Dynamic Motions of Piled Floating Pontoons in the Field and the Influence on Postural Stability

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Abstract

Floating pontoons exist in many sheltered waterways around the world and provide an important point of access, facilitating the movement of people between vessels and land. Within Australia, piled floating pontoons are the most popular design. A piled pontoon system allows minimal, but measurable lateral movement and has less restricted vertical movement and roll. A key challenge for the engineer is providing both structural integrity and longevity, as well as ensuring safety for patrons using the pontoon. To date, engineers have focused on the former, designing the pontoons to withstand design wave conditions and impact forces, with minimal focus on how the dynamic motions relate to a person's stability, despite these being public access structures. Ensuring the comfort of people using floating pontoons is imperative, yet present standards defining an acceptable level of motion for floating pontoons are limited. Furthermore, no standards or guidelines exist defining how postural stability should be considered when designing floating pontoons.

This paper presents new findings based on a set of field experiments conducted to measure the dynamic motions of piled floating pontoons and incident waves resulting from boat wake within Sydney Harbour and the Shoalhaven, NSW, Australia. A survey of the general public was conducted concurrently to determine the perceived level of comfort while on the floating pontoons. Resultant motion data and user perception were compared against previously defined Safe Motion Limits (SMLs) for user comfort and safety. These new prototype scale results identified that even under mild wave conditions, the pontoons at three of the four sites exceeded the nominated peak acceleration SMLs in all three axes and RMS accelerations in both lateral axes. Only the site with very mild waves ($H/L = 0.006$) did not exceed the nominated SMLs. Users described discomfort at all four sites, ranging from feelings of motion sickness, to discomfort due to the bumping of the pontoon against the piles. Overall, these results suggest more prototype data is needed to fully understand human perception and stability on floating pontoons under wave action for better engineering design.

Keywords: accelerations, roll angles, safe motion limits, boat wake, Sydney Harbour.

1. Introduction

Floating pontoon structures have been used since ancient times to cross rivers and provide a safe path of access to vessels from land and vice versa. In Sydney Harbour alone there are more than 137 public access points (wharves, jetties and pontoons) for boat users [3] frequented by more than 172,000 commuter passengers per month as well as thousands of tourists.

Understanding the hydrodynamics and body/wave interactions of these structures is important during their design as it ensures excessive motions can be minimised and users will remain both comfortable and safe. While data exists for acceptable dynamic response limits for both land-based structures and sea going vessels, piled floating pontoon structures fall somewhere in between. To date, there has been limited research on this topic and design standards defining motion limits for floating pontoons are limited.

In this paper, we present new field measurements of the dynamic motions of four distinct floating pontoons within Sydney Harbour and the Shoalhaven, NSW, Australia. These are compared to measurements of the incident wave properties and to a set of previously defined safe motion limits (Section 2). In addition, as the safe motion limits were derived from literature based on human stability and comfort on moving land and sea based modes of transport, user surveys were undertaken at the three public access pontoons to better understand the suitability of the safe motion limits and ascertain how people felt while using these floating structures.

2. Safe Motion Limit Criteria

The Safe Motion Limits (SMLs) related to postural stability of a patron with respect to dynamic motions of a floating pontoon will be related to those motions originating from the moving environments described by Freeman et al. [1], due to the absence of information directly relating to floating pontoons. A summary of the nominated SML is provided in Table 1. The SML nominated assign both acceleration and rotation limits and are based on ensuring that able bodied people (aged 7 - 65 years) remain both comfortable and safe while standing on floating pontoons. Dynamic motions exceeding these limits have the potential to result in motion sickness, body instability, fatigue and discomfort.

