Hydrodynamical Analysis of Bottom-hinged Oscillating Wave Surge Converters

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Abstract

In this work an analysis of the performance of a bottom-hinged, fully-submerged oscillating wave surge converter is presented. This analysis was performed in order to obtain the necessary insight in how the different parameters of the device influence its power extraction and efficiency. A mathematical model for a single oscillating wave surge converter as part of an infinite in-line array of devices is presented, assuming it is subjected to the action of regular, monochromatic waves. Potential fluid flow is also assumed. This mathematical model was implemented in a MATLAB algorithm and a brief overview of its convergence analysis is presented. Using this algorithm, the influence of several parameters of the system (flap width, spatial period between devices, flap height, water depth and flap thickness) over the performance of the device is evaluated. It is shown that best performance is attained by wide flaps which block the full water column, from seabed to water surface. Also, to maximise efficiency the device must be designed for the most common sea states.

Keywords: Oscillating wave surge converter, wave energy, energy converter, nearshore resource, ocean engineering

1. INTRODUCTION

Renewable energy sources are being largely developed in order to replace fossil fuels. Wave energy represents a huge resource, largely unexploited. Unlike other renewable sources of energy, it is not yet well developed and there is no unique leading technology to exploit this resource. The potential of wave energy is vast and has stimulated the interest of many countries that could employ wave energy as a secure and reliable source of electricity in the future.

In order to make wave energy technologies economically viable, it is necessary to study the parameters which influence their performance and find the best parameter set. To achieve this goal regarding oscillating wave surge converters (OWSC), this work describes an hydrodynamic analysis of a bottom-hinged flap in which is studied the influence of several parameters in the performance of this type of wave energy converters (WEC), using an semi-analytical approach by implementing a MATLAB algorithm.

In Section 2 the characteristics of an OWSC are presented.

The mathematical model and governing equations of the device are explained in Section 3.

Section 4 comprises the hydrodynamic coefficients analysis and the summary of its results is divided in 4 subsections, one for each parameter studied: flap width, spatial period, flap height and water depth, and flap thickness.

In Section 5 the conclusions of the analysis are summarised and the possibilities for future work on this subject are briefly explored.

2. OSCILLATING WAVE SURGE CONVERTER

Wave energy technologies are still in their early stages of development and a wide range of different technological solutions exists, with a great variety in terms of design and working principle, each exploiting different characteristics of the location in which they are deployed.

The OWSC is a nearshore device usually located at water depths between 8 m and 20 m. These converters
interact with the dominant surge forces found in the nearshore wave climate: as the waves approach the shore, the movement of the water particles becomes elliptical and the horizontal acceleration of those particles increases, making this location optimal to an OWSC device [1].

A bottom-hinged OWSC consists of a buoyant oscillating flap hinged to a foundation on the seabed. The pitching movement of the oscillator drives hydraulic pistons pressurising fluid (either water or oil) and the hydroelectric plant, which can be onshore or attached to the device, converts the hydraulic pressure into electrical power by causing the pressurised fluid to turn an electrical generator. An example of such a configuration is illustrated in Fig. 1. The device used for the presented analysis, as in Fig. 1, is considered to have a submerged PTO system, although it is totally submerged unlike what is illustrated below.

![Fig. 1 - Bottom-hinged OSCW equipped with a submerged electrical generator (adapted from [2])](image1)

As many other wave energy converters, OWSCs comprise three main components: the prime mover, the foundation and the PTO system. The prime mover is the buoyant flap (the paddle in Fig. 1) reacting to the horizontal motion of water particles. It is responsible for converting wave energy into mechanical energy, before it is turned into electricity. The foundation is the part to which the flap is hinged and keeps it attached to the bottom of the sea. Finally, the PTO system activated by the movement of the flap is responsible for transforming the device’s mechanical energy to a more suited form of energy to be converted into electricity by the generator. This is important for OWSCs in particular because the pitching movement is not useful in driving the generator directly and so a transmitting system is necessary. Single or multiple PTOs can be embedded to one device or be located at the shore.

Pitching-flap converters operate by following the movement of the incident waves without being highly tuned. Folley et al. [3] and Renzi and Dias [4] have shown that the coincidence of natural tuning and maximised wave torque are mutually exclusive, since the natural frequency of pitching of this kind of converters is not close to the predominant incident wave frequencies that are registered at the most favourable locations.

