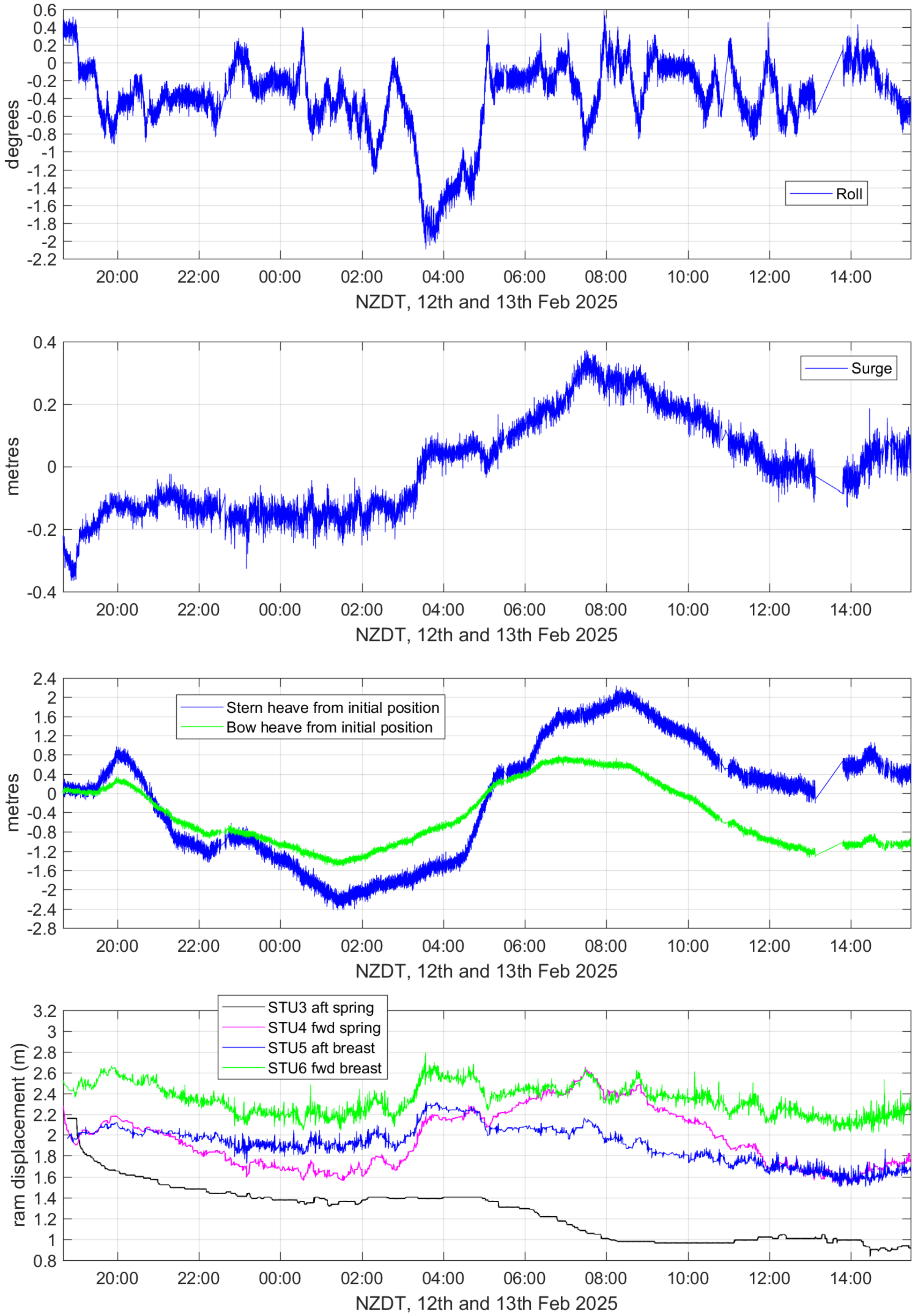

Figure 8: Measured roll, surge, heave and ram displacements for NYK Futago

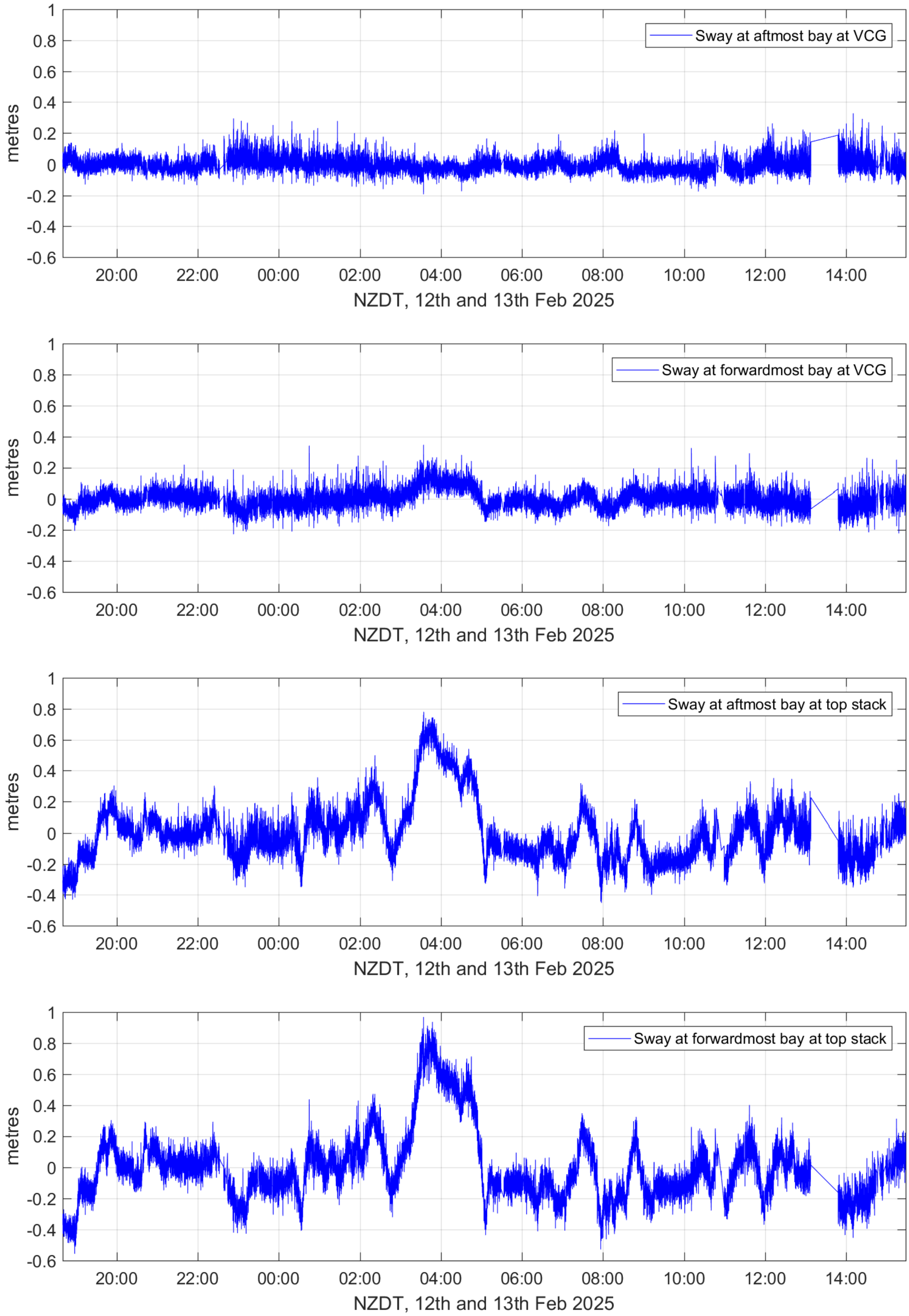

Figure 9: Measured sway motions for NYK Futago

8. Five minute snapshot – Capitaine Baret

