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OWC형 파력발전 공기실의 파랑집중장치의 효과에 대한 수치적인 연구

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Effects of Wave Focusing Device on Performance of OWC Chamber

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요 약

OWC 파력발전장치는 에너지 변환장치로 널리 사용되고 있고 공기실의 작동성능을 향상시키기 위하여 파랑집중장치를 고안 하였다. 본 논문에서 사용된 수치조파수조는 two-phase VOF모델을 기반으로 하여 구현되었고 재생된 규칙 입사파는 공기실까지 전달되어 내부의 왕복 유동장을 형성하게 하였다. 수치조파수조는 연속방정식, Reynolds-averaged Navier-Stokes방정식, two-phase VOF 법으로 구성 되었고 standard k- 난류모델, 유한체적법, NITA-PISO 알고리즘 그리고 dynamic mesh기능을 채택하였다. OWC 공기실 파랑집중장치의 성능에 대하여 수치적으로 고찰하였다.

Abstract – Oscillating Water Column (OWC) device has been widely employed in the wave energy conversion. Wave Focusing Device (WFD) is proposed to be helpful for improving the operating performance of OWC chamber. In the present paper, a Numerical Wave Tank (NWT) using two-phase VOF model is utilized to simulate the generation and propagation of incident regular waves, water column oscillation inside the chamber. The NWT consists of the continuity equation, Reynolds-averaged Navier-Stokes equations and two-phase VOF functions. The standard k- turbulence model, the finite volume method, NITA-PISO algorithm and dynamic mesh technique are employed. Effects of WFD on the operating performance of OWC chamber are investigated numerically.

Keywords: Wave energy conversion(파력발전변환장치), Oscillating water column(진동수주), Wave Focusing Device(파랑집중장치), Numerical wave tank(수치조파수조)

1. INTRODUCTION

Wave energy is one of the most promising forms of ocean renewable sources because of its high energy density. Oscillating Water Column (OWC) devices have 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. The air turbine linked to the electric generator is installed in the air duct.

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. Jos-

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set 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.

The development and utilization of OWC wave energy convertor are always restricted by low converting efficiency. It is necessary to find some valuable ways to improve the converting and absorbing efficiency. Wave focusing device (WFD) is one of the useful techniques to extend the wave crest line the front skirt faces. More wave energy is proposed to be absorbed by OWC air chamber.

In the present paper, a numerical wave tank using two-phase VOF model based on the commercial CFD code Fluent V 6.2.16 is utilized to simulate the generation and propagation of incident regular waves, air pressure and air flow rate variation in the chamber-duct system, which have been validated by the corresponding experimental data. Effects of wave focusing device on the operating performance of OWC chamber are investigated numerically.

2. NUMERICAL WAVE TANK

The 3D regular incident waves are generated by the piston motion of the wave making plate at one end of the flume. In this study, the fluids are incompressible and immiscible. At the interface of two fluids, no phase change and no-slip between fluids are assumed. The interface tracking between air and water phases is accomplished by the Volume of Fluid (VOF) method (Hirt and Nichols, [1981]).

The continuity equations, Reynolds Averaged Navier-Stokes (RANS) equations and volume fraction equations are employed in the numerical model. The standard k- model, which is widely used in engineering application, is required to close the above system of equations and applied to describe the turbulence phenomenon in the water and air dynamic motions.

In addition, the face fluxes through the computational cells are obtained as the geometric reconstruction approach. The interface between two fluids is calculated by the piecewise-linear scheme (Youngs, [1982]), which assumes the linear slope in each cell.

On the opening boundary, the Sommerfeld radiation boundary condition (Sommerfeld, [1949]) is used to obtain the relation between the horizontal velocity component and the free surface elevation. The wave absorption can be performed by controlling the motion of the opening boundary within the velocities opposite to the water particles adjacent to the opening boundary on the x-direction.

The motion of the wave generating and absorbing boundaries can be achieved by defining UDF (User-Defined Function) programs. Fluent also provides the layering remeshing method in dynamic mesh model to govern the grid reconstruction adjacent to the moving boundaries. The geometries and meshes are created by the grid generation software Gambit V 2.2.

Second-order upwind discretization is employed for the convection terms. The pressure-velocity coupling is calculated by the NITA (None-Iterative Time Advancement) – PISO (Pressure Implicit with Splitting of Operators) algorithm compatible with VOF model, which requires only one global iteration per time step, and reduces solution time significantly.

