COFFS HARBOUR BOAT RAMP – LONG WAVE DATA COLLECTION TO EVALUATE PERFORMANCE OF BASIN EXTENSION WORKS

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Introduction

Coffs Harbour is located on the NSW mid-north coast 430 km north of Sydney. The Coffs Harbour boat ramp is located in a small basin on the southern side of the harbour **(Figure 1)**. Since the boat ramp basin was constructed in the mid-1970s there is a history of reports by mariners of difficulties launching and retrieving boats and navigating vessels in the entrance channel to the boat ramp. Reports suggest the boat ramp basin regularly suffers from water level surges and operational difficulties are also experienced in the vicinity of the boat ramp during times that north-easterly swell enters the harbour.

Figure 1 Coffs Harbour boat ramp location

It is recognised by previous studies that long period oscillations (or seiching) of the harbour can drive water level oscillations within both the inner harbour (on the north side of the main harbour) and the boat ramp basin. In addition to the surging experienced in the vicinity of the boat ramp, sediment migrates into the boat ramp basin creating further navigation or operational problems. As a result, periodic removal of sediment from the boat ramp basin and navigation channel is required to maintain the serviceability of the boat ramp.

Background

Previous studies, including MHL (1986) and MHL (1989) recognise that long period oscillations of the main harbour can drive seiching in the boat ramp basin. Coffs Harbour City Council (CHCC) obtained a Better Boating Program (BBP) and a special grant through the NSW Roads and Maritime Services' (RMS) to examine the nature of the seiche in the boat ramp basin and develop a range of options to mitigate the seiche. These studies were undertaken by Water Technology (2012, 2014). The option preferred was an extension of the boat ramp basin that also incorporated a porous dissipative beach to reduce surge action at the boat ramp.

Two alternative basin extension layouts were developed by Water Technology/Geolink and the success of each option in reducing seiche in the boat ramp basin was evaluated using numerical wave modelling techniques. The numerical modelling indicated that the larger Option 2 basin extension shown in **Figure 2** reduced wave action and seiche in the larger boat ramp basin in the order of 50%.

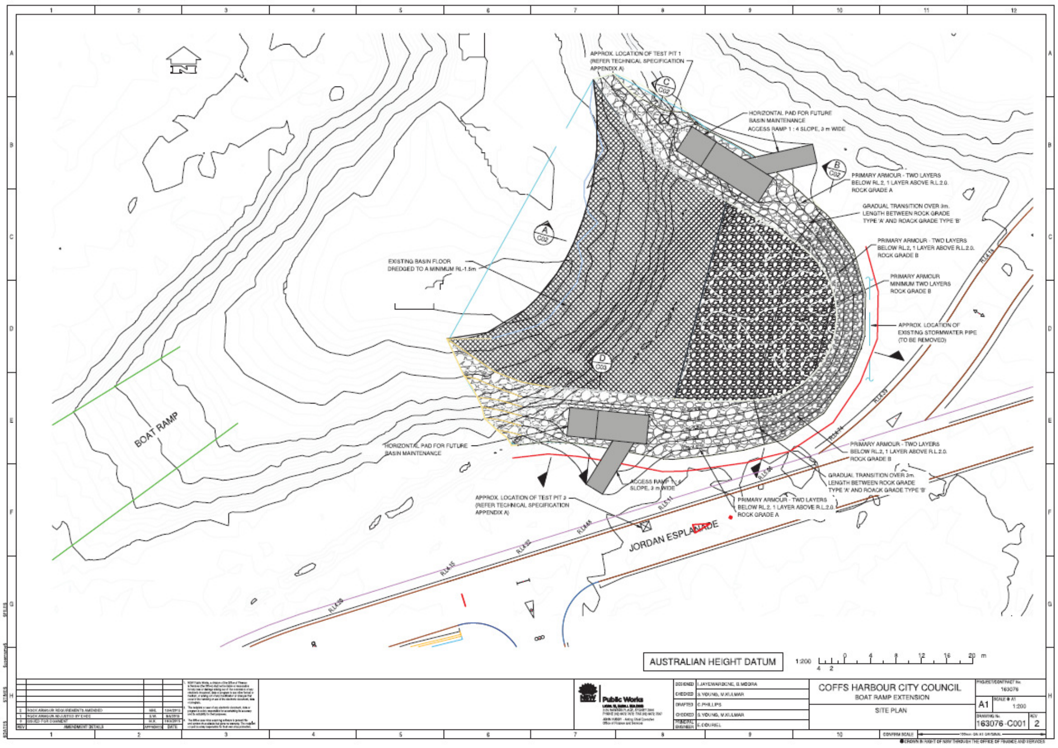

Figure 2 Option 2 boat ramp basin extension configuration

Long-wave phenomena such as that disrupting the serviceability of the boat ramp are very complex and difficult to model numerically. Hence MHL advised CHCC that proceeding to detailed design based on numerical results alone was risky and that a 3D physical model should form part of the detailed design. This would greatly improve understanding of expected seiche behaviour and allow optimisation of the final basin configuration.

In 2014 CHCC secured a special grant from RMS to undertake the physical model verification testing. If the physical model results confirmed acceptable mitigation of seiche action in the proposed extended boat ramp basin funding would also be provided by RMS for construction with CHCC contributing in-kind support by project managing the construction works.

Seiche at Coffs Harbour

The phenomena of seiching is a resonant standing long wave motion that can occur naturally in any enclosed or semi-enclosed basin. Other terms to describe the phenomenon include harbour resonance, surging and ranging. Typically the vertical motions are small but horizontal motions can be significant. The period(s) of such resonant motion depend on the mode(s) or pattern(s) of oscillation, which are also dependent on the basin geometry. Seiching can often be a problem in harbours, particularly when the period of oscillation coincides with the natural resonant period of the harbour. Seiching can result in dangerous berthing and mooring conditions, and damage to vessel mooring lines and fender systems is not unusual.