Table 1 Safe Motion Limits (SML) for Older Children and Adults (Ages 7 – 65 years)

Criteria	**Limit**
Operation (Peak Values)	
Peak Vertical Acceleration	0.1g
Peak Lateral Acceleration	0.1g
Peak angle of tilt	6°
Comfort (RMS Values)	
RMS Vertical Acceleration	0.02g
RMS Lateral Acceleration	0.03g
RMS Roll	2°

3. Field Testing Methodology

3.1 Study Area

Data was collected from four piled floating pontoons. Two located in Sydney Harbour and two in the Shoalhaven, NSW, Australia (Figure 1). All four sites are exposed to boat wake resulting from passing and berthing vessels as well as local wind-generated waves. As the research was focused on assessing the effect of boat wake on the dynamic motions of piled floating box pontoons, the days of field testing were selected based on ensuring boat wake was the main contributing factor and wind waves were negligible.

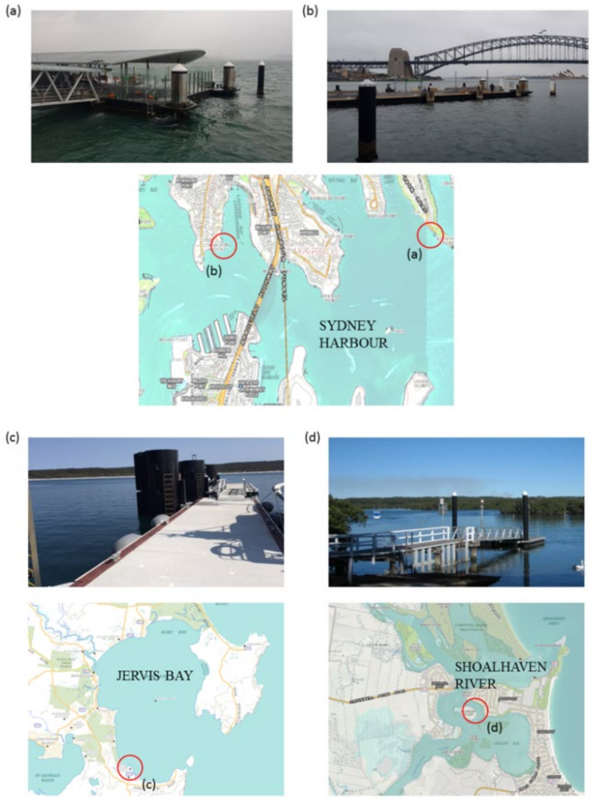

Figure 1 The Four Field Testing Sites. (a) Cremorne Point, Sydney Harbour (Top Left), (b) McMahons Point, Sydney Harbour (Top Right), (c) HMAS Creswell, Jervis Bay (Bottom Left) and (D) Orient Point, Shoalhaven.

Each of the pontoons tested were piled rectangular box floating pontoons. They had six degrees of freedom: surge (short axis, x_b), sway (long azis, y_b) and heave (vertical, z_b), as well as three rotations around the centre of gravity (roll (ϕ), pitch (θ) and yaw (ψ))). The pontoons located in Sydney Harbour (Figure 1a,b) had piles located on each corner (4 off) and those in the Shoalhaven (Figure 1c,d) had piles on the seaward side only (2 off). All pontoons tested had similar restraint and freedom of movement.

3.2 Instrumentation

3.2.1 Ultrasonic Wave Sensor XB

Ultrasonic wave sensors were used to capture the water surface adjacent to the floating pontoons in order to obtain wave heights. The basic operating principle of the sensors is to measure the ultrasound travel time from the instrument to the water surface. Each ultrasonic sensor was attached to a horizontal arm secured to one of the pontoon piles. The sensors recorded data at a sample rate of 32Hz for a period of 60 minutes and returned a time-varying free surface signal. The free surface signal was de-spiked to remove erroneous short-impact signals and then analysed using a zero-up-crossing method to determine mean wave heights and periods of the incoming waves.

Figure 2 shows a sample of the water level time series for each of the chosen sites, prior to filtering to remove the short duration peaks. Cremorne Point (Figure 2a) and McMahons Point (Figure 2b) are located in Sydney Harbour and are influenced by heavy and consistent ferry and boat traffic along with wind waves. In contrast HMAS Creswell (Figure 2c) and Orient Point (Figure 2d) are sheltered locations with the waves generated by passing small recreational boat craft.

