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Application of Numerical Wave Tank to OWC Air Chamber for Wave Energy Conversion

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ABSTRACT

In this paper, a numerical wave tank (NWT) based on FLUENT using two-phase VOF model for incompressible viscous flow is presented for the investigation of wave energy converting performance of the Oscillating Water Column (OWC) chamber. The NWT consists of the continuity equation, the Reynolds-averaged Navier-Stokes' equation and the two-phase fractional VOF function. The standard $k-\varepsilon$ turbulence model, finite volume method, NITA-PISO algorithm and dynamic mesh technique are employed to generate the 2D and 3D regular incident waves. The oscillating amplitude of water column in the chamber and bi-directional air flow in the duct installed on the top of the chamber are calculated, and compared with experimental data to verify the validation of the present NWT. The nozzle effects of the chamber-duct system on the relative amplitudes of the inner free water surface and air flow rate in the duct are investigated.

KEY WORDS: Wave energy conversion; oscillating water column; air chamber; numerical wave tank; two-phase VOF model; nozzle effects.

INTRODUCTION

Wave energy is one of the most promising forms of ocean renewable sources because of its high energy density. The oscillating water column (OWC) device has been widely employed in the wave energy conversion. It comprises a partially submerged air chamber with an opening in the front skirt, and the water column exposes to the incident wave field through the underwater opening. Waves can force the water column in the chamber to oscillate in the same manner as a simple piston, which will produce the bi-directional air flow through the air turbine in the duct. Capable of operating in the reversing flow conditions, the Wells turbine or the impulse turbine linked to the electric generator in the air duct, is generally used to convert the air static and dynamic pressure into the mechanical energy. The converting efficiency is related to the incident wave conditions and shape parameters of the chamber-duct system.

A number of efforts have been made to study the performance of OWC air chamber. Evans (1982) first developed the analyzing theory of OWC wave energy absorption. Physical model with different bottom slopes was constructed and tested in a wave tank under regular wave conditions by Wang et al. (2002). Liang et al. (2003) studied the air chamber performance under incident wave heights and nozzle ratios experimentally. Hong et al. (2007) performed an experiment concentrating on the effects of several shape parameters of OWC chamber in wave energy absorbing capability. You (1993) presented a boundary element method to study the influence of coastal topography and the harbor shape on the oscillations of the OWC plant. Lee et al. (1996) first utilized low order 3D boundary element methods to predict the response of an isolated OWC accounting for the appropriate interior free surface boundary condition. The effects of the bottom slope on the hydrodynamic performance of on shore wave-power devices were investigated by using the boundary element method based on 3D shallow water Green's function by Wang et al. (2002). Hong et al. (2004) calculated the motions and time-mean horizontal drift forces of floating backward-bent duct buoy wave energy absorbers in regular waves taking account of the oscillating surface pressure due to the pressure drop in the air chamber above the oscillating water column within the scope of the linear wave theory. Josset and Clement (2007) applied the low order boundary element method for efficient hydrodynamic modeling of generic bottom mounted OWC power plants to estimate the annual performance of the wave energy plant on Pico Island.

It can be seen that most of former numerical simulations just focus on the oscillating amplitude of the inner water column, which is employed to show the wave energy absorbing performance of the air chamber totally open without covers. It has been pointed out that the wave motion in the opening chamber is quite different from that for the chamber with the cover by Hong et al. (2007). However, the oscillating amplitude of the water column in the chamber with an air duct should be investigated to show the performance of the chamber-duct system. Furthermore, the air flow velocities in the duct, which demonstrates the wave energy converting capability more accurately, should be studied. It is also necessary to establish a numerical method to simulate the air flow motion in the duct and water-air interaction at the free surface directly.

In the present paper, a numerical wave tank using two-phase VOF