Hydrodynamic Performance of the floating rectangular shaped OWC device in Random Waves Environment

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Keywords
Floating Oscillating Water Column device, Efficiency, Boundary element method, Radiation, Wave spectrum.

Abstract
The annual averaged performance of the floating-OWC device placed over uniform bottom is analyzed in random waves environment. To model the random local wave climate around the OWC plant, Pierson-Moskowitz spectrum is considered. The influence of the front wall draft, device chamber length and turbine damping coefficient on the efficiency of the device is discussed in details. It is observed that the local wave climate plays a vital role on the performance of the OWC device along with the variation in device parameters.

1. Introduction
In the energy-producing industry, renewable energy has become more valuable and beneficial due to their significant and lasting availability. Further, renewable energy sources are characterized as clean energy because there is no negative impact on the environment during the production of electricity. In this aspect, wave energy will play a critical role in upcoming future. The OWC device is most widely used wave-power generation technique due to low operating cost and simple working mechanism.

There have been many research studies both experimental and mathematical regarding the modelling of an OWC device. Mahnamfar and Altunkaynak (2017) [1] examined the performance of an OWC-WEC experimentially under the influence irregular waves. It was reported that the shape of spectrum inside the device chamber is influenced by the incident wave spectrum. Recently, Trivedi and Koley (2021) [9] investigated the performance of an OWC-WEC placed over the stepped bottom in the influence of random waves. It is found that the local wave climate plays a crucial role on the performance of the OWC device along with the variation in device parameters.

The overall organization of this paper is as the following. Firstly, the mathematical formulation along with solution methodology is provided. Various parameters related with the OWC device's functionality are provided in Section 4. Finally, the results and conclusions are given in Section 5.

2. Mathematical Formulation & Solution Methodology
The present section contains the mathematical formulation for the floating OWC-WEC placed over an uniform seabed. For the sake of modelling, the 2D Cartesian coordinate system is considered. The schematic representation of the physical problem is shown in Fig:1. The floating OWC-WEC contains the collector chamber of length \( h \) with submergence depth \( \alpha \). Further, the back-side wall is placed at \( x = 1 \). The seabed is uniform in nature as shown in Fig:1. Due to the presence of OWC-WEC, the free surface is separated into two parts: (i) external free surfaces \( \Gamma_1 \) and \( \Gamma_2 \) occupy the region \( \Gamma_1 = \{(x,z):z = 0, L < x < r\} \) and \( \Gamma_2 = \{(x,z):z = 0, 0 < x < L – b – 2d\} \) respectively, and (ii) internal free surface \( \Gamma_3 = \{(x,z):z = 0, L – b < x < L\} \). Further, \( \Gamma_1 \) represents the bottom boundary. Moreover, \( \Gamma_1 \) and \( \Gamma_2 \) are the rigid and impassable boundaries of the floating OWC-WEC. For the solution procedure, two auxiliaries boundaries are introduced at \( x = 0 \) and \( x = r \). Further, the flow motion is time-harmonic with circular frequency \( \omega \). The velocity potential will exist in the form \( \Omega(x,z) = \Re \left[ \left( \frac{1}{r} \right) \exp(j\omega t) \right] \). With this background, the governing equation is given as

\[
{V}^2\Omega(x,z) = 0
\]
Figure 1. Schematic view of floating OWC-WEC

\[ \dot{\gamma} \text{ contains } \gamma^1 \text{ and } \gamma^2. \text{ Now } \gamma^1 \text{ and } \gamma^2 \text{ satisfy the bc (boundary condition) at } z = 0 \text{ is given by} \]

\[ \frac{\partial \gamma^2}{\partial z} - K\gamma^2 = \chi \left( \frac{\text{isot}}{\rho g} \right), \quad (2) \]

where, \( \chi = 0 \) for \( \gamma^1 \) and \( \chi = 1 \) for \( \gamma^2 \). Here, \( \partial \gamma / \partial n \) is the normal derivative. Now, bcs on the impenetrable boundaries \( \Gamma_1 \cup \Gamma_2 \cup \Gamma_3 \) are given by

\[ \frac{\partial \gamma}{\partial n} = 0, \text{ on } \Gamma_1 \cup \Gamma_3 \cup \Gamma_2. \quad (3) \]

The radiation conditions on \( \Gamma_1 \cup \Gamma_3 \) are given by

\[ \frac{\partial \gamma^2}{\partial n} - i\kappa \gamma^2 = 0, \text{ on } \Gamma_1 \]

\[ \frac{\partial \gamma^1}{\partial n} - i\kappa \gamma^1 = 0, \text{ on } \Gamma_3 \quad (4) \]

