Measuring and Modelling Seiche Phenomena in NSW Harbours

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1

Outline of Presentation

- Brief history of Seiche measurement and modelling in NSW
- Forcing functions
- Numerical modelling of seiche phenomena in NSW-New Developments Such as Wavelet Analysis
- Physical modelling of Seiche phenomena in NSW-Past Errors and New Developments
- Role of seiche analysis in future development of harbours
- Summary

2

Extreme Coastal Seiche in Various Regions of the World (Rabinovich-1996)

- Japan-Nagasaki Bay->4m,35min
- China-Longkou Harbour>2.5m,2h
- Spain-Ciutadella Harbor>4.0m,10.5min
- Canada-Newfoundland-2.0m-3.0m,10-40 min
- Netherlands-Rotterdam Harbour>1.5m,85-100min

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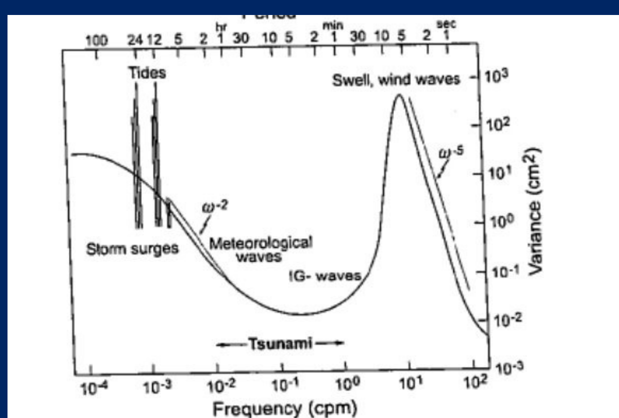
Relative energy of swell, tide and seiche waves



‘The most conspicuous thing about long waves in the open ocean is their absence.’ Prof. Munk, Scripps

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NSW Offshore Waverider buoy network and location of harbours

Wave Station	Date Site Commissioned	Directional Buoy Deployed
Byron Bay	14-Oct-1976	26-Oct-1999
Coffs Harbour	26-May-1976	14-Feb-2012
Crowdy Head	10-Oct-1985	19-Aug-2011
Sydney	17-Jul-1987	03-Mar-1992
Port Kembla	07-Feb-1974	20-Jun-2012
Batemans Bay	27-May-1986	23-Feb-2001
Eden	08-Feb-1978	16-Dec-2011

- 7 Datawell directional buoys
- Moored 6-12 km offshore
- 4 stations > 38 years data
- Sydney > 24 years directional data
- 3 stations > 15 years directional data
- > 230 station years wave data

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The seiche problem – Coffs Harbour layout

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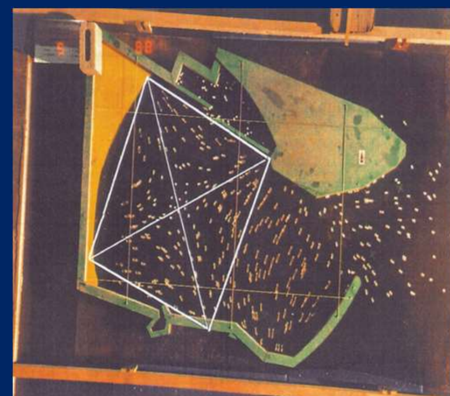
Coffs Harbour modes of oscillation (MHL538 1989)

Distorted Scale Model-Erroneous ?-due to error in reflection simulation

136 s seiche L_x= **800** L_y= **100**



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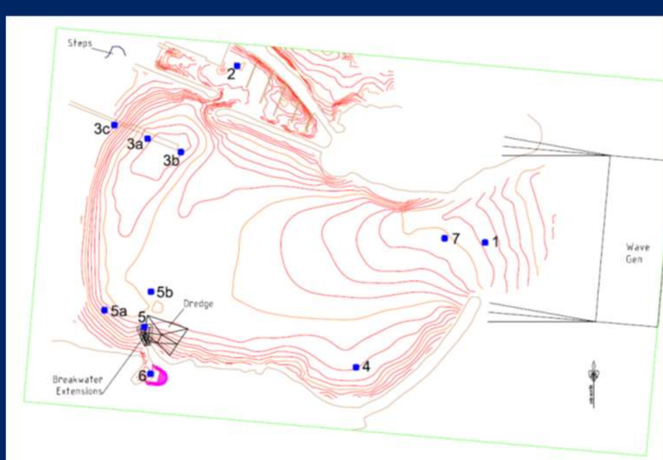
Basin layout – scale 1:58 (2014,2020)



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History of long wave measurement at Coffs Harbour

Long Wave Measurement History at Coffs Harbour

Source: DWAVE Archive

Site	Instrument	Water Depth (m)	First date/ Last date	Record Length (years)	Data Capture (%)
Coffs Harbour Jetty	EWS	7	5/11/86–15/1/96	9.2	83.7
Coffs Inner Harbour	EWS	4	16/1/96–8/10/18	22	83.8

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Offshore conditions during extensive seiching at Coffs Harbour

Date	Peak Offshore Wave Height (m)	Offshore Wave Period (s)	Comment
10/6/12	2.06	13.7	Seiche indicated on YouTube (section 4.3)
5/9/14	4.8	14.85	Seiche experienced and reported to CHCC

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Examples of extreme long wave recording in Coffs Harbour

Date/Time	Hs	Hmax	Tp1	Tp2
09/02/88 22:00	0.53	0.99	712	109
15/05/90 08:00	0.49	0.82	712	132
26/04/89 18:00	0.40	0.62	712	109
23/10/92 18:00	0.49	0.94	109	66
09/03/88 22:00	0.48	0.91	109	138
15/05/90 20:00	0.46	0.84	109	712