Seiche activity within Coffs Harbour may be the result of:

- ocean wave motion outside the harbour entrance, including the grouping of ocean swell (surf beat)
- the abrupt inflow and outflow of water at the harbour entrance due to mass transport effects associated with waves breaking adjacent to the harbour entrance
- fluctuations in storm surge effects due to changes in meteorological conditions, e.g. barometric pressure and wind
- fluctuations in local wind stress effects within the harbour.

Within the harbour, a complex long period wave pattern can be established. For certain long wave periods (termed the natural or resonant periods of the basin), a standing wave system with its concurrent nodes and antinodes can develop. A node is a location where there is no vertical movement of the water surface but where there can be considerable horizontal action. Conversely, at an antinode the water surface rises and falls but there is no horizontal water motion.

Often the amplitude of seiching within a harbour is small (less than 0.5 m) even at the antinodes. However, the horizontal motions can be large (greater than 1.5 m) and often the associated ship ranging at moorings is the most noticeable and undesirable outcome of seiching.

Theoretical Oscillation Periods in Coffs Harbour and Boat Ramp Basin

As the frequency of a periodic disturbance approaches one of the resonant frequencies of the basin, there is a marked increase in amplitude of both the maximum horizontal and vertical oscillations. Given that it is assumed that the basin is closed, it is implied that an antinode is present at the harbour entrance. However, it is most likely that a mixed condition exists at the harbour entrance, that is, a zone between a node and an antinode.

The period of oscillation of a seiche in a closed rectangular basin is given by:

$$T = \frac{2/c}{\sqrt{\left(\frac{n}{b}\right)^2 + \left(\frac{m}{l}\right)^2}}$$

where:

T	=	period of oscillation in seconds
l	=	length of basin
b	=	width of basin
c	=	√(gd) = shallow water celerity
d	=	basin depth
m	=	number of nodal lines across the basin length
n	=	number of nodal lines across the basin width

Using appropriate values for basin length (l), basin width (b) and basin depth (d) the periods of oscillation for the eight lowest seiche modes were calculated for the main harbour and boat ramp basin (original and extended configurations) and are given in **Table 1**.

Table 1 Possible Periods of Oscillation in Coffs Harbour and Boat Ramp Basin

Nodal Parameter		Oscillation Period (seconds)		
m	n	Main Harbour	Original Boat Ramp Basin	Extended Boat Ramp Basin
1	0	254	36	42
0	1	141	21	18
1	1	123	18	17
2	0	127	18	21
0	2	71	10	9
2	1	94	14	14
1	2	68	10	9
2	2	62	9	8

The Physical Model

Initial Physical Model Testing

A scope of works for the 3D physical model testing was developed by MHL in collaboration with CHCC. A length scale of 1:58 was selected for the Coffs Harbour physical model taking into consideration the size of the MHL wave basin, the dimensions of the structures to be modelled, the requirement to model armour stability and the need to minimise scale effects. The layout of the physical model is shown in **Figure 3**. Further details of the physical model and test program are documented in MHL 2015b.

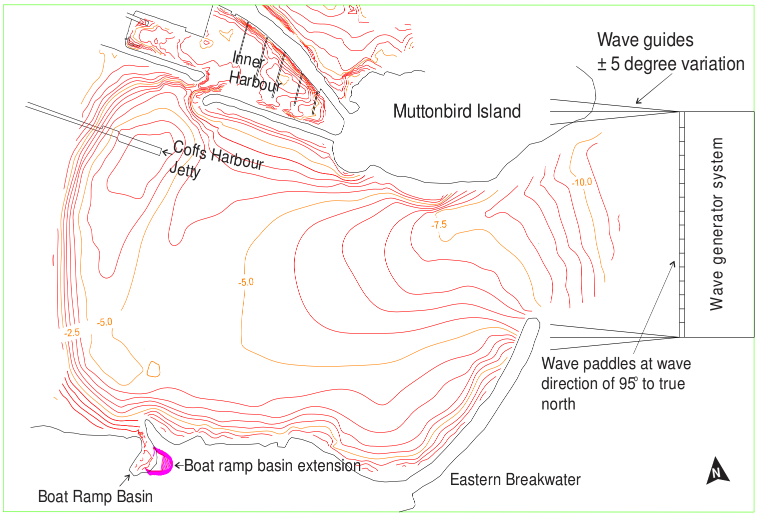

Figure 3 Coffs Harbour physical model layout

An appropriate testing program to record seiche activity in the existing boat ramp basin for a range of offshore wave conditions and two water levels was formulated.

Water Levels

The water depth in the main harbour and the period of the forcing ocean swell have a significant influence on the amount of offshore wave energy reaching the boat ramp basin and the magnitude of the resulting seiche in the boat ramp basin. Reports by mariners using the boat ramp indicate that seiche activity increases at higher tide levels. As a result, the still water levels given in **Table 2** were selected for the physical model testing.

Table 2 Still Water Levels used during physical model testing

Still Water Level	Water Level (m AHD)
Mean sea level (low water level)	0.0
Typical high tide (high water level)	0.8

Wave Conditions

Two days on which significant seiche activity was observed in the boat ramp basin were identified by CHCC and were selected for the model test runs to simulate the seiche activity in the existing boat ramp basin and the proposed extended basin configuration. The offshore wave conditions recorded by the Office of Environment and Heritage (OEH) Coffs Harbour Waverider buoy and used during the model test program are presented in **Table 3**.