### 3. Mathematical model

In order to assess the influence of different parameters of the OWSC in the power extraction and efficiency of the device, it was necessary to know how to describe these variables as functions of those parameters using appropriate functions, for which a mathematical model is necessary. In this section the mathematical model and governing equations of the system are introduced by taking as reference the works of Renzi and Dias [4,5].

#### 3.1 Governing equations and water-solid interaction

Consider an infinite in-line array of bottom-hinged OWSC as illustrated in Fig. 2, parallel to the shoreline, in an open ocean of constant depth h.

Each converter of the array – Fig. 2 b) – is treated as a rectangular flap of width w, height h and thickness a and is placed upon a foundation of height c. The flaps oscillate about a frictionless hinge under the action of monochromatic, regular incident waves of period T and amplitude Aᵢ coming from the right side as represented below. Since the practical application of such a system is typically in the nearshore, where wave fronts are almost parallel to the shoreline because of refraction [6], all the incoming wave fronts are assumed to be parallel to the width of the flap.

![Fig. 2 - Geometry of the system of an in-line array of devices in dimensional variables; a) plan view; b) section](image2)

A Cartesian system of reference O (x, y, z) is set at an origin O on the water level, as illustrated above, and t and θ(t) denote the time and the angular displacement of the flap, respectively. The reference angle θ = 0° corresponds to the vertical position of the flap, being the pitching direction positive when anticlockwise.

The fluid is assumed to be inviscid and incompressible and the flow irrotational. Therefore, there exists a velocity potential Φ(x, y, z, t) which satisfies the Laplace equation

\[
\nabla^2 \Phi(x, y, z, t) = 0
\]  

(1)
In order to fully define the problem, boundary conditions are required at the ocean bottom, at the free-surface and at the surfaces of the flap and hinge. In every boundary, where each particle of the fluid is considered to be adjacent to it and the fluid is assumed to move only tangentially, a condition which links the velocity of the boundary to the velocity of the particle must be imposed.

The surfaces of the flap, hinge and foundation are considered impermeable and so the fluid can only move tangentially to these surfaces. Since only inviscid fluid is being considered, there is no friction between the fluid and the solid surfaces and no condition is required on the tangential component of the fluid velocity. At a static, solid surface the velocity of the fluid perpendicular to the surface will be zero. In particular, if this surface corresponds to the horizontal bottom of the ocean with constant depth $h$, where vertical velocity is considered zero at all times, we have

$$\frac{\partial \Phi}{\partial z} = 0 \quad \text{at} \quad z = -h \quad (2)$$

On the free surface $z = \eta(x,y,t)$, which is the interface between water and open air, two boundary conditions are necessary: one to assure that the fluid particles on the surface stay on the surface (kinematic boundary condition) and another one to relate the fluid pressure to the atmospheric pressure (dynamic boundary condition). As stated in [7], the fluid particles near the surface remain near the surface as long as the waves don’t break, i.e. as long as the wave motion is smooth. Following [7,8], equation (3) is the boundary condition at the free surface and states in mathematical terms that a fluid particle at the surface should remain at the surface at all times.

$$\frac{\partial \eta}{\partial t} + v_x \frac{\partial \eta}{\partial x} = v_z \quad (3)$$

This boundary condition regards the motion of the water surface and for this reason it is usually called the kinematic boundary condition.

The dynamic boundary condition assures that the pressure $p$ at the water surface is equal to the atmospheric pressure, which is assumed to be constant. Applying Bernoulli’s equation to the surface line where $z = \eta(x,y,t)$

$$\frac{\partial \Phi}{\partial t} + \frac{1}{2} (\nabla \Phi \cdot \nabla \Phi) + g \eta = 0 \quad (4)$$

This condition deals with the forces on the surface and is therefore defined as the dynamic boundary condition.

Boundary conditions (3) and (4) can be linearised if we assume that the dynamic variables such as $\Phi, \eta$ and all their derivatives are small and we neglect small terms of second or higher order, such as $(\nabla \Phi \cdot \nabla \Phi)$. Then, neglecting small terms in equations (3) and (4) and combining them, we get the linearised dynamic-kinematic condition:

$$\frac{\partial^2 \Phi}{\partial z^2} + g \frac{\partial \Phi}{\partial z} = 0 \quad \text{at} \quad z = 0 \quad (5)$$

Boundary conditions (2) and (5) are appropriate to any open-ocean problem using the approximations explained. As showed in [4,5], further boundary conditions are necessary to the specific problem in study.