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128s seiche at Coffs Harbour ramp June 2012

Time1:27

Time 2:34

https://www.youtube.com/watch?v=QBqNe36IoVw

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Damage due to seiche – NW, NE breakwater crest

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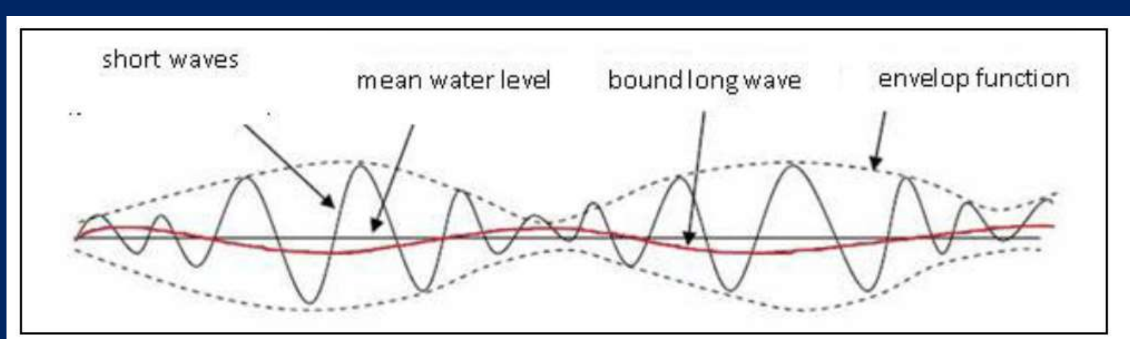
Forcing function – bounded long wave



Other Forcing functions- (1)Surf beat (2) Bounded long Waves (3) tsunami (4)meteo tsunami-greenspan
Proudman forcing (5)Edge waves

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Periods of oscillation of a closed system – Merian's Formula

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 =1125 m
	b	=	width of basin =625 m
	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

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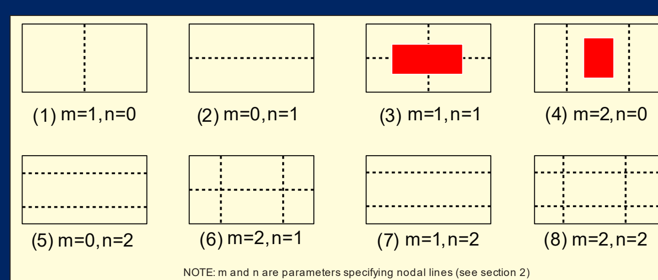
Possible periods of oscillation and modes of oscillation

Nodal Parameters		Oscillation Period (secs)	
m	n	Main Harbour	Boat Ramp Basin
1	0	254	36
0	1	141	21
1	1	123	18
2	0	127	18
0	2	71	10



Possible seiche nodes at Coffs Harbour boat ramp basin

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Testing seiche in boat ramp – original and modified

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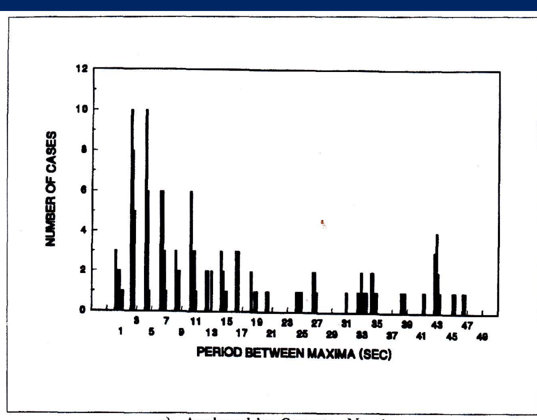
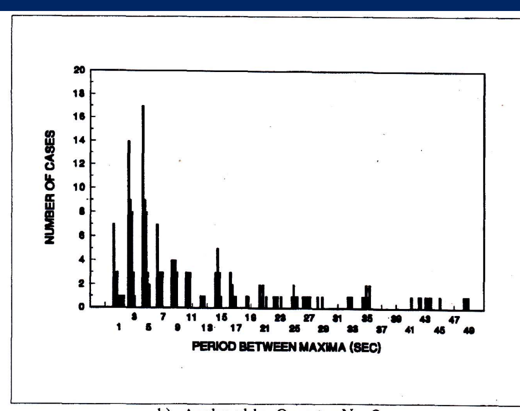
Subjective analysis of runup (Briggs, CERC 1991)



a) Analyzed by Operator No. 1



b) Analyzed by Operator No. 2

Figure 5. Distribution of period between successive runup maxima above a threshold value, RUNUP No. 6. Several different thresholds are represented (Continued)

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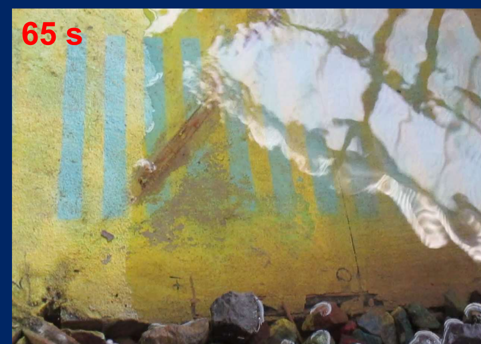
Detecting seiche amplitude – runup measurement 130s wave



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Boat harbour basin wave spectrum vs entrance spectrum – before and after

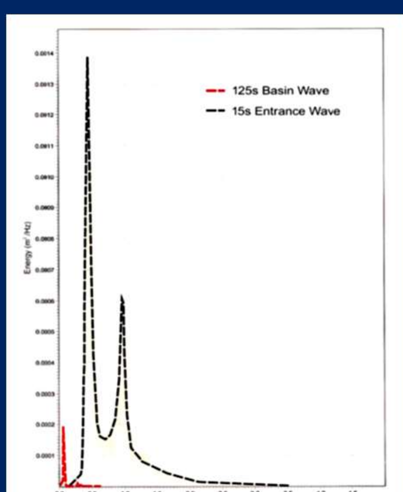

Fig. 5a Indicating long wave spectrum in Probe 6 in the boat ramp basin.

