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Influence of offshore topography on infragravity period oscillations in Two Rocks Marina, Western Australia

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ABSTRACT

Infragravity (IG) period oscillations in harbours and marinas can often lead to interruption in harbour operations due to excessive vessel movements. Field measurements in Two Rocks Marina in south-west Australia have shown that IG period oscillations were always present and the amplitude of the oscillations was related to incident swell climate and was enhanced during storm events. The marina is fronted by two shallow, shore-parallel, reef systems located ~3.2 and ~4.7 km from the shoreline. The area experiences continuous swell and frequent storm systems, particularly during winter months. This paper describes the application of a Boussinesq wave model, validated using field data, to examine: (1) source of the IG waves incident on the marina; and (2) modal characteristics of the IG period oscillations inside the marina. The cross-shore evolution of the IG wave energy was examined using simulations with different contrasting incident wave conditions, which included measured and idealised wave spectra. The model results indicated that free IG waves were generated as the wind/swell waves propagated over the offshore reef systems independent of the external forcing. During stormy sea condition, the IG energy over the primary and secondary reefs increased by a factor ~10 and ~8 respectively, compared to the IG energy at offshore. The IG wave spectrum near the marina entrance did not contain any major energy peaks, and has an almost constant energy distribution across the IG wave frequencies. However, the frequencies similar to the marina's natural oscillation periods were excited within the marina. The predicted energy distribution maps and water level snapshots inside the marina identified different oscillation modes, which included mode 1 and mode 2 oscillations corresponding to a partially enclosed water body and, zeroth mode corresponding to an open-ended water body. This study showed that in coastal regions characterised by complex offshore topography, IG waves are generated independent of offshore wave conditions, and harbours located in such environment are at risk of IG period oscillations, depending on their geometry.

1. Introduction

Many ports and harbours have been designed for protection against wind-generated short period waves with periods between 3 and 25 s. Long breakwaters are able to prevent these shorter period waves from entering a port or a harbour (Demirbilek, 2007; Van der Molen et al., 2004). However, long waves with periods of 25 to 300 s, also defined as infragravity (IG) waves, can cause disturbances in harbours and marinas because of their diffraction through entrance and resonance properties inside harbours (Mei and Agnon, 1989; Rabinovich, 2009).

Natural oscillation period (NOP), or natural frequency, is a fundamental property of a basin which depends on the basin's geometry (Pugh, 1987). When the period of incident long waves is close to one of the natural frequencies of oscillation in the harbour, higher amplitude oscillations can be generated inside the harbour through resonance phenomenon, even if the incident long wave amplitude is small. In such conditions, berthing operations can become unsafe and be interrupted due to excessive vessel movements causing damage to mooring lines and fenders, resulting in harbour downtimes and economic losses (McComb et al., 2005; Rabinovich, 2009; Uzaki et al., 2010).

Several studies have been undertaken to determine forcing mechanisms responsible for inducing long period oscillations in harbours. Wind waves propagate as well-defined groups, from deeper water to water depths less than a few metres deep (Van Rijn, 1990). Longuet-Higgins and Stewart (1964) described a mechanism of 'set-down beneath wave groups' which produce 'bound infragravity waves' associated with wave groups. As waves approach shallow water, the quadratic nonlinear interactions approach resonance, and in water depths of the order of few metres, significant amount of wave energy can be transferred from the wind waves to the IG waves (Bowers, 1977; De Girolamo, 1996; Elgar and Guza, 1985; Mei and Agnon, 1989). This implies that IG wave energy is generally low in deep water and increases where the depth decreases such as near offshore reefs and at the shoreline.

Hydrodynamic studies, using both field and numerical approaches, in the nearshore region have provided information on spectral

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transformation in wave energy as the waves propagate from offshore to nearshore. In many cases, these studies have indicated a shoreward transformation in dominance from wind or swell waves to IG energy (Elgar and Guza, 1985). Similarly, fringing coral reefs and rock platforms have been documented to be effective in generating IG waves (Beetham and Kench, 2011; Péquignet et al., 2009). In a study of wave behaviour in a fringing coral reef Nwogu and Demirbilek (2010) found that majority of the wave energy in the incident wave frequency band was dissipated within a few wavelengths of the reef face, and the IG wave energy increased as the waves moved over the reef flat. Similarly, McComb et al. (2009) found that offshore Geraldton (~360 km north of Two Rocks Marina), majority of the IG wave energy was generated during swell wave transformations over a 3 km wide reef platform located offshore. These studies indicate that in regions of complex topography, such as those with offshore reef systems, there is a source of IG wave energy generation locally and thus may provide an energy source to setup oscillations in harbours.

Two Rocks Marina, the location of this study, is fronted by two offshore-submerged reef systems located parallel to the coastline; hence the focus of the study is on the harbour oscillations led by IG waves generated through swell wave propagation across offshore reef systems. A companion study (Thotagamuwage and Pattiaratchi, in review), based on the analysis of field measurements inside the marina (Fig. 1), revealed four dominant oscillations in the IG band at 61, 98, 124 and 227 s which were related to the NOPs of the marina. These oscillations were always present during measurement period but their magnitude was related to the incident swell climate and was enhanced during storm events. Similar results were found by Gwynne (1993) for the same location.

Here, we use a Boussinesq type numerical wave model to examine IG period oscillations inside Two Rocks Marina to determine the: (1) evolution of the IG wave energy under different incident offshore wave conditions propagating across reef systems; (2) influence of the different offshore conditions on the oscillations within the marina; and (3) effect of the marina layout on oscillation patterns.

