MONITORING MOORED BOAT MOTIONS INDUCED BY WAKE FROM PASSING VESSELS, A CASE STUDY: WILLIAMSTOWN MARITIME PRECINT

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Wash and wake from marine traffic can result in undesirable social and environmental impacts in coastal and waterway areas. This case study focused on identifying the cause-effect relationship between the propagation of wake induced waves from passing vessels and the motions of moored boats in the Williamstown Maritime Precinct, Victoria, Australia. The study involved field monitoring and data analysis, developing methods and insights for the local study area, which can be applied to other areas experiencing similar issues.

Keywords: wake, waves, marine traffic, monitoring

INTRODUCTION

Wash and wake induced waves from passing vessels often presents management challenges in coastal and enclosed waterway areas. Issues around personal safety (e.g., from unexpected motions on moored boats), as well as social and environmental impacts (e.g., bank and shoreline erosion), arise from marine traffic comprising transportation, shipping and/or recreational boating activities. This presents a challenge for local port operators, authorities, and the often conflicting, interests of local communities and stakeholders.

This case study on the Williamstown Maritime Precinct, in Victoria, Australia, was motivated by the need to identify options to mitigate the “wave, wash and surge events”, which are regarded as both inconvenient, damaging, and dangerous by local stakeholders. A key objective of the study was to improve the understanding of the association of such events with the passage of vessels nearby and the properties of wake induced waves. This was approached by designing a novel yet relatively simple field campaign monitoring boat motions, sea state properties and marine traffic, followed by data analysis. The study developed monitoring and analysis methods and insights to aid management of this issue in the study area and applicable to other areas experiencing similar issues.

STUDY AREA

The Williamstown Maritime Precinct is an area of significance to the boating and maritime communities of Melbourne and broader Victoria (Figure 1). It is located within Hobsons Bay in the north end of Port Phillip Bay and is in close proximity to the Port of Melbourne. A series of piers and marinas exist within the Precinct, which extends approximately 1.5km from Point Gellibrand to the mouth of the Yarra River, where the Williamstown Channel (a dredged channel of approximately 13m depth) provides access to shipping in the otherwise shallow waters of Hobsons Bay (of depths generally lower than 5m).

The location and position of the Precinct provides partial natural sheltering to the prevailing seas, with protection enhanced by a number of purposely built structures. At the same time the location makes this waterway one of the busiest in Victoria, with vessel wake induced waves propagating into the Precinct, affecting the infrastructure and the boats moored at the local piers and marinas.

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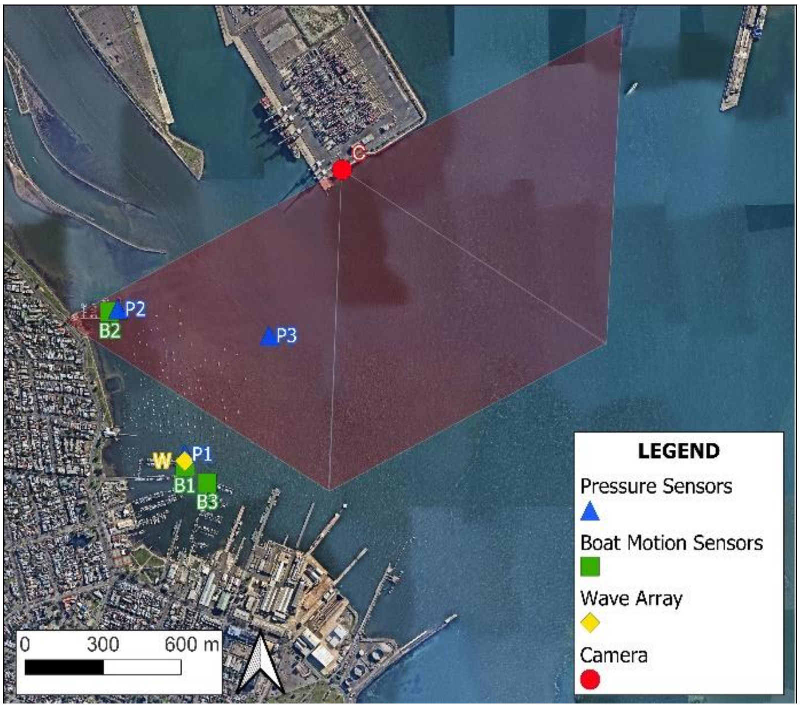

Figure 1. Study Area and Field Monitoring Plan, Williamstown Maritime Precinct, Melbourne, Australia

METHODOLOGY

Field Observations

The study involved a field monitoring campaign and subsequent data analysis. Field measurements were collected of sea state properties, response of moored vessels to the excitations and observation of vessel traffic passage around the study area (Figure 1), over a period of approximately 4 months (from 21 December 2020 to 14 April 2021).

The sea state properties, specifically water level, wave height and period were collected from three pressure sensor units (RBR Solo; locations P1, P2 and P3) and one wave array instrument (location W) comprising of three ultrasonic sensors (Senix Tough Sonic 30).