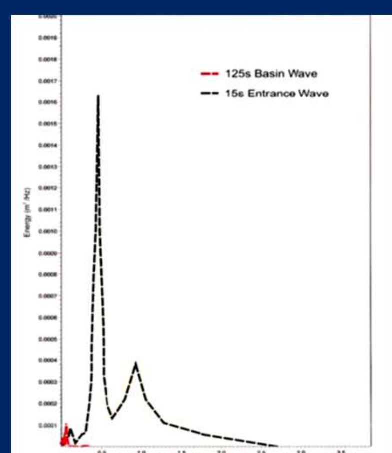

Fig. 5b Indicating long wave spectrum energy reduction in Probe 6 by 25% after basin modification.

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Option 2 Planform change – Raichlan and Poon (MIT 1998, ICCE)

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Test results – comparison with modified basin

Water Level (m AHD)	Harbour Entrance		Existing Basin		Extended Basin		Extended Basin (with roughness)		Maximum Hsig Reduction (%)
	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	
0.0	4.12	17.2	0.45	125	0.39	207	0.34	623	24.5
0.8	3.66	17.2	0.46	125	0.38	104	0.35	125	23.9
0.8	4.40	16.4	0.56	207	0.43	138	0.44	125	23.2
0.8	**4.81**	**15.8**	**0.64**	**125**			**0.45**	**125**	**29.7**
0.8	2.78	13.2	0.44	104			0.33	104	25.0
0.8	**2.30**	**13.1**	**0.41**	**113**			**0.31**	**123**	**24.4**
0.8	1.38	13.3	0.25	104			0.19	144	24.0

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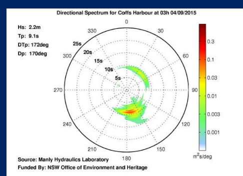
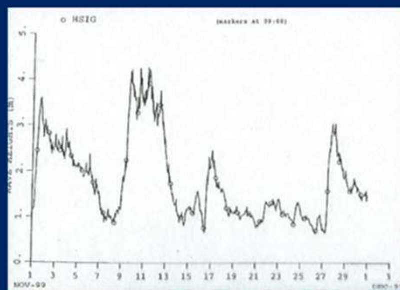
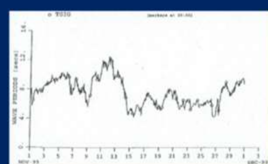
Forcing by released bound waves ?– Hs=4m-A hand calculation







23

Relevant theory – transfer function of long wave spectra (Sand 1982)

$\eta LB(t)/h = G_{nm}\, h\, \{ (a_n a_m + b_n b_m)/h^2 \cos(\Delta\omega_{nm} t - \Delta K_{nm} x_1) + (a_m b_n - a_n b_m)/h^2 \sin(\Delta\omega_{nm} t - \Delta K_{nm} x_1)$

$\eta LB(t)$ = time of long wave surface elevations

h = water depth

G_{nm} = non linear transfer function

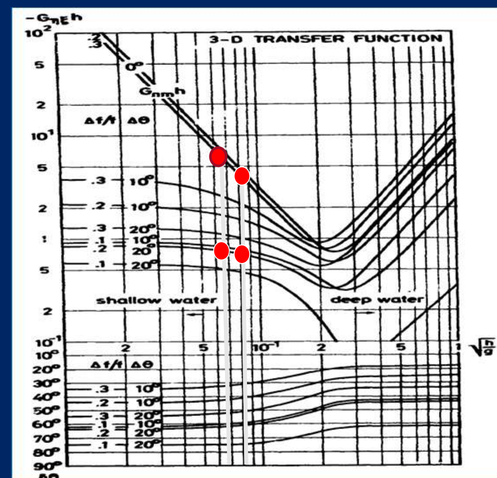
$\Delta\omega_{nm} = \omega_n - \omega_m$

$\Delta K_{nm} = K_n - K_m$ **for 10s and 11s wave long wave of 110s**

24

Directional transfer function for long waves (Sand 1982)

Date	Tp	Hs	$G_{\eta E}^{h}$ (20^0)	$G_{\eta E}^{h}$ (0^0)	η (20^0)	η (0^0)
Sep-14	15	5	0.8	7	0.14	1.22
Jun-12	13	2.5	0.7	4	0.03	0.17



Long Wave Amplitudes (Bowers 1992)

Bound Long Wave-H_{SI} ~ ($H_S T_P$)^2

Surf Beat -H_{SI}~ $H_S T_P$

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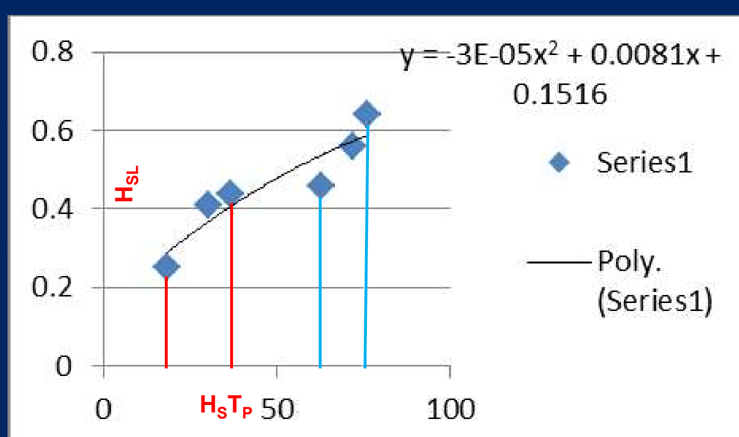
Long wave energy measured at the boat ramp – forcing