Referring again to Fig. 2, each flap is able to oscillate on the vertical plane $(x,z)$ under the action of the incoming waves, pitching about the $y$ axis at $(x,z) = (0,-h+c)$, thus representing a system with one degree of freedom.

As shown by Renzi and Dias [5] the problem here stated is equivalent to that solved for a single bottom-hinged converter in a channel [4]. The conditions of the theory in [4] can be adapted and applied to an array configuration, as long as the converters are laid out as an in-line system aligned along the $y$ axis, in which the spatial period between the flaps, $b$, corresponds to the width of the channel.

The analysis was restricted to monochromatic waves of small amplitude, such as $A_i/b \ll 1$, where $b$ is the spatial period between the flaps and will be the length scale of the system, meaning that the incident wave amplitude is small when compared to the reference length scale of the problem. In this condition, the behaviour of the system can be described recurring to the linearised versions of the inviscid, irrotational equations (1), (2) and (5) and the pitching angle of the device can also be considered small [4,9]. Such hypotheses do not allow considering random sea states, vortex shedding effects neither nonlinear diffraction effects, which are situations out of the scope of this work. Furthermore, since $b \gg a$, the thickness can be considered immaterial for calculating the potential (thin-plate approximation).

Following [4], firstly the system should be non-dimensionalised as follows:

$$(x',y',z',w',h',a',h',c') = \left(\frac{x,y,z,w,h_f,a,h,c}{A}\right) \quad (6)$$

$$t' = \frac{\sqrt{b}}{\sqrt{g} t} \quad (7)$$

$$\theta' = \frac{b}{A} \theta \quad (8)$$
\[ \Phi' = \frac{1}{\sqrt{gbdA}} \Phi \]  

Primes distinguish non-dimensional from dimensional physical quantities and \( A \) is the amplitude scale of the wave field.

Recalling the Laplace Equation (1) and the boundary conditions (2) and (5) – no-flux condition on the bottom of the ocean and linearised kinematic-dynamic boundary condition – these can now be rewritten in their non-dimensional form:

\[ \nabla^2 \Phi'(x', y', z', t') = 0 \]  

\[ \frac{\partial \Phi'}{\partial z'} = 0, \text{ for } z' = -h' \]  

\[ \frac{\partial^2 \Phi'}{\partial t'^2} + g \frac{\partial \Phi'}{\partial z'} = 0, \text{ for } z' = 0 \]

In addition to these three boundary conditions, two other should be considered attending to the specific geometry of the device, assuring only tangential motion along the lateral surfaces of the flap, i.e. assuring impermeability of the device. As shown in [4,5], applying the thin-body approximation to the flap, the statement that every fluid particle on the boundary has the velocity of the solid surface yields

\[ \frac{\partial \Phi'}{\partial x'} = -\frac{\partial \phi'(t')}{\partial t'} (z' + h' - c') H(x' + h' - c'), \quad x' = \pm 0, |y'| < w'/2 \]  

along the flap sides normal to the \( x \) axis, where the Heaviside step function \( H \) is used to model the absence of flow through the bottom foundation, and

\[ \frac{\partial \Phi'}{\partial y'} = 0, \quad y' = \pm w'/2 \]

along the flap sides normal to the \( y \) axis. This boundary condition on the sides of the plate is obtained under the assumption that the body is performing small oscillations and therefore (14) can be applied at the equilibrium position of the oscillating body.

3.2 Body Motion

Being the devices hinged to a foundation on the seabed, the movement of each flap resembles that of an inverted pendulum. Subjected to the simple, harmonic perturbation of the incoming waves, the flap oscillates about its equilibrium position (\( \theta = 0^\circ \)) and, considering the actions exerted over the plate as partly inertial, partly elastic and partly damping, the behaviour of the flap can be modelled as a forced damped oscillator. Denoting \( M, D \) and \( E \) as the inertial, damping and elastic coefficients of the system, respectively, and \( \mathcal{F} \) as the sum of the external torque applied on the plate, the motion equation of the device shall have the form

\[ M \dot{\theta}(t) = D \dot{\theta}(t) + E \theta(t) + \mathcal{F} \]  