A 5-minute snapshot of Capitaine Baret's motions is shown in Figure 10.

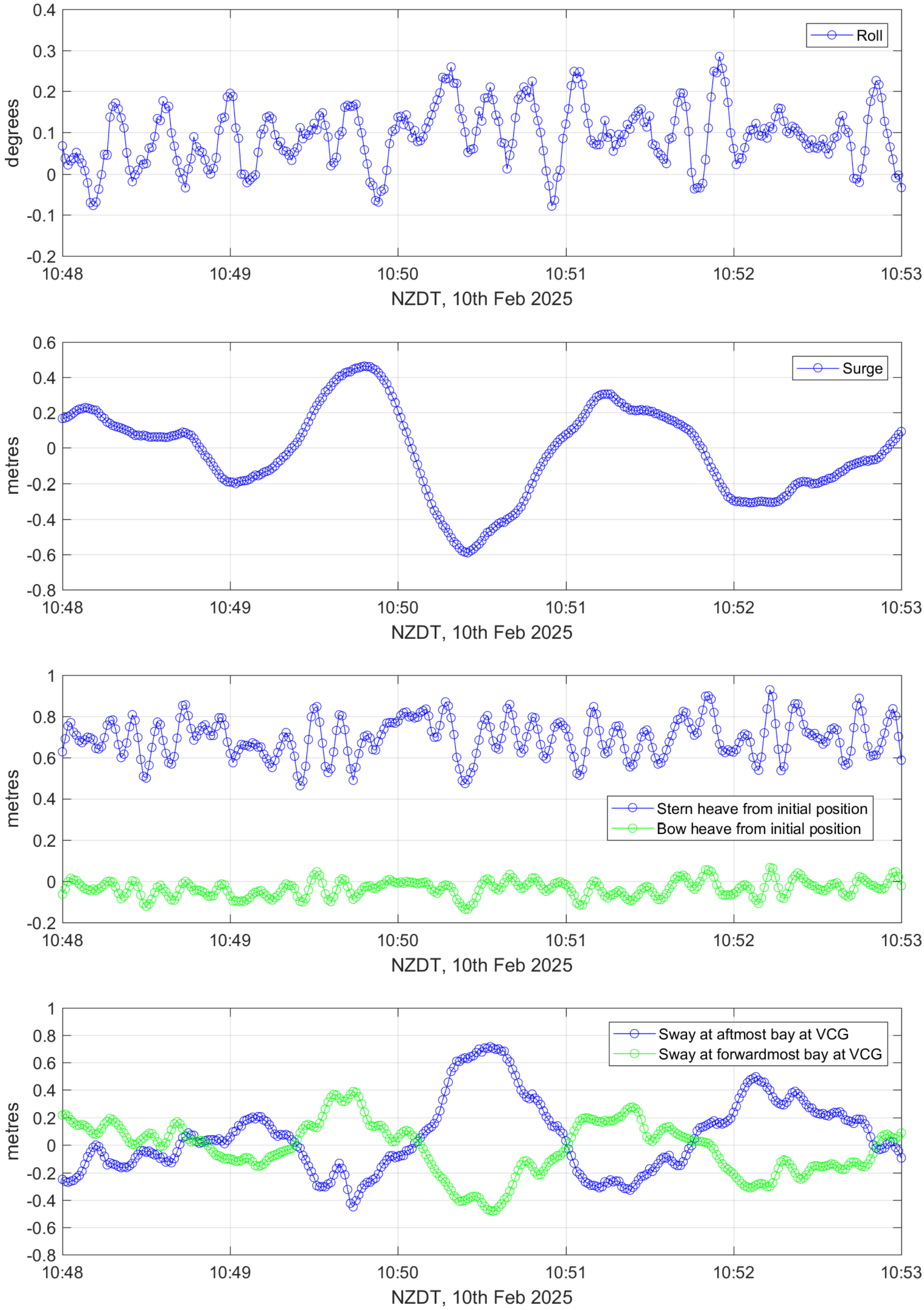

Figure 10: Five-minute snapshot of Capitaine Baret's motions. Data shown at 1-second intervals.

