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Long wave effects on a vessel at berth

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ABSTRACT

Disturbances to load and unload operations caused by excessive vessel movements are a recurrent problem at many ports, among which the Exterior Port of Ferrol (NW Spain). The objective of this work is to investigate whether long waves (with periods above those of swell) may play a role in these movements, and if so, to characterize their effects on the different vessel movements. For this purpose the movements of a bulk carrier in the six degrees of freedom were recorded alongside the sea level oscillations inside and outside the port basin. Large rectilinear motions were measured, with values close to the safety limits for cargo handling operations. We analyze these movements in both the time and frequency domains and their correlation with the swell and long wave energy within two frequency bands: low frequency (LF) and very low frequency (VLF). We find that the vessel movements in the vertical plane (heave, pitch and roll) are mainly determined by the swell energy inside the port basin. On the contrary, the movements in the horizontal plane (sway, surge and yaw) are strongly correlated with the total wave energy in the system and, more importantly, with the ratio of LF band to total energy. These results highlight the relevance of long wave energy levels to cargo handling operations and, more generally, port management.

1. Introduction

Cargo handling is a critical step in improving the cost-time efficiency of ports. A vessel at berth is in continuous movement and its movements can slow cargo handling operations and, occasionally, disrupt them. Very large vessel movements can cause the breaking of mooring lines and, ultimately, damage to the vessel and the port facilities. As regards the influence of waves on the vessel movements, the acceptable conditions at berth that are listed in a number of publications, including national and international standards [1–3], refer only to wind waves and swell (with periods in the range 4–25 s) and do not account for the influence of long waves (with periods above ~25 s), which are known to play a role in the movements of a vessel at berth [4–6] and have been reported as a source of disturbances to port operations [5,7–9]. Long waves can be forced by: barometric pressure disturbances [10–18], wind convection cells [19,20], earthquakes [21–26], submerged landslides [27,28] or nonlinear wave interactions [8,29–33]. These waves can match the natural modes of oscillation of semi-enclosed coastal bodies of water, leading to resonant processes known as seiches. Under resonant events, the vertical displacements of the mass of water increase and induce large horizontal displacements that disturb harbor operations [31,32,34].

The natural periods of moored vessels and port basins are of the order of minutes and cannot be excited directly by very long waves, such as meteorological waves or tsunamis; they can be excited, however, by infragravity waves, whose periods are of the same order of magnitude. Driven by wind waves [35], the importance of infragravity waves to port operations is known [5,36].

In the case of the Exterior Port of Ferrol (NW Spain), disturbances to port operations owing to large vessel movements were reported by López et al. [37], who investigated the resonant behavior of the port basin and characterized its long waves. Based on the values of Pearson's correlation coefficient between the long wave energy inside the basin and SW band energy outside the basin, long waves were classified into three frequency bands: a low frequency (LF) band (2.5–40 mHz), highly correlated; a very low frequency (VLF) band (0.7–2.5 mHz), which exhibited decreasing correlation with decreasing frequency; and an ultra low frequency (ULF) band (0.122–0.7 mHz), poorly correlated with the swell energy. Subsequently, an artificial intelligence (AI) model for determining long wave energy in the basin was developed and successfully validated [38].

In this context the objective of the present work is to elucidate the influence of long waves on the movements of a moored vessel through a case study: a coal bulk carrier at berth in Ferrol. The results highlight the need for considering long waves, in addition to swell, when establishing the operational limits of a port terminal.

This article is structured as follows. In Section 2, the study site, field measurements and data analysis techniques are described. In Section 3, the movements of a moored vessel are examined and their correlation with long wave and swell parameters is investigated. Finally, conclusions are drawn in Section 4.