The zero-up-crossing method was applied in two different ways for the two different types of data collected. For Sydney Harbour locations, where wave action was continuous (Figure 2ab), the analysis was applied over the entire one hour time series. For the more sheltered locations in the Shoalhaven where boat traffic was limited, zero-up-crossing was only applied to the time-series where individual boat passes were identified (Figure 2cd) and the mean of the boat passes calculated.

3.2.2 Accelerometers

On each pontoon tested, two *Life Performance Research Inertial Measurement Units* (IMU) in the form of accelerometers were used to measure triple-axis accelerations and triple-axis gyrations. The Units (IMUs) were positioned on one corner adjacent to the ultrasonic sensor and centrally on the pontoon, within GoPro housing. A cartesian coordinate system was employed with IMUs positioned x-axis positive in the direction of pontoon width and the z-axis positive upwards. Gyroscope calibration was undertaken before testing using manual calibration whereby the sensors were placed in a motionless state and firmware command used to trigger gyroscope calibration. Bluetooth connection between the IMUs and log computer allowed for immediate data recording of accelerations and rotations of the floating pontoons as the motions took place. The accelerations recorded were in units of g (gravity, m/s^2). Data was recorded at a rate of 50Hz. Sampling at a rate above this caused Bluetooth connection errors. Sync mode was used to ensure the IMUs were synced and recording at the same time.

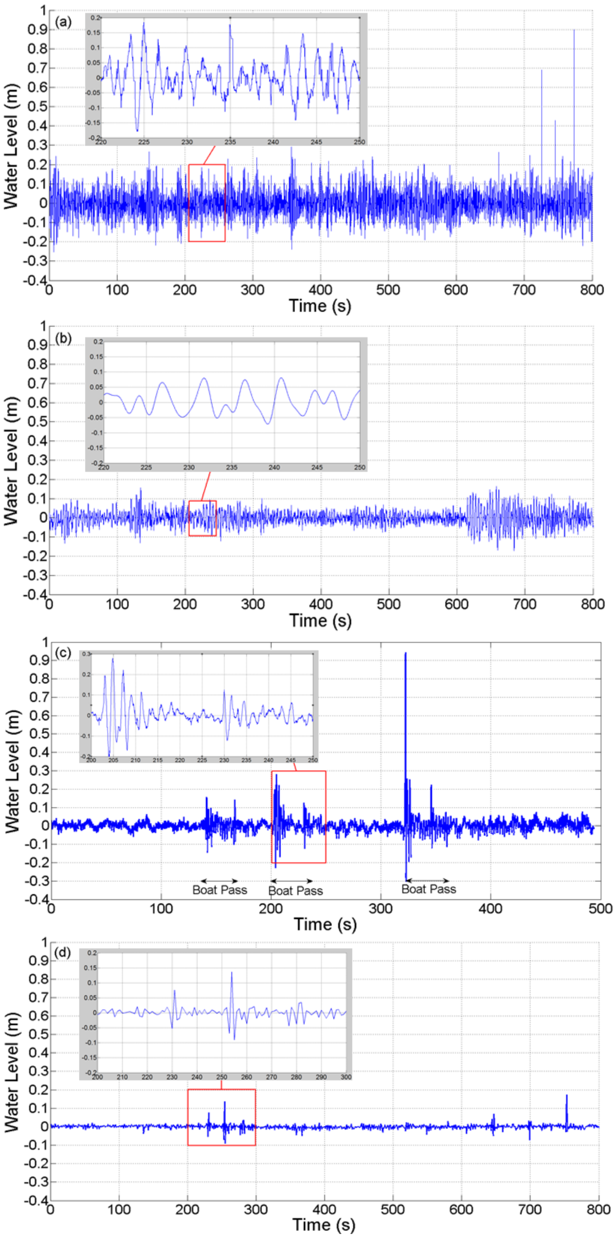

Figure 2 Sample Section of Water Elevation Time Series For Each Field Site: (a) Cremorne Point; (b) McMahons Point; (c) HMAS Creswell; and (d) Orient Point. A Section of Wave Has Been Magnified for Information only.

