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Hydrodynamic analysis of a floating body with an open chamber using a 2D fully nonlinear numerical wave tank

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ABSTRACT: *Hydrodynamic analysis of a surface-piercing body with an open chamber was performed with incident regular waves and forced-heaving body motions. The floating body was simulated in the time domain using a 2D fully nonlinear numerical wave tank (NWT) technique based on potential theory. This paper focuses on the hydrodynamic behavior of the free surfaces inside the chamber for various input conditions, including a two-input system: both incident wave profiles and forced body velocities were implemented in order to calculate the maximum surface elevations for the respective inputs and evaluate their interactions. An appropriate equivalent linear or quadratic viscous damping coefficient, which was selected from experimental data, was employed on the free surface boundary inside the chamber to account for the viscous energy loss on the system. Then a comprehensive parametric study was performed to investigate the nonlinear behavior of the wave-body interaction.*

KEY WORDS: Numerical wave tank; Open chamber; Viscous damping; Wave-body interaction; Chamber surface elevation, Oscillating water column.

INTRODUCTION

There has been a rapid development in energy extraction devices from renewable energy sources in the past few decades. Advancements in renewable energy technology have reduced the cost and increased the reliability and confidence of using such devices. Water waves have emerged as a promising source of renewable energy. In fact, it is easy to visualize the energy of these waves as they forcefully splash against natural and artificial sea walls.

Accordingly, numerous wave energy converters have been proposed, developed, and tested. One of the most promising concepts is the oscillating water column (OWC) device that utilizes specially designed air turbines to achieve pneumatic power take off; examples include the Wells turbine, impulse turbine, and Dennis-Auld turbine. Since Masuda and Miyazaki (1978) first proposed and tested the OWC concept, several commercial-level OWC plants have been constructed and successfully operated. One such prototypical OWC plant is the Land Installed Marine Powered Energy Transformer (LIMPET) located on the Isle of Islay in Scotland (Heath, Whittaker and Boake, 2000).

In this paper, the nonlinear wave-body interaction of a floating body with an open chamber, which is a feasible floating OWC structure, is studied using a 2D fully nonlinear numerical wave tank (NWT) technique. The utilized NWT is based on potential fluid theory and the boundary element method (BEM) with constant panel discretization. This study also uses a mixed Eulerian-Lagragian (MEL) free surface treatment and Runge-Kutta fourth-order (RK4) time-integration techniques, along with a smoothing scheme on the free surface. A specially optimized $\phi_n - \eta$ artificial damping scheme is employed on the free surface to minimize the wave reflection from the end wall and re-reflection from the input boundary.

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This work presents a time-domain analysis of the hydrodynamic behavior of the surface elevation in the gap of a floating body with two input systems. Several researchers have considered a similar system with an open-chamber-type surface-piercing body, including Lin, Newman and Yue (1984), Faltinsen, Rognebakke and Timokham (2007), Koo (2009), and Yong and Mian (2010). However, their works were conducted using only one input e.g., modeling a diffraction problem with incident waves only, or employing forced-body motions to generate radiation waves. In this study, the numerical analysis of such a structure is extended to incorporate two inputs: the incident waves and the forced-heave velocity of the body. This analysis allows us to investigate the effect of the respective inputs and to find the optimal input conditions for the maximum mid-chamber free surface elevation, which can then be used to optimize the design of a floating OWC wave energy converter. Nonlinear time-domain results are compared with the linear results to inspect the nonlinearities of the solutions and the effectiveness of a linear calculation.

MATHEMATICAL FORMULATIONS

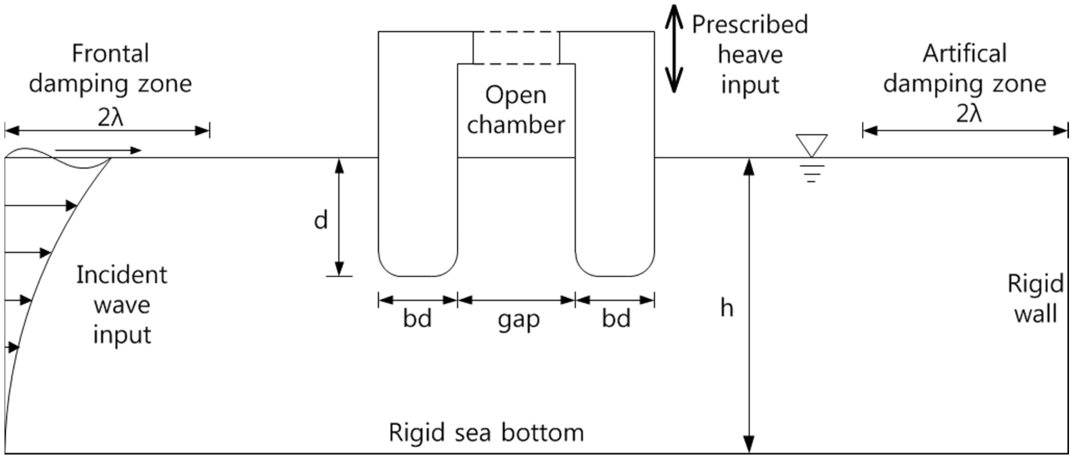

Fig. 1 Overview of the computational domain of a floating body with an open chamber, where h=1.03 *m*, d=0.18 *m*, bd=0.36 *m*, gap=0.18 *m*, and corner radius=0.01 *m*.

In order to analyze the hydrodynamic behavior of a free surface, the mixed boundary value problem can be solved in the computational fluid domain. Fig. 1 shows the overview of a floating body with an open chamber in the computational domain. Assuming an inviscid, irrotational, and incompressible fluid, the Laplace equation can be satisfied as a governing equation in the potential-fluid domain:

$$\nabla^2\phi = 0 \tag{1}$$

Then, the fully nonlinear dynamic and kinematic free surface boundary conditions can be given respectively as

$$\frac{\partial \phi}{\partial t} = -g\eta - \frac{1}{2}|\nabla\phi|^2 - \frac{P_a}{\rho}, \quad \frac{\partial \eta}{\partial t} = -\nabla\phi\cdot\nabla\eta + \frac{\partial \phi}{\partial z} \tag{2}$$

where η is free surface elevation and P_a is the air pressure, which is set to zero on the free surface.

As the boundary condition for the rigid surfaces, including the fixed body surface, the sea bottom, and the vertical end-wall, the normal flux was set to zero:

$$\frac{\partial \varphi}{\partial n} = 0 \tag{3}$$