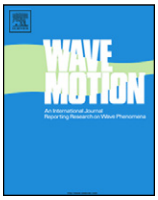
Wave Motion 60 (2016) 1–7

Contents lists available at ScienceDirect

Wave Motion

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



Broadband omnidirectional absorption for linear liquid surface wave

Qi Wei[a], Ying Cheng[a], Xiaojun Liu[a,b,*]

[a] *Key Laboratory of Modern Acoustics, Department of Physics, Collaborative Innovation Center of Advanced Microstructures, Nanjing University, Nanjing 210093, China*

[b] *State Key Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China*

HIGHLIGHTS

- Design of a broadband omnidirectional absorber for linear liquid surface wave.
- Study of absorption for non-dispersive linear liquid surface wave.
- Study of absorption for dispersive linear liquid surface wave.

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 31 August 2015
Accepted 1 September 2015
Available online 9 September 2015

Keywords:
Broadband omnidirectional absorber
Absorption of non-dispersive liquid surface wave
Absorption of dispersive liquid surface wave

ABSTRACT

We investigate the propagation of linear liquid surface wave (LLSW) over an omnidirectional absorber (OA), which has uneven bottom with appropriate gradient depth distribution. The OA consists of a guiding shell with gradient bottom topography and a central absorptive cavity. The non-dispersive shallow-water wave equation model and the dispersive mild-slope equation model are employed to investigate the absorption properties of the OA. The results show that almost omnidirectional incident LLSW can be spirally deflected from the interface to the center in the guiding shell and finally absorbed by the central cavity. The introducing of guiding shell enlarges the absorption cross section of the bare absorptive cavity from the inner diameter to the outer diameter of the OA, resulting in high absorption efficiency. Furthermore, the proposal can be constructed by simple modulation of the liquid bottom, which may significantly facilitate the engineering applications.

1. Introduction

Recently, there has been an increasing interest in the omnidirectional absorption for types of classical waves by mimicking the celestial black hole [1–10]. With the aid of artificial metamaterials, the omnidirectional absorber (OA) strongly interacts with the classic waves and absorbs the radiation for omnidirectional incidence. Previous studies have established the design principles such as the coordinate-transformation theory [1,8,11–16] and the Hamiltonian theory [3–6], which have been used in the designs of OA for the electromagnetic (EM) wave [1–7], the acoustic wave [8,9] and the elastic wave [10]. The OA suggests a variety of potential applications such as wave shielding, energy absorption, and energy collection. The linear liquid surface wave [17–22] (LLSW), as another important type of classical waves, also has various interesting physical properties such as superlensing [17], band gap [18,19], negative effective gravity [20], and focusing [22].

---

[*] Corresponding author at: Key Laboratory of Modern Acoustics, Department of Physics, Collaborative Innovation Center of Advanced Microstructures, Nanjing University, Nanjing 210093, China.
E-mail address: liuxiaojun@nju.edu.cn (X. Liu).

http://dx.doi.org/10.1016/j.wavemoti.2015.09.001

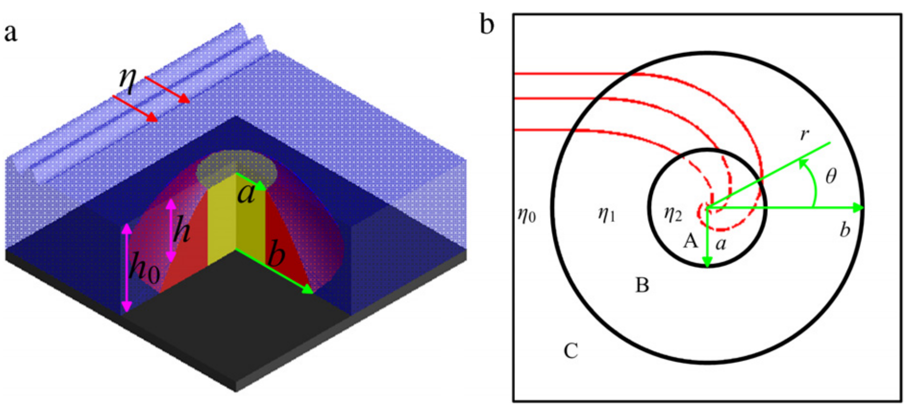


Fig. 1. (Color online) The scheme of the OA for the LLSW: (a) three-dimensional cut-view; (b) two-dimensional view in r–θ plane. A, B and C denote the absorptive cavity, the guiding shell and the background region, respectively. The solid curves in (b) represent the rays deduced from Eq. (4).

