Ocean Engineering 88 (2014) 435–445

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Observations of infragravity period oscillations in a small marina

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ARTICLE INFO

Article history:
Received 8 October 2013
Accepted 2 July 2014
Available online 25 July 2014

Keywords:
Harbours
Oscillations
Australia
Water levels
Wave groups
Seiches

ABSTRACT

We measured water levels in Two Rocks Marina, Western Australia, to investigate infragravity-period (25–300 s) oscillations and their forcing mechanisms. Spectral analyses identified four dominant oscillations in the infragravity band, which were generated through excitation of the marina's natural periods. The oscillations were present at all times, independent of the offshore conditions, indicating that they were forced by a continuous external energy source. The spectral energy of the oscillations increased by ~50 times during storm events (higher incident wave heights), in comparison to calm events (lower incident wave heights). Wave heights of oscillations within the marina were strongly correlated with offshore incident swell wave heights and reached maximum of 0.5 m. The groupiness factor of swell waves around the marina was 0.6–0.85. Bound infragravity waves associated with swell wave groups were identified as potential forcing mechanism of infragravity-period oscillations within the marina. The bound infragravity waves have broad frequency spectrum without dominant periods matched the marina's natural periods however, bound infragravity waves of periods in the proximity of the marina NOPs were adequate to generate oscillations at the NOPs of the marina. Frequencies of the oscillations were independent of the forcing frequency, and determined by the marina's geometry.

1. Introduction

Infragravity period waves are surface gravity waves with periods between 25 and 300 s (frequencies between 0.003–0.04 Hz) and wave lengths between 100 m and 10 km (Rabinovich, 2009). Infragravity waves are generated, mainly through nonlinear interactions of wind generated waves. The propagation of infragravity waves towards coastal areas, which contain, for example, harbours and lagoons, can excite oscillations within these water bodies. Resonance, when the period of incident infragravity waves is close to natural oscillation periods (NOPs) of the water basin, generates higher amplitude oscillations causing undesirable water motions. Such conditions interrupt berthing operations, further resulting in harbour downtime followed by economic losses (McComb et al., 2005; Van der Molen et al., 2006; Rabinovich, 2009; Uzaki et al., 2010).

Very long-period incident waves such as tsunamis (Gilmour, 1990; Hinwood and McLean, 2013), waves originated from atmospheric pressure disturbances (Vilibic and Mihanovic´, 2003; De Jong and Battjes, 2004; Uzaki et al., 2005; Pattiaratchi and Wijeratne, 2014), and internal waves (Rabinovich, 2009), can cause significantly high amplitude oscillations followed by extensive damage to harbour operations. Very long-waves can affect only large harbours because their NOPs are generally longer than 10 min, which matches the very long-period wave band. In contrast, very long-period waves cannot excite NOPs of small harbours (where the surface water area is about 1 km^2 and the depth is about 5–10 m) because, their NOPs are shorter than the very long- period wave band (Okihiro and Guza, 1996). On the other hand, NOPs of small harbours cannot be directly excited by short waves either because short wave periods are typically less than 25 s. However, infragravity waves can excite NOPs of small harbours because their NOPs are in the similar range of the infragravity wave periods (Wu and Liu, 1990). Various harbours and ports around the world, such as Port of Sines Portugal (Gierlevsen et al., 2001), Port of Long Beach California (Kofoed-Hansen et al., 2005), Hualian harbour Taiwan (Chen et al., 2004) experience frequent oscillations in the infragravity period band, excited by short waves (Rabinovich, 2009).

Bowers (1977); Mei and Agnon (1989), and Wu and Liu (1990) carried out theoretical and laboratory experiments to study the influence of incident short waves on infragravity period harbour oscillations. These studies found that bound infragravity waves (associated with regular swell wave groups), and free infragravity waves (generated by breaking of swell wave groups) can excite NOPs of harbours in the infragravity period band. Field observations at few harbours, [Esperance harbour in Australia (Morison and Imberger, 1992), Barbers Point harbour in Hawaii (Okihiro et

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http://dx.doi.org/10.1016/j.oceaneng.2014.07.003
0029-8018/

al., 1993; Harkins and Briggs, 1995; Okihiro and Guza, 1996), Marina di Carrarra in Italy (Bellotti and Franco, 2011) and Port of Ferrol in Spain (López et al., 2012)], have subsequently confirmed those findings by showing strong correlation between infragravity waves inside the harbour and swell waves outside the harbour.

For both bound and free infragravity waves, the primary energy source is the narrow banded regular and uni-directional swell waves (Harkins and Briggs, 1995; Okihiro and Guza, 1996). However, sea surface elevation spectra are not always regular and narrow banded. They are characterized by broad banded wind-induced short waves (Mei and Agnon, 1989; De Girolamo, 1996; Chen and Mei, 2006), which are directional and irregular, especially during storm events. Infragravity wave actions dramatically increase during storm events (Nakamura and Katoh, 1993) and hence dominate the wave energy spectra in the surf zone (Holman et al., 1978; Holman, 1981). Jeong et al. (1997) studied oscillations in Muko harbour Korea, and showed that infragravity waves inside the harbour were strongly excited during storm events.

Excessive water level oscillations occasionally occur in Two Rocks Marina during local storm events, interrupting berthing operations (Shane Lindsay, personal communication, Oct 2011). Gwynne (1993), found existence of infragravity period oscillations in the marina, and further showed that these oscillations correlated with offshore swell waves. We used measured water level data to investigate the oscillation problem in Two Rocks Marina with the aims of identifying (1) dominant oscillation periods in the marina and their relation to the marina's NOPs; (2) different events of marina response to different offshore wave conditions; and (3) potential forcing mechanisms of marina's oscillations. This study contributes for marina management in planning future modifications to minimize disturbance due to infragravity period oscillations.