The response of moored vessels was measured by three motion sensors (Marine Link Sense, MLS) deployed on three representative sailing yachts moored within the Williamstown Maritime Precinct, identified with support from local stakeholders (locations B1, B2 and B3). The boat motion sensors measured and recorded the direction and amplitude of angular motions and translational accelerations (6 degrees of freedom) of the moored boats i.e., three rotational motions: roll, pitch and yaw, and three translational motions: surge (forward/backward), sway (sideways), and heave (vertical). These motions are illustrated in (Figure 2).

Data from the boat motion sensors and wave array were transmitted and streamed in near real-time to a cloud platform (BMT Deep) for storage and visualisation using a purpose-designed online viewing portal.

A system of high-resolution cameras (location C) was also deployed to aid in the monitoring of marine traffic and identification of passing vessel types and characteristics. The camera system consisted of three outdoor bullet network cameras (Vivotek IB9391-EHT) powered by a local 240V source with backup battery. The cameras, of approximately 60° viewing angle each, were arranged next to each other to cover over 180° field of view, approximately 70° to 250° N. Camera imagery was available in real-time, through internet connection to a single network video recorder (NVR, Vivotek ND9541P). In addition to the abovementioned measurements, metocean data and marine traffic data (from Automated Identification System, AIS) provided by the Victorian Ports Corporation Melbourne (VPCM) were collated for the period of field observations. Further, visual observations of events occurring during the data collection period were reported independently in more than 30 reports by the local stakeholders.

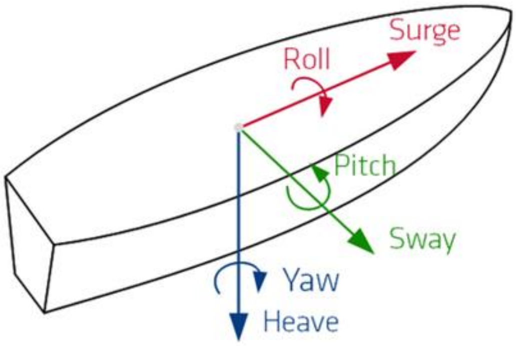

Figure 2. Schematic showing six degrees of freedom of boat motions (angular and translational)

Data Analysis

The field data were time synchronised, quality controlled and analysed through time series and statistical techniques. A dynamic threshold algorithm was developed to analyse the MLS data to identify significant moored boat motion "events" and filter out boat motion response to background sea state (i.e., naturally occurring events). See Figure 3 for an example of applying the dynamic threshold algorithm to a recorded roll motion.

Figure 3. Dynamic threshold event detection algorithm to distinguish between boat motion 'events' and motions in the background sea state

The event detection algorithm was primarily applied to the recorded roll motions from MLS data and an extensive catalogue of detected events with different amplitudes (the limits of a single roll cycle, see Figure 4) and durations (the time to complete a single roll cycle) was collated.

The catalogue of events was then cross analysed against the AIS data allowing to identify specific vessels passing through the study area at speeds that generate wake induced waves and thus associated with the detected events. Key characteristics of the passing vessels, type, size, speed and direction of transit were added to the events catalogue. The video recordings from the camera system were used to verify the AIS identified vessels as well as to identify passing vessel types and their characteristics for detected events that did not have AIS associated vessel passage.

Further, visual observations of events occurring during the data collection period, reported independently (in more than 30 reports) by the local stakeholders, served to validate the analysis methods applied, rendering full detection of all the visually reported events. In addition to roll motions, the surge motions (i.e., translational motions) were another main concern in the study area. To address the issue, the event detection algorithm was customised and used to analyse the records of horizontal accelerations. Additionally, induced motions due to naturally occurring wind and wave conditions were investigated.