The solution methodology for the above-mentioned BVP is discussed using the BEM. In this method, firstly, the BVP related to the \( \gamma^2 \) and \( \gamma^1 \) are converted into the Fredholm integral equations. Now, employing Green’s second identity on \( \gamma^1 \cup \gamma^2 \), and using the Eqs. (2)-(4), we get

\[ \int \left( \frac{\partial G}{\partial n} - KG \right) \gamma^1 d\Gamma + \int \left( \frac{\partial G}{\partial n} - iK \gamma^1 \right) d\Gamma = \int \left( \frac{\partial \gamma^2}{\partial n} - iK \gamma^2 \right) d\Gamma \]

\[ \int \left( \frac{\partial G}{\partial n} - KG \right) \gamma^2 d\Gamma + \int \left( \frac{\partial G}{\partial n} - iK \gamma^2 \right) d\Gamma = 0 \]

Now, Eqs. (5) and (6) are transformed into a system of linear algebraic equations using the BEM method. The details procedure is available in Koley and Trivedi (2020) [5]. Finally, the discrete values of \( \gamma \) and \( \partial \gamma / \partial n \) are obtained over each boundary of the domain.

3. Random Waves Environment

Random ocean waves are represented using the concept of wave spectrum and associated Sea states. Here, the Pierson-Moskowitz spectrum Gomes et al. (2012) [7]is used, and the form is given by

\[ S_f (\omega) = 263 H_{\text{m}}^2 T_{\text{m}}^{-\omega} \exp \left( -1054 T_{\text{m}}^{-\omega} \right). \quad (8) \]

Now, the chamber standard pressure distribution is given as

\[ \bar{p}_i = \int S_f (\omega) P_i (\omega) A_i (\omega) d\omega. \quad (9) \]

The efficiency of floating OWC-WEC is defined as

\[ \dot{\eta}_w = \frac{\bar{W}_w}{\bar{P}_w}, \quad (10) \]

Here, \( \bar{W}_w \) and \( \bar{P}_w \) are termed as average incident wave energy flux, and the average available power to the Wells turbine respectively.

Now, the expressions for the same are given by

\[ \bar{W}_w = \Lambda \frac{\xi^2}{2}, \quad (11) \]

\[ \bar{P}_w = \rho g \int S_f (\omega) C_i (\omega) d\omega. \quad (12) \]

Here, \( C_i \) is the group velocity of the incoming waves. Finally, the expression for annual averaged plant efficiency is given by where, \( \bar{W}_{\text{ann}} \) and \( \bar{P}_{\text{ann}} \) are termed as annual-averaged power to the wells turbine and annual-averaged incident wave energy flux, respectively.

4. Results

The variables associated with the OWC device configuration and random incident waves are taken as follows:

\[ h = 15m, \rho = 1025kg/m^3, g = 9.81m/s^2, L = 1.0h, b = 0.5h, a = 0.25h, c = 0.125h, \]

\[ d = 0.005h, V_p = 1050m/s, y = 1.4, \rho_s = 1.25kg/m^3, r = 2.0h. \quad (13) \]

unless otherwise mentioned.

Table 1. Set of fourteen sea states representing the wave climate at the OWC plant on western coast of Portugal

<table>
<thead>
<tr>
<th>Sea state</th>
<th>( H_s )</th>
<th>( T_s )</th>
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<tbody>
<tr>
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<tr>
<td>14</td>
<td>8.17</td>
<td>13.91</td>
</tr>
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Figure 2. $\eta_{\text{ann}}$ vs $\Lambda$ for various (a) chamber length $h/h$ and (b) submergence depth $a/h$ associated with the OWC plant on the western coast of Portugal.

In Figs. 2(a) and 2(b), the variation of the annual-averaged efficiency $\eta_{\text{ann}}$ versus turbine damping coefficient $\Lambda$ are plotted for different $h/h$ and $a/h$. Figs. 2(a) and 2(b) illustrate that the efficiency of the OWC-WEC initially increases with an increase in $\Lambda$ and attains maximum. Hereafter, the efficiency decreases for further increase in $\Lambda$. Further, it is observed that with an increase in $h/h$, the efficiency $\eta_{\text{ann}}$ increases. In addition, in the long wave regime, $\eta_{\text{ann}}$ increases as $a/h$ becomes lower. However, opposite pattern is observed in the intermediate and short-wave regimes.

5. Conclusions

In the present study, the annual-averaged performance of a floating OWC-WEC is investigated in real sea conditions. The local wave climate at the OWC plant site OWC plant on western coast of Portugal is taken as the incident wave spectrum. It is observed that the annual averaged efficiency of the floating OWC-WEC initially increases with an increase in turbine damping coefficient. Hereafter, the efficiency of an OWC-WEC decreases for further increase in turbine damping coefficient. In addition, the magnitude of the efficiency of the OWC-WEC is increases with an increase in the chamber length. Moreover, in the long-wave regime, the amplitude of the efficiency curve decreases with an increase in submergence depth, and a reverse trend is observed for intermediate and short incident waves.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References