Hydrodynamic investigation on an OWC wave energy converter integrated into an OWT monopile

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INTRODUCTION

The oscillating water column (OWC) wave energy converter (WEC) is a promising technology due to its simplicity and reliability. Offshore wind turbine (OWT) technologies have been seen a significant acceleration around the world, with the sector installing a record of 6.1GW in 2019. However, the OWT monopiles are subject to not only aerodynamic loads from wind but also hydrodynamic loads from wave and currents.

Combining the wind and wave energy converters together could be beneficial for utilizing the space and enhance energy extraction (Wan et al., 2015). It would also be beneficial for the wind and wave energy converters to share the infrastructures such as foundations, piles, power substations and cables to reduce the cost. Following Perez-Collazo`s concept, we proposes an updated design of the integrated system, as shown in Fig. 1.

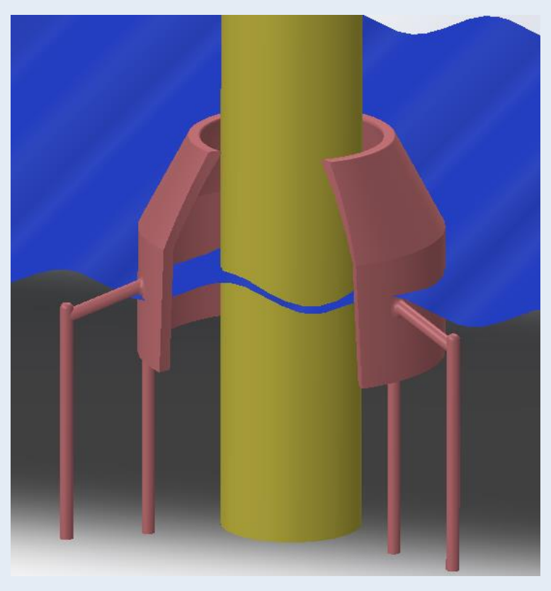


Fig.1 Concept of the OWC-OWT integrating system

EXPERIMENTAL SETUP

A physical 3D model of the OWC integrated system was studied at a 1:20 scale in a wave-current flume in Dalian University of Technology. The single OWT monopile, as shown in Fig. 2, was also investigated for the comparative purpose. A circular orifice on the ceiling of the chamber was introduced to simulate the effects of nonlinear turbine damping. In the present study, Three wave gauges were positioned to measure surface elevations. Twelve pressure sensors were placed around the OWT monopile and the OWC chamber wall to measure the pressure variations.

Fig.2 Sketch of the experimental setup

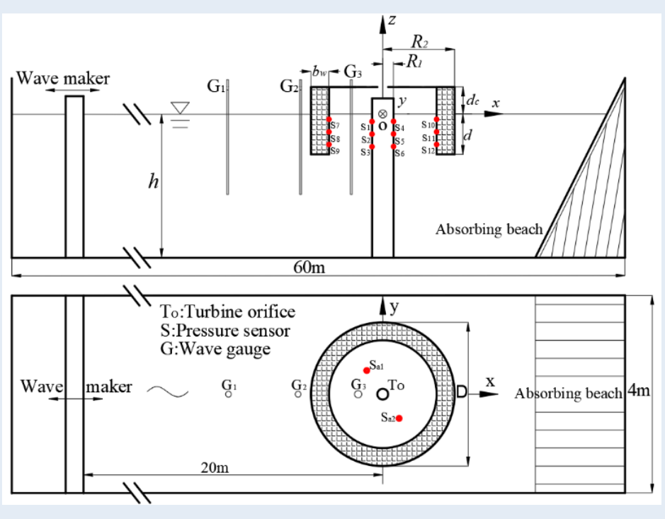


Fig.3 Sketch of the experimental setup

NUMERICAL MODEL AND VALIDATION

Based on linear potential-flow theory, a 3D time-domain HOBEM was applied to investigate the hydrodynamic performance of the OWC integrated system. Laplace equation and the following boundary conditions are satisfied:

$$\nabla^2\phi_s(x,y,z,t)=0$$

$$\frac{\partial\phi_s}{\partial n}=-\frac{\partial\phi_i}{\partial n}\quad \text{on } S_b$$

$$\begin{cases}\dfrac{\partial\eta_s}{\partial t}=\dfrac{\partial\phi_s}{\partial z}-\nu_{(r)}\eta_s\\[2ex]\dfrac{\partial\phi_s}{\partial t}=-g\eta_s-\dfrac{P_{air}}{\rho}-\mu_1\dfrac{\partial\phi}{\partial n}-\nu_{(r)}\phi_s\end{cases}\quad \text{on } S_f$$