Table 3 Physical model test wave conditions

Design Wave Condition	Offshore Hsig (m)	Offshore TP1 (s)
10 June 2012	1.8 – 2.1	12 – 15
4 and 5 September 2014	2.5 – 4.8	12 – 14

Following the completion of the testing program for the existing boat ramp conditions, the testing was repeated for the proposed extended boat ramp basin configuration and the results compared to determine the reduction of the seiche activity achieved by the larger boat ramp basin configuration. It was determined that the reduction in seiche achieved by the extended basin ranged from zero to 29.7% and hence did not attain the 50% reduction indicated by the numerical modelling techniques.

Additional Physical Model Options Testing

To determine if other design configurations could potentially further reduce seiche action, the following design options were selected by CHCC for further physical model testing:

Option 1 – a 15 m extension of the boat ramp basin entrance breakwater with the existing north-west alignment

Option 2 – a 30 m extension of the boat ramp basin entrance breakwater with the existing north-west alignment

Option 3 – a 50 m extension of the boat ramp basin entrance breakwater with the existing north-west alignment

Option 4 – a 50 m extension of the boat ramp basin entrance breakwater with a north alignment

Option 5 – a dredged basin offshore from the boat ramp basin entrance with only the extended boat ramp basin configuration.

A testing program comprising a wide range of wave conditions and up to four water levels was developed by MHL in consultation with CHCC. The success of each design option to mitigate seiche action in the boat ramp basin (both the existing and extended basin configurations) was assessed.

A series of tests, utilising a range of water levels and wave conditions, were undertaken for each design option in conjunction with the existing boat ramp basin configuration as detailed in **Table 4**. Measurement of wave conditions at a number of locations in Coffs Harbour and within the boat ramp basin were completed and then repeated after the boat ramp basin was extended to the preferred configuration shown in **Figure 2**. This procedure allowed any further reduction in seiche activity due to each design option within the extended boat ramp basin to be determined.

Table 4 Seiche mitigation design options test schedule

Design Option	Option Description	Water Level (m AHD)	Wave Conditions at Harbour Entrance	
			Hsig (m)	TP1 (s)
1	15 m extension to the boat ramp basin entrance breakwater on the existing north-west alignment	0.8 0.8 0.0 0.8	3.0 1.5 1.7 4.5	13 13 13 15
2	30 m extension to the boat ramp basin entrance breakwater on the existing north-west alignment	0.8 0.8 0.0 0.8	3.0 1.5 1.7 4.5	13 13 13 15
3	50 m extension to the boat ramp basin entrance breakwater on the existing north-west alignment	0.8 0.8 0.8 1.5	3.0 1.5 4.7 5.0	13 13 15 15
4	50 m extension to the boat ramp basin entrance breakwater with a north alignment	0.8 0.8 0.8 1.5	3.0 1.5 4.7 5.0	13 13 15 15
5	Dredging a volume of 30,000 to 50,000 m^3 of sand offshore from the boat ramp basin entrance breakwater	0.8 0.8 1.5	3.0 4.5 5.0	13 15 15

The results indicated that each design option resulted in a reduction in seiche action in both the existing and extended boat ramp basin configuration. For the existing boat ramp basin, mitigation of seiche height of less than 30% was recorded for all options, with the reduction in seiche improving up to 33.3% when the design options were incorporated with the extended boat ramp basin configuration. The pattern dredged basin offshore from the boat ramp basin entrance, when combined with the extended basin configuration, resulted in minimal improvement of up to 15% in seiche action at the boat ramp. Whilst the design options contributed to mitigation of seiche action in the boat ramp basin (for both the existing and extended basin configuration), the improvements were not significant and still well below the target 50% reduction for the proposed basin extension works.

In summary, the results of the physical modelling indicated a reduction in seiche of up to 30% could be expected (verses 50% expected from numerical modelling). This was considered sufficient for CHCC and RMS to proceed to construction. Adopting the original Water Technology Option 2 basin extension working drawings, the final construction drawings and technical specifications for the construction works were then prepared by MHL (MHL 2015a).

Boat Ramp Basin Extension Construction

Stakeholder Consultation

CHCC undertook stakeholder consultation activities prior to the boat ramp basin extension investigations and after finalisation of the design. The main consultation activities included:

- a public forum at the Coffs Harbour Deep Sea Fishing Club on 28 August 2012 to discuss matters relating to the Coffs Harbour boat ramp, in particular, potential options available for mitigating surge at the boat ramp
- the creation and engagement of the Coffs Harbour Boat Ramp Working Party, which included members from Coffs Harbour Deep Sea Fishing Club, Coffs Harbour City Councillor and council staff
- in February 2015 Council hosted a community information session that presented details of the proposed boat ramp basin extension, other seiche mitigation options investigated and the construction work program.

Construction Approvals

An Environment Assessment was completed for the boat ramp basin extension works (CHCC, 2015). The works were undertaken on land managed by Coffs Coast State Park Trust and W.E Smith Engineering Ltd (through a licence with Crown Lands) with both entities approving the construction works. The works were also approved by Department of Primary Industries through a Permit for dredging and reclamation works under Part 7 of the Fisheries Management Act 1994. The proposed works were also consistent with the Coffs Harbour Jetty Foreshores Plan of Management.

Construction Overview

The construction works footprint is wholly within the fill material utilised to establish the South Coffs Island connection with Corambirra Point that was completed in 1914. It was estimated that approximately 8000 cubic metres of material would be excavated to extend the basin with some material being used to construct the basin batters and the porous dissipative beach within the extended basin. After site preparation works construction of the basin extension commenced on 21 May 2015 **(Photo 1)**.

