Water wave power extraction by a floating surge oscillating WEC comprising hinged vertical and horizontal flaps

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A surge oscillating flap-type device is one of the most usable wave energy converters for extracting power from ocean waves. The relative movement of the piston and cylinder of a hydraulic power take-off system attached to the vertical flap and the base is responsible for converting the mechanical oscillations of the flap into hydraulic pressure in a bottom-hinged flap-type converter. This study proposes a new design to investigate its hydrodynamic characteristics and output power, including a vertical buoyant flap hinged to a horizontal gravity flap. This analysis is done by solving the governing Laplace equation through the BEM approach in ANSYS AQWA. The steady-state relative displacement between flaps is obtained through a time-domain analysis, which is used to calculate the output power. The results show that the proposed floating design can extract power from ocean waves at offshore sites. The WEC is designed to match its power resonance periods with the most wave dominant periods of 8-10 s.

keywords: *bottom hinge converter, floating WEC, surge oscillating flap-type converter, time-domain analysis, regular wave*

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NOMENCLATURE

PTO	Power Take-off
OSWEC	Oscillating Surge Wave Energy Converter
BHOSWEC	Bottom-hinged Oscillating Surge Wave Energy Converter
FOSWEC	Floating Oscillating Surge Wave Energy Converter
Dof	Degree of Freedom
WEC	Wave Energy Converter
I	Moment of inertia
A	Wave amplitude
t	Plate thickness
L	Plate height
W	Plate width
BEM	Boundary Element Method

1. INTRODUCTION

The high potential of ocean wave energy encourages many researchers to design and develop many types of wave energy converters[1, 2]. The most usable wave energy converters are wave-activated body devices, including a moving object relative to its base [3]. The relative velocity can be translational as a point absorber[4] or rotational as flap-type oscillating surge wave energy coveters OSWEC [3]. A hydraulic PTO composing a hydraulic cylinder-piston pump, one end is attached to the flap, and the other side is joined to a base, is responsible for converting the mechanical vibration into the high-pressure fluid. This pressurized fluid rotates a rotor to generate electricity. The first attempt for such a device was the concept of a buoyant cylinder oscillating rotationally around a hinge under the wave velocity. Oyster was also one of the pioneer ideas for bottom hinge OSWEC (BHOSWEC), with 315 kW and 800 kW output power in 13 m [5]. Renzi et al. [6, 7] proposed a semi-analytical methodology to obtain the hydrodynamic coefficients and calculate the pitch displacement of the plate in a range of incident wave periods. Linear wave theory was assumed, and the capture factor with respect to wave period was derived. In terms of efficiency, different parameters can affect the performance of a WEC. Gomes et al. [8] investigated the effect of change in key parameters such as plate dimensions and the linear PTO damping on the efficiency and power