In Equation (15) \( M, D \) and \( E \) should be replaced with their corresponding contributions. The inertial term comprehends: the moment of inertia of the flap, \( I \); the added inertia, \( \mu \), due to the mass of the water displaced by the flap with its movement; and the inertial characteristic of the PTO system, \( \mu_{pto} \). In the damping coefficient, \( D \), are included the damping characteristic of the PTO system, \( \nu_{pto} \) and the damping due to the radiation of the incoming waves, \( \nu \). Finally, the elastic term considers the elastic characteristic of the PTO system, \( C_{pto} \) and also the elastic characteristic of the flap given by the hydrostatic restoring coefficient, \( C \), which is a restoring moment due to the buoyancy of the flap (the effect of the buoyancy of the flap as it attempts to go back to the vertical position). Replacing these terms in Equation (15) and rewriting it non-dimensionally in the frequency domain, the motion equation of the pitching flap becomes:

\[ \left[ -\omega^2 \left( I' + \mu' + \mu'_{pto} \right) + C' + C'_{pto} \right. \\
\left. - i \omega \left( \nu' + \nu'_{pto} \right) \right] \theta' = F' \]

In a first approach, with the purpose of explaining how the movement of the flap can be determined using expression (16), the PTO system will be considered as a damper, i.e. \( \mu_{pto} = C_{pto} = 0 \). Consequently, the inertial, elastic and damping coefficients of equation (16) will depend only on the geometry of the flap and are easily calculated using the values chosen for the geometric properties.

The moment of inertia about the pitching axis \( y \) is

\[ I = \frac{\rho_{flap} t w (h_y)^3}{3} \]  

and for it to be used in equation (16) it should also be written non-dimensionally, as in (18).

\[ I' = \frac{I}{\rho_{flap} b^5} \]

The hydrostatic restoring coefficient uses the assumption that the centre of gravity of the plate coincides with the centre of buoyancy and that they are locate at half of the height of the plate [10]. The
\[ C = \frac{1 - \rho_f \omega_g}{2\rho_w g twh_f^2} \]  
(19)  

\[ C' = \frac{C}{\rho_f \omega g b^4} \]  
(20)  

The added torque due to inertia and the radiation damping depend on the solutions of the waves' radiation and scattering problem of the system being studied. These problems were addressed in the literature \([4,9]\), in which it is demonstrated that  

\[ \mu' = \frac{\pi w'}{4} \text{Re} \left( \sum_{n=0}^{\infty} \alpha_{on} f_n \right) \]  
(21)  

\[ \nu' = \frac{\omega' \pi w'}{4} \text{Im} \left( \sum_{n=0}^{\infty} \alpha_{on} f_n \right) \]  
(22)  

are the non-dimensional added torque due to inertia and the non-dimensional damping radiation, respectively. In expressions \(21\) and \(22\), \(f_n\) and \(\alpha_{on}\) are real and complex constants, respectively, depending on the solutions of the dispersion relationships. Finally, the non-dimensional complex exciting torque is given by Equation \(23\) corresponding to the action exerted over the plate as if it was held fixed in incoming waves.  

\[ F' = -\frac{\pi w'}{4} i\omega' A_0' \rho f_0 F_0 \]  
(23)  

The damping coefficient of the PTO system can be maximised by tuning the incident wave frequency, \(\omega\), and the natural pitching frequency of the flap, \(\omega_{\text{flap}}\). As shown in \([4]\), for the typical dimension of a OWSC, the natural pitching frequency is not likely to be achieved in normal operating circumstances, attending to the typical sea states in the North Atlantic coast where the ordinary wave period of the incident waves is between 5 and 15 seconds. Therefore, the optimal \(v'_{\text{pto}}\) can be found through \(\frac{\partial P}{\partial v'_{\text{pto}}} = 0\) \([4]\), which yields  

\[ v'_{\text{pto}} = \sqrt{\frac{C + C_{\text{pto}} - \omega^2(1 + \mu' + \mu''_{\text{pto}})}{\omega^2}} + v^2 \]  
(24)  

With all the variables determined up to this point, it is now possible to calculate the average extractable power over a period:  

\[ P' = \frac{1}{T} \int_0^T \left( v'_{\text{pto}} \frac{\partial \theta'}{\partial t'} \right) dt' \]  
(25)  

\[ = \frac{1}{2} \left[ C + C_{\text{pto}} - \omega^2(1 + \mu' + \mu''_{\text{pto}}) \right] + \omega^2 \left( v' + v''_{\text{pto}} \right)^2 \]  

The last variable that needs to be known for the analysis in the next chapter is the capture factor, \(C_p\). This factor allows us to adequately assess the efficiency of the system by dividing the extractable power per unit flap width by the power of the incident wave field per unit crest length.  

\[ C_p = \frac{P}{2 \rho g C_0 A_f^2 w} \]  
(26)  