Surf beat

Bound long waves

Bound Long Wave-H_{SI} ~ ($H_S T_P$)^2

Surf Beat -H_{SI}~ $H_S T_P$



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Configurations for concept designs – Stage 2

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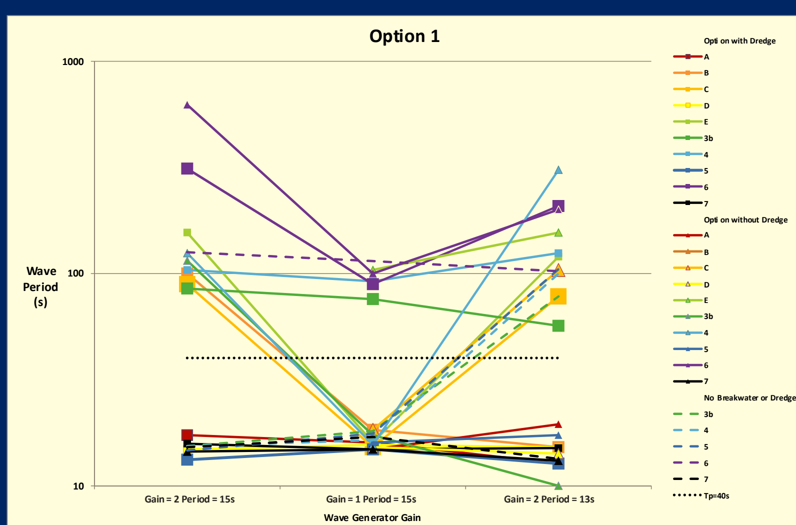
Case study for seiche motions for Option 1



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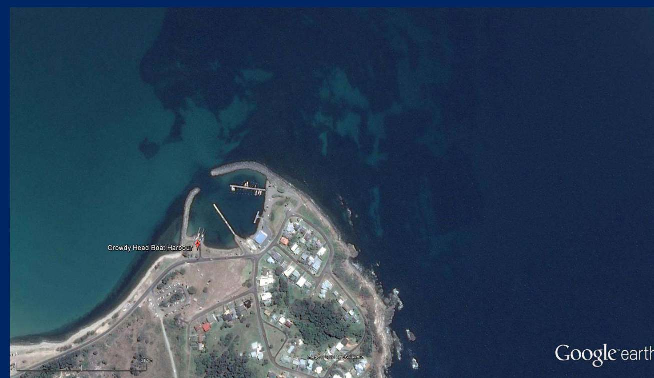
Crowdy Head – location and orientation



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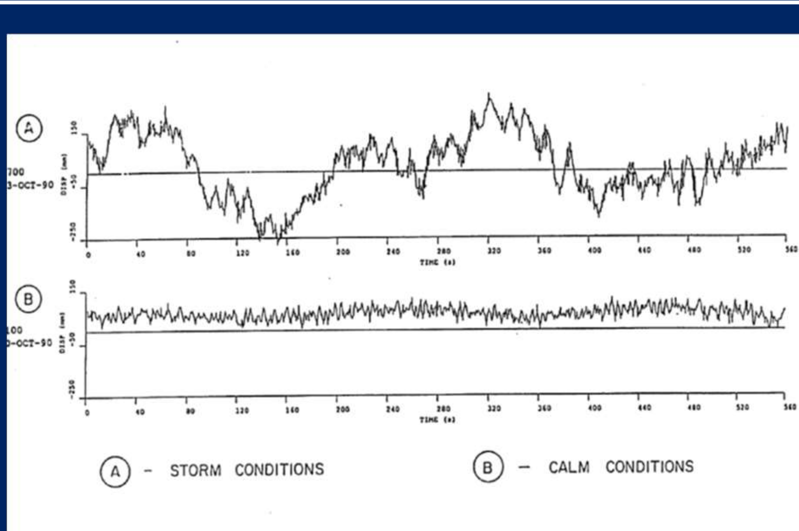
Crowdy Harbour seiche measurement during storm and calm conditions >200s



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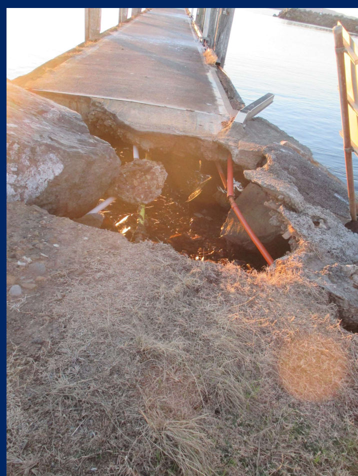
30

Damage due to seiche – Crowdy Harbour –June 2016



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Oscillations in a circular harbour using cylindrical coordinates – an analytical result

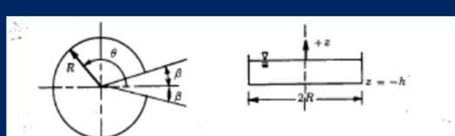
DE: $\nabla^2\varphi = \nabla^2\psi = 0$ (1)