obtained.
Similar concepts have been used by other researchers [9, 10]. Dividing the flap into smaller sizes and creating a modular or array of flaps is a specified design that has also been investigated. Sarkar et al. [11] studied the dynamic properties of the divided flap into several segments with their Degrees of Freedom (DoF). It was observed that the modular concept leads to more energy at higher wave periods compared to the single one. Saeidtehrani [12] presented a methodology to study the behavior of an array of flaps installed on breakwater utilizing experimental and numerical simulation.
The concept of floating OSWEC in offshore sites leads to specified designs that many researchers are motivated to develop such devices due to the abundant offshore wave energy. Ruehl et al. [13] conducted the experimental tests on a floating OSWEC (FOSWEC), including the two flaps attached to the floating platform. A linear controller was tested in regular and irregular waves in a similar suggested design for a dual-flap floating oscillating surge device [14]. The other floating concept was proposed by Li et al. [15], which is made of two flaps with an average density equal to the water density. The upper flap is buoyant, and the lower one is gravity. The output power directly depends on the relative pitch rotational speed between two flaps and the imposed rotational PTO in the hinge. The numerical results showed that the floating device has a smaller resonant period and optimal power take-off damping than a traditional bottom-hinged flap. This concept of a self-floating wave energy converter was also shown to be efficient only in a short range of wave frequency and PTO damping.
As mentioned, the concept of FSOWEC is associated with design complexities to achieve efficient operation. Most researchers tend to design FSOWEC devices to capture abundant wave power in oceans. The present study aims to examine the possibility of extracting power from ocean waves by a new proposed design, including a vertical flap and floating horizontal plate. One of the main objectives of the present research is to check if such a design works appropriately in deep-sea locations and determine which specified dynamic behavior contributes to the output power. The upper one is a vertical buoyant flap, and the lower one is a horizontal base with the role of gravity. A Boundary Element code-based software is utilized to investigate this concept's hydrodynamic behavior and performance. It will be shown that such a design is able to capture higher wave power in the anti-phase displacement condition of two flaps in the specified value of damping. Therefore, this concept can be developed to overcome the shortcomings of the floating WEC concepts proposed now.
Several concepts for Oscillating Surge Wave Energy Converters have been invented and presented so far. Compared to other devices that are excited by the surge motion of the incoming waves, our concept is novel as the motion of the upper and the lower flap are coupled in a way that takes advantage of both the heave and surge motion of the body to generate anti-phase motions. Conventional OSWECs are fixed at the sea bottom, and they generate wave power only by the surge motion of water particles. A major limitation for bottom-fixed WECs is that for a constant wave amplitude, one needs to increase the dimension of the flap to capture higher wave power, which is associated with higher costs and structural loads. This novel concept is based on the idea of capturing wave kinematics in Surge and Heave Dofs to generate power from anti-phase motions of the upper and lower flaps. This way, the structural loads due to fixing the flap to the sea bed will be diminished. Additionally, the offshore area will be accessible to capture abundant wave energy in remote areas. To our understanding, the only published work that can be similar in terms of capturing wave energy by anti-phase motions is [15], which is limited to a narrow range of wave frequencies. However, our concept overcomes this problem and shows efficiency in a wide range of waves.
This paper is structured as below: Section 2 introduces the components of such a device and the considered case studies. In section 3, the theoretical background and the governing mathematical equations of the proposed design are presented. In section 4, the power results for FSOWEC are presented and discussed.

Table 1. Specifications for FOSWEC

	FOSWEC	
	Upper Flap	Base
$L\ (m)$	9	9
$W\ (m)$	18	18
$t\ (m)$	1.8	1.8
$Mass\ (kg)$	94650	552950
Submerged volume (m^3)	291.6	291.6
$I_{x,G}(kg.m^2)$	3.25E+06	1.49E+07
$I_{y,G}(kg.m^2))$	6.97E+05	1.95E+07
$I_{z,G}(kg.m^2))$	2.56E+06	4.60E+06

2. CASE STUDY

The new proposed WEC device in the present study is a floating double flap hinged to each other with a rotational joint. The system should be designed in such a way that the total weight and buoyancy are the same. The other crucial point is related to the reserve buoyancy of the upper vertical flap responsible for restoring the WEC oscillating part to equilibrium in vertical oscillations. The dimensions and specifications are presented in Table 1. The schematic view of these two systems BHOSWEC joined on a fixed base as a sea bed, and FSOWEC located at an offshore site are depicted in Figure 1 and Figure 2 respectively.

3. MATHEMATICAL GOVERNING EQUATION

The governing equations (1)- (8) for a floating WEC composed of a vertical buoyant flap and horizontal gravity base can be derived through Newton's second law in the translational and rotational directions. Each flap has 6 degrees of freedom, and a hinge constraint limits these degrees of freedom. The equations are just presented in pitch and heave direction for each flap to present a better understanding for the readers about the dynamic behavior of the problem. However, all the results are automatically obtained based on the considered exact equations in the solver of AQWA. Due to the exerted constrain, the motion of the upper flap is linked to the lower one, and each flap's movement affects the other flap's dynamic motion. Therefore, the equations are coupled with each other. It is noted

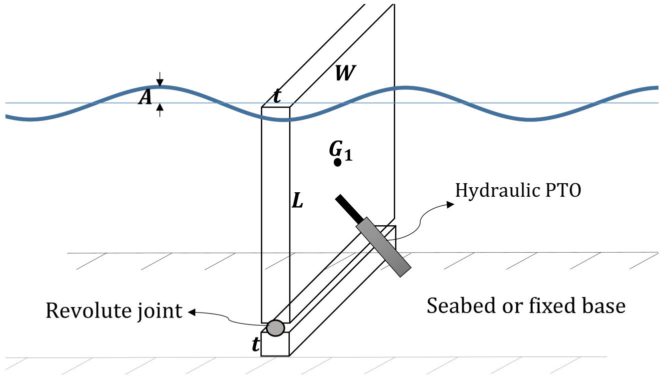


Fig. 1. Bottom-Hinged OSWEC (BHOSWEC)