2. Material and methods

2.1. Study area: the Exterior Port of Ferrol

The Port of Ferrol is located in Ria de Ferrol, an estuary in Galicia, NW Spain (Fig. 1). The Galician rias are classified into Higher and Lower Rias, with markedly different geomorphological characteristics: the Higher Rias (*Rias Altas*) are smaller, less deep, and less homogeneous in their orientation than the Lower Rias (*Rias Baixas*), although their tectonic predetermination is similar [39]. Ria de Ferrol belongs to the Higher Rias group. Due to the configuration of the coastline (Fig. 1), waves are always from the IV quarter at the entrance to the ria. More specifically, the prevailing wave direction is WNW, as may be seen in the wave rose (Fig. 2) obtained from the records of a wave buoy in the area (Fig. 1). Until recently, the port was established only in the inner basin, with a maximum depth value of 14 m. However, since the construction in 2005 of a 1070 m long rubble-mound breakwater across the mouth

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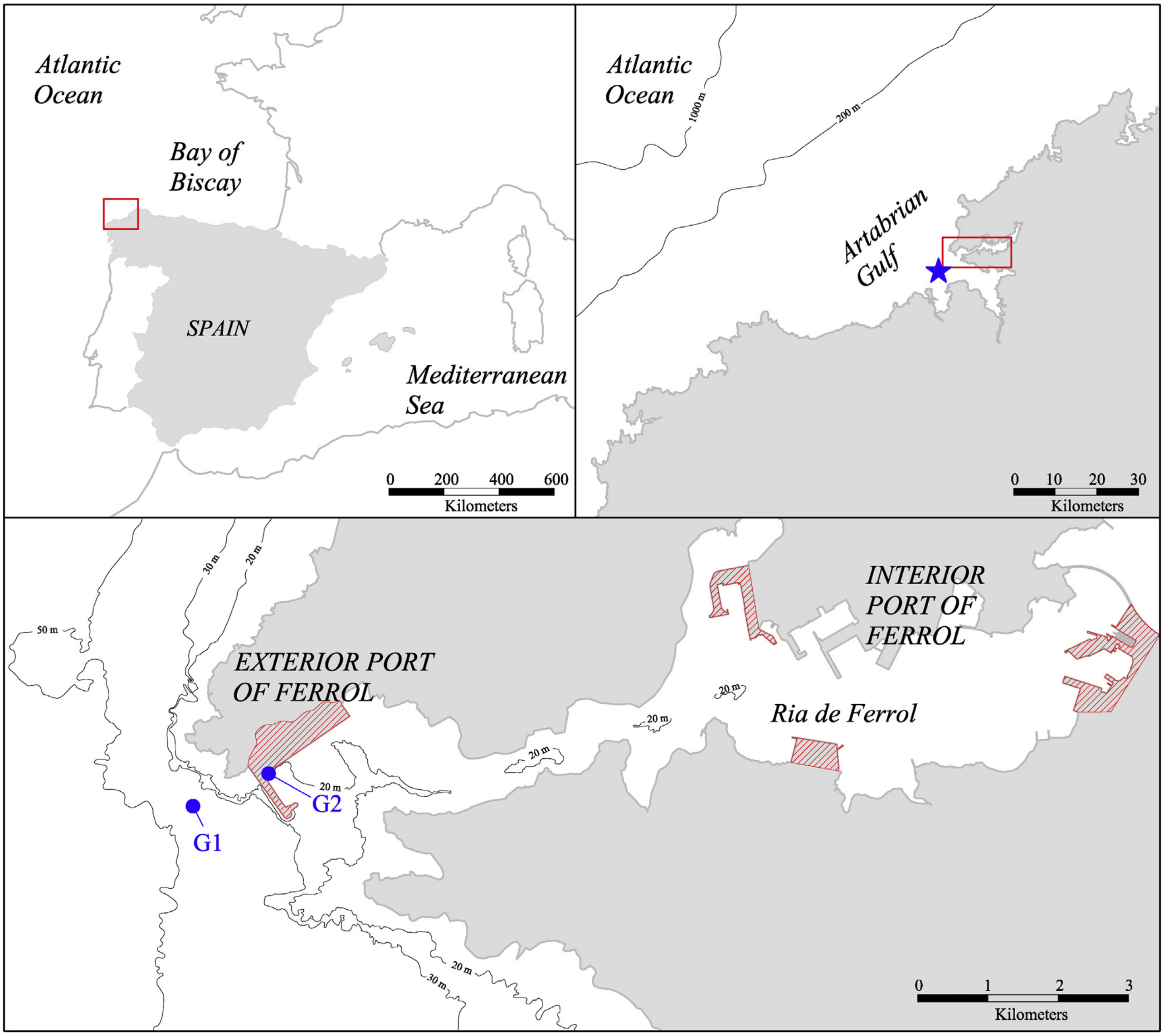