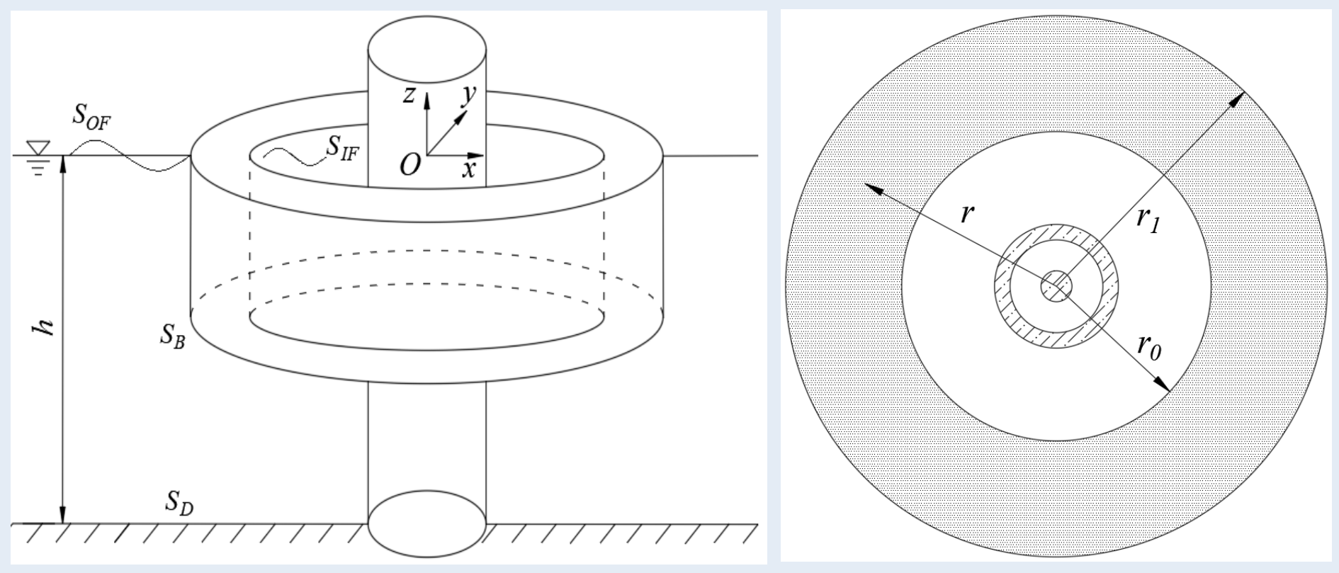


Fig.4 Sketch of the numerical model

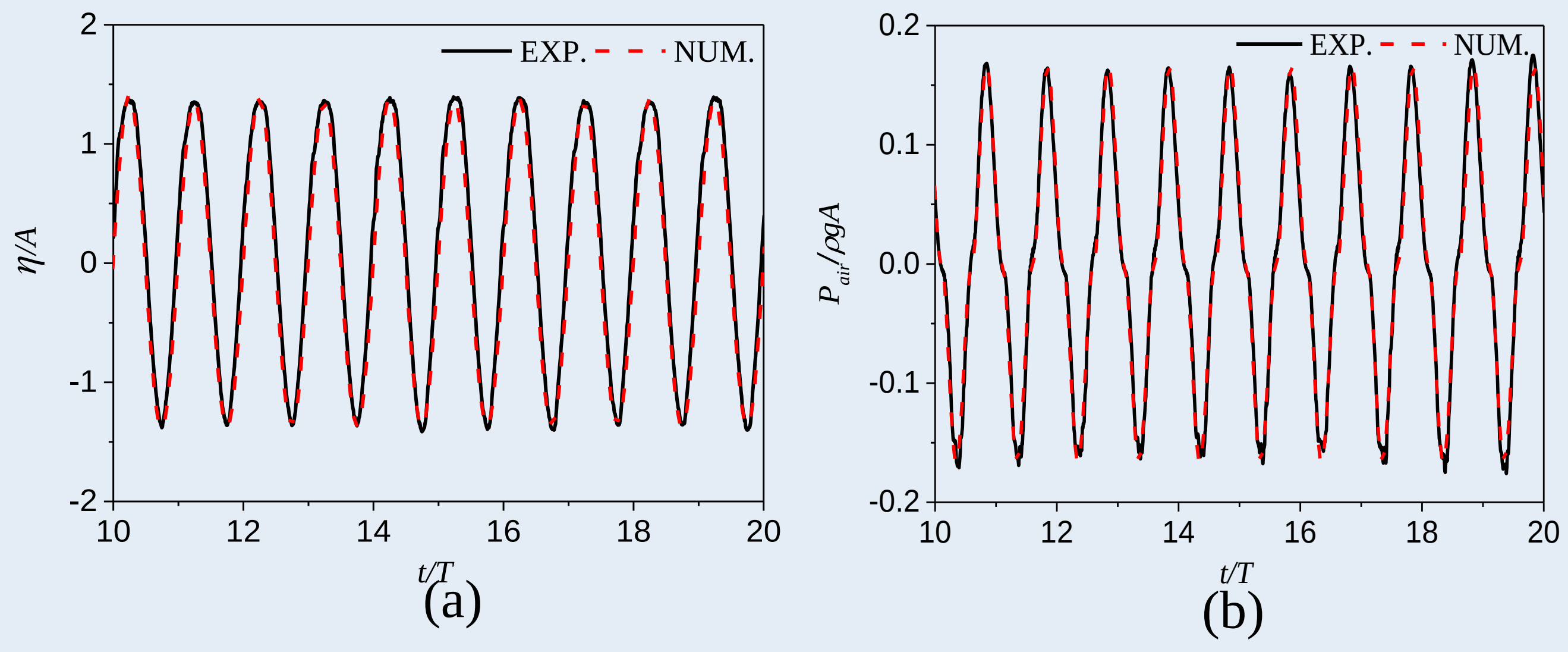
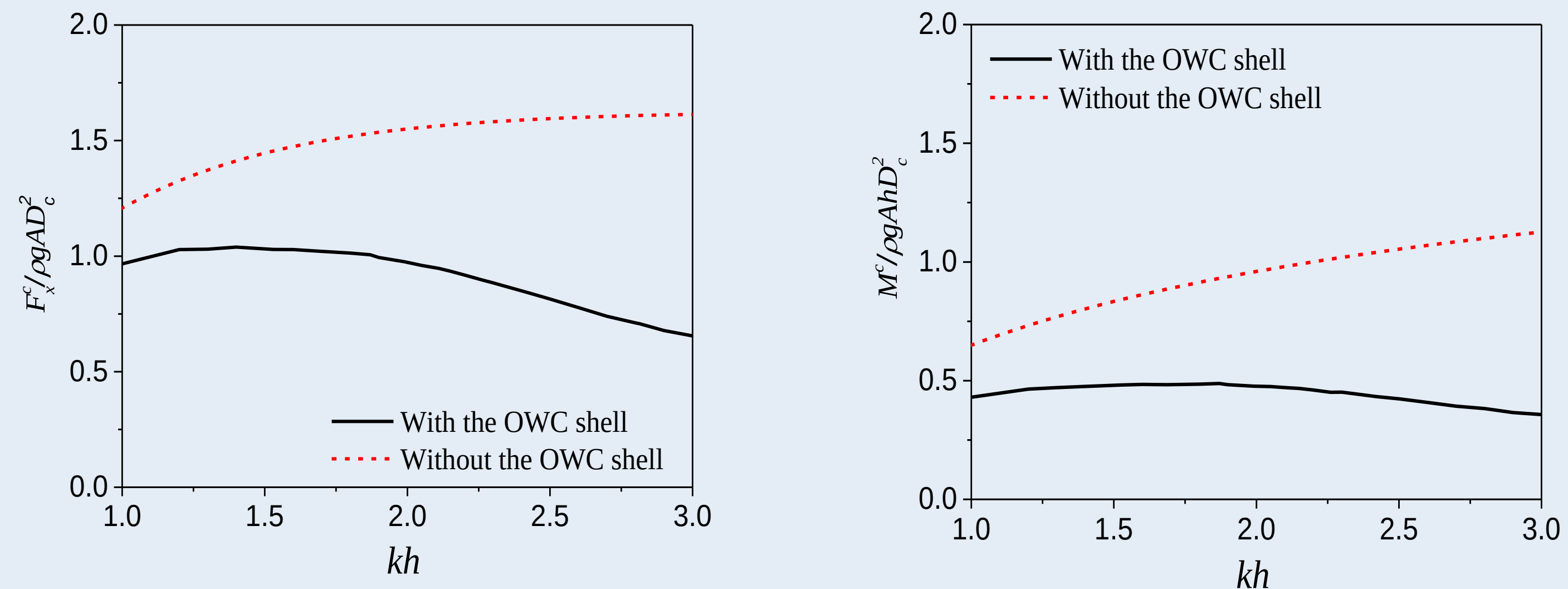


Fig.5 Time series of the simulated and measured (a) surface elevation and (b) air pressure(kh=1.99)

RESULTS AND DISCUSSION



(a) Horizontal force (b) Overturning moment

Fig.6 illustrates the wave loads on the OWT monopile with and without the OWC chamber shell. The non-dimensional horizontal force and overturning moment were reduced with the introduction of the OWC shell, especially for the high-frequency waves.