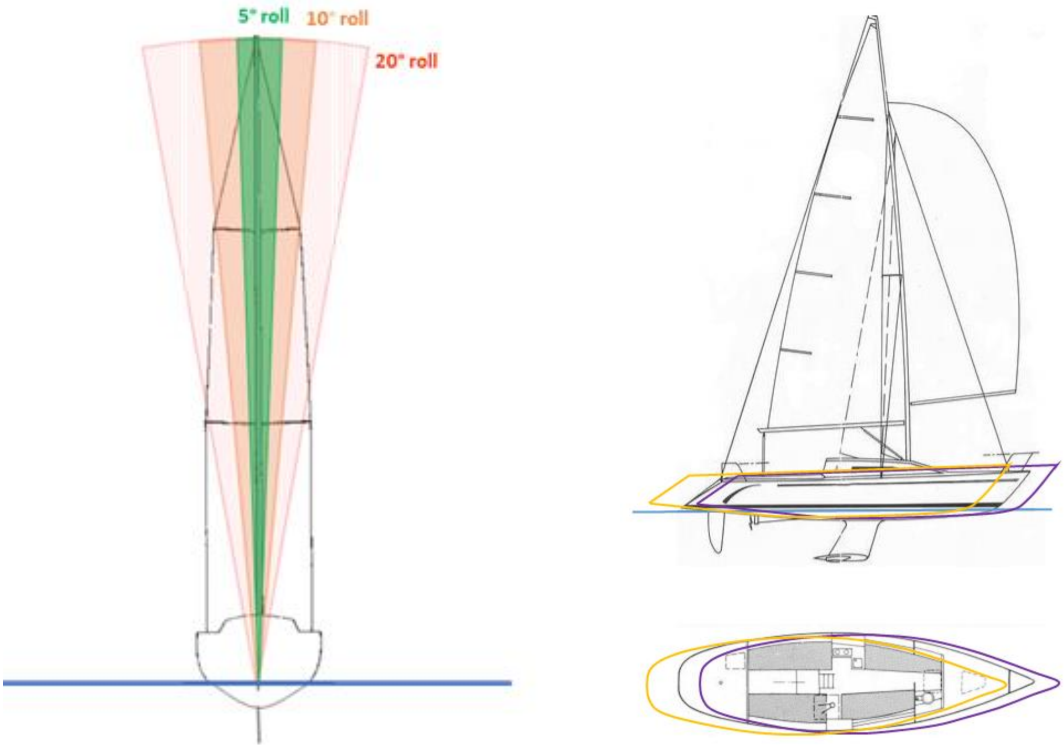

Figure 4. Left – Illustration of measured amplitude of the roll angular motion detected by the three motion sensors, B1, B2 and B3. Right – Diagrammatic representation of 'surge' motions of a vessel, back and forth along the bow-stern direction

RESULTS

Angular Motion ("Roll") Events

The catalogue of detected events amounted to over eight thousand roll event detections (8,378 in total) from the three boat motion sensors. Events were detected on every day of the filed monitoring campaign, with an average of approximately 70 event detections per day (Figure 5).

The marine traffic AIS data, analysed for passing vessels with speeds more than 5 knots (potentially generating wake induced waves), showed a variety of "vessel types" with over 6,000 vessel passages counted, averaging approximately 50 passages per day, over the monitoring period (Figure 6).

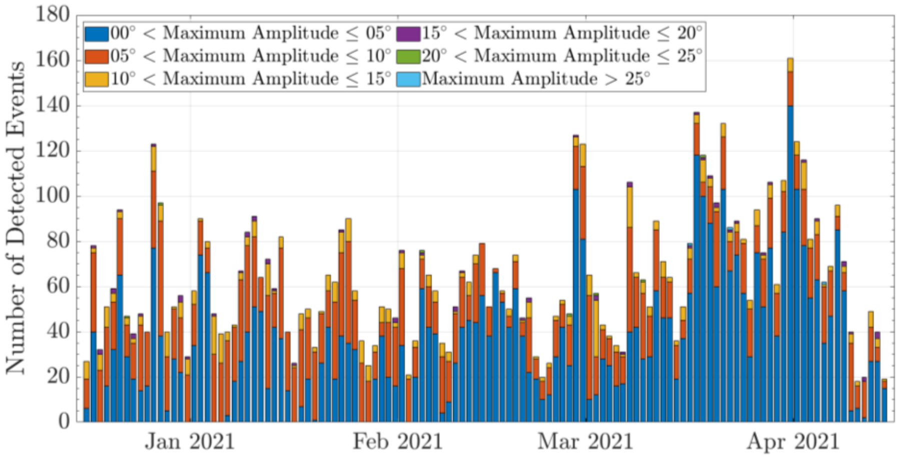

Figure 5. Number of detected roll events, over the monitoring period. Each bar represents one day, with stacked colours showing the amplitude of events measured as roll motions (see Figure 4)

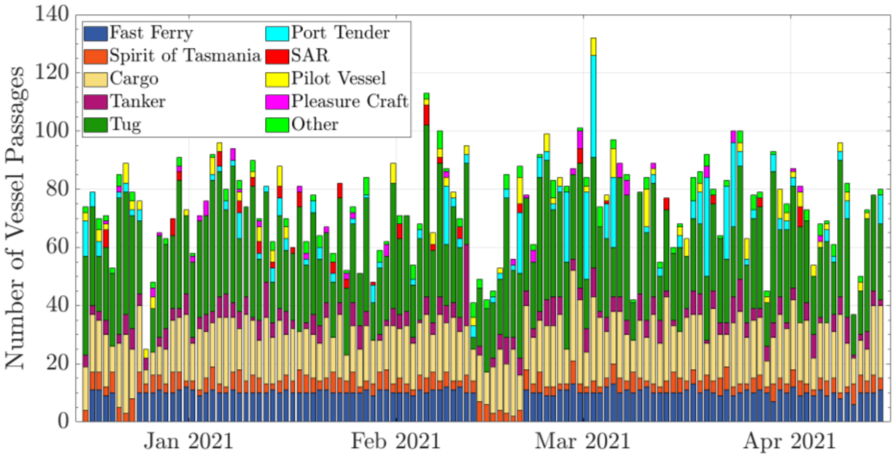

Figure 6. Number of vessel passages (at speeds >5 knots) through the study area and monitoring period. Each bar represents one day, with stacked colours showing different vessel types identified from the AIS data

From the cross analysis of the moored boat motion measurements and marine traffic datasets, 14 categories of “vessel types” were identified in association with the detected events catalogues. These categories were further summarised into the following five functional groups: i) No-AIS-recorded Vessels (generally small to medium motorboats not carrying AIS equipment), ii) Fast Ferries (of demi-hull vessel shape), iii) Port Support Vessels (tugs, pilot boats and port tenders), iv) Large Commercial Vessels (deep draught cargo ships, tankers, vehicle carriers, and cruise ships), and v) Other (search and rescue, water police motor boats).