9. Notes on measured ship motions

Some notes on the measured ship motions are:

- Slow changes in absolute roll are “heel” due to uneven port/starboard loading of the ship.
- Positive heel (to starboard) correlates with decreased STU ram displacements, as the fairleads move toward the STU sheaves, and negative sway (i.e. toward the berth) at the top container stacks.
- Changes in heave follow changes in tide height (see Figure 2) as well as changes in draft and trim due to loading/unloading of the ship.

The 5-minute snapshot shows us that heave and roll oscillate quickly (with the swell), while surge oscillates slowly (with the long waves). Sway oscillates with both swell and long waves.

10. Comparison with PIANC motion limits – all ships

Here we compare the measured 15-minute ship motion single significant amplitudes (SSAs) to the modified limits shown in Table 3. Results are shown in Figure 11.

We see from Figure 11 that:

- Capitaine Baret has the largest motion amplitudes of the three ships measured.
- For Capitaine Baret, aft sway motions are on the 95% efficiency line, where the PIANC loading criteria suggest a noticeable drop in container loading efficiency. This is in line with comments from the crane drivers for this ship, who reported a noticeable drop in loading efficiency because of the ship motions.

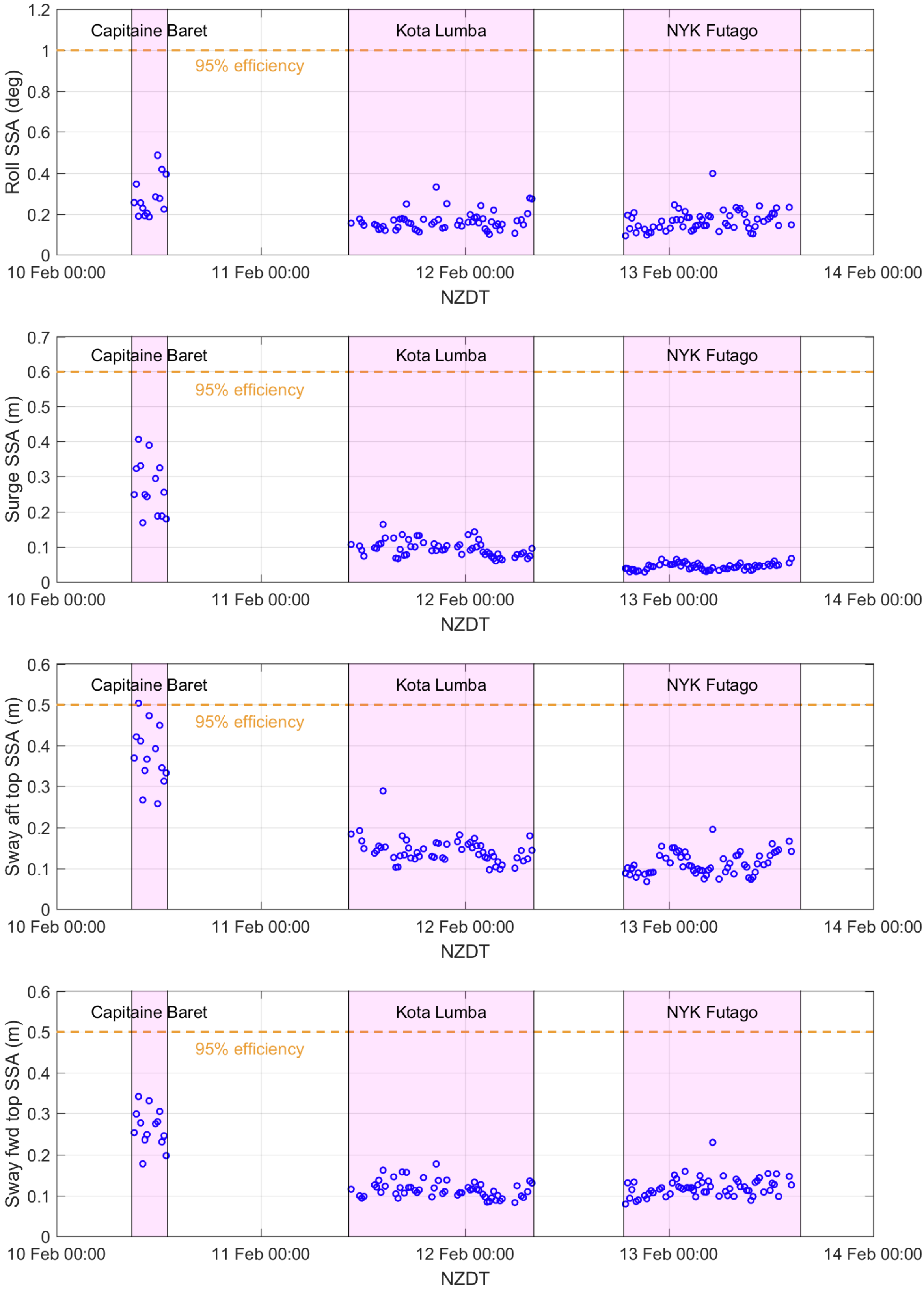

Figure 11: Measured motions, compared to container loading criteria shown in Table 3

11. Ship motions validation – Capitaine Baret

The measurements on Capitaine Baret are chosen for method validation, as they contained the largest measured motions of the three container ships.

Figure 12: Capitaine Baret moored at No. 6 Wharf, 10th Feb 2025

The mooring arrangement of Capitaine Baret at the time of the measurements is shown in Figure 30. Ship layout is taken from the General Arrangement. Only mooring lines on winches are modelled. Bridge mark position and mooring line runs are taken from berth camera photos and photos taken during the trials.

