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Response of a harbor with two connected basins to incoming long waves

Marta Marcos [a,b,*], Sebastià Monserrat [a,b], Raúl Medina [c], Pedro Lomónaco [c]

[a] Grup d'Oceanografia Interdisciplinar, IMEDEA (UIB-CSIC), Mallorca, Spain
[b] Departament de Física, Universitat de les Illes Balears. Crta. de Valldemossa, km 7.5, 07122 Palma de Mallorca, Balears, Spain
[c] Grupo de Ingeniería Oceanográfica y de Costas, Universidad de Cantabria. Av. Los Castros, s/n, 39005 Santander, Spain

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Abstract

The general features of the resonant response for a given basin, including the determination of the normal modes and relative amplification of incoming long waves can be easily determined by using a numerical model. However, when the relative role of the different geometric parameters want to be studied, the use of analytical solutions becomes extremely useful. An analytical model is developed to determine the coupled oscillations between two rectangular basins connected through a gap, when only one of them is opened to the ocean. This geometry resembles the topographic features of Ciutadella inlet and its adjacent sub-basin (Cala Busquets) in Menorca, Balearic Islands. The analytical solutions show a good agreement with numerical simulations and capture well the changes induced by some hypothetical modifications of Ciutadella–Cala Busquets system. The agreement shown justifies the use of the analytical model as a basis for the discussion on the influence of the geometrical parameters in the normal mode characteristics of the coupled system.

Keywords: Long-waves; Harbor resonance; Coupled oscillations

1. Introduction

Ciutadella inlet is an elongated and shallow harbor located on the west coast of Menorca, on the Balearic Islands (Western Mediterranean). It is of particular interest due to the large sea level oscillations periodically observed, which can reach up to 3 m trough-to-crest amplitude. The phenomenon, locally known as rissaga, has been widely studied. It consists on the excitation of the fundamental mode of the inlet which is close to 10 min and its origin has been established and attributed to some atmospheric pressure disturbances travelling over the continental shelf of the islands and generating long waves that force the harbor resonance [1–4]. The interest lead to an intensive field study carried out during the summer of 1997 (LAST97). A set of high quality bottom pressure and atmospheric pressure data were recorded inside Ciutadella and in the surrounding shelf. The examination of these data has already provided useful information on the resonant characteristics of the inlet [5–8].

The harbor contains a small basin located approximately at the middle of its western side, known as Cala Busquets (see the bathymetry in Fig. 1). An engineering project developed in the region and addressed to enlarge the size of Cala Busquets has motivated the examination of the harbor response under different new geometries. A change in the shape of the two-harbor system involves the development of coupled oscillations between the two basins, with characteristics that will depend on the size of the new basin. Therefore, the new responses need to be estimated for each possible configuration and a numerical model becomes necessary.

A two-dimensional finite-difference numerical model, developed by the Ocean and Coastal Research Group at the University of Cantabria (GIOC [9]), is used to simulate the responses of the real bathymetry of Ciutadella harbor under different modifications of Cala Busquets basin. The model is based on the non-linear shallow-water wave equations and integrates the depth-averaged equations of continuity and momentum, which are written on a staggered grid (Arakawa C). It does not include the effects of the Earth's rotation (which is negligible due to the relative small dimensions of the study area). The model's parameters are calibrated for the region using data from the LAST97 experiment. The bathymetry shown in Fig. 1, is discretized with a grid size of $\Delta x = \Delta y =$ 10 m. Sea level time series recorded with an instrument on the shelf during a calm period of the LAST97 deployment is used

* Corresponding author. Address: Departament de Física, Universitat de les Illes Balears. Crta. de Valldemossa, km 7.5, 07122 Palma de Mallorca, Balears, Spain. Tel.: +34 97 117 2806; fax: +34 97 117 3426.
E-mail address: marta.marcos@uib.es

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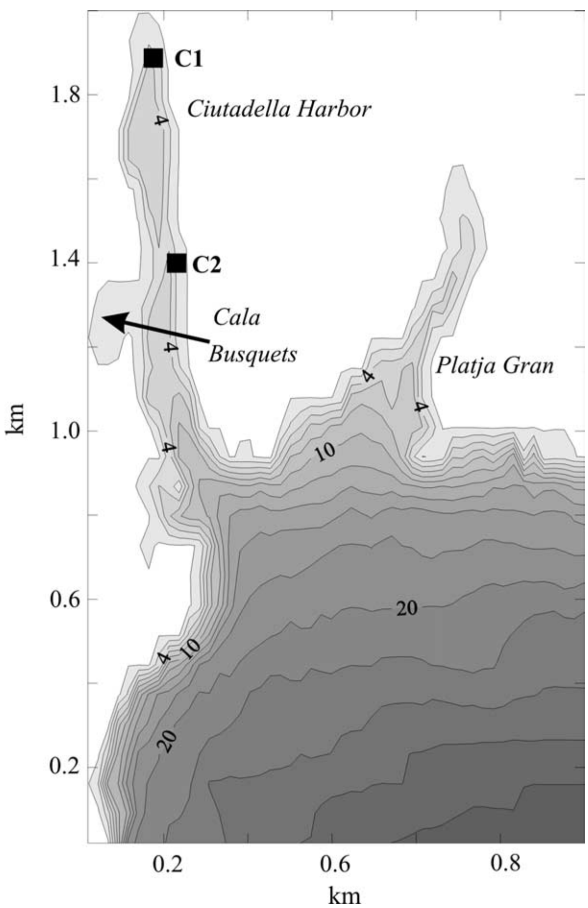