In Fluent, the symmetry definition is applied for the wave making and absorbing boundaries. The bottom and chamber structures are set as the wall boundaries using the standard wall functions. The pressure outlet boundary is taken account for the top boundaries of the computational domain adjacent to the air phase (free in or outflow of air).

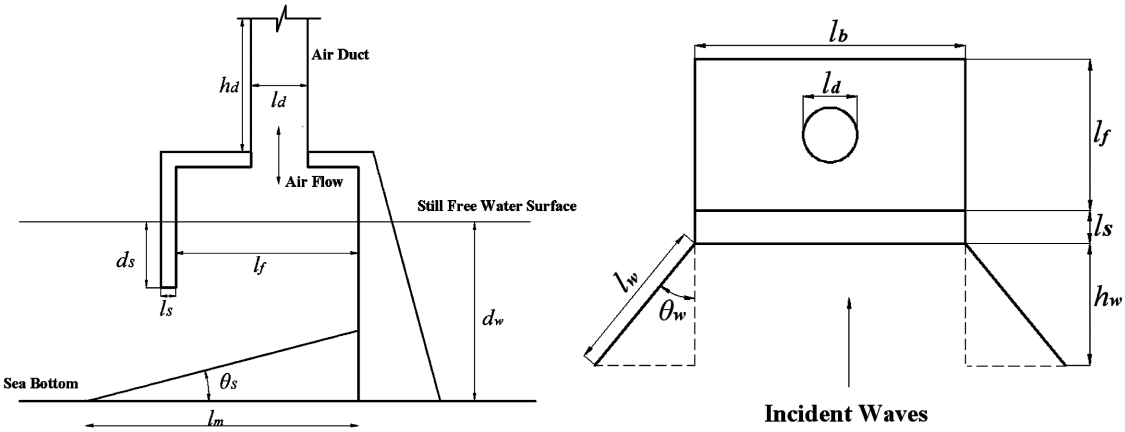
The capability of the numerical wave tank on the simulation of wave elevations, air pressure and air flow variation inside the chamber has been proved by Liu *et al*. [2008a] and Liu *et al*. [2008b]. The numerical prediction of the operating performance of the OWC chamber has shown good agreement with the corresponding experimental data.

3. NUMERICAL ANALYSIS ON WAVE FOCUSING DEVICE

3.1 Wave Focusing Device and OWC chamber

The schematic of the OWC air chamber with an cylinder duct installed at the center of the top cover is shown in Fig. 1(a), where l_f denotes the chamber width, d_s the draft of the chamber skirt, l_s the thickness of the chamber skirt, l_d the diameter of the cylinder duct, h_d the length of the duct. The still water depth is d_w=16m. The slope angle of bottom θ_s and the base length of the slope l_m are fixed as 26° and 23m, respectively.

The schematic of Wave Focusing Device (WFD) is illustrated in Fig. 1(b). The WFD consists of two symmetrical vertical walls. One side of the vertical walls is connected with one corner of the front skirt of OWC air chamber, and the other end extends to the sea. The two vertical walls show bell-mouthed shape to the incident wave direction. When the incident waves arrive at the facility, the water surface will be enhanced during the propagation because of the effects of wave focusing device. The standing waves appear in front of the chamber and the amplitudes are evidently higher than the case of the chamber



(a) OWC air chamber (b) Wave Focusing Device

Fig. 1. Schematic of OWC chamber and Wave Focusing Device

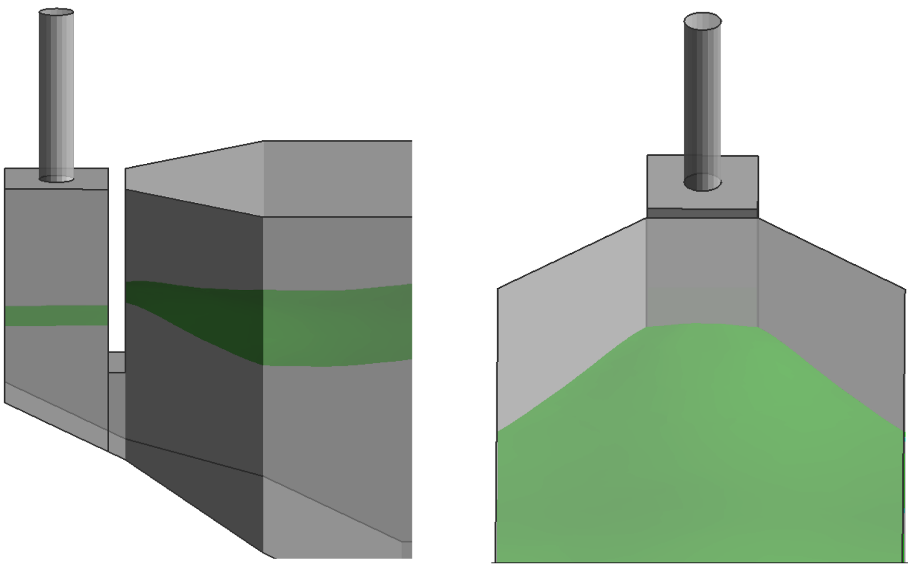
Table 1. Testing Case in the Numerical Simulation