Material excavated during the basin construction was transported off site and processed for use on other CHCC construction projects. Material was excavated in layers down to near the high tide level with the objective to excavate to –1.5 m AHD. A rock bung was left in place between the existing basin and the growing basin extension excavation works to manage the sediment and water interface. There was a thin layer of clay at around the high tide mark which caused issues with turbidity. The original environmental assessment did not consider the impact of harbour waters infiltrating through the rock bung and did not propose a methodology to treat the water.

The environmental assessment was revised and approval completed for dewatering the works area to continue the excavation and installation of the geotextile layer and rock armour batter slopes. The following de-watering activities were undertaken:

- clean ocean water was pumped prior to any works back to the boat ramp basin though a silt curtain
- minor sand scraping and excavation occurred on Boambee Beach to build the de-watering basin
- inside the works area water was drained to a sump and well lined with geotextile
- during excavation water was pumped through the filtered well and pumped to the basin on Boambee Beach. The basin was 35 m x 6 m x 3.5 m to allow sediments enough time to settle before disposing of the water back to the ocean
- a dewatering pipe extended for 550 m across a road bridge on Jordan Esplanade and then along the access track to Boambee Beach.

Photo 1 Site prior to construction works – 21 May 2015

Excavation continued to design levels and geotextile fabric and rock armour were placed around the perimeter and floor of the extended basin **(Photo 2)**. The final excavation took place with the removal of the rock bung on 27 July 2015.

To assist with future clearance of sand entering the boat ramp basin two horizontal maintenance pads were included on either side of the extended basin to support long-reach excavators that will be utilised for such operations. The construction works were completed on 4 August 2015**. Photo 3** shows the completed basin extension in October 2015.

Photo 2 Construction in progress – 15 July 2015

Photo 3 Completed basin extension – 3 October 2015

Seiche Monitoring in the Boat Ramp Basin

Methodology

Suitable subsurface pressure transducer wave monitoring instruments were used to gather wave and surge data in the boat ramp basin. A data recording regime was designed to collect information on the wave energy spectrum to identify the range of wave and surge conditions that prevails in the boat ramp basin. The instruments were fixed to one of the pontoon support piles below low tide level about 1 m above the seabed to ensure that wave conditions were monitored for all water levels and the influence of tide level on wave action could be assessed **(Photo 4)**.

Photo 4 Wave sensor location in boat ramp basin

Two sensors were used which allowed the collection of about two months of data before the basin extension works commenced. Data collection continued during the basin construction phase and for about four months after the basin extension works were completed. The seiche action in the basin before and after the extension was then compared to determine if any measureable changes to the seiche behaviour was detected.

Instrumentation

Data collection was undertaken within the boat ramp basin using two RBR® solo D|wave loggers. The loggers measured water pressure, wave period, wave height and wave energy. The instruments were configured to measure 16,384 samples at a frequency of 2 Hertz (0.5 second) every 3 hours. Two instruments were used on first deployment for redundancy and to ensure that both sensors provided similar results. The instruments were then swapped for each subsequent deployment.

To provide offshore wave conditions, data recorded by the Coffs Harbour, Byron Bay and Crowdy Head Directional Waverider buoys were utilised. These buoys are operated by MHL for OEH. Data from the Coffs Harbour buoy were used as the principal offshore wave reference with data from Byron Bay and Crowdy Head used when the Coffs Harbour buoy was not available due to buoy loss or system faults.

Available Data

The data collected by the RBR solo instruments deployed in the boat ramp basin is summarised in **Table 5**.

Table 5 Boat ramp basin available wave/seiche data

RBR Solo Serial No.	Start Data	End Data	Comments
41307	17-Mar-15	24-May-15	Before basin extension works
41308	17-Mar-15	01-May-15	Before basin extension works
41308	19-May-15	23-Jul-15	During basin extension works
41307	13-Aug-15	13-Sep-15	After basin extension works
41308	01-Dec-15	09-Mar-16	After basin extension works

Selected samples of the offshore wave conditions and the coincident conditions recorded in the boat ramp basin before the extension works and after the basin extension completion are presented in **Figure 4** and **Figure 5** respectively.