Here we use the method described in Gourlay et al. (2025) to calculate motions and loads of this ship in the measured wave conditions. The method may be summarized as follows:

- The correct ship dimensions, position, loading condition, ShoreTension arrangement and mooring line arrangement are modelled.
- 6-DoF wave loads on the ship are initially calculated for a complete range of incoming wave heights, frequencies and directions, using the coupled ship-and-harbour method in WAMIT.
- Based on Oceanum FUNWAVE modelling, principal incoming swell direction just outside the harbour is modelled as 035°T, with cosine-squared wave spreading.
- As modelled by Oceanum in FUNWAVE, the long wave climate inside Napier Harbour is generated by multiple sources, with a wide range of directionality. In the WAMIT coupled ship-and-harbour method, we have modelled an even spread of incoming long wave directions from 270°T – 045°T. The resulting long wave pattern in the harbour then shows localized directionality and amplification according to the shape of the harbour.
- The incoming long wave heights are tuned to give the correct measured long wave conditions at the mid-wharf wave gauge (CH157).
- The incoming sea and swell heights are tuned to give the correct measured sea and swell conditions at CH157. Where the calculations are to be done based on a single

input of long wave height, the sea and swell parameters are chosen based on their average percentage of long wave height, from measured data.
- Based on the calculated incoming wave spectrum, wave loads on the ship are fed into MoorMotions to give dynamic ship motions and mooring loads.

The exact mooring line type for Capitaine Baret was not known. We have modelled mixed polypropylene lines with 65 tonne MBL, as is typical for this size of ship. Also, the line pre-tension is not known, as there are no load cells on the shore bollards. Therefore, we have run MoorMotions with line pre-tensions of 1% MBL and 10% MBL, to assess the sensitivity. A line pre-tension of 10% MBL is recommended in PIANC (2019, p.172). This corresponds to a pre-tension of 6.5 tonnes in this case. Winch heaving capacity for this type of ship is typically 5 – 10 tonnes.

As advised by the mooring crew, the ShoreTension pay-out tension (Valve 2 tension) was set to 25 tonnes for all units on 6 Wharf for the duration of the trials. This pay-out tension has been modelled in MoorMotions, together with the unit and line characteristics as supplied by ShoreTension BV.

Results from this method are shown below, as compared to measured results. Wave statistics are taken over each hour during the measurements, and MoorMotions is run as 1-hour simulations, corresponding to each hour of wave data. Measured results are averaged over the four 15-minute SSA values in each hour. Measured data is only shown for hours with >90% measured data availability.

