International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 32, No. 2, June 2022, pp. 193–200; https://doi.org/10.17736/ijope.2022.mm27

http://www.isope.org/publications

Efficient Properties of Different Types of Wave Energy Converters Placed in Front of a Vertical Breakwater

Dimitrios N. Konispoliatis, Anargyros S. Mavrakos and Spyridon A. Mavrakos
Laboratory for Floating Structures and Mooring Systems, School of Naval Architecture and Marine Engineering
National Technical University of Athens, Athens, Greece

The present paper aims at investigating the efficiency of a cylindrical WEC placed in front of a vertical, surface-piercing breakwater of infinite length. A theoretical model is presented based on the linearized velocity potential, the image theory, and the matched axisymmetric eigenfunction expansion formulations. The WECs under examination are the heaving absorber and the oscillating water column device. From the present analysis, it is demonstrated that the absorbed wave power by the examined WECs in front of a vertical wall is strongly affected by the geometrical parameters of the converters and their mechanical components; thus, they should be properly considered when designing the WEC-breakwater system to increase its wave power efficiency.

INTRODUCTION

Ocean waves have vast energy potential. However, harnessing wave power is more complex than the process of converting other renewable energy sources like wind or solar into electricity. Wave conditions (i.e., wave heights and wave frequencies) can vary wildly over time and from one installation location to another. As a result, the wave energy sector is focusing on developing efficient solutions, which at the same time will be capable of withstanding the demanding environmental conditions in the installation areas. In this respect, various wave energy converters (WECs) characterized by different working principles, i.e., modes of power absorption, have been proposed and designed (Falnes, 2007; McCormick, 1981; Pelc and Fujita, 2002) with the oscillating water column devices (OWCs) and the heaving WECs (heaving absorbers) representing the most advanced device types (Magagna et al., 2016).

To increase the efficiency of a WEC, several parameters have been examined up to date, namely (a) the optimization of the WEC's geometrical characteristics, in the scope of harnessing maximum wave energy at the installation location; (b) the optimization of the WEC's characteristics with respect to their mechanical components, to withstand the demanding environmental conditions, as well as to reduce the energy losses associated with the transformation of the wave power into electricity; and (c) the installation of WECs close to other near- or onshore maritime structures, such as a breakwater, a harbor, or a pier, so as to use already existent infrastructures (electric grid, etc.), reducing in parallel the WECs' environmental impact (Konispoliatis et al., 2020; Mustapa et al., 2017).

Looking towards the possible advantages provided by the installation of WECs in front of a vertical breakwater, several studies have been presented in the literature. Indicatively, in Mavrakos et al. (2004), the performance characteristics of an array of five heaving WECs placed in front of a reflecting vertical wall of infinite length were numerically and experimentally studied, whereas in Konispoliatis and Mavrakos (2020a), the absorbed wave power by an array of heaving WECs, in front of a reflecting vertical wall, was investigated. Furthermore, in Konispoliatis and Mavrakos (2020b), an orthogonal breakwater was studied to amplify the efficiency of the WEC when compared to an isolated converter. Moreover, the efficiency of an OWC device placed in front of a vertical wall was investigated in Konispoliatis (2020).

The objective of this paper is to compare the efficiency properties of several types of WECs placed in front of a vertical breakwater to obtain an optimum configuration. The WECs under examination are the heaving absorber and the oscillating water column device. The examined heaving absorbers consist of (a) a vertical cylindrical floater, C_1 (see Fig. 1a); (b) a hollow vertical cylindrical floater, C_2 (moonpool; see Fig. 1b); and (c) two concentric cylindrical floaters moving in-phase, C_3 (see Fig. 1c). The wave energy is absorbed through the floater's motion in heave at/near the water surface. Concerning the examined OWC devices, they consist of (a) a hollow vertical cylindrical body, C_4 (see Fig. 1d); and (b) an exterior partially immersed hollow vertical toroidal body supplemented by a coaxial internal cylinder, C_5 (see Fig. 1e). Inside the moonpool and in the annulus between the internal cylinder and the external torus, a finite volume air chamber is formed in which the air is oscillating. The vertical motion of the sea surface alternately pressurizes and depressurizes the air inside the structure, generating a reciprocating flow through a self-rectifying turbine that is installed beneath the roof of the device. The Power Take Off (PTO) mechanism, actuated by the WEC's heave motion, is modeled as a linear damping system. The latter is described by a damping coefficient that is equal to the heave radiation damping of the same absorber at its heaving natural frequency when it is considered isolated (i.e., without the presence of the wall). As far as the OWC devices are concerned, the air compressibility in the chamber is neglected and the air turbine's pneumatic admittance is considered equal to the optimum coefficient, which maximizes the absorbed power by the same isolated OWC device (no presence of the wall) at its pumping resonance frequency (Evans and Porter, 1997). Furthermore, the OWC is assumed fixed to the incoming waves. This assumption is made since the absorbed power of a restrained OWC was found to attain higher values than the corresponding values of a freely floating device (Konispoliatis and Mavrakos, 2016). In the

Received October 2, 2021; updated and further revised manuscript received by the editors March 28, 2022. The original version (prior to the final updated and revised manuscript) was presented at the Thirty-first International Ocean and Polar Engineering Conference (ISOPE-2021), Rhodes, Greece (virtual), June 20–25, 2021.

KEY WORDS: Hydrodynamic power efficiency, heaving device, oscillating water column, breakwater, geometric characteristics.