The associated percentage distribution of the detected events by passing vessel type and roll motion amplitude are presented in Table 1. The events detected varied in amplitude and duration, with events ranging from 0° to more than 25° roll, although approximately 90% of the event detections being of amplitude 10° or less. The duration of events ranged between less than 30 seconds and up to more than 6 minutes (360 seconds), with more than half of the detections lasting for less than 1 minute (60 seconds).

Two examples of detected roll events triggered by the marine traffic are shown in Figure 7 and Figure 8. Figure 7 shows a Fast Ferry (Bellarine Express) on an inbound transit and passing the pressure sensorP3, propagating to P1, shortly before the event was detected by the boat motion sensors B1 and B3. Figure 8 shows an example of an event detected when a Tanker (Haruna Express) transit outbound (coming from the Yarra mouth) through the area of interest and passes very close to the P3 pressure sensor.

Table 1 – Percentage distribution (%), of "roll events" detected (from the 8,378 detections catalogue), by passing vessel type and measured boat roll angular motion amplitude

Vessel Type	0-5°	5-10°	>10°	Total
No-AIS-recorded Vessel	30.5	12.8	2.1	45.3
Fast Ferries	9.4	8.3	3.4	21.1
Port Support Vessels	5.3	1.7	0.4	7.4
Large Commercial Vessels	12.9	7.2	2.0	22.1
Other	2.6	1.2	0.4	4.2
Total	60.7	31.1	8.2	100.0

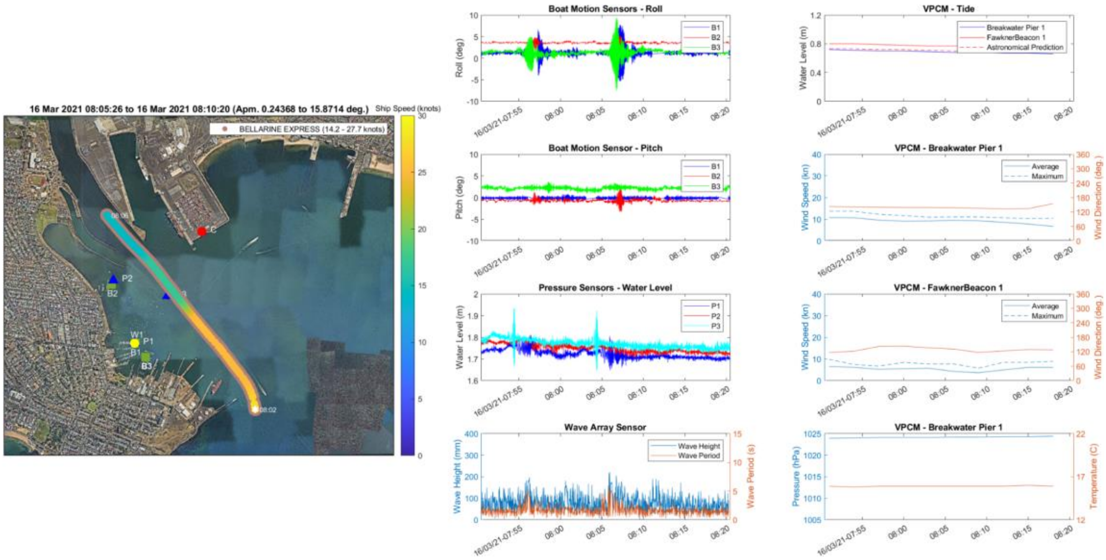

Figure 7. Summary plot for an example of a roll event detection associated with a passing "Fast Ferry" vessel

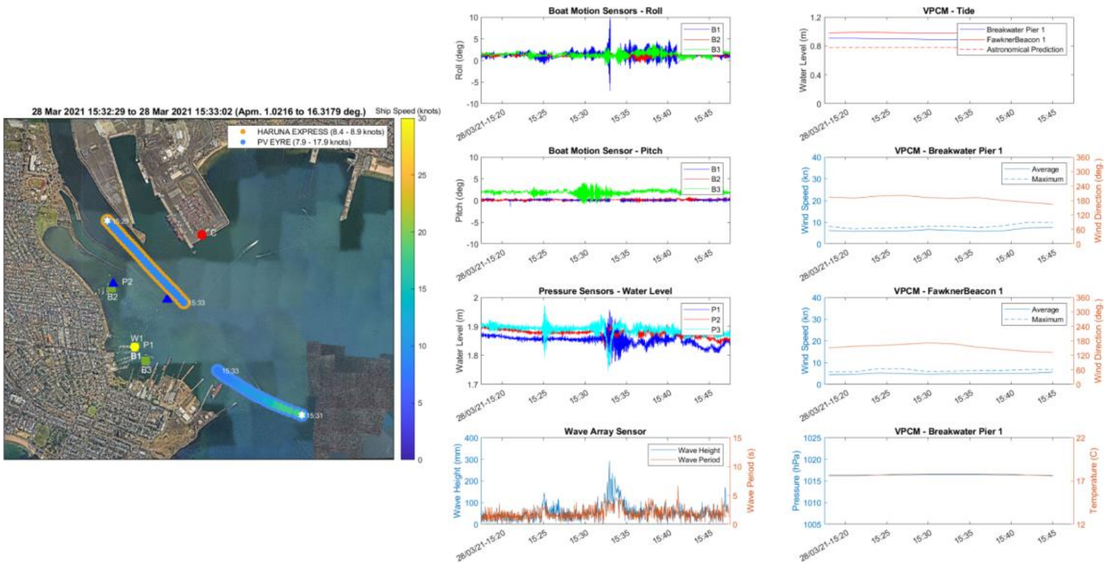

Figure 8. Summary plot for an example of a roll event detection associated with a passing "Tanker" and "Pilot" vessels

Translational Motion (“Surge”) Events

The statistical analysis of the detected events indicated that the translational motion (“surge”) events detected with the largest horizontal accelerations (>1.5 m/s2), corresponding to the surge motion, were actually associated with co-occurring roll motion event detections. This outcome is summarised in Table 2 for the top 15 events detected with the largest horizontal accelerations.