Besides, it is well known that rich energy is stored in the LLSW of oceans, which is considered as one of the clean renewable energy to defuse the incoming energy crisis. However, the OA is seldom reported for the LLSW, which represents vast areas of fascinating applications such as the harvesting of the ocean wave energy.

In this paper, we investigate the LLSW propagation over an OA, which consists of an absorptive cavity and a guiding shell with appropriate radial depth distribution. The absorption performance of the OA is demonstrated based on the non-dispersive shallow-water wave equation (SWWE) model and the dispersive mild-slope equation (MSE) model [18]. The non-dispersive model indicates that the velocity of the LLSW changes with the radius linearly. The OA can thus capture and deflect the LLSW impinging on it from all directions to the central absorptive cavity and finally absorb the incidence, which are demonstrated by the theoretical derivations from the classical ray-tracing and the scattering-theory. The guiding shell expands the absorption cross section (ACS) of the absorptive cavity and increases its efficiency significantly. The dispersive MSE model is of higher accuracy which is solved by using the finite-element method (FEM) in this study. Due to the nonlinear dispersion relation the velocity of the LLSW changes more slowly than that in the non-dispersive model, especially in the high frequency region. The waves with very high incident angles cannot be captured by the OA, leading to a weaker omnidirectional absorption than that in the non-dispersive model. However, the OA still exhibits well absorption capacity than the bare absorptive cavity over a broad bandwidth. It is noted that the proposal can be constructed by simply modulating the liquid bottom, which may significantly facilitate the engineering applications.

2. Absorption of non-dispersive LLSW

Fig. 1(a) illustrates the configuration of the OA in three-dimensional (3D) view. The corresponding two-dimensional (2D) vertical view is shown in Fig. 1(b) for convenience, where r and θ are polar coordinates of the cylindrical coordinate system. The OA consists of an inner absorptive cavity A ($r < a$) and an outer guiding shell B ($a < r < b$). The background region C ($r > b$) outside the OA is liquid with the constant depth of h_0. The inner absorptive cavity may be realized by periodic resonator arrays [20] or wave energy devices [23] to absorb the LLSW. In contrast to previous OA for other classes of waves fabricated by complex artificial metamaterials, the LLSW OA is simply filled with regular inviscid liquid with radial depth distribution. There is no absorption in background region and guiding shell. The distribution of the depth h in B is expressed as

$$h(r) = h_0(r/b)^{\alpha}, \tag{1}$$

where α is a constant factor ($\alpha \geq 2$). This study focuses on the improvement of the absorption induced by the guiding shell B, so the absorptive cavity A is assumed to be an ideal homogeneous absorber with complex velocity $c_0(a/b)^{\alpha/2}\sqrt{1-\gamma i}$, where c_0 is the velocity of LLSW in the background region, γ describes the absorptive ability of the absorptive cavity and i indicates the imaginary component. It can be found in Eq. (1) that the depth h matches at the outer boundary, leading to a minimum interface scattering.

We employ the SWWE model and the MSE model to investigate the LLSW propagation over the OA. The SWWE model has a simple linear dispersion relation and can be solved analytically, which gives accurate results when $kh \ll 1$. Here k is the wave number in SWWE model. In addition, we take the higher-order terms and the capillary effect under consideration in MSE model to give more reliable results in broad band. The MSE model has a nonlinear dispersion relation and a complex equation, which is numerically solved by FEM in this study.

We first model the OA by the non-dispersive SWWE, which takes the form (when $kh \ll 1$) [21]

$$\nabla \cdot (h\nabla\eta) + g^{-1}\omega^2\eta = 0, \tag{2}$$