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主　論　文　の　要　旨

論文題目　Nonlinear Hydrodynamic Analysis and Optimization of Bottom-Hinged Oscillating Wave Surge Converters in Shallow Water
（浅海域における下部ヒンジ型振子式波力発電装置の最適化に関する非線形流体解析）

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論　文　内　容　の　要　旨

This doctoral dissertation studied the nonlinear hydrodynamics and optimization of bottom-hinged oscillating wave surge converters (OWSCs) in shallow water.

In Chapters 1–4, the background and methodologies were introduced. Firstly, the nearshore environments—in particular, shoaling regular and irregular waves, were described. The typical irregular wave spectrums were contrastively illustrated. The spectral values in shallow water should be modified according to the water depth. Based on boundary element method (BEM), the equations of time-varying environmental loads were presented, considering the effects of instantaneous wet surface on the hydrostatic restoring moment and drag moment. The frequency-domain and time-domain mathematical models were established. The linearization of nonlinear stiffness, drag moment, and power take-off (PTO) friction moment was applied in the nonlinear frequency-domain analysis. Python codes were developed to solve the dynamic equations and hydrodynamic performances. Furthermore, the numerical wave tank (NWT) of two-phase flow (water and air) based on computational fluid dynamics (CFD) was built for high-fidelity simulations.

Chapter 5 simply considered the still water surface to calculate the time-varying wet surface for the computation of nonlinear hydrostatic restoring moment and drag moment. The BEM-based numerical results of the pitch amplitude in study cases were compared well with the published experimental data. The nonlinear items cannot be neglected, especially when the pitch amplitude grows up to 30°. Surface-piercing OWSC can capture more power than the same-sized fully submerged one in most wave conditions. The moderate increase of the PTO stiffness for a thin OWSC helps to enhance the peak of capture width ratio (CWR). A proper PTO damping helps to maximize the CWR for peak energy conditions. The PTO friction can significantly reduce the CWR at the whole wave period range, whereas the maximum influence of the viscosity occurs at the resonant wave period.

Chapter 6 studied the resonant behaviors, based on time-domain BEM, of a bottom-hinged OWSC as well as the relationship of resonance with the response and CWR. To improve the accuracy, a corrected wave surface was introduced to calculate the time-varying wet surface. The wave surface correcting factor and drag coefficient were calibrated with CFD. An intermediate initial angle in free decay is appropriate for use to determine the natural period. Under regular waves, the resonance occurs near the natural period for the uniform wave amplitude, rather than the uniform wave torque amplitude, and can disappear due to the amplification of PTO friction. Under unit-amplitude regular waves, the period of maximum CWR is relatively close to the period of maximum velocity, but far from the natural period. Under irregular waves, no stable resonance is observed because the maximum equivalent pitch angle appears at different peak periods with the variation in PTO damping. When the period of a regular wave or the peak period of an irregular wave is close to the natural period, a phase hysteresis of velocity relative to wave torque always occurs.

Chapter 7 used the frequency-domain BEM method to study the feasibility of performance promotion of a bottom-hinged OWSC under regular and irregular waves in shallow water via adjusting PTO parameters. Under regular waves, the adjusting approaches are classified as: (1) no artificial resonance, (2) perfect resonance, and (3) near resonance. The results show that the adjustment towards resonance can boost the capturing power, although the flap-type absorber was recognized as a wave torque dominating device. A near-resonance situation is more effective to improve the hydrodynamic performance than a perfect resonance, in which the amplification of the damping item is disadvantageous. An increasing hysteretic phase angle of velocity relative to wave torque with the increase of wave period represents the best status of wave energy harvesting. Under irregular waves, the performance at a short peak period can be improved by adjusting PTO stiffness, while, adjusting PTO inertia torque is almost ineffective.

Chapter 8 designed an assembling OWSC with adaptive sizes for the target wave energy farms around Japan and evaluated the mean annual CWR under irregular

waves. Unlike the inflexible drag coefficients in a steady flow, the drag coefficients in irregular waves are strongly affected by OWSC thickness. Multi-objective genetic algorithm (MOGA) optimization of OWSC geometric sizes, internal water filling, and PTO parameters was conducted for two objective functions: maximizing the mean annual CWR and minimizing the structural mass per unit width. The optimized result presents a slender OWSC that neutrally balances these two objectives. The effects and local sensitivities of the width, thickness, axis depth, water filling, PTO stiffness, damping, and friction were comprehensively discussed. The results show that the axis depth has the greatest positive influence on the CWR, and the increase in thickness creates a significant economic disadvantage due to a heavier structure. However, inertia adjustment by filling water does not benefit the mean annual CWR.

Chapter 9 presented the conclusions, innovations, and future research.

Keywords: OWSC; hydrodynamics; BEM; CFD; resonance; PTO system; CWR; performance enhancement; optimization