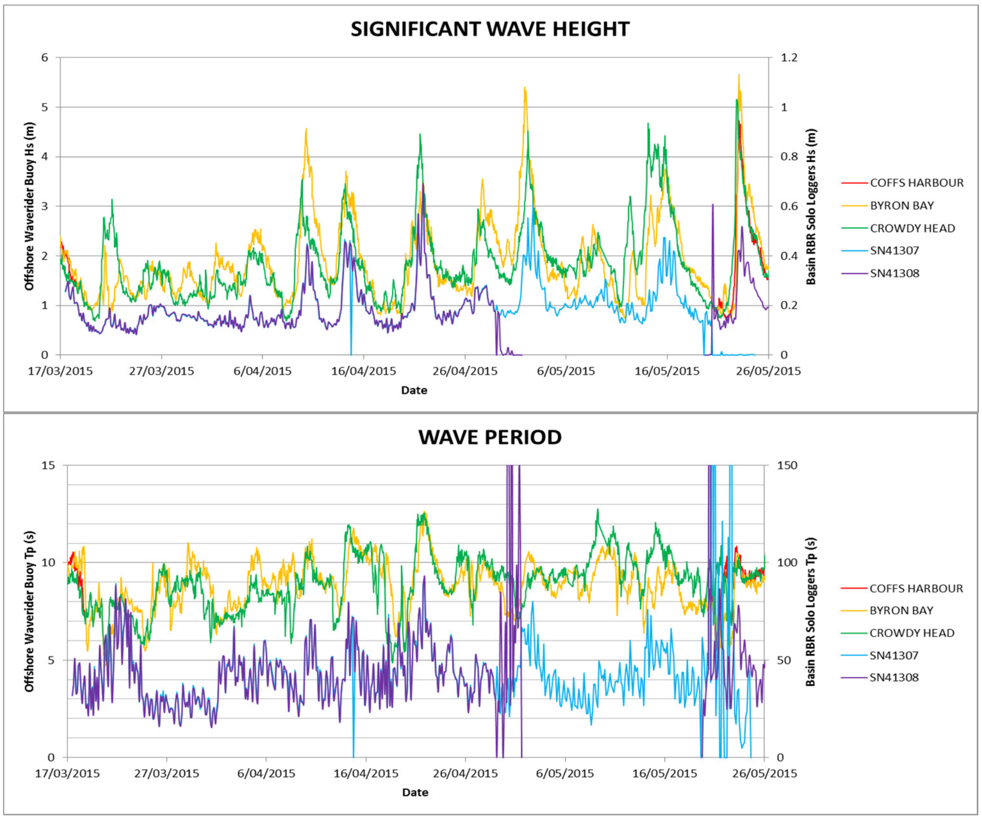

Figure 4 Comparison of offshore and basin wave conditions – Before basin extension

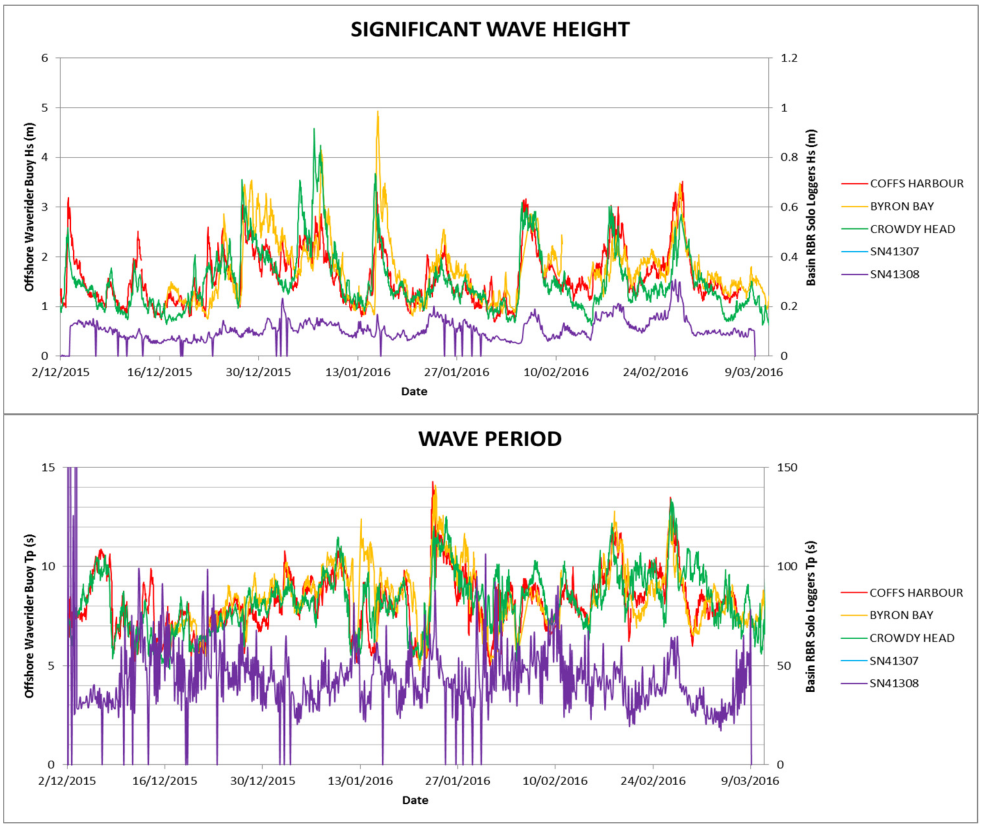

Figure 5 Comparison of offshore and basin wave conditions – After basin extension

Data Analysis

The data from the instruments were extracted using RBR propriety software to generate raw pressure and analysed wave data files. These files were further processed in Matlab® to formats suitable for Fourier Transform analysis. The wave and pressure data were analysed in 3 hour segments using the Matlab Fourier transform function. To allow valid comparison of data from before and after the boat ramp basin extension, it was necessary to select and compare events with similar offshore wave forcing conditions. This discretisation of events was achieved with reference to wave parameters recorded by the Coffs Harbour Waverider buoy (or the Byron Bay and/or Crowdy Heads buoys when Coffs Harbour data were not available). The offshore wave data used comprised hourly records of significant wave height (Hsig), peak spectral wave period (TP1), and principal wave direction (Dir).

Every 3-hour dataset recorded by the RBR solo loggers was classified in terms of the three offshore wave parameters averaged over 3 hours. Several event categories were defined, grouping events with similar averaged wave parameters. Each category defines a Hsig band of 0.3 m, a TP1 band of 2 seconds, and a wave direction band of 22.5 degrees. It should be noted that a large number of categories (or windows) only have a very small number of occurrences. **Table 6** and **Table 7** present the 16 event categories with the largest number of occurrences measured by each RBR solo instrument.