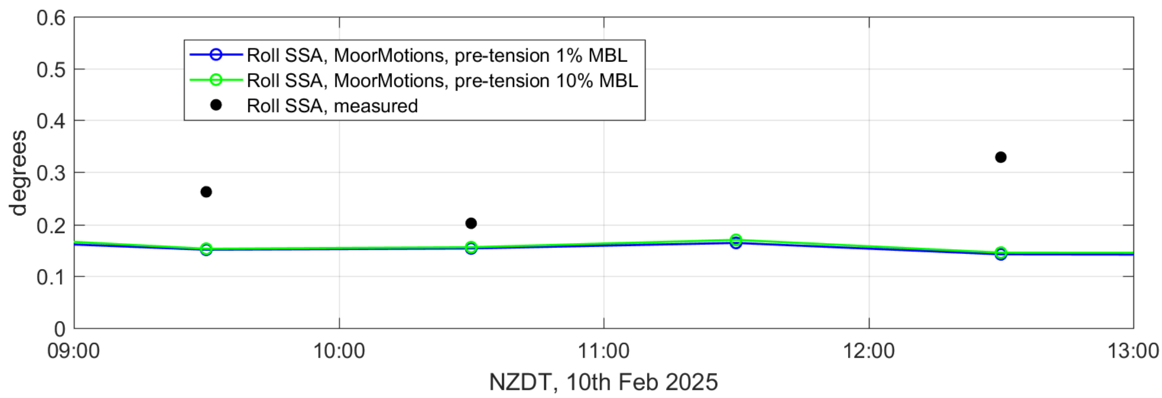

Figure 13: Predicted and measured roll for Capitaine Baret

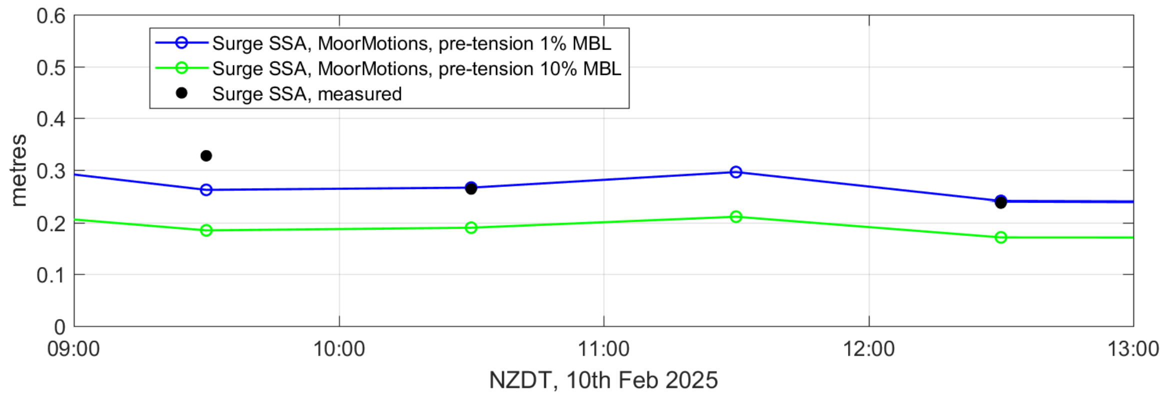

Figure 14: Predicted and measured surge for Capitaine Baret

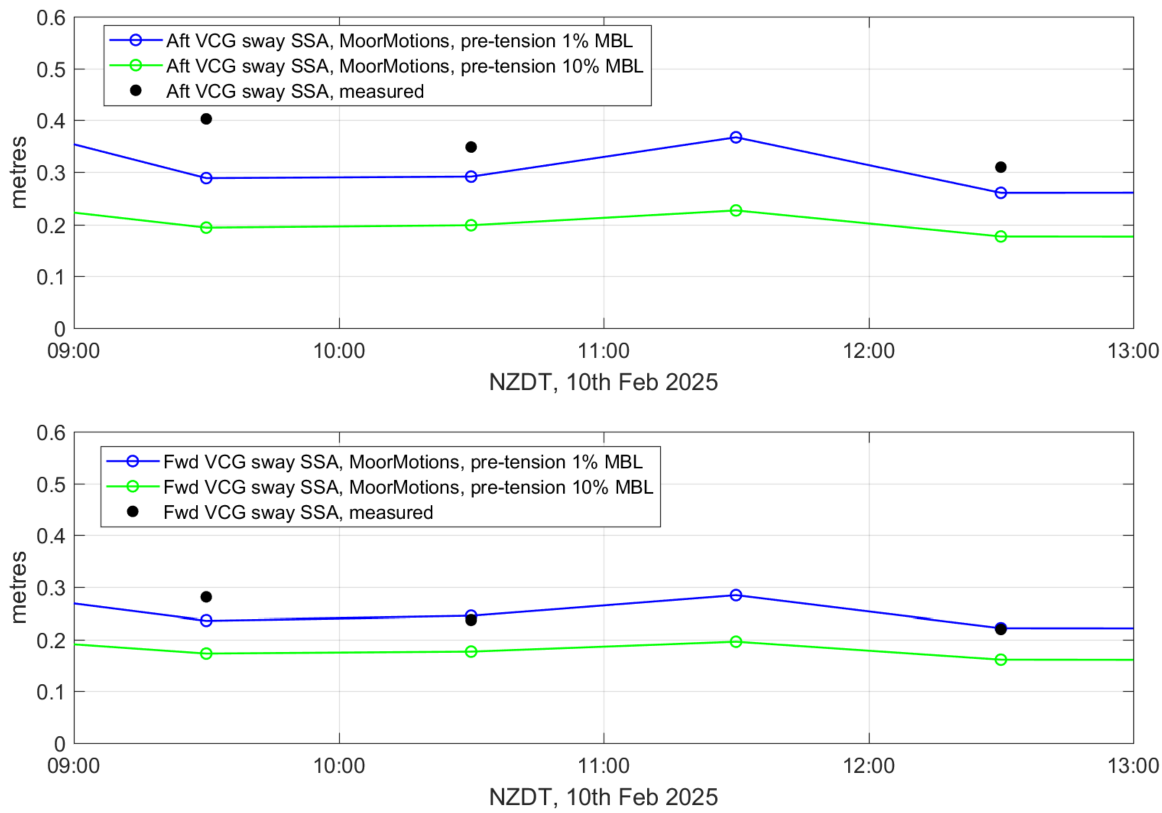

Figure 15: Predicted and measured sway motions at aftmost and forwardmost container bay, at VCG

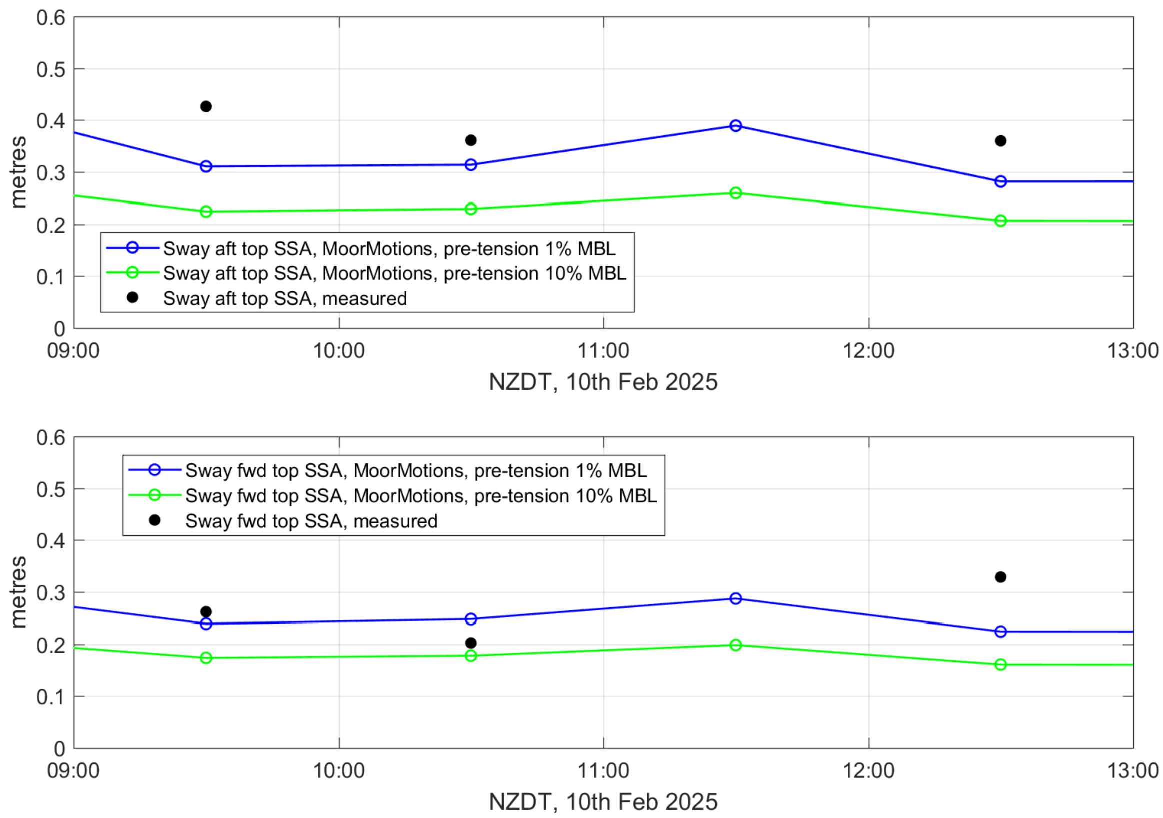

Figure 16: Predicted and measured sway motions at aftmost and forwardmost container bay, at top container stack height, for Capitaine Baret

