Performance Evaluation of the Floating Pendulum Wave Energy Converter in Regular and Irregular Waves

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In this paper, we carried out a numerical investigation of the hydrodynamic performance of a floating pendulum wave energy converter (WEC). This movable-body-type device consists of three main parts: floater, pendulum and damping plate. The performance of the WEC device was evaluated under regular and irregular wave conditions using frequency-domain floating body dynamics. In this study, the higher-order boundary element method (HOBEM) based on potential flow model was applied to obtain the hydrodynamic coefficients and wave exciting forces acting on floating bodies. The hinged motion of the pendulum was simulated by applying the penalty method. In order to avoid an unrealistic resonant response, numerical body damping was adopted. The coupled dynamics of floater and pendulum were analyzed as a hinged multi-body model. First, the wave force and motion characteristics of the device in regular waves were studied. Then, the performance of the WEC device was evaluated under irregular wave conditions. The effects of the main shape parameters on power absorption and floater motion were numerically investigated.

INTRODUCTION

Many kinds of wave energy converter (WEC) have been proposed recently. They can be categorized as one of three basic types: an oscillating-water-column (OWC) type, a wave-overtopping type and a movable-body type. The oscillating-water-column types use the air-flow induced by wave motion to generate power via an air turbine, whereas the overtopping type makes use of the potential energy of overtopping water via a water turbine. However, movable-body WECs adopt a direct energy transfer system, whereby the translation and rotational motion of an incoming wave directly induces mechanical motion of the power generator. Among the three types of converter, the movable-body type is possibly the most efficient device. However, the movable-body WEC device is vulnerable to structural damage, because the device is directly exposed to harsh environmental loads. Therefore, the floating type wave energy converter is preferred to the fixed type. In the deep sea, in particular, the floating device is necessary, because the fixed type is limited to areas near the shore.

The pendulum WEC was invented and studied by a research group at the Muroran Institute of Technology in Japan (Watabe, 2005). Their research has mainly been focused on the fixed pendulum WEC device. In this device, a rotary vane pump is used to convert rotational torque into oil pressure. Alves et al. (2002) performed a hydrodynamic analysis of the fixed pendulum device in the frequency domain using the 3D radiation-diffraction panel codes. They studied the influence of some geometric parameters on the pendulum’s performance based on numerical results. Toyota et al. (2011) carried out a series of experiments involving a floating pendulum WEC device in a two-dimensional wave tank and reported the power outputs and motions of the device in regular waves. Recently, Nam et al. (2011) published the numerical results related to the wave-induced motion of a floating pendulum WEC. The latter study showed that the efficiency of the floating WEC device is less than that of the fixed device, whereas the wave forces acting on the floating device are relatively small because of the motion relative to the incident wave. In order to maintain high efficiency within a target wave period, the design parameters of a floating WEC device need to be better optimized based on an analysis of wave load and wave-induced motion.

In this study, we applied the higher-order boundary element method (HOBEM) based on a potential flow model in order to obtain the hydrodynamic coefficients and wave exciting forces of floating bodies. Integral equations for boundary value problems were formulated with wave Green function in the frequency domain. The hinged motion of the pendulum was simulated by applying the penalty method, in which equivalent stiffness matrices corresponding to the hinged constraint condition are included in the motion equations. Numerical body damping was adopted in order to avoid an unrealistic resonant response. First, the hydrodynamic performances of a floating pendulum WEC were evaluated under regular wave conditions. The motion responses and the characteristics of hydrodynamic wave loads were suggested. Then, numerical calculations were carried out for the WEC device under irregular wave conditions and the effects of main shape parameters on power absorption and floater motion were investigated.

FLOATING PENDULUM WAVE ENERGY CONVERTER

Basic Configuration

The basic geometry of the floating pendulum WEC is shown in Fig. 1. This device consists of three main parts: floater, pendulum, and damping plate. The floater is designed to collect the incoming wave and create resonance inside the reservoir. The pendulum is subjected to one degree-of-freedom angular motion, with two hinged points connected to the floater. The pendulum transfers energy from the wave motion to an electrical generator via a rotating bearing. The relative pitch motion of the pendulum with