Table 2 Summary of the 15 detected events with largest surge motion (measured as horizontal acceleration, Acc X) and co-occurrence with detected roll motions. Note, events with this co-occurrence were associated with a variety of passing vessel types

No.	Surge Event Detection			Roll Event Detection			Start Time Difference (minutes)	Vessel Passages Category
	Start Time	Duration (s)	Max. Amplitude (m/s2)	Start Time	Duration (s)	Max. Amplitude (deg.)		
1	2020-Dec-23 14:59:11	34.86	2.09	2020-Dec-23 14:54:51	72.56	2.18	5	Pilot Vessel (only)
2	2020-Dec-28 17:45:47	21.75	1.58	2020-Dec-28 17:47:35	39.92	10.21	2	Cargo (only)
3	2020-Dec-30 11:03:55	22.92	1.59	2020-Dec-30 11:00:05	113.55	4.23	3	Fast Ferry (only)
4	2020-Dec-31 13:00:29	34.03	1.68	2020-Dec-31 13:00:08	216.85	19.25	0	No AIS
5	2021-Jan-01 18:02:45	34.90	2.15	2021-Jan-01 18:00:17	305.24	11.61	2	Fast Ferry (only)
6	2021-Jan-11 16:46:54	38.99	1.62	2021-Jan-11 16:39:37	76.97	5.33	7	No AIS
7*	2021-Jan-11 18:32:49	38.28	1.76	2021-Jan-11 18:32:57	73.17	5.66	0	Fast Ferry + other
8	2021-Jan-21 20:52:34	22.23	2.07	2021-Jan-21 20:51:53	70.18	10.80	1	Tug + large ship (cargo/tanker)
9	2021-Jan-25 15:19:26	34.88	1.61	2021-Jan-25 15:17:58	98.00	5.60	2	No AIS
10	2021-Feb-10 15:19:44	54.34	1.55	2021-Feb-10 15:17:51	50.21	5.52	2	Tug (only)
11	2021-Feb-28 19:14:37	64.12	1.72	2021-Feb-28 19:14:48	35.90	2.98	0	Fast Ferry + other
12	2021-Mar-01 09:31:33	24.92	1.65	2021-Mar-01 09:31:00	51.62	3.80	0	No AIS
13	2021-Mar-03 12:12:47	55.65	2.14	2021-Mar-03 12:05:03	49.08	3.06	7	No AIS
14	2021-Mar-12 10:41:26	29.83	1.79	2021-Mar-12 10:39:43	97.26	2.65	2	No AIS
15	2021-Mar-25 16:22:34	41.21	1.65	2021-Mar-25 16:22:21	207.31	8.79	0	No AIS
16	2021-Apr-03 11:06:17	30.33	2.06	2021-Apr-03 11:07:18	94.48	5.84	1	Fast Ferry + other
17	2021-Apr-08 19:27:42	27.17	1.59	2021-Apr-08 19:27:18	70.91	4.01	0	No AIS

* Event reported by local stakeholder

An example demonstrating this co-occurrence is presented in Figure 9, which corresponds to the same event as Figure 8, and clearly shows increased horizontal acceleration oscillations recorded at B1 and B3 co-occurring with angular motions, i.e., Acc X (surge motions) in association with pitch oscillations, Acc Y (sway motions) in association with roll oscillations.