Case	h_w (m)	θ_w (°)	Case	h_w (m)	θ_w (°)
01	0	0	08	4.0	45
02	1.0	30	09	8.0	45
03	2.0	30	10	1.0	60
04	4.0	30	11	2.0	60
05	8.0	30	12	4.0	60
06	1.0	45	13	8.0	60
07	2.0	45			

without WFD.

The expending angles of vertical walls shown in Fig. 1(b) are θ_w. l_w denotes the wall length, l_b the chamber width and h_w the projected length of the wall in the incident wave direction. In order to be convenient for the calculation and analysis, the vertical walls are connected with sea bed in the present paper. The top heights equal to that of the air chamber.

Thirteen cases with various test conditions are summarized in Table 1. In all the cases, there are no air turbines installed in the duct and effects of the turbine were not induced in this study yet. The incident waves whose period varies from 3.5s to 8.0s are employed for each case. In the numerical simulation, the OWC chamber is settled at the end of the wave tank, which is opposite to the wave maker plate. 8 to 10 regular waves were simulated and employed after the incident waves arrived the front skirt of the chamber. The corresponding shape parameters of OWC chamber is as the follows: l_f = 6.0 m, d_s=3.0 m, l_s=1.0 m, h_d=10.0 m and l_d=2.0 m. The incident wave height is fixed as 2.0 m.



(a) Side View (b) Front View

Fig. 2. 3D Instantaneous Snapshot of free water surface inside WFD, Case 09, T=5.0s

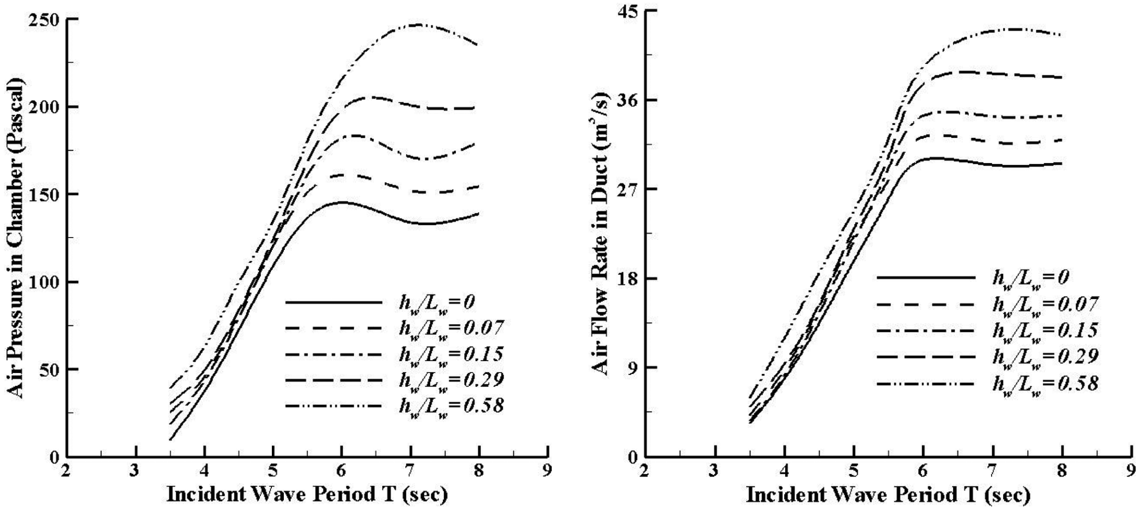
3.2 Effects of Wave Focusing Device on the Performance of OWC Chamber

The free water surface elevation in front of the front skirt of OWC air chamber and effects of Wave Focusing Device are illustrated in Fig. 2. It can be seen that the incident waves included in the length of the WFD crest line will be collected by WFD and the free water surface is lifted by the vertical walls, then propagate to the OWC chamber. The elevation of the incident wave can be seen higher than that without WFD facility.