Fig. 1. Location, bathymetry and general layout of the Port of Ferrol. The main port areas are shaded and the positions of the wave buoy (blue star) and the two bottom pressure gauges deployed in winter 2011 are marked (G1 and G2). (For interpretation of the references to color in this legend, the reader is referred to the web version of the article.)

of the estuary, the port occupies also the outer basin. At present, this so-called Exterior Port has a 1515 m long berthing line dredged at −20 m and a 89.3 ha stockyard for bulk, fuel and container handling. In particular, the coal terminal – where more than 5 million tons were unloaded in 2012 – is equipped with quay cranes for the unloading of Capesize vessels.

2.2. Vessel motion and sea-level measurements

The movements of a Capesize coal bulk carrier docked at the coal terminal of the Exterior Port of Ferrol were recorded between 19th and 21st February 2011. The vessel, a Vogebulker, had the following characteristics: length overall, 289 m; beam, 45 m; maximum draft, 18 m; 169,168 deadweight tonnage (DWT); and 86,192 gross registered tonnage (GRT). A total of 5 robotic total stations with laser distance meter were deployed surrounding the vessel to measure its displacements at a 2 s sampling rate. The layout of the stations and the vessel position within the port during the measurements are shown in Fig. 3.

The vessel has six degrees of freedom (DOFs). The translations in the vertical, transverse, and longitudinal axes are referred to as heave, sway and surge, respectively, while the corresponding rotations are referred to as yaw, pitch and roll. On the basis of simultaneous records at different stations, the time series of rectilinear motions: $\partial^{heave}(t)$, $\partial^{sway}(t)$ and $\zeta^{surge}(t)$, and angular motions: $\theta^{yaw}(t)$, $\theta^{pitch}(t)$ and $\theta^{roll}(t)$, were obtained. A sample of the time series of the different motions is shown in Fig. 4.

Sea-level oscillations in the port area were recorded between February and April 2011, but only the records concurrent with vessel movement data were considered in this work. Two bottom-mounted pressure gauges were deployed at stations: G1, outside the basin, and G2, inside the basin (Fig. 1). One sample of each time series with the tidal components filtered out, $\eta^{G1}(t)$ and $\eta^{G2}(t)$, is shown in Fig. 5.

2.3. Data analysis

A time-domain analysis was performed on the different vessel movements and a frequency-domain analysis was performed on both the vessel and sea-level records. Prior to this, the time series of rectilinear and angular vessel movements, $\zeta(t)$ and $\theta(t)$, and of sea-level oscillations inside and outside the port, $\eta^{G1}(t)$ and $\eta^{G2}(t)$, were split into segments (or sub-records) with a duration of 2048 s to analyze the SW and LF bands, and with a duration of 10,240 s to analyze the VLF band. The complete procedure and the parameters obtained for each sub-record are described in the following.

2.3.1. Time-domain analysis

In the time-domain analysis each sub-record of a vessel movement was split into N individual motions characterized by their amplitude: Z_i (translations) or Θ_i (rotations), and period: T_i, where the subscript $i = 1, \ldots, N$ indicates that the motions are ranked from the highest to the lowest amplitude. Following Elzinga et al. [1], a peak-to-peak criterion was applied to identify each individual motion, except in the case of $\zeta^{sway}(t)$, for which the zero-peak criterion was used.