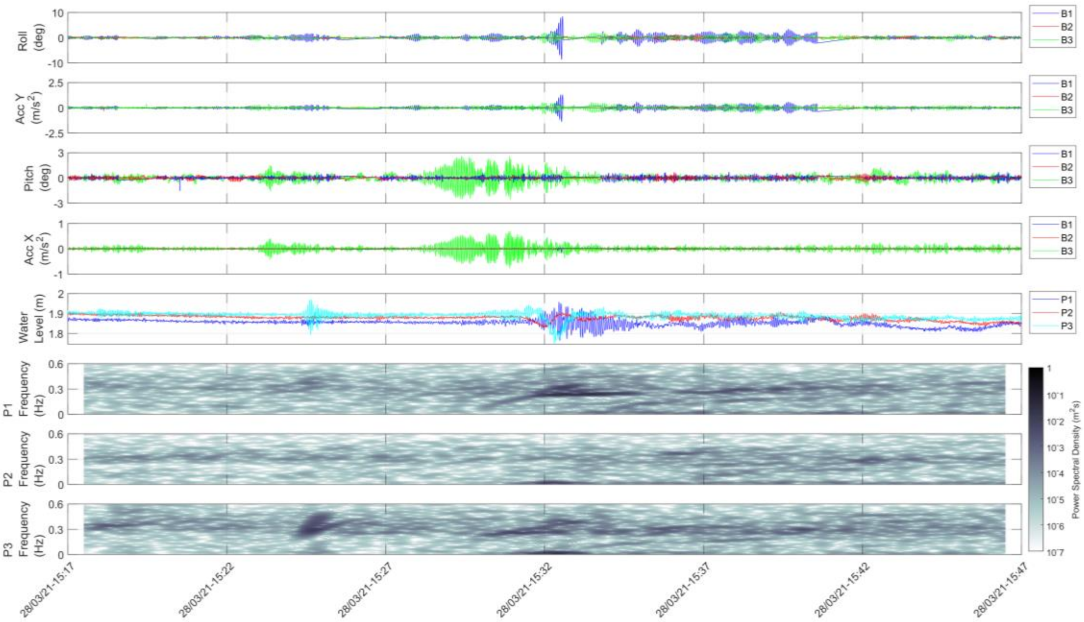

Figure 9. Example of moored boat translational (surge and sway) motions event detection, recorded as horizontal accelerations (Acc X and Acc Y), co-occurring with angular (pitch and roll) motions, in response to the propagation of wake waves from the "Tanker" and "Pilot" vessels (shown in Figure 8 above) passing by. The three bottom panels show the spectrograms of wake waves recorded in the pressure sensors; noticeable "chirping" indicates waves of varying frequency (and thus varying period and wavelength) form part of wake waves "packages" generated by the passing vessels

Another example of such co-occurrence is shown in Figure 10 and Figure 11 where passage of a Fast Ferry leads to a surge event with an amplitude of 1.59 m/s^2 within about 3 minutes of a roll event with 4.23 degrees amplitude.

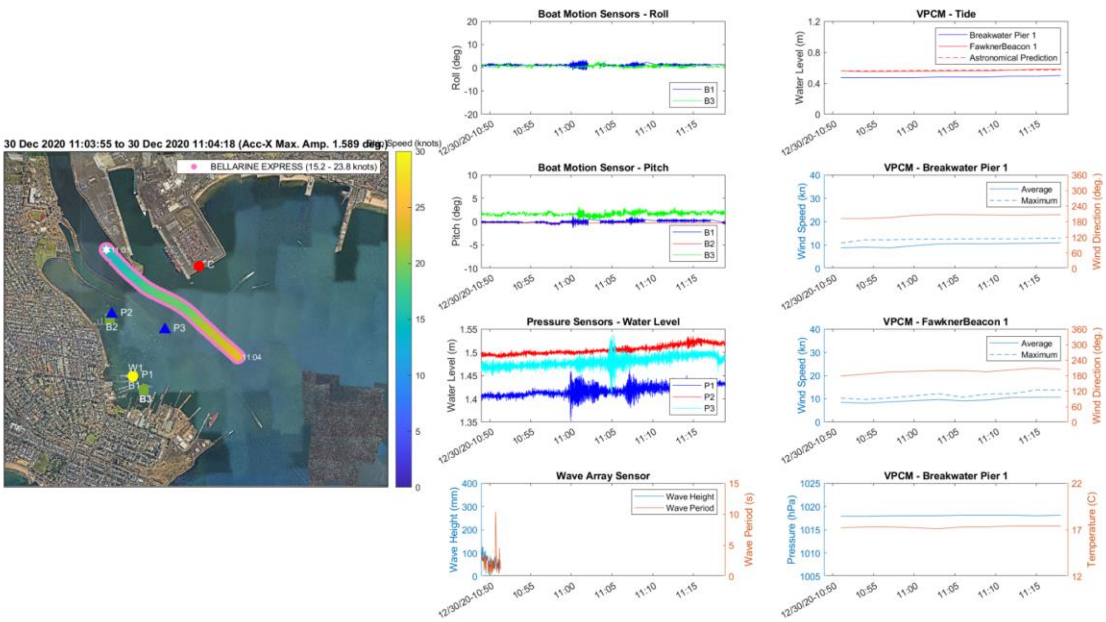

Figure 10. Summary plot for an example of a co-occurring surge and roll events detections associated with a passing "Fast Ferry" vessel