Two Rocks Marina is located on the Western Australian coast (Fig. 1a) which experiences a diurnal, micro tidal conditions and has a mean tidal range of ~0.5–0.8 m (Pattiaratchi, 2011; Pattiaratchi and Eliot, 2008). The marina comprises of two main sections (Fig. 1b) with a total surface water area of ~0.15 km^2 and an average water depth of ~3.5 m MSL. The northern basin (Fig. 1b) is 290 m long and 150 m wide, and configured to moor ~100 vessels. The southern basin, which has fewer berthing facilities, is reserved for future developments. The marina experiences excessive water level oscillations during local storm events.

The site is located in a region of complex offshore bathymetry consisting of a system of offshore limestone reefs (Fig. 2) where considerable wave attenuation occurs (Masselink and Pattiaratchi, 2001). The reef system runs parallel to the coastline at distances of 3.2 and 4.7 km from the shoreline, respectively (Fig. 2). The crest level of the reef systems varies between 4 m and 7 m below MSL. At Yanchep, located 7 km to the south of Two Rocks Marina, the wave attenuation across the reef systems were ~80% for offshore swell waves of 5 m wave height (Gallop et al., 2012). Using a high-resolution numerical model (with ~10 m resolution to resolve the reef systems) study at Yanchep, Bosserelle (in preparation) found that the waves dissipate on the reef ridges. For a storm with an offshore wave height (H_s) of 9 m, the offshore primary reef reduces the wave height from 7 to 5 m, the

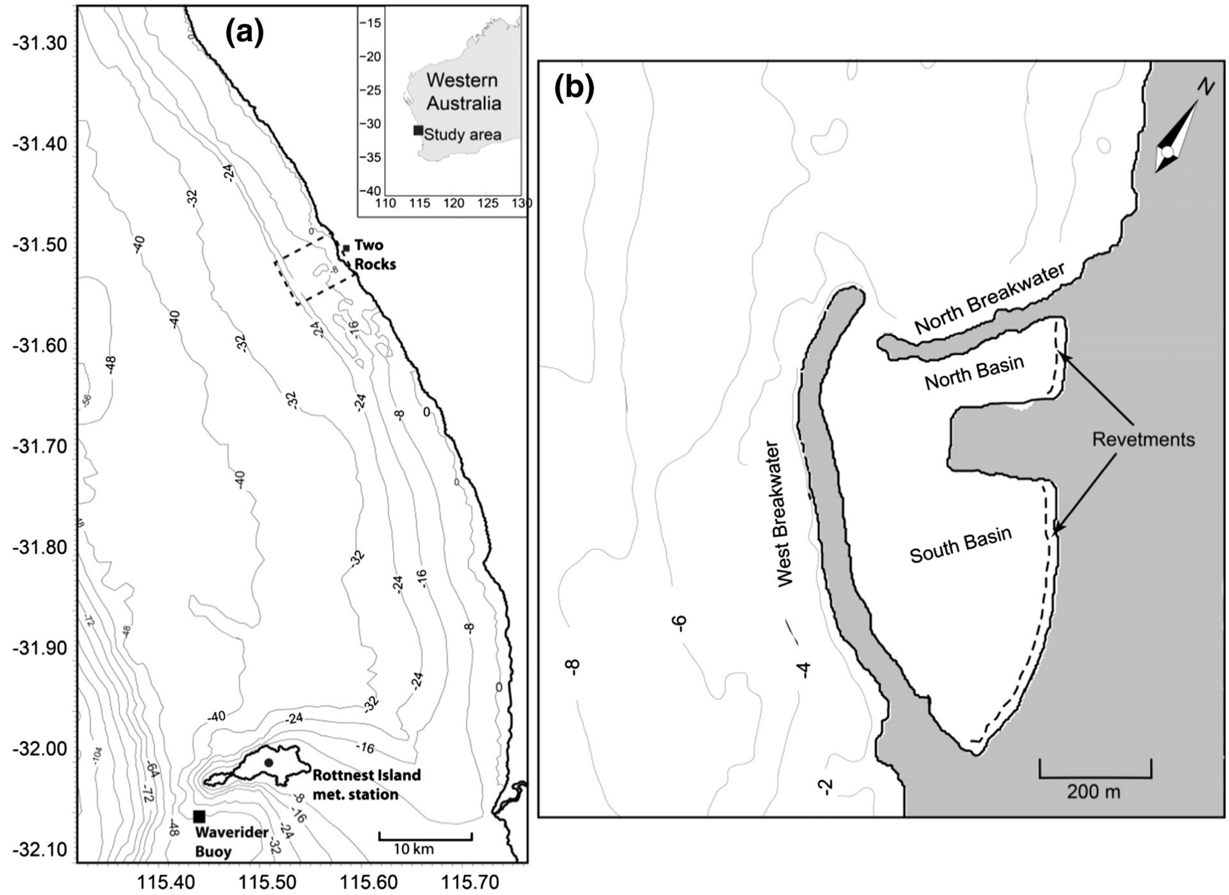

Fig. 1. (a) Location of study area. The extent of the map shows the spectral wave (SW) model domain and the small dash line square shows the Boussinesq wave (BW) model domain. The locations of the meteorological station (marked by a dot) at Rottnest Island and the offshore wave rider buoy (marked by a square) are shown; (b) Two Rocks Marina, showing main marina elements.