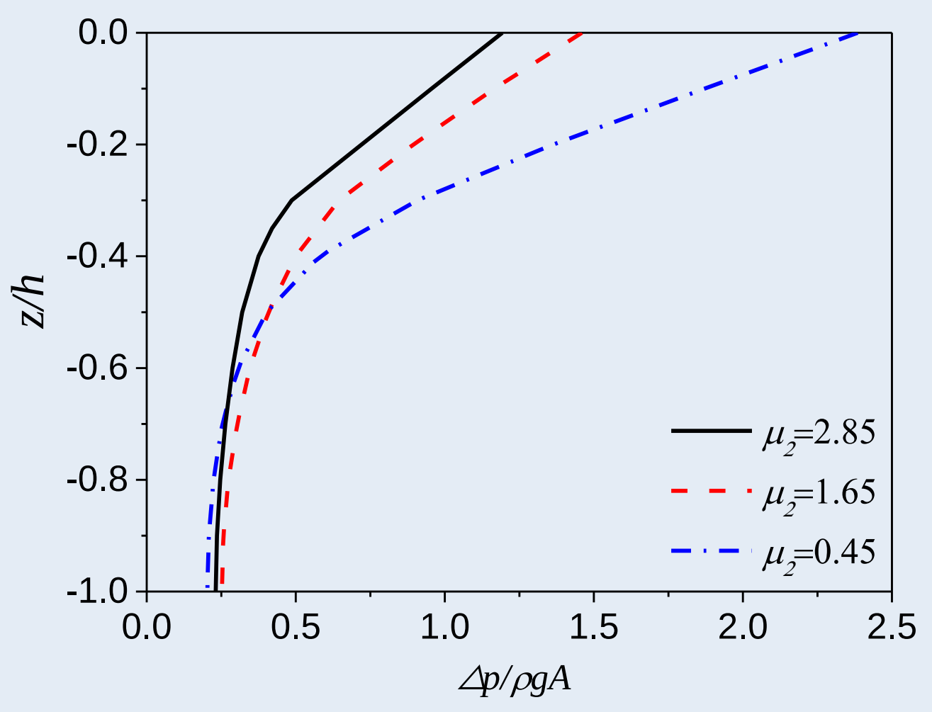
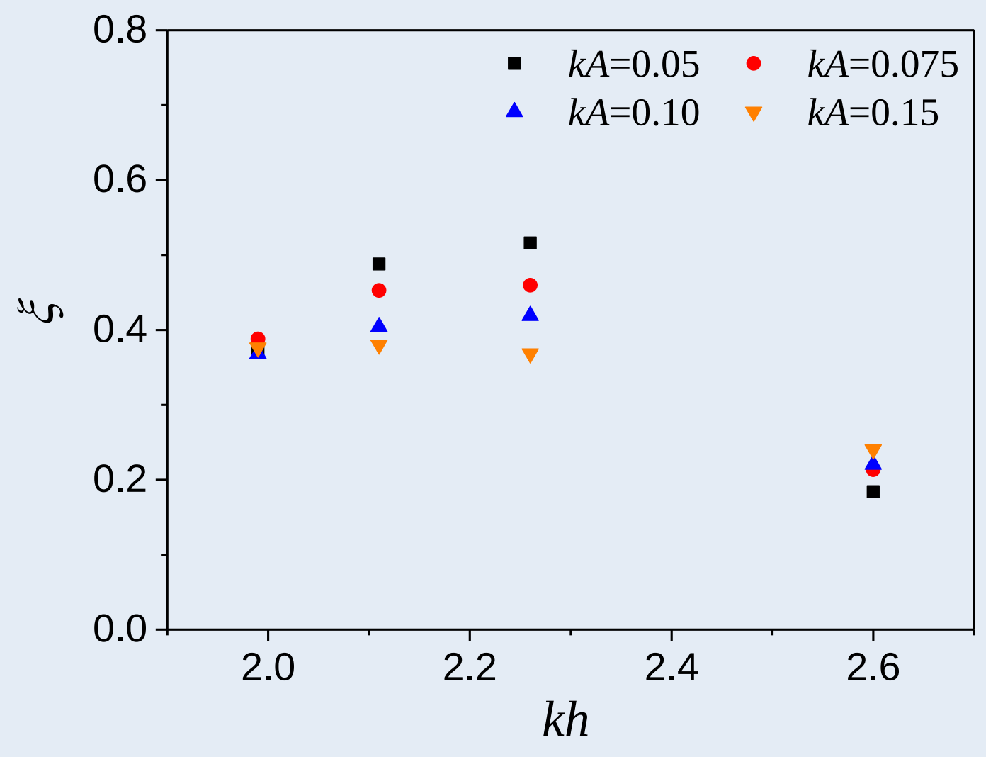
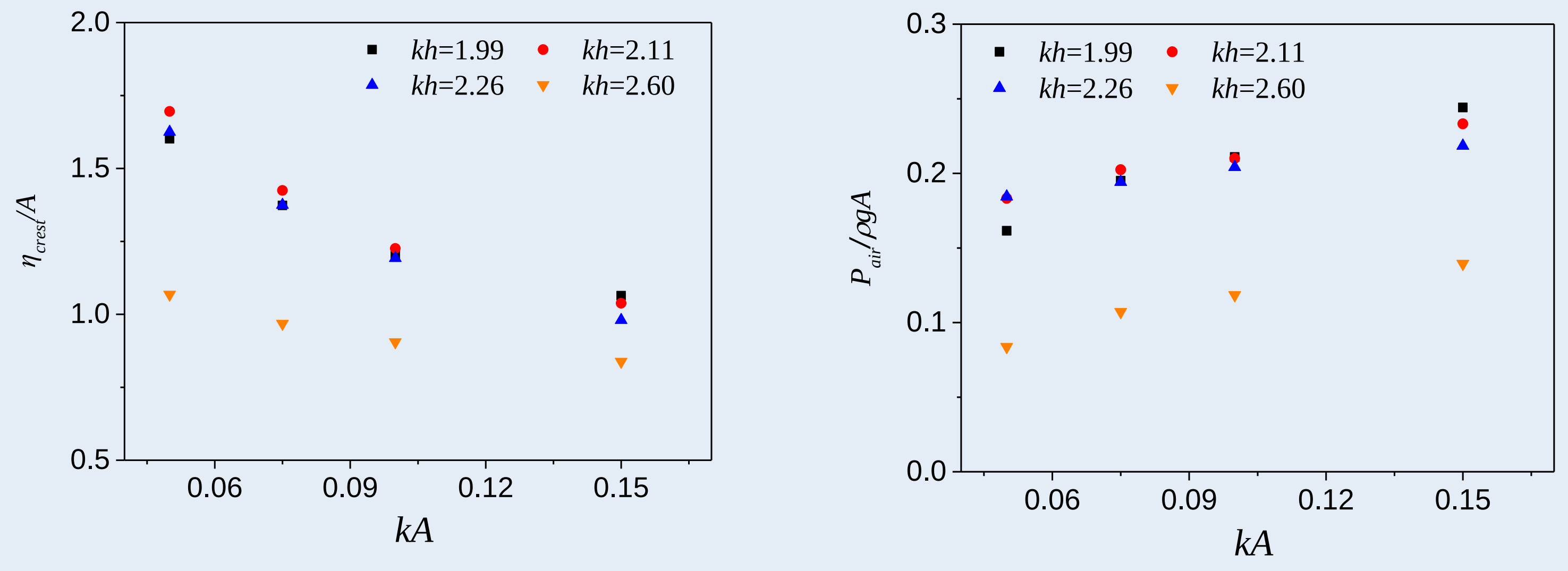


Fig. 7 shows the effects of the turbine damping on the pressure distribution along the seaside of the OWT monopile (kh=2.2). It is clear that a huge pressure drops (65%) occur under the relative water depth z/h=0.4.



(a) Efficiency



(b) Surface elevation (c) Air pressure

Fig. 8 shows effects of the wave steepness kA on the efficiency, surface elevation and air pressure of the OWC device. As the wave steepness kA increases, the hydrodynamic efficiency generally decreases, especially near the resonant frequency (kh=2.2).

CONCLUSIONS

The hydrodynamics of an OWC WEC integrated into a fixed OWT monopile was investigated numerically and experimentally. The OWC chamber shell can reduce the horizontal force and overturning moment on the monopile. The OWC system with larger turbine damping can reduce the local pressure on both the OWC shell and monopile. As the wave steepness kA increases, the hydrodynamic efficiency generally decreases.

REFERENCES

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