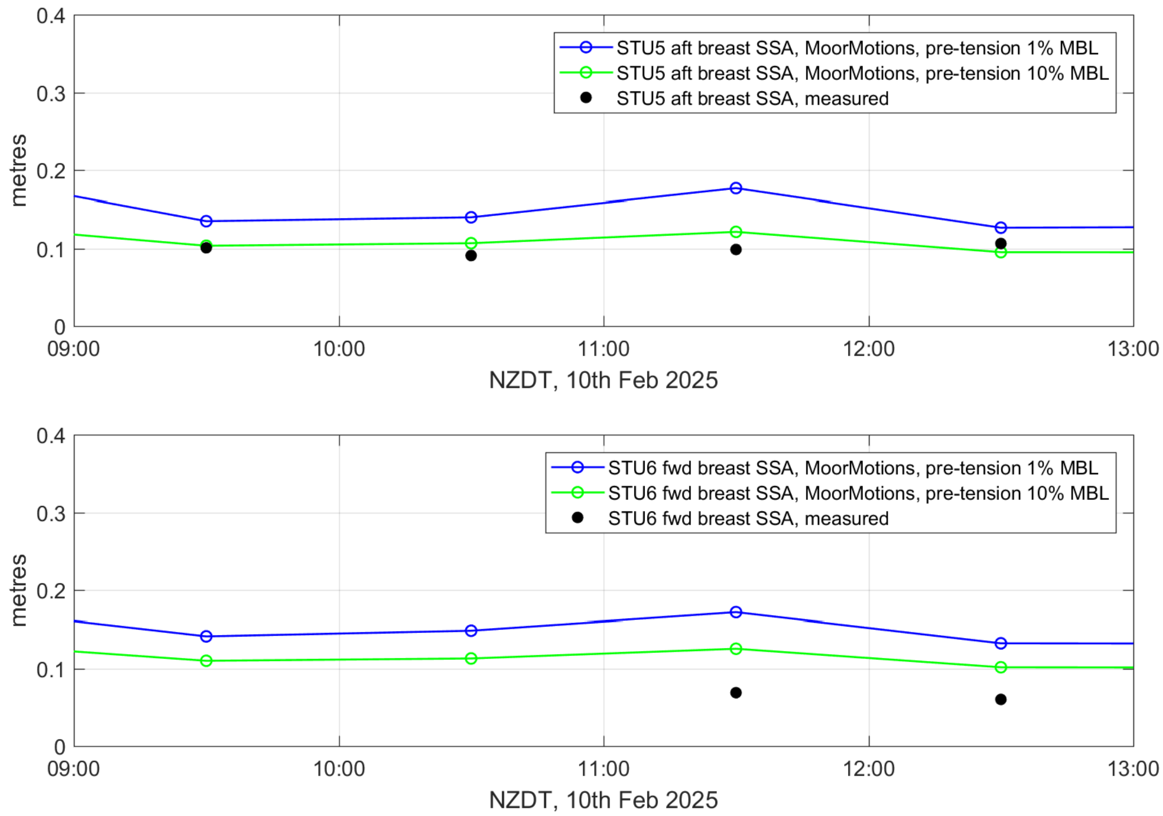

Figure 17: Predicted and measured wave-induced ShoreTension ram displacements for Capitaine Baret

Points to note from the modelled and measured ship motions include:

- Modelling shows that ship's line pre-tension has a large effect on surge and sway motions. Higher pre-tension gives lower motions. With two ShoreTension units on a ship of this size, the ShoreTension units are not doing all of the work; having sufficient pre-tension in the ship's lines is still important.
- Ship's line pre-tension has negligible effect on roll motions.
- Surge and sway at VCG are reasonably well predicted by the modelling. As found in previous modelling for No. 6 Wharf, surge and sway at VCG are primarily influenced by long waves rather than swell. The fact that surge and sway are in approximately the correct ratio indicates that the assumed directionality of incoming long waves (i.e. broad-band directionality) is valid.
- Roll is under-predicted in the modelling. The natural roll period of this ship is 15 seconds, which is in the swell range. The swell height at the berth is chosen according to measured data, however it is possible that the incoming swell directionality to the berth is not quite right. This will be discussed in the next section.
- Sway motions at the top container stack are affected by roll motions, hence under-prediction of roll motions affects the predicted sway motions at the top container stack.
- Although hourly averages are used for the validation, it is noted that there is significant scatter in the 15-minute averages (shown in Figure 11). Bearing in mind this scatter in the measured results, the predictions can be said to agree quite well with the measurements.

12. Wave modelling validation

A good check on wave modelling in the coupled ship-and-harbour method is the relative height of waves at each end of the berth. The measured ratios are shown in Figure 18 for the duration of the trials. Also shown are the modelled ratios, which remain constant.