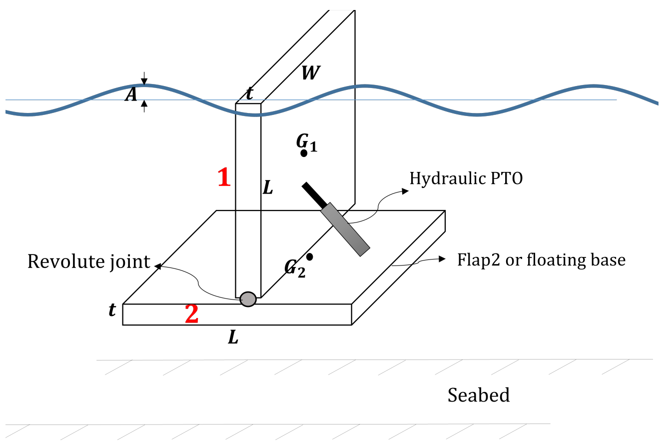


Fig. 2. Floating OSWEC (FOSWEC)

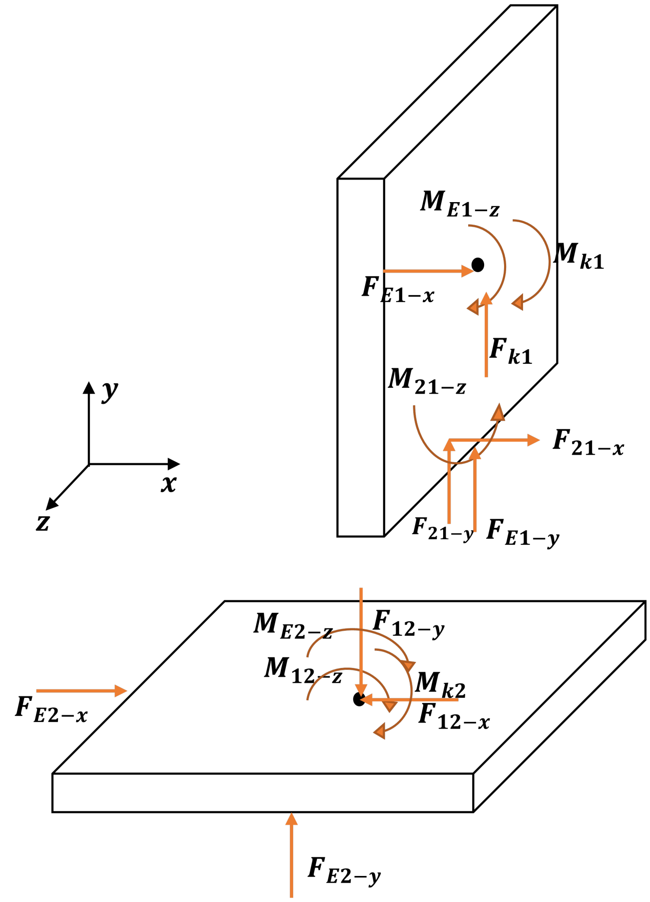


Fig. 3. Free body diagram of exerted forces and moments on the vertical buoyant flap and horizontal base.

that the PTO hydraulic piston that exists in real conditions can be mathematically modeled by applying a linear, rotational damping value in the joint through the Aqwa software. Equations (1) and (2) are related to the total applied toque on the Flap1 (upper) and Flap2 (lower) around the center of mass which is equal to the mass moment of inertia value multiplied by rotational acceleration. Equations (3) and (4) are the translational second law of Newton in the y-direction, and Equations (5) and (6) are similar for the x-direction. Equations (7) and (8) are the two flaps' kinematic translational and rotational relations. These equations are generally nonlinear

$$I_{G1-z}\,\ddot{\theta}_1 = M_{E1-z} - M_{21-z} - F_{21-x}\,(0.5L_1) + F_{21-y}\,(0.5L_1)\,\theta_1 + \; M_{k1} \tag{1}$$