The effects of vertical wall length of WFD under different expending angles are shown in Fig. 3-5. The non-dimensional parameter h_w/l_b is employed in the present paper to demonstrate the effects of length of vertical wall of Wave Focusing Device.

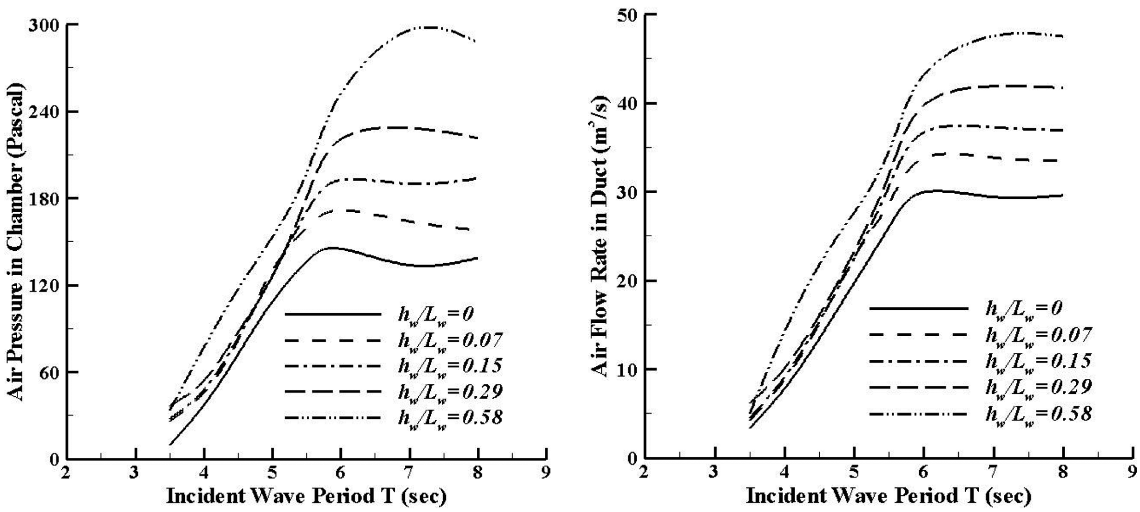
The air pressure inside the chamber and flow rate measured in the duct are utilized in this study. Comparing with the wave elevation in the chamber, the above two parameters are more valuable than the oscillating amplitude. In Fig. 3, it can be seen that the difference of the air pressure and flow rates for various wall length is minor in the short wave period domain when the expending angle is 30°. On the other hand, the evaluating parameters will converge in the long wave period domain and the values will increase as the length of the vertical walls increases.

The same increasing trend of the air pressure and flow rates can be observed for expending angles 45° and 60° as shown in Fig. 4-5. The evaluating parameters of OWC air chamber with-



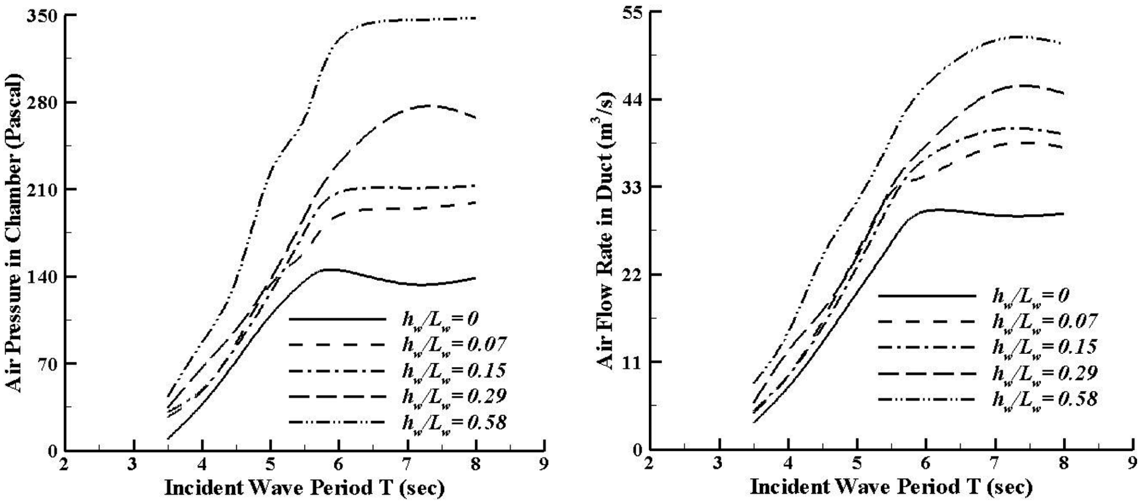
(a) Air Pressure Variation (b) Air Flow Rate Variation

