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Analytical determination of the reflection coefficient by the evanescent modes model during the wave–current–horizontal plate interaction

Détermination analytique du coefficient de réflexion par le modèle des modes évanescents lors l'interaction houle–courant–plaque

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ABSTRACT

Our work presents an analytical study of the determination of the reflection coefficient during the interaction between the regular wave current and a horizontal plate. This study was done using the linearized potential flow theory with the evanescent modes model, while searching for complex solutions to the dispersion equation that are neither real pure nor imaginary pure. To validate the established model, it has been confronted with the experimental results of V. Rey and J. Touboul, in a first phase, and then compared to those of the numerical study by H.-X. Lin et al. Then, this model was used to study the effect of current on the reflection coefficient.

RÉSUMÉ

On présente dans ce travail une étude analytique de la détermination du coefficient de réflexion lors de l'interaction houle–courant–plaque. Cette étude a été faite dans le cadre de la théorie potentielle linéarisée moyennant le modèle des modes évanescents, en cherchant des solutions complexes de l'équation de dispersion qui ne soient, ni réelles pures, ni imaginaires pures. Pour valider le modèle établi, on l'a d'abord confronté aux résultats expérimentaux de V. Rey et J. Touboul, puis à ceux, issus de la modélisation, de H.-X. Lin et al. Ensuite, on a utilisé ce modèle pour étudier l'effet du courant sur le coefficient de réflexion.

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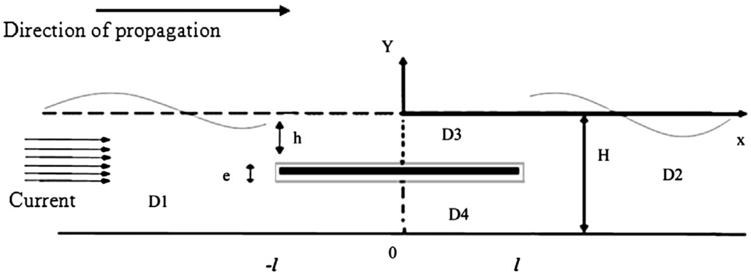

Fig. 1. Geometry of the problem.

1. Introduction

The protection of beaches, and of other coastal structures such as harbors, lakes etc. requires the maximization of wave reflection, hence the importance of wave reflectors. In certain circumstances, the wave is accompanied by currents. Wave reflectors, in these cases, have to consider the interaction wave–current.

The wave–current interaction has been the subject of several studies. We can name that by P. Osuna and J. Monbaliu in 2004 on the North Sea [1], the one by Y.-Y. Chen et al. in 2012 on the particle trajectory in Lagrangian description [2], and a theoretical and a numerical study by D. Zhifei and J.-T. Kirby on the interaction between a gravity wave of weak amplitude and a sheared current [3].

A submerged horizontal plate is a reflector of regular wave that enables the circulation of water, above and beneath; hence its environmental impact is minimal. In the last decades, the interaction between regular wave and plate has progressively attracted the interest of the researchers. In 1984, Patarapanich [4] showed, with the plane wave model, that the reflection coefficient of a gravity wave by a submerged horizontal plate depends on the ratio of the water depth to the wavelength of the incident wave, the ratio of the depth of the plate immersion to the depth of water, and on the ratio of the plate length to the wavelength of the wave that propagates above the plate. In 1986, Guevel [5] brought out that the body of water below the plate behaved as an oscillating wall. In 1990, H. Kojima et al. [6] presented an experimental study on energy transfer from the fundamental toward the transmitted second harmonic by the method of Goda using multiple probes. In 1993, Molin and Betous [7], to minimize the efforts on the structure, used a perforated tile and made an experimental and analytical study on the reflection coefficient, using the evanescent modes model. In 2001, Brossard et al. [8] showed experimentally, using a mobile probes technique, that during the interaction between a regular wave and plate, there is free upper harmonic production. In 2012, K. Wang et al. [9] presented an analysis of the velocity field using a numerical method (BEM). In 2014, H. Behera and T. Sahoo [10] studied the interaction of a gravity wave and of a flexible porous horizontal plate.

In 2003, V. Rey et al. [11] conducted an experimental study on wave–current–plate interaction for regular and irregular waves. In 2014, H.-X. Lin et al. [12] made a numerical study on the wave reflection and production of harmonics during the current–wave–plate interaction.

In this work, we present an analytical study of the determination of the reflection coefficient during the regular wave–current–plate interaction. This study was carried out as part of the linearized potential flow theory using the evanescent modes model. To take account of evanescent modes in the presence of current, the dispersion equation had to be solved by looking for complex solutions that are, neither pure real, nor pure imaginary.

To validate the established model, it has been confronted with the experimental results of V. Rey and J. Touboul [13], in a first phase, and then compared to those of the numerical study by H.-X. Lin et al. Then, this model was used to study the effect of current on the reflection coefficient.

2. Formulation of the problem

We are interested in the calculation of the reflection coefficient of a regular wave in the presence of uniform current, when interacting with a fixed horizontal plate totally immersed in a channel. The studied regular wave is potential and of low wave steepness, whereas the surface tension is negligible. A monochromatic wave is emitted upstream, and downstream, the wave does not undergo any reflection. The area of study is divided into four sub-domains, as shown in Fig. 1.

Seeking for the potential in the form of a superposition of potential associated with the current $\phi_c(x,y,t) = Ux$ and that associated with a monochromatic regular wave $\phi_h(x,y,t) = \varphi(x,y)\mathrm{e}^{\mathrm{i}\omega t}$, the total potential is written:

- in sub domains D_p, $1 \le p \le 3$:

$$\begin{aligned}\phi_p(x,y,t) = Ux &+ \left[A_p \mathrm{e}^{\mathrm{i}k_p^- x}\cosh\left(k_p^-(y+H_p)\right) + B_p \mathrm{e}^{\mathrm{i}k_p^+ x}\cosh\left(k_p^+(y+H_p)\right)\right]\mathrm{e}^{\mathrm{i}\omega t} \\ &+ \left[\sum_{n=1}^{N}\left(A_{pn}\mathrm{e}^{k_{pn}^- x}\cos\left(k_{pn}^-(y+H_p)\right) + B_{pn}\mathrm{e}^{k_{pn}^+ x}\cos\left(k_{pn}^+(y+H_p)\right)\right)\right]\mathrm{e}^{\mathrm{i}\omega t}\end{aligned} \tag{1}$$

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