3.3 User Survey

During field testing, the public (pontoon users) were invited to take part in a 2-minute survey (UNSW ETHICS HC20003) ascertaining their level of comfort/discomfort resulting from the pontoon movements at the three public pontoons: Cremorne Point, McMahons Points, and Orient Point. The surveys were aimed at gathering information on the comfort level of people of different age, gender, and level of fitness while standing on the pontoons. Surveys were dated, time-stamped and correlated to the dated and time-stamped motion response data with comparisons made against the nominated SML detailed in Table 1. It should be noted that people were apprehensive about completing surveys due to the onset of COVID-19, as such survey numbers and days of survey were limited.

4. Results

4.1 Wave Characteristics

Table 2 provides results on the analysed wave parameters for each of the sites. Wave heights (H_m) and periods (T_m) presented are the mean determined using methods described in Section 3.2.1. Results are presented relative to Beam (B) to Draft (D), Beam (B) to wavelength (L), and pontoon displacement (Disp) in tonnes for each location. At all four sites mean wave heights were relatively small with short wave periods, typical of pleasure craft boat wake and ferries. The largest waves were at the two sites in the Shoalhaven (HMAS Creswell (HC) and Orient Point (OP)) where individual boat passes were clearly identifiable in the time series (Figure 2cd). In contrast, the data from the two Sydney Harbour locations (Cremorne Point (CP) and McMahons Point (MP)) were influenced by both near-field boat traffic, as well as far-field boats, wind chop and reflections off the Harbour walls (Figure 2ab).

As the dynamic motions of the pontoon will be directly related to wave steepness, this is also presented in Table 2 for the four sites. Orient Point experienced the steepest waves, followed by HMAS Creswell and Cremorne Point, and then McMahons Point experiencing the mildest wave climate of the four sites.

Table 2 Field Testing Parameters for Each Site: Cremorne Point (CP); McMahons Point (MP); HMAS Creswell (HC); and Orient Point (OP).

	Location			
	CP	**MP**	**HC**	**OP**
Disp (tonnes)	276	249	30	18
B/D	10	11.1	5.0	7.2
B/L	0.94	0.78	0.22	0.33
H_m (m)	0.16	0.08	0.25	0.3
T_m (s)	2.4	3.26	2.3	2.1
H/L	0.015	0.006	0.018	0.025

4.2 Dynamic Motion Response of Pontoons

As detailed in Table 1, the motions of the four pontoons can be considered in terms of either operational-based or comfort-based safe motion limits. Both are important to understand the safety and comfort of patrons using these public spaces.

4.2.1 Peak Vertical and Lateral Accelerations

Figure 3 shows the peak acceleration in each axis (heave, surge and sway) relative to wave period and the operational SML criteria of 0.1g. Even with significant differences between the size of each pontoon three out of the four sites exceeded the nominated SML even in the mild wave conditions presented here.