Fig. 1. Current bathymetry of Ciutadella harbor. Depths are labelled in meters.

to feed the model through the lower boundary. The output of the model inside Ciutadella is compared with simultaneous data recorded by two instruments. One point is located at the end of the harbor and the second one close to the middle (C1 and C2 in Fig. 1). A linear version of the numerical model has been previously used to simulate the resonant coupling between the neighbour inlets [6]. The numerical results showed a good agreement with data. Comparison with data has now been further improved by using a better resolution bathymetry for the region. This agreement supports the widely known fact that a numerical simulation is able to capture the major aspects of the resonant response of a given geometry. However, there are a large number of variables involved in the design of any new geometry, like the size of the new basin and the width of the gap connecting the small basin to the main harbor, among others.

With the aim of studying the particular influence of any of these parameters and the general features of the responses, a simplified analytical model has been developed for an idealized geometry of two rectangular connected basins, representative of the two-inlet system. Such a simplification allows the computation of an analytical solution, which will serve as an indication of the general behavior, and to set the limits of the relevant parameters.

In Section 2, the analytical model is presented. Then, the solutions obtained for two cases of interest are compared with results obtained with the numerical model. The agreement shown justifies the use of the analytical model as a basis for the discussion on the influence of the geometrical parameters.

2. Analytical model

The idealized geometry consists on two rectangular basins connected through a narrow gap where only one of them is opened to the ocean through the junction J (see Fig. 2). For simplicity, we consider that the water depth is constant all over the domain.

Assuming that the system is linear the wave field in the open ocean far away from the junction J of basin B can be expressed as the sum of the incident and reflected wave, which combine in the form of a stationary sinusoidal wave, plus the radiation from J. This radiation may be written as a Hankel function of second kind, which is an oscillating spherically symmetric function with a singularity at the origin and amplitude rapidly decreasing with distance away from the mouth (see for example [10])

$$\eta = \zeta_0 e^{i\omega t} \tag{1}$$

$$\zeta_0 = 2A\cos(kx) - \frac{i\omega}{g} Q_0 \left(\frac{i}{2} H_0^{(2)}(kr)\right) \quad x > 0 \tag{2}$$

where ω is the incident frequency, A is the amplitude, $H_0^{(2)}$ is the Hankel function of second kind and Q_0 represents the mass flux across the harbor mouth. On the other hand, following the paper by Mei [11], the solutions inside the two basins can be expressed as

$$\zeta_B = -\frac{i\omega}{g}(Q_1 G_1 + Q_2 G_2) \tag{3}$$

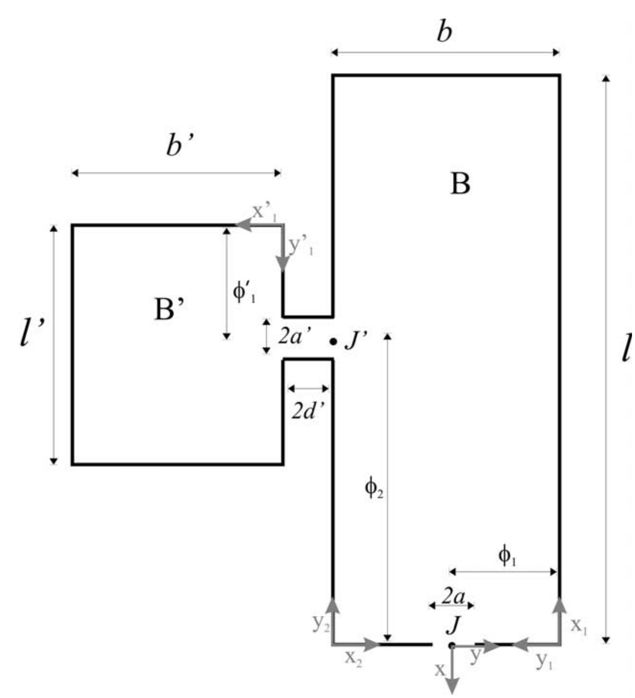

Fig. 2. Idealized geometry.