BC's

$$\frac{\partial^2 \Phi}{\partial t^2} + g\frac{\partial \Phi}{\partial z} = 0 \quad \text{on} \quad z = 0$$ (2)

$$\frac{\partial \Phi}{\partial r} = 0 \quad \text{at} \quad r = R \qquad 2\pi - \beta > \theta > \beta$$

$$\frac{\partial \Phi}{\partial z} = 0 \quad \text{at} \quad z = -h$$



Definition sketch

$$\frac{\partial \Phi}{\partial r} = f(r,\theta,z,t) \quad \text{at} \quad r = R \qquad 2\pi - \beta < \theta < \beta$$

Solution

$$F(r,\theta) = \sum_{n=0}^{\infty} A_n J_n(kr) \cos n\theta$$ (3)

$$\eta = A_n J_n(kr) \cos n\theta \cos \sigma t$$

$$kR = 1.841,\ 5.33,\ 8.53,\ \text{etc.}$$

$$T = 3.41 \frac{R}{\sqrt{gh}}$$

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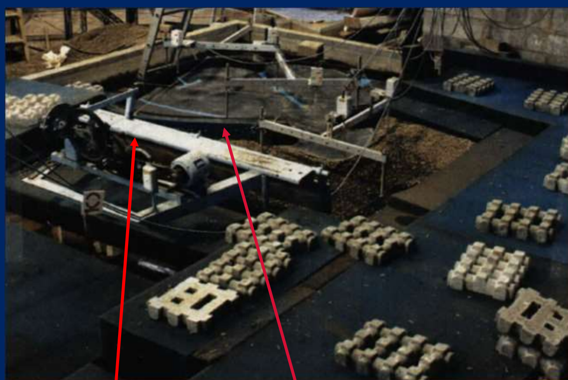
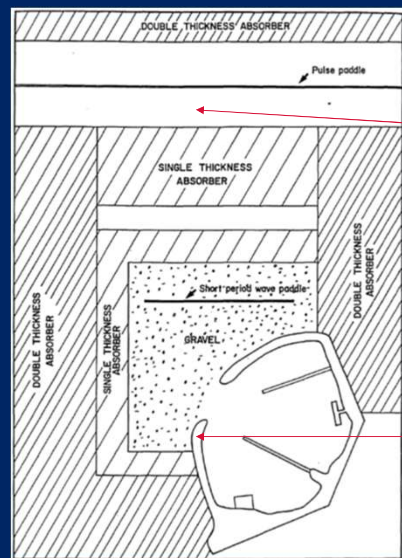
Distorted scale physical model H 1:100, V 1:50-1994



Short wave paddle

Crowdy Harbour



Seiche paddle

Crowdy Harbour

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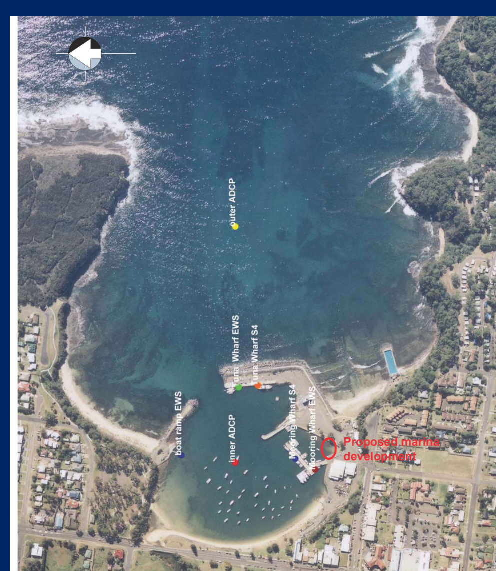
Ulladulla Harbour – location and orientation-2006



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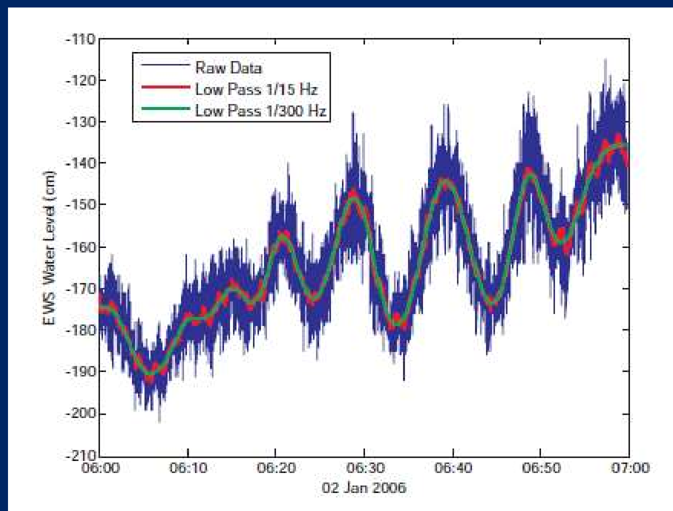
Bay oscillations on 2 January 2006 – 600s



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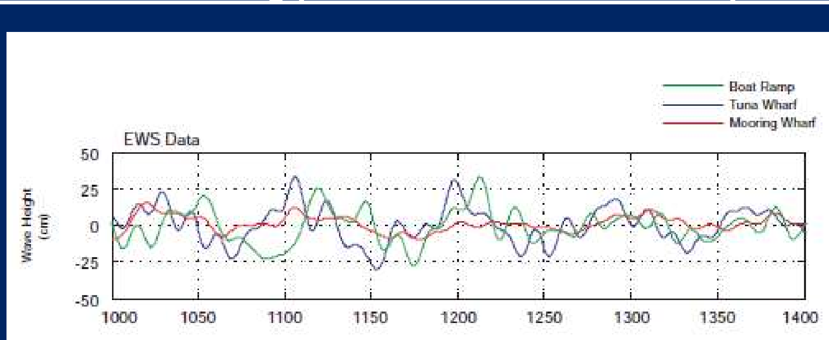
Measurement of long periods in harbour on 9 April 2006 (83s–91s)