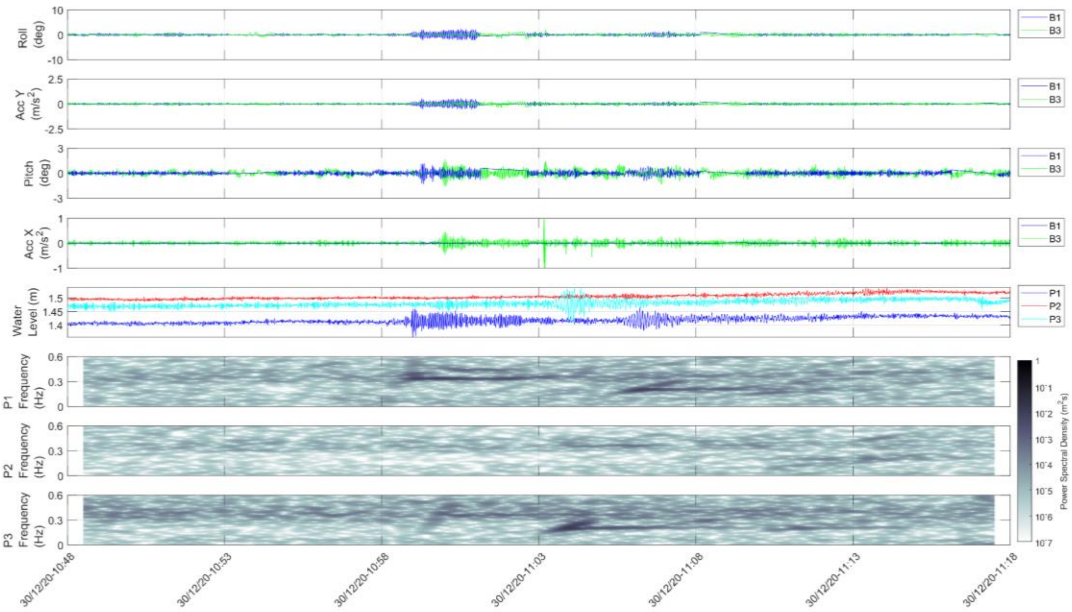

Figure 11. Example of moored boat translational (surge and sway) motions event detection, recorded as horizontal accelerations (Acc X and Acc Y), co-occurring with angular (pitch and roll) motions, in response to the propagation of wake waves from the "Fast Ferry" (shown in Figure 10 above) passing by. The three bottom panels show the spectrograms of wake waves recorded in the pressure sensors; noticeable "chirping" indicates waves of varying frequency (and thus varying period and wavelength) form part of wake waves "packages" generated by the passing vessels

DISCUSSION

Moored Boat Motions Associated with Different Passing Vessel Types

The response of a moored boat to the water disturbances is commonly likely to result in motions of varying amplitude in all 6 degrees of freedom, however, the mooring system constrains most of these motions. The least constrained motions are roll and pitch and the reported accounts of damage to moored boats, indicate that the roll motion has been noted as one of the key movements associated with response to propagation of wake waves within the study area.

The category of passing vessel types with the largest percentage of detected events, comprising 45% of the event detections, did not have any associated vessels in the AIS data (see Table 1 in Results section). Of these, approximately 30%, 13% and 2% corresponded to event detections of maximum amplitude roll measurements of less than 5°, less than 10° and more than 10°, respectively. In consistence with the stakeholder reports, review of the camera footage showed a variety of vessels transiting through the area at the time leading to such events. This mostly included small and medium size motorboats, which appeared to be of both recreational and work-boats.

Fast Ferries were identified in 21% of the event detections, with 11.5% of the detections showing only these vessels in the AIS data and another 9.5% showing the Fast Ferries as well as other vessels.

Vessels directly related to Port activities accounted for 30% of the total event detections. For 13% of the event detections, a combination of tugboats with large ships (e.g., cargo, tanker, or container ships) appeared in the AIS data. Additionally, 4% of the event detections involved tugs only, 6% cargo ships only, 2% tankers only, 2% the (large passenger and freight ferry) Spirit of Tasmania only, 2% port tender vessel only and 1% pilot vessels only.

The remaining 4% of the event detections were made up of:

- 2% showed multiple vessels, excluding fast ferries, in the AIS marine traffic data
- An additional 1% showed Search and Rescue (SAR) vessels as the only vessels passing by the study area; note, this category includes Victoria Police boats.
- Less than 1% of the event detections showed vessels classified as 'Pleasure craft' fitted with and transmitting AIS data; note this category relates mostly to private, recreational motorboats.

It is worth noting that review of camera footage for a random sample of event detections indicated that, in some of the event detections, a combination of vessels with and without AIS data transmission were visible transiting through the area of interest at varying speed and generating wake waves. This indicated that non-AIS transmitting vessels (e.g., recreational and work motorboats) can be associated with a further proportion of the events detected.

Further, in some cases the analysis of the AIS data and camera footage revealed no specific vessels passing by that could be associated with event detections, particularly for some of the low amplitude (<5°) and short duration (<60s) events. A closer review of the metocean data indicated that some of these detections may have been related to naturally occurring wind and wave conditions, however, this would be the case for only a small percentage of the total number of events.

Wake Waves Propagation and Initiation of Translational and Angular Motions of Moored Boat

The initiation of the angular (e.g., roll and pitch) and translational (e.g., surge and sway) motions of moored boats in association with wake waves can be explained when considering the process of wake propagation and the properties of the resulting incoming waves. As wake waves diverge from the source of generation, e.g., vessels transiting through the study area, including the navigational channel adjacent to P3 (see Figure 1), the mixture of wavelengths and periods in a 'package' of wake waves gradually gets separated due to the fact that longer waves travel faster in water than shorter ones. This makes the longer and faster waves leading the package (generally of lower height) very difficult to detect by the naked eye but of physical properties and shape (i.e., wavelength, height and steepness) such that a slight inclination in the water surface takes place over a length of order of magnitude comparable to the size of moored vessels in the marinas, which in turn initiates the translational, surge and sway motions; e.g., wavelength of approximately 20 to 40 m as shown at P1 and P3 in the example in Figure 12 (which correspond to the co-occurring "surge" and "roll" event presented in Figure 8 and Figure 9). The leading longer waves are followed by shorter, slower, and slightly higher waves that propagate behind in the package with a lower period that makes moored boats resonate and initiates the angular (e.g., roll and pitch) motions.