In the above equation \(C_0\) is the group velocity of the incident waves given by expression \(27\), where \(k\) is the wavenumber given by the dispersion relations.  

\[ C_p = \frac{P_{\text{opt}}}{2 \rho g C_0 A_f^2 w} \]  
(27)  

4. HYDRODYNAMIC COEFFICIENTS ANALYSIS  

Following the formulation presented in the previous chapter, a MATLAB algorithm was implemented in order to assess the hydrodynamical performance of the WEC in study. Once this algorithm was running properly, a convergence analysis was necessary so that the precision of the results could be improved without compromising the computation time needed to execute the proposed calculations. After this convergence analysis, the hydrodynamical analysis was performed and the influence of the geometric characteristics of the flap in the device performance was assessed.  

Taking into account the typical values of the dimensions of OWSC found in the bibliography \([5,11,12,13]\), the initial parameter set was define as presented in Table 1.
### Table 1 - Initial parameter set for the convergence and hydrodynamical analysis

<table>
<thead>
<tr>
<th>Parameter [units]</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>w [m]</td>
<td>26</td>
</tr>
<tr>
<td>h [m]</td>
<td>10</td>
</tr>
<tr>
<td>a [m]</td>
<td>1</td>
</tr>
<tr>
<td>h [m]</td>
<td>16</td>
</tr>
<tr>
<td>b [m]</td>
<td>91,6</td>
</tr>
<tr>
<td>c [m]</td>
<td>4</td>
</tr>
<tr>
<td>A [m]</td>
<td>1</td>
</tr>
<tr>
<td>ρ [kg.m$^{-3}$]</td>
<td>250</td>
</tr>
</tbody>
</table>

The analysis performed consisted in changing the flap width, $w$, the spatial period, $b$, the flap height, $h$, the water depth, $h$, and the flap thickness, $a$, one by one and assessing the influence of changing these parameters in the performance of the device for periods of the incoming waves from 5 to 15 seconds. Three important parameters were studied when changing each geometrical characteristic of the system: the exciting torque exerted by the wave on the surface of the flap; the average extractable power from the OWSC over a period; and the capture factor.

For each change in every set of geometrical characteristics studied, the problem in Section 3 was solved in order to determine the values of $F$, $P$ and $C_F$. In this section, $|F|$ and $P$ were used in their dimensional forms, as given by (28) and (29).

$$|F| = (\rho g A b^3)|F'| \quad (28)$$
$$P = \rho A^2 b^{3/2} g^{3/2} P' \quad (29)$$

In this section, the PTO inertial and linear terms were considered equal to 0. These disregarded terms will be taken into account in Section 5 where the PTO system analysis is discussed.

#### 4.1 Flap width, $w$

The first influencing parameter to be studied was the width of the flap, which was increased from 14 m to 30 m. Increasing the width of the flap corresponds to an increase of the surface area exposed to the action of the incoming waves. Consequently, a larger width determines higher exciting torque, as illustrated in Fig. 3, and since the power is proportional to the square of $|F|$ it also increased with $w$ (Fig. 4).

It was also noted that the 26 metre wide flap captures approximately three times as much power as the 14 metre wide flap, while it is less than two times as wide (considering only the average values of $P$ for each period considered).

Fig. 3 - Behaviour of $|F|$ for different values of $w$

Fig. 4 - Behaviour of $P$ for different values of $w$

Fig. 5 illustrates the behaviour of $C_F$ for different widths and it shows that for periods of the incoming waves below 7 s the capture factor is higher for smaller widths, while for higher values of $T$ the capture factor is higher for wider flaps. This means that the most frequent sea states should be considered when analysing the capture factor of a device and that it is not enough to know which dimension has larger power extractions.

It was also noted that the rate of increase of the capture factor decreases as the width increases (Fig. 6). For instance, the increase of $C_F$ between $w = 14$ m and $w = 18$ m is larger than between $w = 26$ m and...
w = 30 m. These results are illustrated in Fig. 6 and suggest that there is an upper limit above which it is no longer profitable to increase the width of the device in addition to the consequent increased structural loads, which in turn will increase design challenges and structural cost.

4.2 Spatial period, \( b \)

A range of values from 50 m to 200 m was used for the analysis of the influence of \( b \) over the performance of the device. Since it was assumed in Section 3 that the incident wave amplitude is small, such as \( A/b \ll 1 \), values of \( b \) below 50 m were not considered.