Site	Amplitude	Phase (secs)	Period (secs)	Correlation Coefficient
Boat Ramp EWS	11.1 cm	16.8	83.9	0.792
Main Wharf EWS	6.9 cm	– 80.7	90.8	0.755
Tuna Wharf EWS	13.3 cm	38.6	87.6	0.874
Tuna Wharf Cross Shore Current	3.1 cm/sec	39.6	87.9	0.568
Tuna Wharf Long Shore Current	15.5 cm/sec	– 49.1	88.7	0.868

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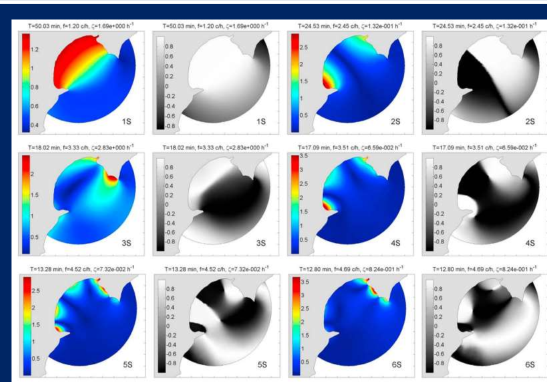
Empirical Orthoganal Function (EOF) Analysis

- In signal processing, empirical orthogonal function (EOF) analysis finds both time series and spatial patterns.
- A space-time data set (such as numerical model outputs) is decomposed into a set of othognal (i.e. statistically independent) space patterns ('EOF') and time-dependent coefficients ('principal components') – e.g. Bellotti et al (2012), Tolkova & Power (2012).
- Decomposition of real-valued EOFs interprets water surface variations within a harbour as a combination of standing waves.
- Fourier analysis of the principal components will all potential resonant frequencies of the harbour basin
- Reconstruction of each EOF mode shows a 'map' of each resonance patten within the harbour
- Typically, the first resonance pattern is responsible for the largest part of the signal variance, the second for the largest part of the remaining variance, and so on.



Example resonant modes of Poverty Bay, reconstructed from EOF analysis of simulated water level variations during a tsunami. From Bellotti *et al*., 2012.

Bellotti, G., Briganti, R. and Beltrami, G.M. (2012). The combined role of bay and shelf modes in tsunami amplification along the coast. Journal of Geophysical Research 117, C08027

Tolkova, E. & Power, W. (2011). Obtaining Natural Oscillatory Modes of Bays and Harbours via Empirical Orthoganol Function Analysis of Tsunami Wave Fields. Ocean Dynamics 61(6), pp 731 - 751

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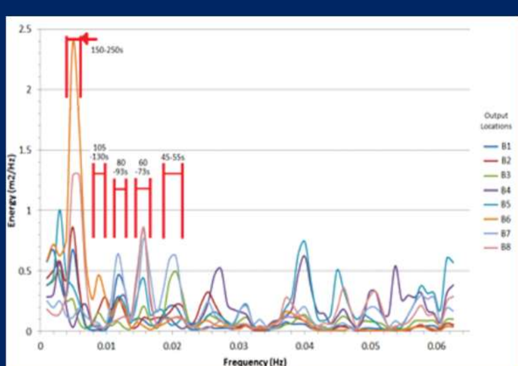
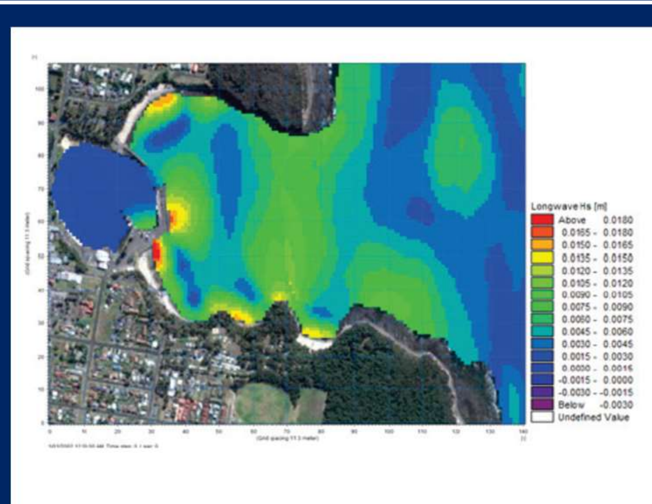
White noise forcing of the whole of Ulladulla Bay (80s–93s)





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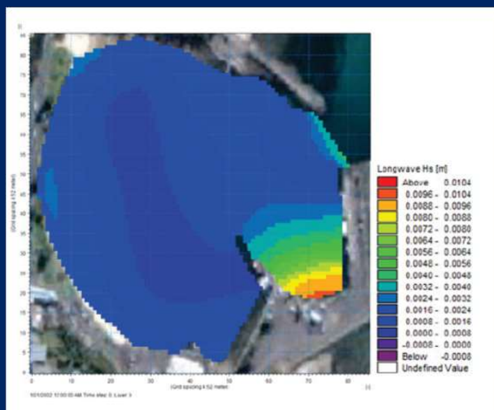
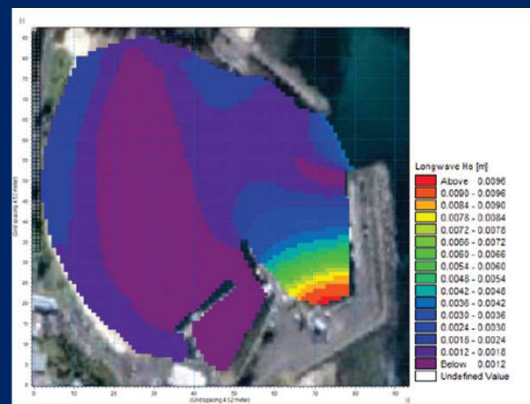
White noise forcing (82s–95s) Ulladulla Harbour