Table 6 Top 16 event categories for RBR solo S/N 41307

Hsig Band (m)	TP1 Band (s)	Direction Band (°TN)	Before Basin Extension (Deploy 1)	After Basin Extension (Deploy 2)	All Events
1.2-1.5	10-12	135-157.5	16	21	**37**
1.5-1.8	10-12	157.5-180	8	20	**28**
1.5-1.8	8-10	135-157.5	17	10	**27**
1.2-1.5	10-12	90-112.5	6	19	**25**
1.2-1.5	8-10	67.5-90	9	15	**24**
1.2-1.5	8-10	135-157.5	5	18	**23**
1.5-1.8	10-12	135-157.5	14	8	**22**
1.2-1.5	12-14	90-112.5	10	10	**20**
1.5-1.8	8-10	112.5-135	14	5	**19**
0.9-1.2	12-14	135-157.5	6	12	**18**
2.1-2.4	10-12	157.5-180	16	1	**17**
1.8-2.1	10-12	157.5-180	8	9	**17**
0.9-1.2	10-12	135-157.5	12	5	**17**
2.4-2.7	10-12	157.5-180	15	0	**15**
1.2-1.5	12-14	135-157.5	3	12	**15**
1.2-1.5	8-10	90-112.5	14	1	**15**

Table 7 Top 16 event categories for RBR solo S/N 41308

Hsig Band (m)	TP1 Band (s)	Direction Band (°TN)	Total Before Extension (D1 + D2)	Total After Extension (Deploy 3)	All Events
1.2-1.5	8-10	90-112.5	16	32	**48**
0.9-1.2	10-12	90-112.5	15	26	**41**
1.2-1.5	10-12	135-157.5	26	14	**40**
1.2-1.5	12-14	90-112.5	11	26	**37**
1.5-1.8	8-10	90-112.5	13	21	**34**
1.5-1.8	8-10	135-157.5	19	13	**32**
0.9-1.2	10-12	112.5-135	18	14	**32**
1.5-1.8	10-12	135-157.5	29	2	**31**
2.4-2.7	10-12	157.5-180	23	7	**30**
2.1-2.4	10-12	135-157.5	13	17	**30**
1.2-1.5	12-14	135-157.5	27	3	**30**
1.8-2.1	10-12	135-157.5	17	12	**29**
1.2-1.5	10-12	112.5-135	16	13	**29**
1.5-1.8	12-14	135-157.5	24	3	**27**
1.2-1.5	12-14	112.5-135	13	14	**27**
1.2-1.5	8-10	67.5-90	12	15	**27**

Using Matlab, a Fourier Transform was used to analyse the frequency components of the time series signal. This assessment used an averaged periodogram method. A Fast Fourier Transform (a computational approximation for a Fourier Transform) was applied to calculate the power (and thus, energy) contained within the different frequency signals for each 3-hour measurement period. By applying this procedure the energy residing within different wave period bands was identified.

The smallest period longwave (or seiche) which can be detected by a Fourier Transform in this case is one second, equal to twice the 0.5 second sampling rate of the RBR solo instruments. Since the change to seiche response in the boat ramp basin conditions after the extension works is expected to be for oscillations of less than 300 seconds, wave analysis was undertaken for periods of 12 minutes and shorter.

Results

For each selection window, two analyses were carried out between the data from before and after the basin extension works. The first analysis sought to detect change in energy present within the basin during comparable offshore wave event categories. The total power (synonymous with energy) of the entire RBR solo datasets before and after the basin extension works was calculated. The distributions of total power arising in before and after basin extension events were then overplotted on frequency graphs. Hence **Figure 6** presents the power spectrum and power spectrum density based on the pressure data for Deployment 1 (before basin extension) and Deployment 2 (after basin extension) for RBR solo logger S/N 41307.