1.1. Study site

Two Rocks Marina, located in south-west Australia (Fig. 1) has a surface water area of $\sim$0.15 km^2 with a length and width of 650 m and 260 m respectively. The average water depth of the marina is $\sim$3.5 m to mean sea level (MSL). The marina has two basins, which provide berthing facilities for about 125 small vessels. The north basin is long and narrow and the south basin is approximately circular (Fig. 1b). Having comprised two linked basins, the marina geometry probably permits for complex oscillation patterns. Oscillations in harbours and bays with similar geometries have been studied by few authors (Lee and Raichlen, 1972; Luick and Hinwood, 2008; Asano et al., 2010). In such harbour geometries, single basin or coupled basin modes or their combination could appear by supper positioning of the individual basin responses to generate the resultant response of the entire harbour system.

The coastal region of Western Australia experiences about 30 storms a year, with associated mean offshore H_s values of more than 4 m (Lemm et al., 1999). Two submerged reef systems are located parallel to the coastline at distances of $\sim$3.2 and 4.7 km offshore from the shoreline respectively. The crest level of the reef systems varies 4–7 m below MSL. These reef systems act as

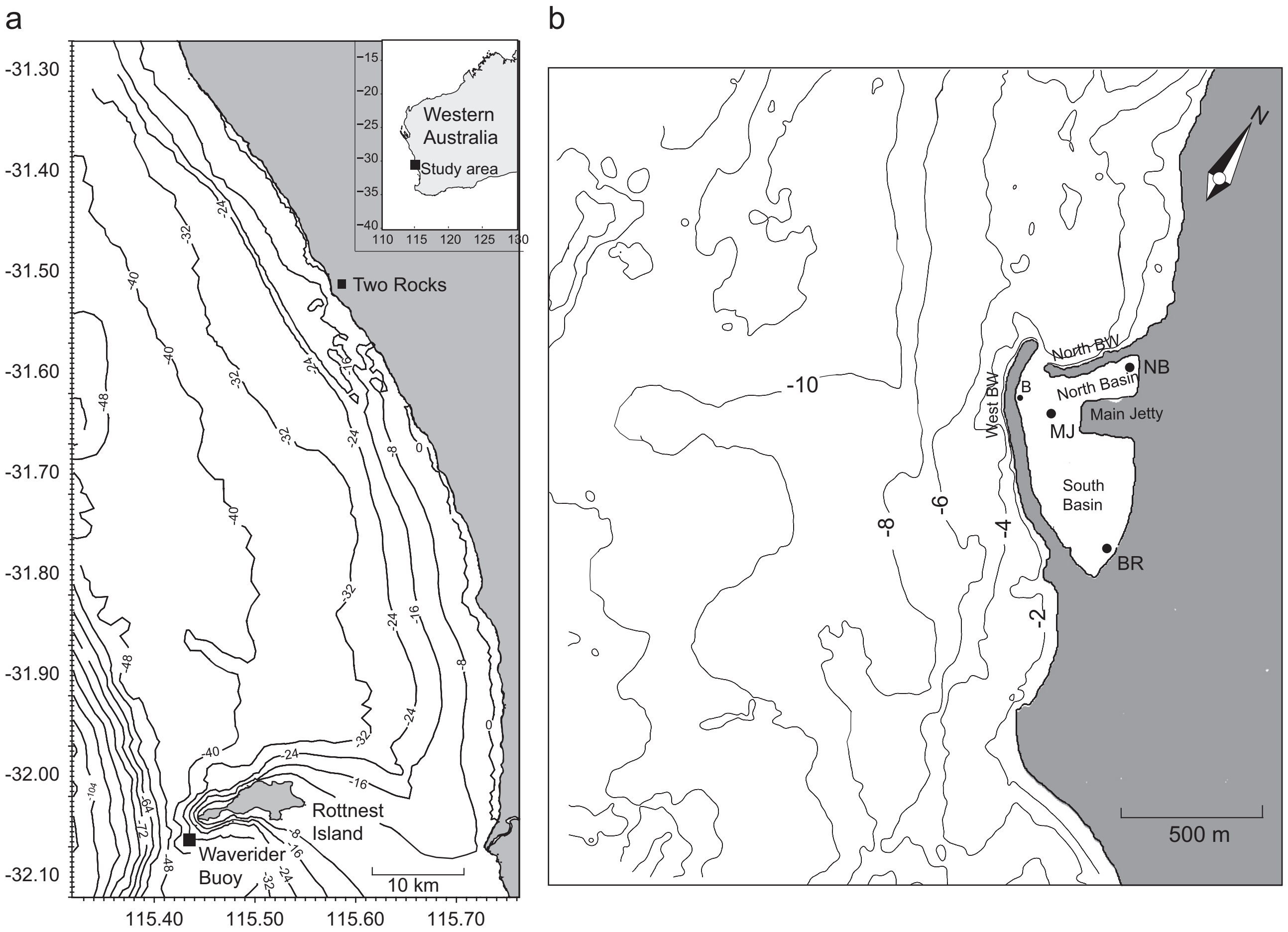

Fig. 1. Two Rocks Marina: (a) map of study area showing the locations of Two Rocks and the offshore waverider buoy near Rottnest Island. (b) Instrument stations. Pressure sensors deployed at NB, MJ and BR (marked with black dots).