Permeable T Jetty



Impermeable T Jetty

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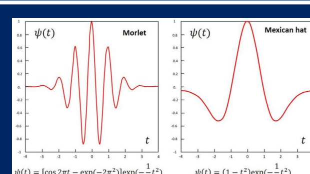
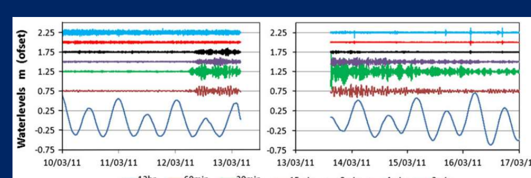
Wavelet Analysis

- Fourier analysis: assumes signals are constant with time ("stationary") - almost never the case within the coastal environment. Infragravity waves are both stochastic and continually evolving with time – "non-stationary".
- Wavelet analysis: Instead of using sinusoids (as Fourier analysis), a discrete function called the "mother wavelet" is used to decompose (filter) the signal over a wide range of time scales.
- Particularly adept at identifying transient features such as solitary waves or non-stationary processes such as a continually evolving infragravity wave field
- Choice of wavelet shape influences signal reconstruction and statistical estimators (e.g., Bigrelle et al, 2013; Gilles, 2013).
- The closer the wavelet shape is to the underlying signal, the more strongly the wavelet decomposition is able to identify it



Example "Mother Wavelets"



Example wavelet decomposition of water level records within Port Kembla to different frequency bands during the 2011 Japan tsunami. *From* Hinwood & Luick (2012).

Bigrelle *et al.* (2013). *Relevance of Wavelet Shape Selection in a Complex Signal.* Mechanical Systems and Signal Processing. 41(2), pp 14 – 33
Gilles, J. (2013). *Emperical Wavelet Transform.* IEEE Transactions on Signal Processing. 61(16), pp 3999 – 4010
Hinwood, J. & Luick, J. (2012). Closed Basin Modes of a Dual Basin Harbour. Pure Appl. Geophys., 170(11), 1881 - 1897

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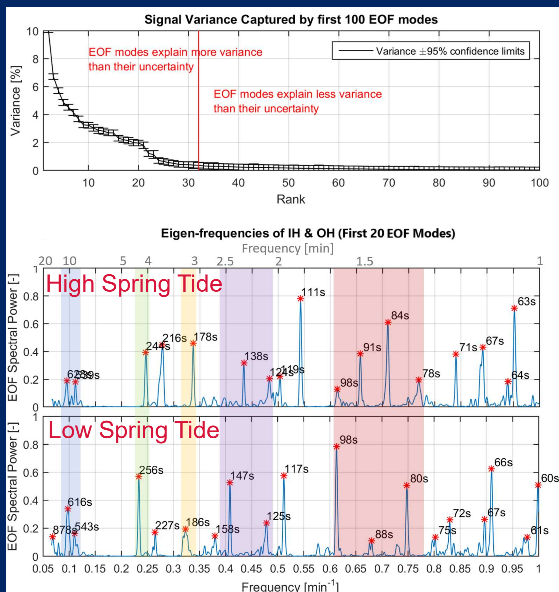
Port Kembla: EOF Analysis of Resonant Modes from 'White Noise' Simulation



Observed period (min)	Location and source	Description	Predicted period (min)
1.3	IH[a]	Closed basin mode[b]	1.33[a]
1.2, 1.6	OH[c]	–	–
2.1	NTFA[d]	–	–
2.4	NTFA[d]	–	–
2.5	OH[e]	Lenticular mode[f]	2.5[e]
3	OH[a]	Closed basin mode[g]	3.15[a]
3.1	NTFA[d]	–	–
4	NTFA[d]	–	–
8	NTFA[d]	Closed basin mode[h]	9.0[i]
10.5	NTFA[d]	–	–

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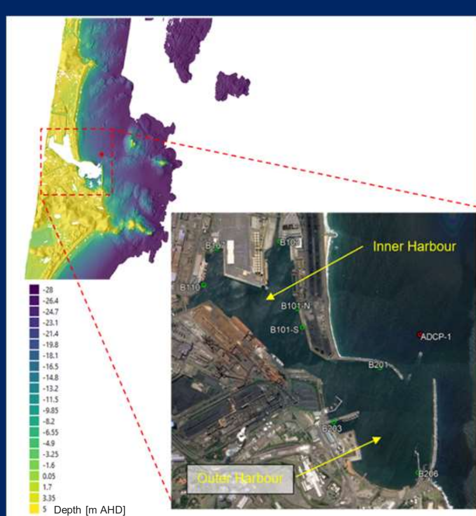
Port Kembla: Infragravity Wave Observations & Simulations



- NSW Ports undertook data collection campaign to measure infragravity wave processes occurring within the Inner and Outer Harbour of Port Kembla, and relate these to meteorology and deep-water swell wave processes (see Williams, 2019)
- Eight RBRsolo³ pressure transducer data loggers were installed within the Inner and Outer Harbour for a period of approximately one year, sampling continuously at 2Hz.
- Continuous surface elevation data was also collected at the ADCP instrument located approximately 450m north of the Port entrance to determine conditions outside the Port.
- A combination of signal processing and numerical modelling has been undertaken to understand potential resonance patterns within the Inner and Outer Harbour
- A brief analysis of some results is presented in the following slides.