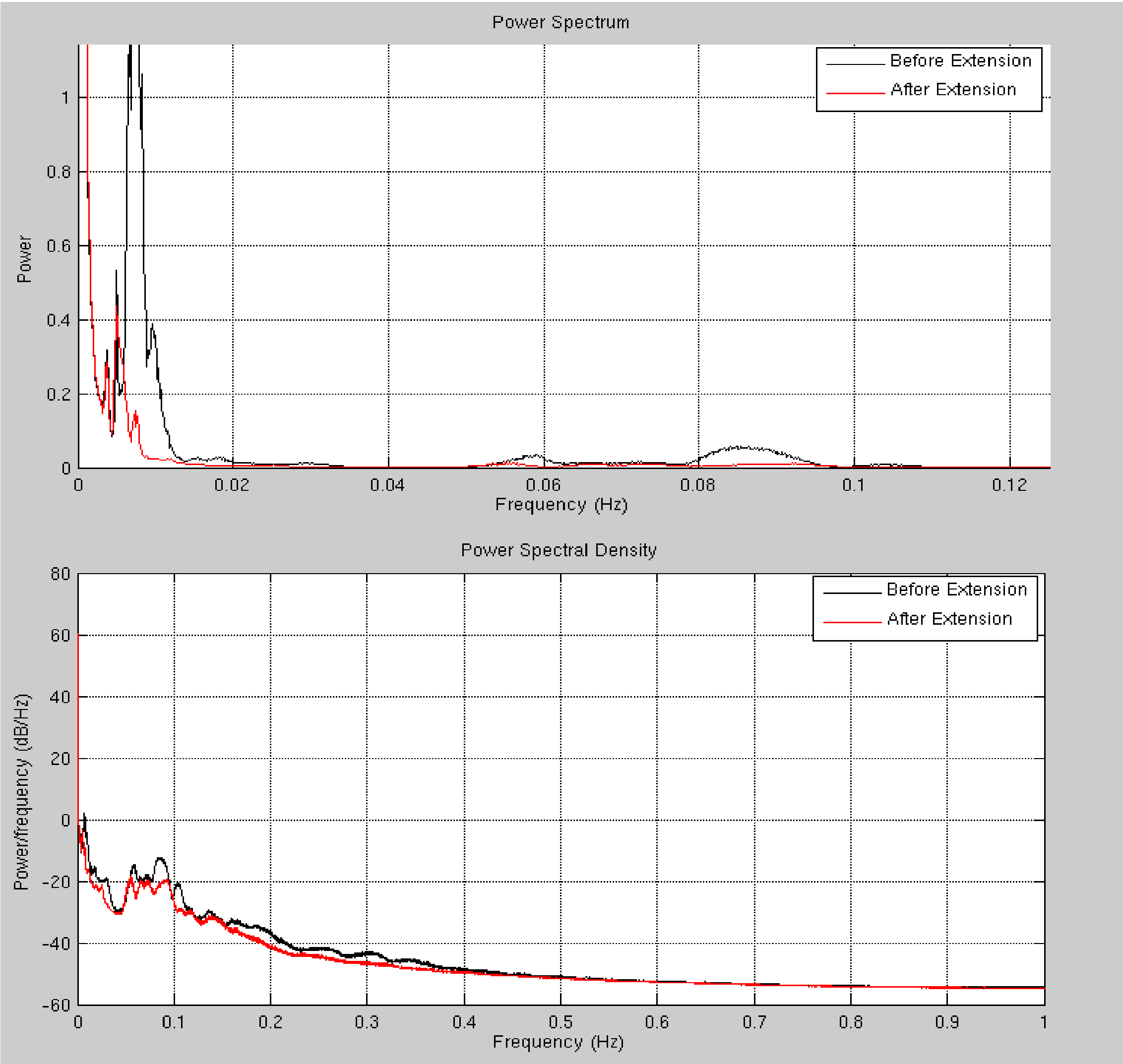

Figure 6 Power spectrum (top) and power spectrum density (bottom) based on recorded pressure data (RBR Solo S/N 41307)

The plots presented in **Figure 6** indicate a reduction in wave energy after the basin extension was completed. However, this conclusion is not definitive since the number of events before and after the extension of the boat ramp basin was different. Furthermore, as illustrated in **Figure 7**, using the before basin extension offshore Hsig record as the baseline (red line), the offshore Hsig record was lower during the basin construction works (yellow line), and even lower after the completion of the basin extension (green and blue lines).

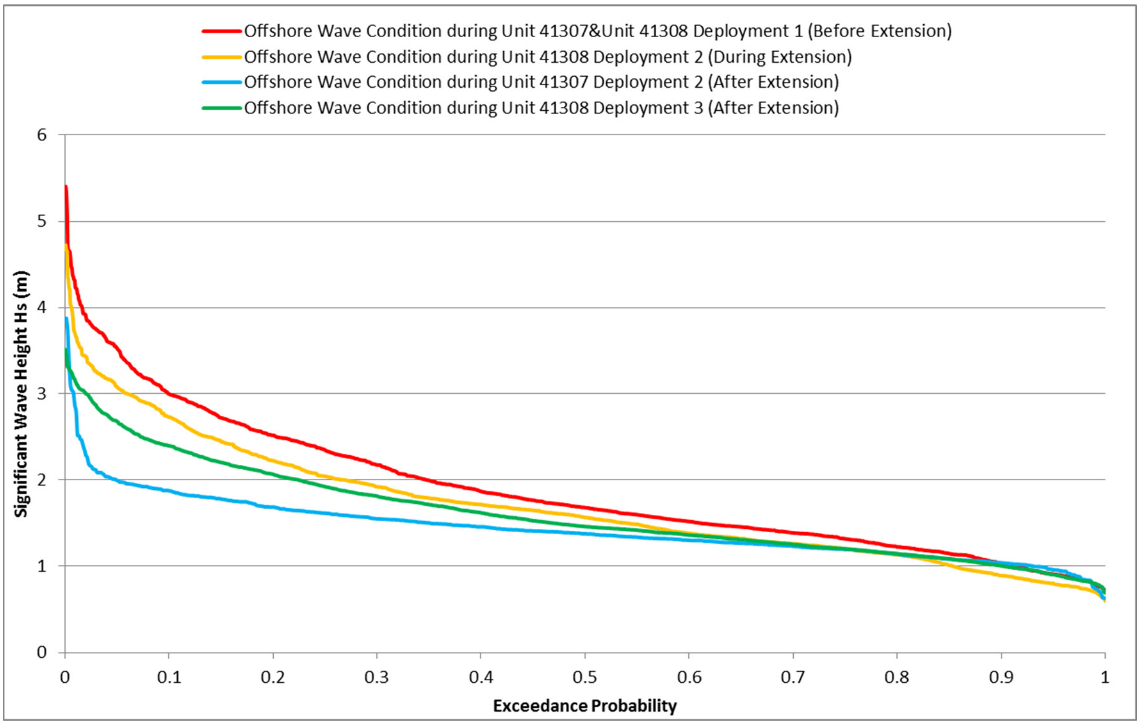

Figure 7 Offshore Hsig exceedance probability comparison – Before, during and after basin extension works

For this reason, the events categories were reassessed and the categories having occurrences only before or only after the basin extension were discarded. Only the categories having at least two occurrences before and after the basin extension works were considered in the power comparison. The power spectrum of all events within each category was averaged to obtain an average event per category. This prevented the comparison from being unbalanced as most categories do not have the same number of events occurring before and after the basin extension. The averaged power spectrums for each of these selected categories were summed and the power spectrum similar to that presented **Figure 6** was recreated as shown in **Figure 8**.

