Wave Motion 80 (2018) 1–19

Contents lists available at ScienceDirect

Wave Motion

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

Propagation and scattering of waves by dense arrays of impenetrable cylinders in a waveguide

K.A. Belibassakis [a,*], G. Arnaud [b], V. Rey [b], J. Touboul [b]

[a] School of Naval Architecture and Marine Engineering, National Technical University of Athens, Zografos 15773, Athens, Greece
[b] Université de Toulon, Aix Marseille Université, CNRS, IRD, Mediterranean Institute of Oceanography (MIO), La Garde, France

HIGHLIGHTS

- Coupled modal-BEM for propagation and scattering by dense arrays of impenetrable cylinders in a waveguide.
- Comparison of modal-BEM with simplified model based on Foldy–Lax theory and experimental data.
- Efficient calculation of reflection and transmission properties, supporting design and optimization studies.
- Present models can be used for similar scattering problems in acoustic and electromagnetic waveguides.

ARTICLE INFO

Article history:
Received 28 September 2017
Received in revised form 16 March 2018
Accepted 30 March 2018
Available online 11 April 2018

Keywords:
Wave–structure interaction
Porous breakwater
Modal expansion
BEM

ABSTRACT

A coupled numerical scheme, based on modal expansions and boundary integral representations, is developed for treating propagation and scattering by dense arrays of impenetrable cylinders inside a waveguide. Numerical results are presented and discussed concerning reflection and transmission, as well as the wave details both inside and outside the array. The method is applied to water waves propagating over an array of vertical cylinders in constant depth extended all over the water column, operating as a porous breakwater unit in a periodic arrangement (segmented breakwater). Focusing on the reflection and transmission properties, a simplified model is also derived, based on Foldy–Lax theory. The latter provides an equivalent index of refraction of the medium representing the porous structure, modeled as an inclusion in the waveguide. Results obtained by the present fully coupled and approximate models are compared against experimental measurements, collected in wave tank, showing good agreement. The present analysis permits an efficient calculation of the properties of the examined structure, reducing the computational cost and supporting design and optimization studies.

1. Introduction

Porous structures are often studied in the context of shoreline protection, see, e.g., [1,2]. A particular kind is artificial coastal cellular breakwaters which contain openings of very narrow width, typically much less than one wavelength; see, e.g., [3–6] and the references cited there. The latter structures permit part of flow and energy to propagate to the lee side, and are exploitable for dissipation of incident wave energy and improvement of water quality in a basin. Furthermore, wave transformation and attenuation in mangrove forests and marine vegetation is also a subject of interest in coastal engineering, taking into account their role in supporting local economy and stabilizing and protecting the coastal zone. In many studies

* Corresponding author.
E-mail address: kbel@fluid.mech.ntua.gr (K.A. Belibassakis).

https://doi.org/10.1016/j.wavemoti.2018.03.007

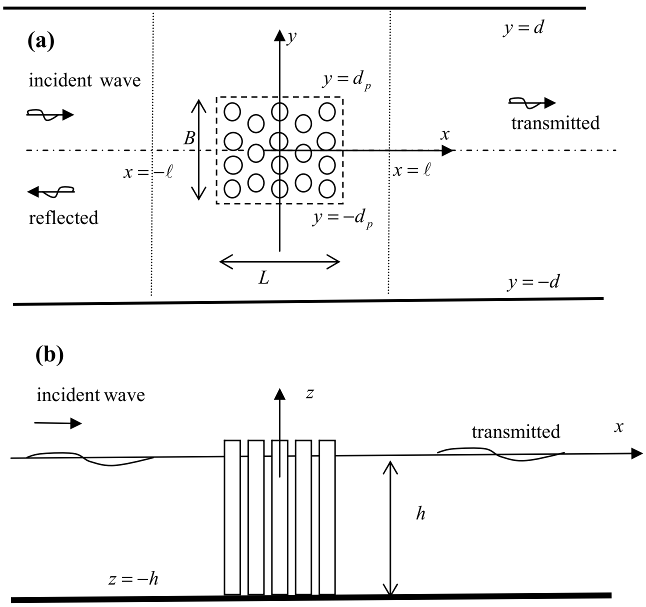

Fig. 1. Schematic presentation of the waveguide containing a porous scatterer constituted by many vertical cylinders in the middle. (a) Top view, (b) vertical section through the channel centerline.

mangrove trunks and roots are treated as vertical cylindrical elements located in the water column, [7]; see also [8]. Particular arrangements used in experiments and numerical models are regular arrays of vertical cylinders; see e.g., [9–12]. In the case when the scatterer diameter is very small compared to the characteristic wavelength, typically of the order of a few percent, the structure could be macroscopically considered as porous medium. For waves of small steepness the problem is treated in the framework of linear theory. Also, if the length of the porous structure is small, viscous dissipation can be approximately omitted.

For protection structures composed by dense arrays of vertical cylinders, laboratory physical models have been recently used to study and characterize the complex hydrodynamic processes involved during wave propagation within such porous media; see [3]. Furthermore, sloshing experiments in a rectangular tank, completely filled with vertical cylinders undergoing forced horizontal motion around the natural frequency of the first sloshing mode, have been used by Molin and Remy [13] to identify the dispersion equation of linear waves propagating through such dense arrays of vertical cylinders; see also [12]. However, when considering the same porous structures with gaps, as e.g. in periodic arrangements (as in the case of segmented porous breakwaters) or during tests in a rectangular wave tank where the structure occupies the middle region, as studied by Arnaud [14], additional phenomena enter into play, like scattering and interaction with the tank walls, which forms a waveguide, and the appearance of critical frequencies.

When the vertical cylinders in the examined finite-width protection structure extent from the top (free surface) to the bottom surface and the depth is constant, the problem can be treated by the Helmholtz equation on the horizontal plane, supplemented with additional conditions at the sides of the tank or for accounting for the effects of periodic boundaries in the case of segmented porous breakwater. The latter constitutes a scattering problem by many impenetrable bodies in a waveguide. Similar problems are frequently encountered in acoustics, elasticity and electromagnetism; see, e.g., [15–17] and the references cited there. Also, similar applications have been studied by Li and Mei [18] in the case of array of cylinders in a long channel, where multiple scattering can excite Bragg resonances if the frequency falls within one of the band gaps.

In this work a coupled numerical scheme, based on a modal expansions, in conjunction with boundary element technique, is developed for treating propagation and scattering by finite structures consisted of regular arrangements of impenetrable cylinders inside a waveguide. Numerical results are presented and discussed concerning the wave details both inside and outside the porous structure, illustrating its applicability operating as breakwater unit in a periodic arrangement. Subsequently, focusing on the reflection and transmission properties far from the structure, a simplified model is derived, based on Foldy–Lax theory; see, e.g., Martin [16]. The latter model provides an equivalent refraction index for the wave scattering by the porous structure located strictly inside the waveguide; see e.g., [19,20]. Results obtained by the present fully coupled and simplified methods are compared against experimental measurements collected in the wave tank of SeaTech of University of Toulon, France, showing good agreement. The present models support further design and optimization studies concerning the examined porous structures, and can be used for studying similar scattering problems in acoustic and electromagnetic waveguides.