Williams, B.G. (2019). Predicting Infragravity Wave Height in Harbours using Artificial Intelligence. Australasian Coasts & Ports 2019 Conference, Hobart

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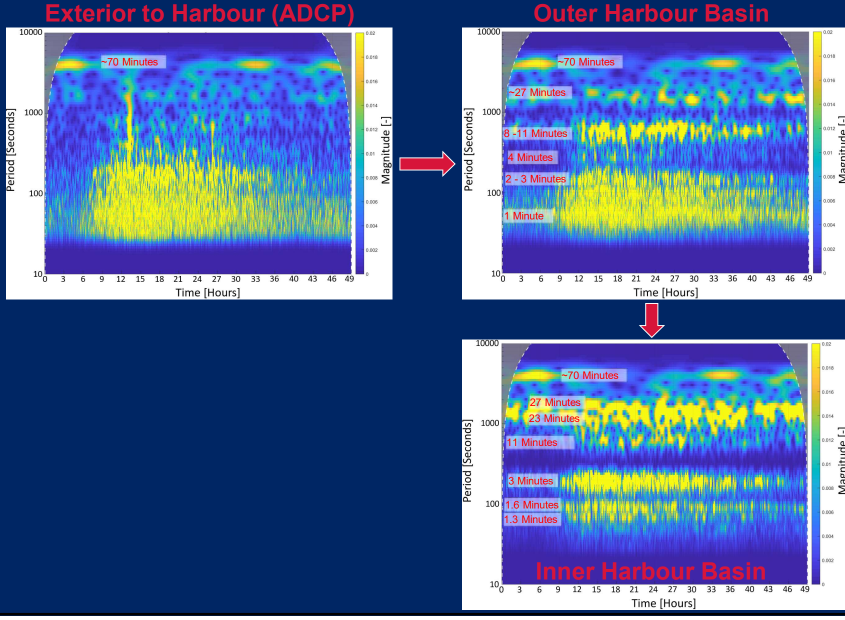
42

Port Kembla: Wavelet Analysis (Magnitude Scalograms)



Observed period (min)	Location and source	Description	Predicted period (min)
1.3	IH[a]	Closed basin mode[b]	1.33[a]
1.2, 1.6	OH[c]	–	–
2.1	NTFA[d]	–	–
2.4	NTFA[d]	–	–
2.5	OH[e]	Lenticular mode[f]	2.5[e]
3	OH[a]	Closed basin mode[g]	3.15[a]
3.1	NTFA[d]	–	–
4	NTFA[d]	–	–
8	NTFA[d]	Closed basin mode[h]	9.0[i]
10.5	NTFA[d]	–	–
23.3	IH[a]	Open basin mode[j]	22.8[a]
23.8	NTFA[d]	–	–
26.3	NTFA[d]	k	–
26.6	OH[a]	k	–
34.5	NTFA[d]	k	–
60–75	Allans Creek[a]	k	55–73[a]
67	NTFA[d]	k	–

From: Hinwood, J. & Luick, J. (2012). *Closed Basin Modes of a Dual Basin Harbour*. Pure Appl. Geophys., 170(11), 1881 - 1897

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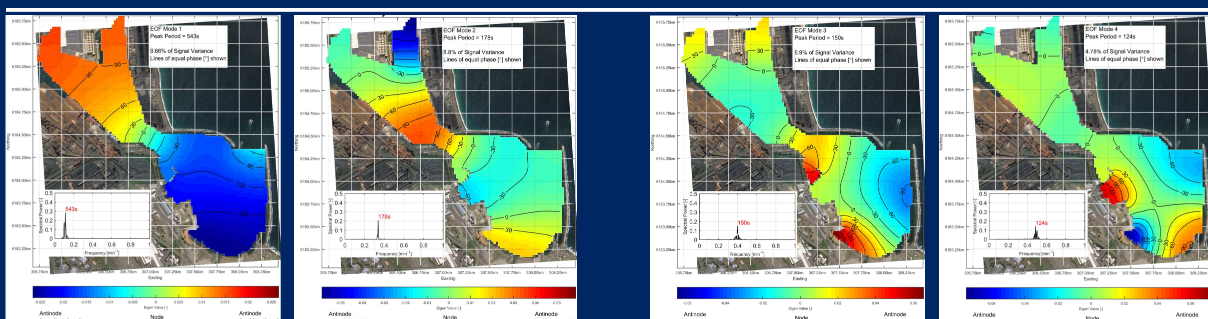
Port Kembla: EOF Analysis of Oscillation Modes from White Noise



Observed period (min)	Location and source	Description	Predicted period (min)
1.3	IH[a]	Closed basin mode[b]	1.33[a]
1.2, 1.6	OH[c]	–	–
2.1	NTFA[d]	–	–
2.4	NTFA[d]	–	–
2.5	OH[e]	Lenticular mode[f]	2.5[e]
3	OH[a]	Closed basin mode[g]	3.15[a]
3.1	NTFA[d]	–	–
4	NTFA[d]	–	–
8	NTFA[d]	Closed basin mode[h]	9.0[i]
10.5	NTFA[d]	–	–

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Conclusions

- Possible modes of oscillation and forcing functions attributable to surf beat from Jetty Beach during mild offshore conditions and bounded long waves during extreme offshore conditions were identified.
- Testing of the above conditions with basin modified resulted in a reduction of less than 30% in long wave energy in the modified boat ramp. This reduction in long wave energy was also measured in the prototype.
- Seiche testing at Crowdy Harbour did not provide a solution to attenuate long waves, however, the short wave model optimised concept designs.
- White noise testing was utilised to indicate the attenuating function of an impermeable jetty in Ulladulla.
- EOF and Wavelet Analysis provided insight into seiche response
- at Port Kembla

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45