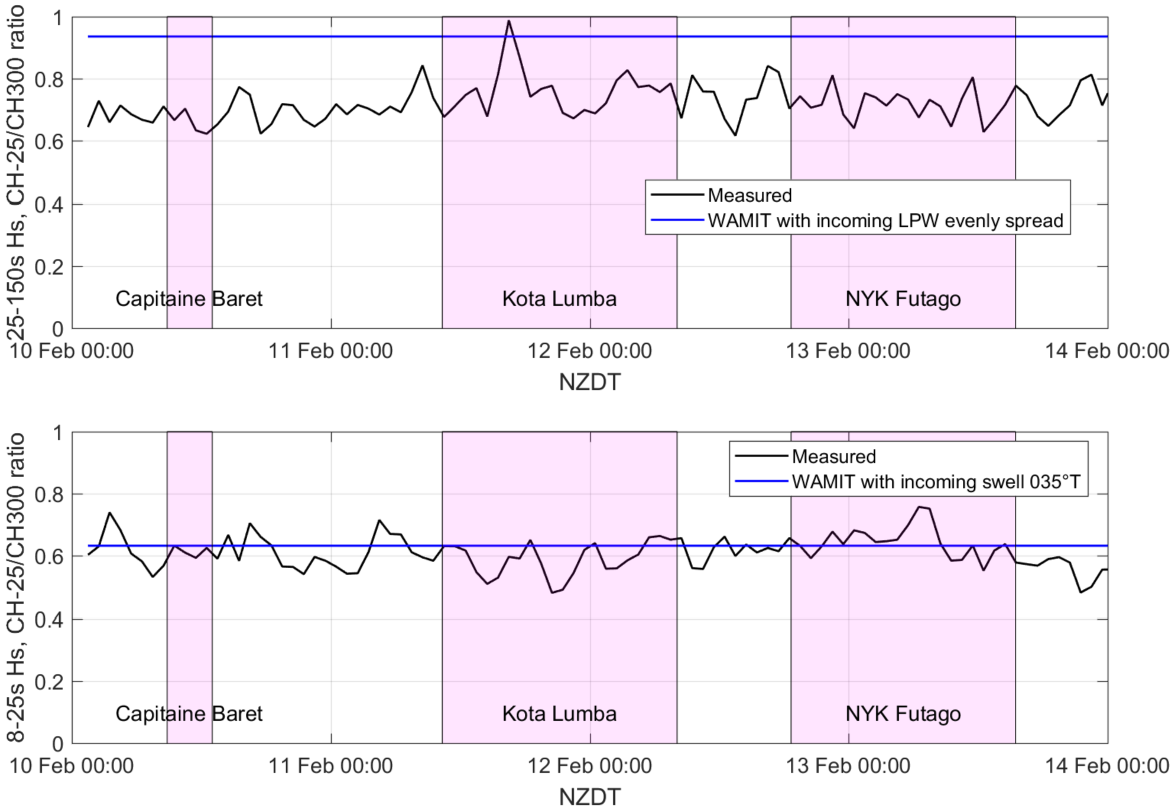

Figure 18: Wave height ratios at each end of the berth. (Top) LPW. (Bottom) Swell.

LPW height at the eastern end of the berth is around 0.7 times LPW height at the western end, according to the measurements. The modelling method predicts similar LPW heights at each end of the berth. As seen in Figure 2, LPW heights are fairly similar from CH300 to CH65, with a sudden drop at CH-25. Closer investigation of the FUNWAVE modelling previously undertaken by Oceanum may help to explain this result.

Swell height at the eastern end of the berth is around 0.6 times swell height at the western end of the berth, according to the measurements and the modelling method. It is important to note here that WAMIT is a constant-depth wave diffraction code. Therefore, although it appears to capture the decrease in swell height toward the eastern end of the berth, this does not mean that it is accurately capturing the directionality. The real bathymetry (which is modelled in FUNWAVE) slopes down from the breakwater, so that waves both diffract and refract around the breakwater. Refraction increases the “wrapping” effect of swell waves coming around the breakwater, so we may expect that the real swell direction at No. 6 Wharf is more beam-on than the diffracted swell direction. This topic is addressed in the following section.

13. Roll motions

Having a more beam-on swell direction than in the WAMIT+MoorMotions model may increase the roll motions, as roll motions are caused by the swell band of frequencies. This was checked by running a sensitivity analysis, using 035°T and 000°T incoming swell directions.

Another simplification used is the averaged swell period. As a sensitivity check on the effect of swell period, we use the measured swell period at CH157 from Figure 2, just prior to the arrival of Capitaine Baret, namely Ts = 11 s, or Tp = 14 s if assuming a Bretschneider spectrum. This is closer to the Capitaine Baret natural roll period of 15 s, as compared to the long-term average at CH157 of Tp = 11 s.

Results are shown in Figure 19.

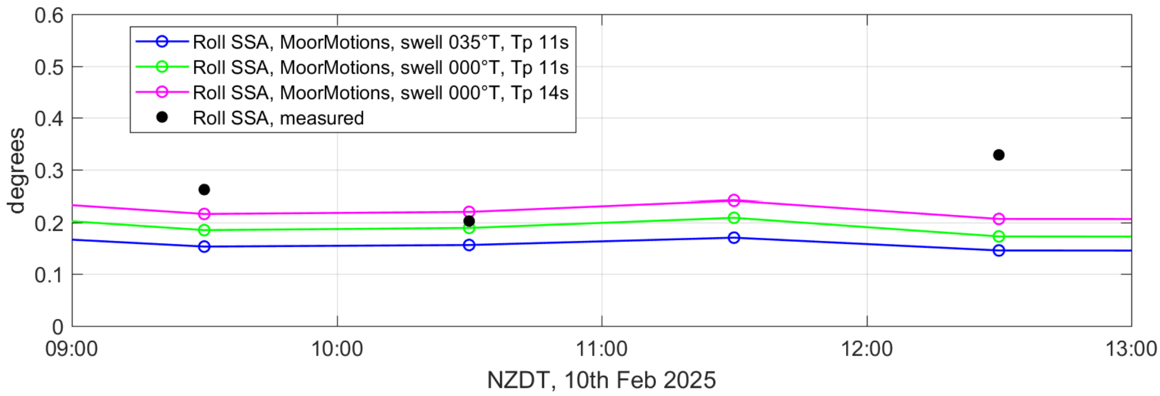

Figure 19: Sensitivity analysis into effect of incoming swell direction and period on roll motions

It should be pointed out that container ship roll motions are very difficult to predict, even in open water (Ha and Gourlay 2018). This is partly because roll response is very tuned to the natural roll period, and the roll damping has a large effect.

Acknowledgements

This work was supported by the Port of Napier. Wave analysis was undertaken by Oceanum.

References

Gourlay, T.P., Jensen, R., McComb, P. (2025) Dynamic mooring analysis for cruise ships at the Port of Napier. Proceedings, Coasts and Ports 2025, Adelaide.

Ha, J.-H., Gourlay, T.P. (2018) Full-scale measurements and method validation of container ship wave-induced motions at the Port of Fremantle. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 144, No. 6.

PIANC (2023) Criteria for acceptable movement of ships at berths. Report of Working Group 212.

PIANC (2019) Design principles for dry bulk marine terminals. Report of Working Group 184.