Fig. 3. Effects of WFD wall length on performance of OWC chamber, θ_w=30°.



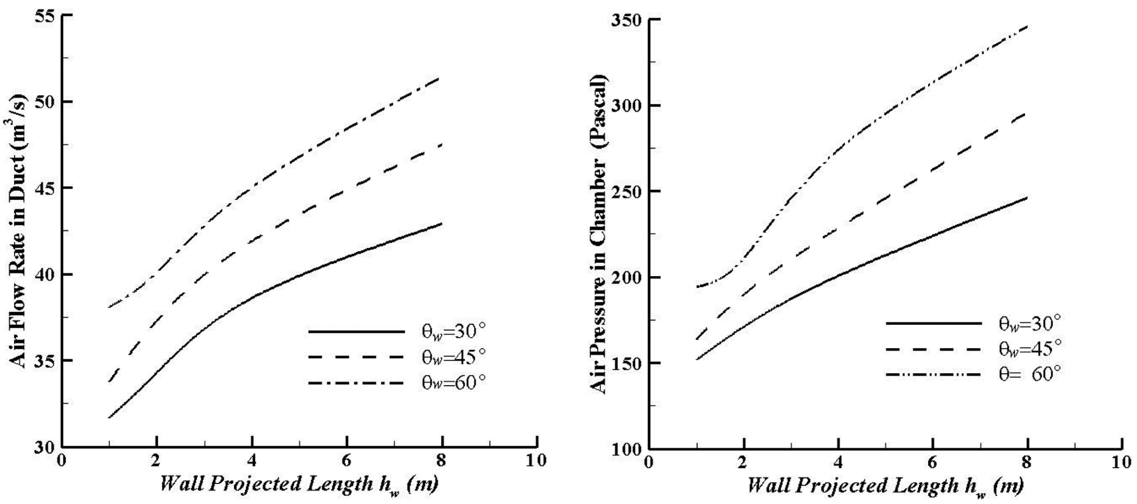
(a) Air Pressure Variation (b) Air Flow Rate Variation

Fig. 4. Effects of WFD wall length on performance of OWC chamber, θ_w=45°.



(a) Air Pressure Variation (b) Air Flow Rate Variation

Fig. 5. Effects of WFD wall length on performance of OWC chamber, θ_w=60°.



(a) Air Pressure Variation (b) Air Flow Rate Variation

Fig. 6. Effects of WFD expanding angles on performance of OWC chamber, θ_w=45°.

out WFD are evidentially smaller than the chamber with WFD. It also can be concluded that the peak value always occurs at the period T=7.0s. In general, the wave energy converting efficiency of OWC chamber will increase as the wall lengths increase under the fixed chamber width and expending angles.

The comparison of operating performance of OWC chamber within WFD for various expending angles is shown in Fig. 6. The incident wave period investigated here is T=7.0s. It can be seen that the air pressure and flow rate will increase as the expending angle increases when the length of the WFD is fixed. Furthermore, the WFD with larger expending angles shows better performance than that with smaller angles.

4. CONCLUSIONS

A 3D numerical wave tank based on the commercial CFD software Fluent 6.2.16 using VOF model has been developed to simulate the wave propagation in this paper. The RANS equations, standard turbulence model and dynamic mesh technology were employed in the present model.

The Wave Focusing Devices within bell-mouthed shaped vertical walls are employed to improve the wave energy converting efficiency of OWC air chamber. The numerical results indicate that the Wave Focusing Devices has minor effects on the performance of OWC chamber in the short wave period and significant effects on the wave energy absorbing. The operating performance of OWC chamber also will increase as the length of vertical walls and expending angles. The investigation here indicates that the Wave Focusing Device is a useful facility to improve the wave energy converting ratio of OWC chamber, and it still needs more effort to be studied in the future.

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