$$I_{G2-z}\,\ddot{\theta}_2 = M_{E2-z} - M_{21-z} - F_{12-x}\,(0.5L_2) + \; M_{k2} \tag{2}$$

$$F_{21-y} + F_{E1-y} - m_1 g + \; F_{k1} = m_1\,\ddot{y}_1 \tag{3}$$

$$F_{12-y} + F_{E2-y} - m_2 g = m_2\,\ddot{y}_2 \tag{4}$$

$$F_{21-x} + F_{E1-x} = m_1\,\ddot{x}_1 \tag{5}$$

$$-F_{12-x} + F_{E2-x} = m_2\,\ddot{x}_2 \tag{6}$$

$$\ddot{x}_1 = \ddot{x}_2 + 0.5L_1\left(\ddot{\theta}_1\,cos\theta_1 - \dot{\theta}_1^2 sin\theta_1\right) \tag{7}$$

$$\ddot{y}_1 = \ddot{y}_2 + 0.5L_1\left(-\,\ddot{\theta}_1\,Sin\theta_1 - \dot{\theta}_1^2 Cos\theta_1\right) \tag{8}$$

In Equations (1)-(8), I_{G1-z}, I_{G2-z} are the mass moment of inertia around z-axis for vertical flap and base, respectively, and M_{E1-z} and $M_(E2-z)$ are the summation of incident, diffraction, and radiation wave torques applied on flaps, F_{E2-y} are the incident, diffraction, and radiation wave force in the heave direction applied on flap 2. M_{21-z}, M_{12-z}, F_{12-y}, F_{21-y}, F_{12-x} and F_{21-x} are the reactive torques and forces between two flaps. y_1 and y_2 are the displacement of the mass center of the two flaps, M_{k1}, M_{k2} are the restoring moment that can be introduced by pitch stiffness in motion equations. The pitch stiffness depends on the second-moment area of the cut water-plane area, submerged volume, the coordinate of the center of gravity, the flap mass, and the y-coordinate of the center of buoyancy. F_{k1} is the hydrostatic force exerted on flap 1 that can be defined by the linear stiffness value multiplied by the y-displacement parameter. As flap 2 is fully submerged and does not have a cut water-plane surface area, there is not any assigned restoring force or stiffness value. These eight equations create a system of equations including eight unknown parameters that can be calculated through a frequency domain analysis. This type of analysis needs the governing equation to be linear. Consequently, the equations can be linearized when oscillation amplitude is assumed to be

small enough; that is not the scope of the present study. The present study uses the time domain analysis of Ansys Aqwa to derive the desired results.
To transform the time domain equation into a frequency domain equation, the wave excitation forces are considered to be in the form of amplitude multiplied by the term $e^{i\omega t}$ The rotational amplitude response of each flap can be defined in complex form as $\Theta_1 e^{i\omega t}$ and $\Theta_2 e^{i\omega t}$. Θ_1 and Θ_2 are not totally real numbers, and they can be complex numbers, including the specified phase. This means that the rotational displacement of each flap has a phase difference with wave excitation force and even with each other. Hence, in this condition, the averaged output power of FSOWEC is defined through the average of the instant power in a cycle as equation (9). The averaged power is dependent on the relative rotational displacement amplitude between the flap and base.

$$\begin{aligned}\bar{P}(\omega) &= \frac{1}{T}\int_0^T P(\omega)\,dt = \frac{1}{T}\int_0^T B_{pto}\dot{\theta}_{12} * \dot{\theta}_{12}dt \\ &= \frac{1}{T}\int_0^T B_{pto}\left|\Theta_{12}\right|\sin(\omega t+\varphi) * \left|\Theta_{12}\right|\sin(\omega t+\varphi)\,dt \\ &= \frac{1}{2}\omega^2 B_{pto}\left|\Theta_{12}\right|^2 = \frac{1}{2}\omega^2 B_{pto}\left|\Theta_1-\Theta_2\right|^2\end{aligned} \tag{9}$$