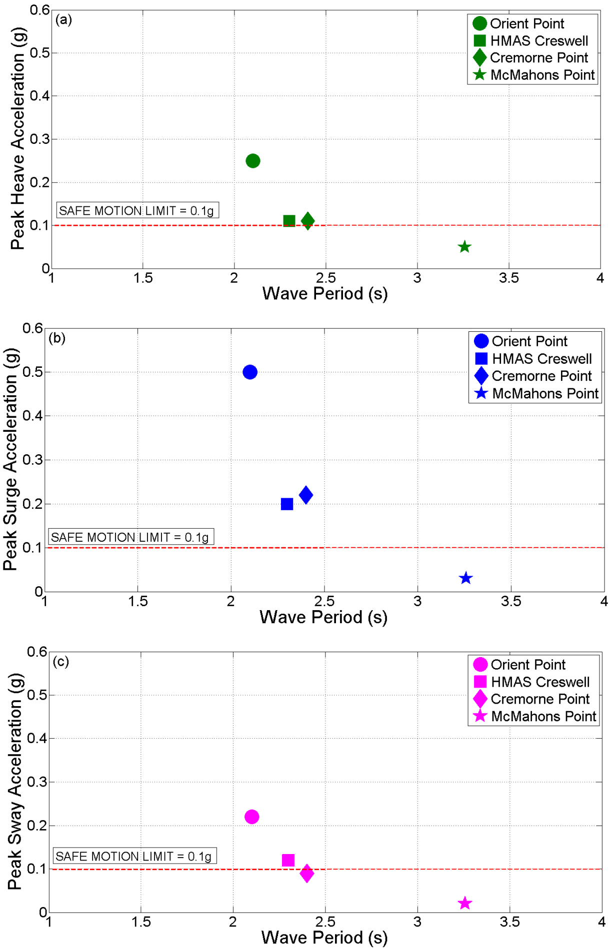

Figure 3 Peak in Single (Heave, Surge and Sway) Axis of Acceleration Plotted Against Wave Period for Each of the Field Pontoons and Compared Against the Safe Motion Limit of 0.1g. (a) Heave Acceleration, (b) Surge Acceleration and (c) Sway Acceleration. Points Represent the Mean of the Two Sensors.

Orient Point recorded the highest peak acceleration for each axis (Figure 3abc), with peaks ranging from 2 to 5 times above the SML guideline of 0.1g. This pontoon had the smallest displacement (18t) and was subject to the steepest waves (H/L=0.025). For three of the pontoons, the largest peak acceleration was recorded in the surge (x-axis) direction resulting from the influence of the incoming wave pushing against the front face of the pontoon. Cremorne Point and HMAS Creswell had very different pontoon characteristics in terms of Beam and Displacement, however, were impacted by waves of similar steepness and recorded very similar peak acceleration in all three axes. This suggests the attributes of the incoming waves, rather than the specific design of the pontoon is likely the main contributor to the observed peaks in acceleration.

The only pontoon to not exceed the SML in each axis was McMahons Point. This pontoon had a large displacement (249t) and was subject to much flatter waves (H/L = 0.006).

4.2.2 Root Mean Square Acceleration

Table 4 summarises the results relative to the comfort criteria SML (root mean square (RMS) acceleration). The values presented are based on the mean RMS of the two IMU sensors used at each site. The highest RMS accelerations in both surge and heave were recorded for Orient Point, (0.09g and 0.01g, respectively). Similar to the observed peak accelerations (Figure 3), the RMS acceleration for surge (x-axis) exceeded the comfort SML (0.03g) for all sites except McMahons Point. Heave (z-axis) RMS accelerations did not exceed the SML (0.02g) at any site. The RMS sway (y-axis) acceleration exceeded the SML (0.03g) criteria at three of the four sites and was as high as 0.07g (Cremorne Point). These results indicate that accelerations in the direction of wave propagation (surge and sway) are consistently large enough to cause discomfort for passengers using floating pontoons exposed to relatively small monochromatic boat wake.

Table 3 Root Mean Square (RMS) Acceleration in x-, y- and z- Axis for Each of the Tested Sites. All Values in g. Bold Indicates Exceedance of SML. Values are Based on the Mean RMS From Two Sensors.

	a_x surge	**a_y sway**	**a_z heave**
SML Acceleration Criteria	**0.03**	**0.03**	**0.02**
Orient Point	**0.09**	**0.05**	0.01
HMAS Creswell	**0.06**	**0.03**	0.01
Cremorne Point	**0.08**	**0.07**	0.01
McMahons Point	0.003	0.001	0.005

4.3 User Perception Surveys

As the SML presented in Table 1 are based on literature related to land-based moving modes of transport and sea-going vessels, it was important to also understand how people using the pontoons felt and compare these to the defined SMLs. Based on the survey results collected from a varied demographic of adults (Table 5), more than half the users felt uncomfortable at the time of data collection. At Cremorne Point, 7 out of 13 users reported levels of discomfort, 6 out of 10 users at McMahons Point and 3 out of 3 users at Orient Point even on the relative mild days of testing. Recalling that McMahons Point did not exceed the comfort SML (RMS acceleration), it is interesting to note that more than half the people felt uncomfortable, suggesting that the comfort SML criteria in Table 1 may be too high. It was the 'bumps' that people found uncomfortable with one user at McMahons Point commenting that it can be *'uncomfortable when the ferry bangs against the wharf'*. Daily users at Cremorne Point reported that at times '*the rocking can be disconcerting'*. With respect to understanding the operational SMLs, Orient Point users felt unstable during the peaks in acceleration that were as high as 5 times the SML defined in Table 1.