From Better Understanding of Cause-Effect to Informing Mitigation Options

Despite the differences in the mechanisms that initiate the roll and surge motions, the analysis of the measured data, clearly show that these motions generally coincide along the timeframe associated with the propagation of wake waves of the transiting vessels. Therefore, mitigation strategies would apply to both roll and surge events, and thus, in general mitigation measures should target to either control wake generation as a source of the disturbances or reduce the effect of the motions induced by the propagation of wake waves within the study area at the Williamstown Maritime Precinct. The optioneering of mitigation measures, assessed through multi criteria analysis (MCA) based on a comprehensive and holistic set of constraints, is the subject of a subsequent stage of this study.

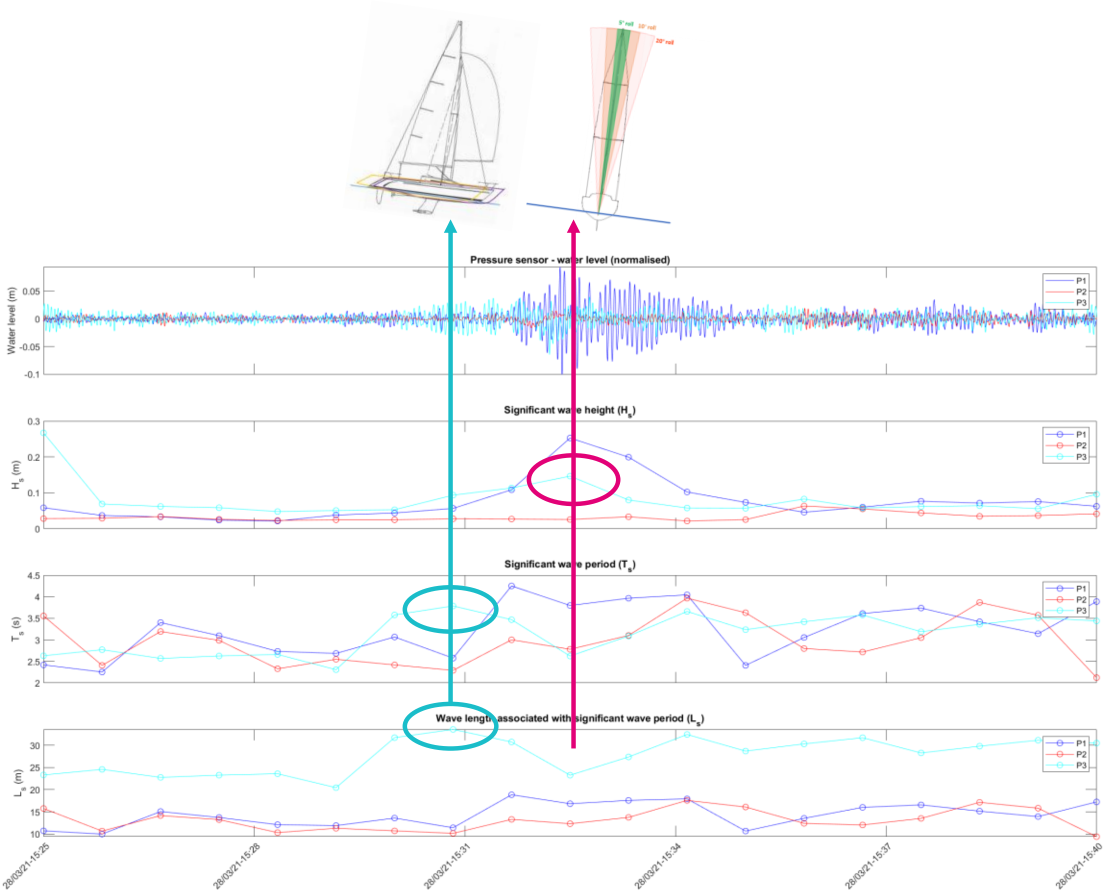

Figure 12. Wave characteristics determined from the pressure sensors for the example co-occurring surge and roll event shown in Figures 8 and 9. The cyan ovals, arrow and pictorial diagram highlight the time of peak in wavelength (and wave period) associated with the initiation of the translational (surge) motion. Similarly, the magenta oval and arrow and pictorial diagram highlights the time of peak in wave height (of waves shorter wavelength and period) associated with the initiation of the roll motions.

CONCLUSIONS

The monitoring campaign purpose designed for this study, using a relatively simple set of instruments and methodology, was able to detect and identify a large number of motion events on the moored boats and associated these to various passing vessel types. Characterisation of the wake induced wave properties and measured moored boat motions enabled a better understanding of the cause-effect relationship between marine traffic and the (angular and translational) boat motion events occurring in the study area. The data collected and the subsequent analysis is proving useful for the identification and assessment of potential mitigation options, which include: operational options, such as managing transit and speed limits of different vessel types; structural options for attenuating incident waves (including wake induced waves); and/or options to reduce the effect of the incident waves on the moored boats and infrastructure within the study area. Given that the field and data analysis methods developed in this study are based on physical principles and wave theory, these methods can be readily applied to other coastal and waterway areas experiencing similar wake induced wave issues, and in turn improve understanding and inform local management of these issues.

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