B_{pto} is the PTO damping modeled by a damped hinge, ω is the wave frequency, Θ_1 and Θ_2 are the complex pitch amplitude of flap1 and 2, respectively. $\dot{\theta}_{12}$ and Θ_{12} is the amplitude of the relative pitch velocity and displacement between the vertical flap and horizontal base. It should be emphasized that relative pitch amplitude can be calculated using time-domain analysis. This is explained in the next section.
It is worth mentioning that each of the radiation forces and moments due to the radiation wave can be decomposed into two terms in the phase of velocity and acceleration. Translational radiation force is the multiplication of added mass and translational acceleration plus the multiplication of damping and translation velocity. The radiation moment is calculated in the same procedure, only the translational terms should be changed in the rotational direction. The mentioned excitation force and moments due to incident, diffraction, and radiation waves can be calculated through an accurate method of Computational Fluid Dynamics (CFD), which is time-consuming. In most marine hydrodynamic analyses, the fluid can be assumed to be irrotational and inviscid such that determining the potential function is a criterion to distinguish the fluid properties as velocity and pressure.
On the other hand, the diffraction theory based on the solution of the Laplace equation of the potential function is the other proper approach that can result in the precious values of the mentioned forces and moments. ANSYS AQWA software is utilized to compute the desired values based on the diffraction theory and Boundary Element approach for solving the dynamic governing equation. The total potential function of the fluid can be expressed as the equation (10).

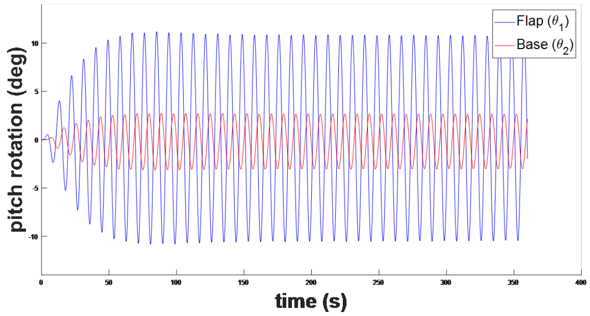
$$\varphi = \varphi_i + \varphi_r + \varphi_d \tag{10}$$

Where φ_i, φ_r and φ_d are the potential functions of the incident wave, radiation wave, and diffraction wave, respectively. φ_i can be computed by the airy linear theory, and the diffraction theory is utilized for deriving φ_r and φ_d. The pressure can be extracted through the Bernoulli equation when the potential functions are determined. In the end, the integral of pressure on the total wet surface area results in the applied wave excitation forces that are conducted in AQWA software. It is noted that, although the expressed equations (1)- (8) are related to just heave and pitch direction, ANSYS AQWA solves each flap's six-degree freedom equations.

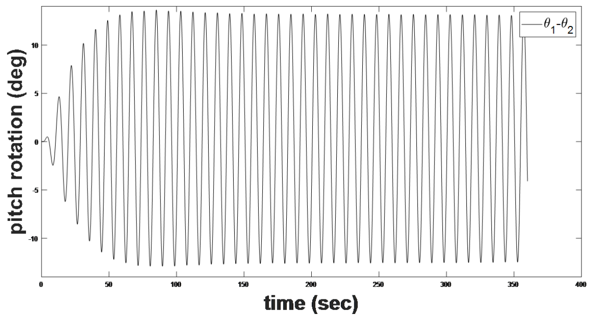
4. RESULTS AND DISCUSSION

This study examines if a floating flap-type WEC can extract power on an offshore site. The previous study of Abazari and Aziminia checked the validity of the used approach in Ansys Aqwa for a BHOSWEC with a fixed base [16], and the oscillating flap was fully submerged. Therefore, the same procedure is used to analyze the hydrodynamic behavior of that flap attached to a floating horizontal plate while it is floating as a surface-piercing body near the free surface in still water conditions.
The power performance of the BHOSWEC is evaluated by applying the specified PTO damping for each wave excitation period. It was shown that the power depends on the frequency, damping, and rotational displacement[16]. Therefore, the optimum damping for each considered excitation period should be computed separately. A control system can adjust this variable damping to its optimum value for each wave excitation period in real conditions.
For analyzing the FOSWEC and deriving its hydrodynamic response, it is simulated and analyzed based on the BEM code in time domain analysis under a regular wave with an amplitude of 0.3 m and a wide range of the wave excitation period, between 3 to 14 seconds. As indicated in equation (9), the power for a FOSWEC depends on the relative displacement amplitude. For this reason, the resulted pitch time history of flap1 is subtracted from the ones related to flap 2 to derive the relative pitch amplitude. Figure 4 shows the pitch displacement time signals of flap1 and flap2 and their relative displacement for a wave period of 9 s.