These results indicate that users often felt uncomfortable as a result of the frequent, yet short duration spikes in acceleration related to the pontoon-pile interaction, even on the mild days of testing.

Table 4 Survey Results From Three of the Four Field Testing Locations.

Cremorne Point		**Comfort Level**	
Age	**People Count**	**Uncomfortable**	**Comfortable**
18-35	3	2	1
36-50	5	3	2
51-65	4	1	3
> 65	1	1	0
Total	**13**	**7**	**6**
McMahons Point		**Comfort Level**	
Age	**People Count**	**Uncomfortable**	**Comfortable**
18-35	2	1	1
36-50	2	1	1
51-65	1	1	0
> 65	5	3	2
Total	**10**	**6**	**4**
Orient Point		**Comfort Level**	
Age	**People Count**	**Uncomfortable**	**Comfortable**
18-35	2	2	0
36-50	-	-	-
51-65	-	-	-
> 65	1	1	0
Total	**3**	**3**	**0**

5. Discussion

5.1 Safe Motion Limits

Despite their widespread use throughout Australia, research on how the motions of floating pontoons impact on a person's comfort and stability are rare. The preliminary data collected during this study suggests that patrons often felt a degree of discomfort or instability whilst standing on the pontoon.

Days of field testing were mild and yet the nominated peak SML (all axes) and lateral RMS criteria were exceeded at three of the four pontoons tested. 62% of surveyed users felt uncomfortable/unstable with many identifying the 'bumps' associated with pontoon/pile interaction as disconcerting. Given the limitations presented in collecting this data during a global health pandemic, there is a clear indication that extended field user survey and more pontoon motion data is needed. This will provide a greater understanding of the range and levels of motion, as well as comfort/discomfort patrons feel to further inform safe motion limits for floating pontoons.

5.2 Design Considerations

Field testing of existing structures is an important aspect in informing more detailed laboratory scale testing. In particular, the four pontoons tested here varied in size (dimensions), mass, exposure and pile location, all of which influence the pontoon motion response. Of the four field sites tested, Orient Point most closely resembled the pontoon dimensions and wave conditions adopted in a series of detailed laboratory scale tests. In the laboratory tests, measured peak and RMS accelerations were in good agreement with what was recorded in the field at Orient Point. In particular, the observation that steep waves result in high accelerations, irrespective of pontoon size. Detailed lab tests showed high peaks in lateral acceleration, irrespective of pontoon size, due to pontoon/pile interaction as the pontoon bumped against the pile with the passing wave.

Laboratory results have additionally suggested relationships between observed peaks in acceleration and pontoon dimensions such as beam, draft and the natural period of the pontoon. Both lab and field data suggest that the pontoon-pile connection is a key component in understanding the magnitude of acceleration experienced and should be considered in future research. By adopting a combination of changes in the form of increasing draft, mass and beam width of the structure, considering what the natural period of the pontoon, and the pontoon-pile connections at the design stage, the motion response can likely be reduced.

6. Summary

Field testing at four distinct sites under typical wave conditions has shown that even under the relative mild wave conditions the nominated peak SML were exceeded at three of the four sites and user discomfort was experienced. Orient Point, the most comparable in size and design to previous laboratory testing recorded the highest peaks in all axes (0.25g (heave), 0.5g (surge) and 0.22g (sway) and all surveyed users were uncomfortable. In surge and sway the RMS comfort criteria was exceeded at three of the four sites with results comparable to previous laboratory data, seen most evidently at Orient Point.

The high lateral RMS accelerations were a result of the constant 'bump' of the pontoon against the piles which was also observed in previous laboratory data. Field testing has indicated that the nominated SML may underestimate the level of discomfort users of floating pontoons experience. Further testing at both field and laboratory scale, as well as patron surveys are recommended.

7. References

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