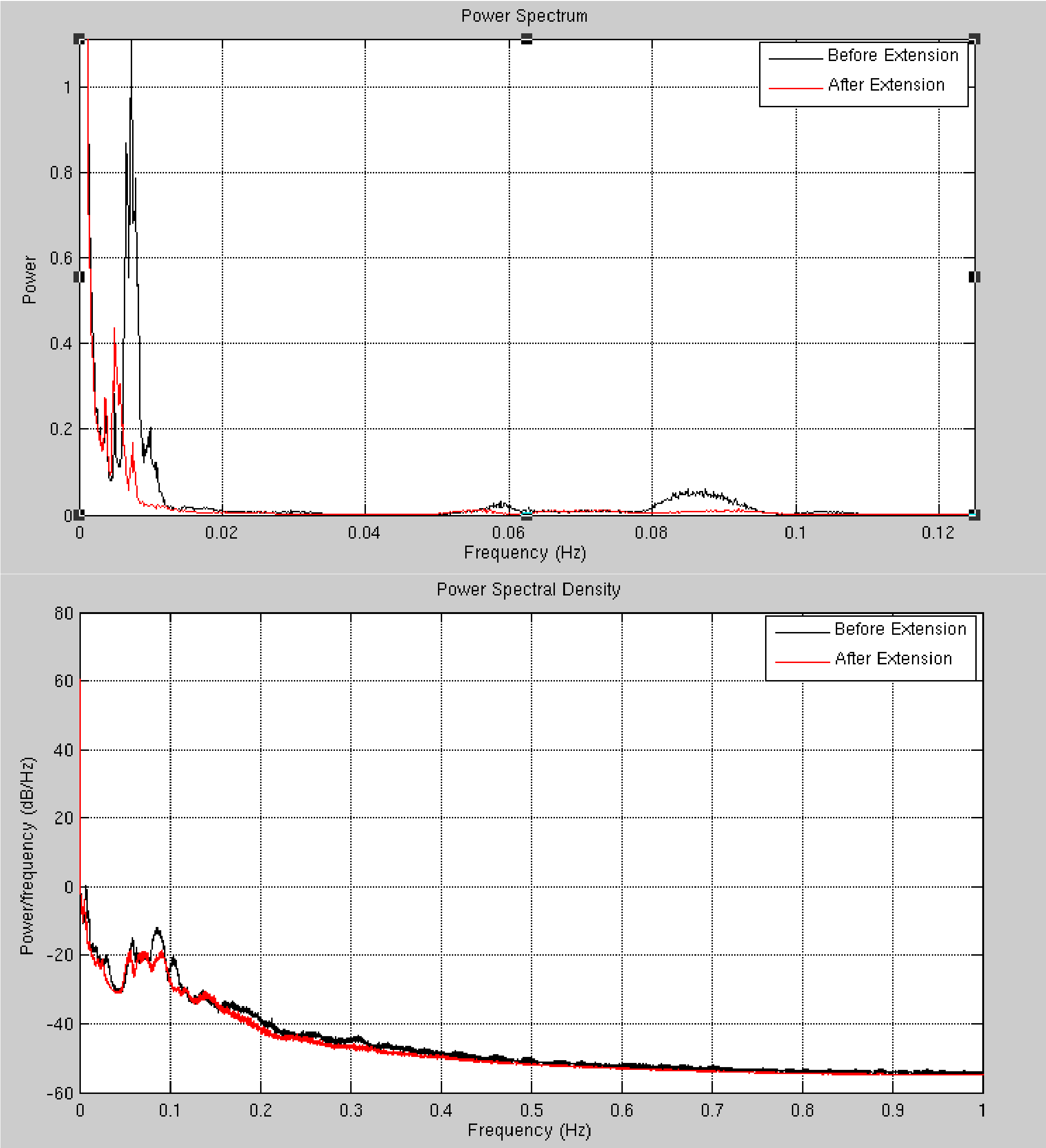

Figure 8 Power spectrum (Top) and power spectrum density (Bottom) based on recorded pressure data and selection event categories (RBR solo S/N41307)

Following this reassessment, the power spectrum appears slightly smaller but still very similar to the original power spectrum. Therefore, the results suggest there is an overall reduction in power since the basin extension. In particular, power reduced significantly for the wave frequency in the order of 0.0073 Hertz (or about 137s period).

The same analyses were undertaken for RBR solo S/N 41308 and similar results were obtained for the before and after basin extension datasets. Both instruments present the same change in spectrum shape between the before and after basin extension (MHL 2016).

Conclusion

Analysis of the data suggests a reduction in wave power in the boat ramp basin following the extension works. In particular, it shows a significant reduction in energy for a wave period of about 137 s. However, it should be noted that analysis of offshore Waverider buoy data indicated higher wave energy in the two months before the basin extension works than over the four months after works were completed.

No doubt the investigation would have benefited from longer before and after basin datasets. Nevertheless, recent reports and observations from mariners using the boat ramp indicate that seiche action has decreased since basin extension was completed. It will be of interest when offshore wave conditions known to have generated significant seiche activity in the original boat ramp basin (typically long period swell from the east to north-east) occur to observe if boat launching and recovery operations are effected by seiche action in the new extended basin.

Acknowledgements

The Coffs Harbour boat ramp basin extension physical model and basin data collection program were funded by grants to Coffs Harbour City Council from the Roads and Maritime Services. Coffs Harbour City Council contributed in-kind support through project management of the basin extension construction works. The authors acknowledge the support of both organisations in the preparation of this paper. Offshore wave data used in the data analyses for the investigation was collected for the Office of Environment and Heritage by Manly Hydraulics Laboratory.

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