Generally, the relative rotational amplitude is not exactly the difference between the amplitude values of each flap. This is attributed to the fact that there is a phase difference between the pitch time signals of each flap. The optimum situation occurs when there is a 180° phase difference between the pitch displacement of flap1 and flap 2, as shown in Figure 5. In this condition, the relative pitch amplitude is maximum and defined as the sum of each assigned pitch amplitude. Consequently, the output power is the maximum value. It is noted that the time history of the displacement signals is not totally steady-state. At the beginning steps of the motion, its behavior is transient, and gradually the displacement will be a steady-state signal showing a constant amplitude versus time. This steady-state amplitude should be considered as the recorded amplitude.
It is emphasized that only an anti-phase situation for the displacements of the two flaps is not the main reason for occurring maximum power. Based on equation (9), the power is dependent on the damping value. On the other hand, damping can affect each flap's amplitude value and the phase difference between the two flaps. It means that increasing the damping has two effects. One is the direct positive effect of damping on the output power, and the other may be negative due to decreasing relative displacement. The expanded and developed forms of the governing equations are required to derive the exact optimum value of the PTO damping for the FOSWEC device.



(a) Pitch displacement of flap1 and flap 2



(b) Relative pitch displacement between flap1 and flap2

Fig. 4. Time history of pitch displacements

Then, based on the analytical solution of the linear equation, the optimum PTO damping can be calculated. This procedure is not in the scope of the present study.

However, in this research, a constant damping value for a wide range of wave periods was considered in FOSWEC. This specified value of PTO damping is tuned such that a phase difference closed to 180° is observed between the relative pitch displacement of the vertical flap and horizontal base in FOSWEC at a range of wave periods between 3 s to 14 s. Additionally, the inertial parameters of this device are adjusted such that the highest pitch rotation occurs at waves with a period of 8-10 s, which is known as the dominant wave periods for unknown sea states. Consequently, the proper damping value for the dominant wave excitation period can be estimated approximately through several runs in Ansys Aqwa. In this study, a damping value of 10^6 Ns/m is selected in the hinge as the PTO damping for the considered wide range of wave periods. The observed relative displacement is approximately maximum because the flaps' displacement motion is anti-phase. The relative pitch rotational displacement between the vertical flap and the horizontal base is computed by supposing the constant value for PTO damping of FOSWEC. Figure 6 shows the steady-state relative pitch amplitude in FOSWEC at three different wave amplitudes of 0.3 m, 0.5 m, and 0.7 m. Although the linear airy wave theory is considered, the AQWA solves governing equations accurately through the time domain analysis and convolution integral in nonlinear form.
The weight of the upper and the lower body are important parameters influencing the system's performance. As the total weight of the device must stay constant and equal to the buoyancy force from the fluid, the weights can be changed in a way that the summation of the total weights stays constant.