Appendix A – GNSS receiver locations

Figure 20: GNSS base station on west end of 6 Wharf, used for all GNSS measurements

Figure 21: Port bridge wing GNSS receiver on Capitaine Baret

Figure 22: Starboard bridge wing GNSS receiver on Capitaine Baret

Figure 23: Bow GNSS receiver on Capitaine Baret

Figure 24: Port bridge wing GNSS receiver on Kota Lumba

Figure 25: Starboard bridge wing GNSS receiver on Kota Lumba

Figure 26: Bow GNSS receiver on Kota Lumba

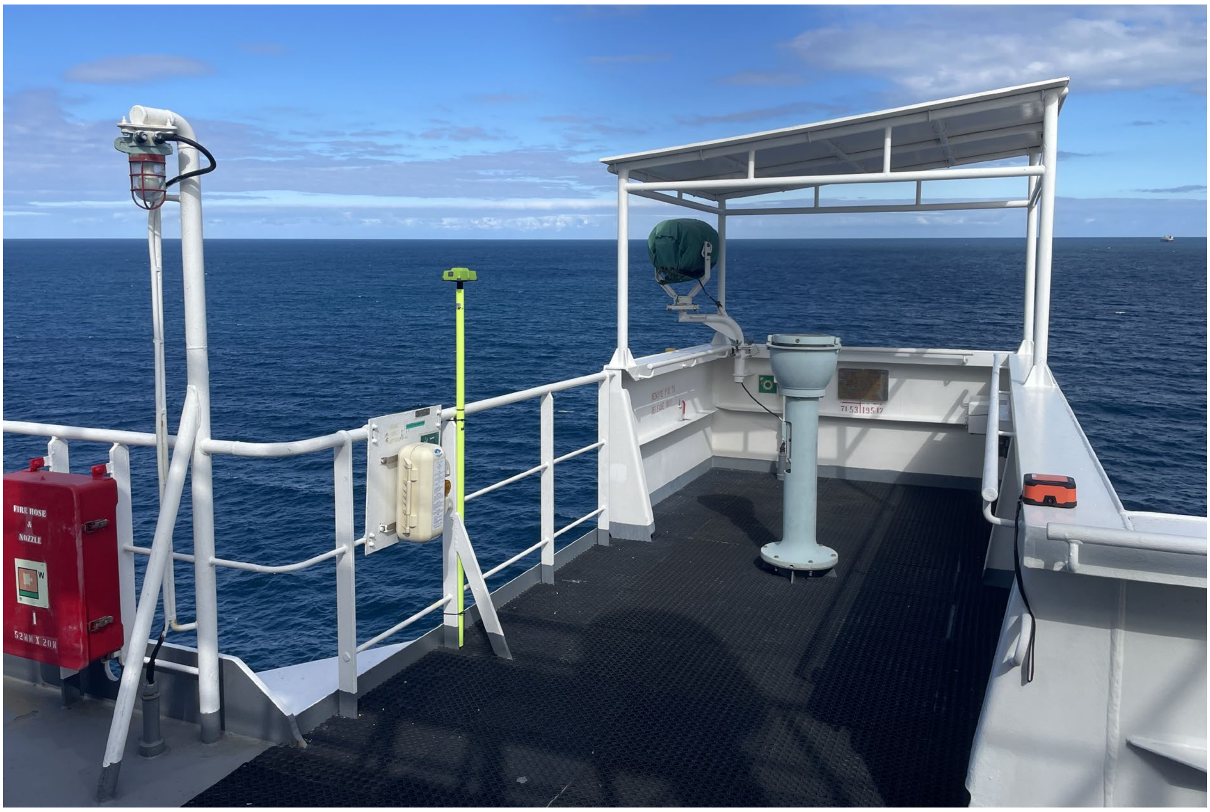

Figure 27: Port bridge wing GNSS receiver on NYK Futago

Figure 28: Starboard bridge wing GNSS receiver on NYK Futago

Figure 29: Bow GNSS receiver on NYK Futago

Appendix B – Capitaine Baret mooring arrangement

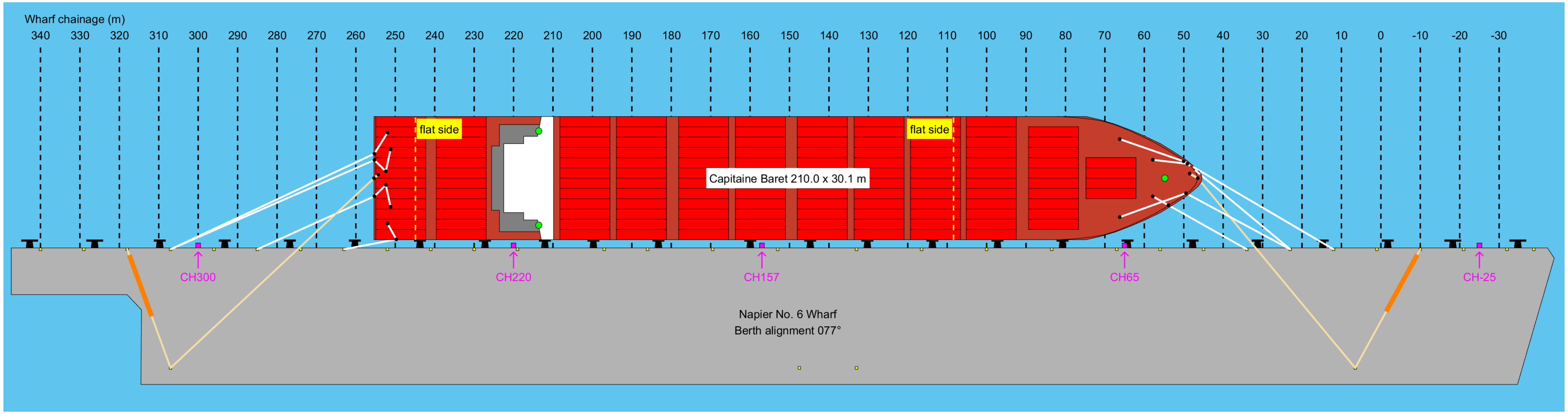

Figure 30: Plan view of Capitaine Baret on 10th February 2025 at Napier No. 6 Wharf, showing ship's lines (white), ShoreTension lines (orange), GNSS receivers (green), ship flat side at fender height (yellow) and long wave gauges (pink)