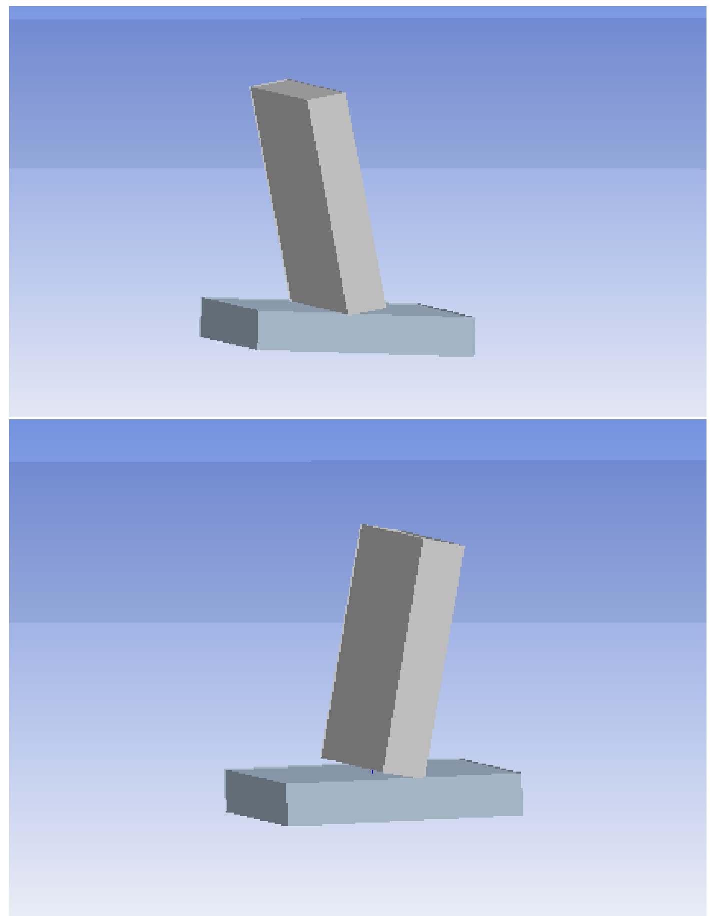


Fig. 5. A schematic view from the anti-phase pitch displacement of the vertical flap and horizontal base of FOSWEC

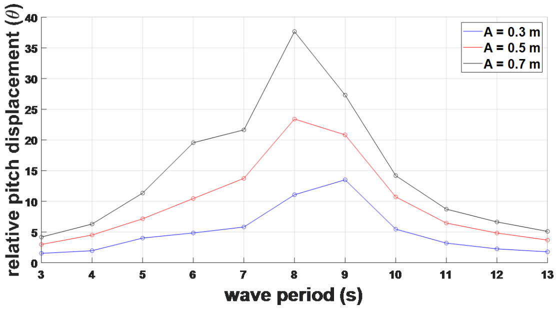


Fig. 6. Relative pitch displacement amplitude versus wave period at different wave amplitudes

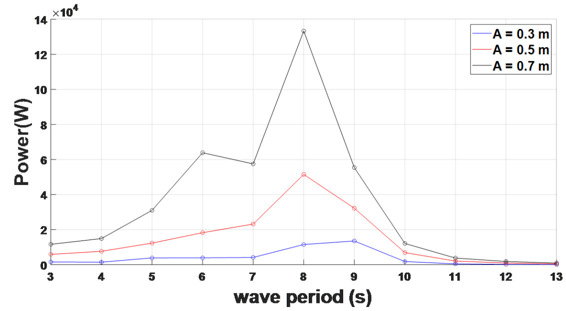


Fig. 7. Output power of FOSWEC versus wave periods at different wave amplitudes

However, as the weight of the upper and lower body changes, the moment of inertia and hydrostatic restoring moments will be changed. Therefore, the natual period of the system and the period at which the maximum power can be generated will be altered. It worth mentioning that hydrodynamic coefficients such as added moment of inertia and radiation damping will not change as long as the dimensions are constant.

It is demonstrated from Figure 6 that the peak period of relative displacement is around the most dominant wave periods of 8-9 s at different wave amplitudes.

After determining the relative displacement amplitude, the power of FOSWEC is computed based on equation (9). The results of FOSWEC power are shown in Figure 7, considering constant damping for all the considered excitation periods. This confirms that the suggested floating WEC works properly for extracting an efficient power at dominant sea states. Although the generated power of FOSWEC is for the assumption of constant damping, it is expected that the power improves by considering the optimum damping at each wave period. Therefore, the obtained power in Figure 7 is an underestimated outpower for FOSWEC by a constant damping value. The damping that should be tuned for each wave period increase costs due to the required control system. The other crucial point is related to the resonance power periods. Looking at the graphs in Figure 7, it is also clear that the peak period is approximately the same as the peak period of the relative displacement around the most dominant wave periods. The drop down power value for T=7 s compared to T=6 s may be attributed to this fact the larger displacement of T=7s relative to one for T=6 s can not overcome the effect of corresponding frequencies based on equation (9).

It is noted that the power values of about 15-120 KW can be generated at most wave dominant periods of 8-9 s. The range of power values related to the new proposed FOSWEC is in order of power values of the BHOSWEC specially for A=0.3 m [16].

The diffraction theory in AQWA based on the solution of the Laplace equation does not consider the viscose effects as in the vortex shedding phenomenon around the flap. The vortex shedding may influence the dynamic behavior of the floating device. Moreover, mooring is needed for station keeping of the WEC under more realistic and comprehensive sea states. Consequently, these effects should be investigated in future works.

5. CONCLUSIONS

Changing the constrain on the base of a BHOSWEC may change the dynamic properties and resulting power. A new floating wave energy converter is suggested in the present study. It is assumed to include a base as the horizontal plate attached to one end of the hydraulic piston and a vertical flap attached to the other end of the hydraulic PTO system. The hydrodynamic analysis of this system was conducted by commercial BEM-based code by solving the Laplace equation. The results showed that even by considering a constant PTO damping for FOSWEC, an acceptable power value of about 15-120 KW can be extracted at most wave dominant periods of 8-9 s. The results showed that the new proposed system works well in calm sea states with amplitudes of 0.3, 0.5, and 0.7 m. Moreover, increasing the wave amplitudes more than the considered values in the present study considerably enhances the output power that requires a station-keeping mechanism as a mooring for stabilizing the WEC.

REFERENCES

1. F. d. O. Antonio, "Wave energy utilization: A review of the technologies," Renewable and sustainable energy reviews, vol. 14, pp. 899-918, 2010.
2. M. Folley, B. P. Suarez, and T. Whittaker, "An autonomous wave-powered desalination system," Desalination, vol. 220, pp. 412-421, 2008.
3. A. Babarit, "A database of capture width ratio of wave energy converters," Renewable Energy, vol. 80, pp. 610-628, 2015.
4. S. Zou, O. Abdelkhalik, R. Robinett, G. Bacelli, and D. Wilson, "Optimal control of wave energy converters," Renewable energy, vol. 103, pp. 217-225, 2017.
5. T. Whittaker and M. Folley, "Nearshore oscillating wave surge converters and the development of Oyster," Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 370, pp. 345-364, 2012.
6. E. Renzi and F. Dias, "Hydrodynamics of the oscillating wave surge converter in the open ocean," European Journal of Mechanics-B/Fluids, vol. 41, pp. 1-10, 2013.
7. E. Renzi, K. Doherty, A. Henry, and F. Dias, "How does Oyster work? The simple interpretation of Oyster mathematics," European Journal of Mechanics-B/Fluids, vol. 47, pp. 124-131, 2014.
8. R. Gomes, M. Lopes, J. Henriques, L. Gato, and A. Falcão, "The dynamics and power extraction of bottom-hinged plate wave energy converters in regular and irregular waves," Ocean Engineering, vol. 96, pp. 86-99, 2015.
9. T. Mäki, T. Mucha, and M. Vuorinen, "Waveroller one of the leading technologies for wave energy conversion," in Proceedings of the 4th International Conference on Ocean Energy (ICOE), 2014.
10. W. Chehaze, D. Chamoun, C. Bou-Mosleh, and P. Rahme, "Wave

roller device for power generation," Procedia Engineering, vol. 145, pp. 144-150, 2016.
11. D. Sarkar, K. Doherty, and F. Dias, "The modular concept of the oscillating wave surge converter," Renewable Energy, vol. 85, pp. 484-497, 2016.
12. S. Saeidtehrani, "Flap-type wave energy converter arrays: Nonlinear dynamic analysis," Ocean Engineering, vol. 236, p. 109463, 2021.
13. K. Ruehl, D. D. Forbush, Y.-H. Yu, and N. Tom, "Experimental and numerical comparisons of a dual-flap floating oscillating surge wave energy converter in regular waves," Ocean Engineering, vol. 196, p. 106575, 2020.
14. D. D. Forbush, G. Bacelli, S. J. Spencer, R. G. Coe, B. Bosma, and P. Lomonaco, "Design and testing of a free floating dual flap wave energy converter," Energy, vol. 240, p. 122485, 2022.
15. Q. Li, J. Mi, X. Li, S. Chen, B. Jiang, and L. Zuo, "A self-floating oscillating surge wave energy converter," Energy, vol. 230, p. 120668, 2021.
16. M. M. A. A. Abazari, "Enhanced power extraction by splitting a single flap-type wave energy converter into a double configuration," Renewable Energy Research and Applications, 2022.