Fig. 7 to Fig. 9 illustrate the behaviour of the exciting torque, power and capture factor for different values of \( b \). Different maximum and minimum values of \( |F| \), \( P \) and \( C_F \) were registered for different values of \( b \), but there isn’t one value of the spatial period which is the most favourable to these parameters.

It was concluded that the most common sea climates are the most important factor. As we could establish from Fig. 5, previous knowledge about the most frequent sea states is of the foremost importance when designing a single wave energy converter. From the analysis of figures Fig. 7 to Fig. 9 we find out we can extend this conclusion from a single converter to an array of WEC.

4.3 Water depth, \( h \), and flap height, \( h_f \)

The influence of the water depth and the flap height were analysed together, since increasing \( h \) for a constant \( h_f \) or decreasing \( h_f \) for a constant \( h \) produce equivalent results. In this section the complex exciting torque will not be taken into account, since its expression in the model used does not regard changes in the flap height.

As the water depth decreases the horizontal component of the water particle increases, as a result of the surge phenomenon, and therefore the power and the capture factor increase for smaller depths, as illustrated in Fig. 10 and Fig. 11. This behaviour is also due to the fact that decreasing \( h \) for the same flap height corresponds to increasing the area from the seabed to the water surface that is covered by the device and thus corresponds to reducing the wave energy unexploited in the gap between the top of the flap and the water surface.

Fig. 10 and Fig. 11 show the behaviour of \( P \) and \( C_F \) for different water depths and constant flap height of 10 m. It was found that using higher flaps the rate of increase in the values of \( P \) and \( C_F \) with changing \( h \) was larger. This suggested that different flap heights can influence the way that water depth changes the values of \( P \) and \( C_F \), suggesting a relationship between the
performance of the flap and the ratio \( h_f/h \). This ratio gives the proportion of water from the seabed to the water surface which is swept by the flap, excluding the height of the foundation.

![Fig. 10 - Behaviour of \( P \) for different values of \( h \)](image)

In summary, for the same water depth, the absorbed power and the capture factor will increase as the ratio of \( h_f/h \) increases, because there is a larger area of the flap exposed to the action of the incoming waves. It is important to know in what measure the increase in water depth will increase the structural and maintenance costs, in order to accurately predict the influence of the parameters in study in the performance and cost of the project.

4.4 Flap thickness, \( a \)

The results show that the changes in the flap thickness do not have a noticeable influence on the hydrodynamic coefficients, which validates the initial assumption of neglecting the thickness of the flap. For different values of the flap thickness, the exciting torque exhibited negligible changes, with values differing less than 0.1%. Increasing the flap thickness increased both the power capture (Fig. 14) and the capture factor (Fig. 15).

![Fig. 13 - Behaviour of \( C_F \) for different ratios of the covered water: 50% (solid line) and 70% (dashed line)](image)

![Fig. 14 - Behaviour of \( P \) for different values of \( a \)](image)
It was concluded that the effect of changing the flap thickness is not as significant as the effects of the other parameters, particularly when comparing to the effects of changing the flap width, which variation had the most noticeable effects. Increasing the thickness in 100% (from 0.6 m to 1.2 m) caused the average power and the average $C_F$ to increase in 2% and 1%, respectively, while an increase of 86% in the flap width (from 14 m to 26 m) lead to an increase of almost 200% in the power and 48% in the capture factor. It is important to have in mind that these results would be affected by not using the thin plate approximation and by including the effects of viscosity, which are out of the scope of this work.

5. **Conclusions**

The dynamics of a fully submerged bottom-hinged plate were described by a linear model based on the assumption of potential, irrotational flow. Using a semi-analytical approach, the governing equations of the OWSC were solved using a MATLAB algorithm, in order to study the influence of the hydrodynamical parameters in the performance of the device. Different combinations of flap width, spatial period, flap height, water depth and flap thickness were studied, assessing the impact of these changes in extractable power and efficiency of this type of devices. The analysis was performed for a single device as part of an in-line array of devices.

Results have shown that, in general, the extractable power and capture factor increase with flap width, flap thickness and portion of the water column swept by the plate; it was also concluded that the range of most frequent periods of the incoming waves is the most important factor when defining the converter’s dimensions.

Throughout all the analysis viscous effects were neglected. This assumption is suited for this investigation, since the purpose of this work was not to identify the exact motion and power output of the WEC, but to compare different working conditions and assess those which are favourable to improving the device performance.

During the analysis incident waves were assumed to be harmonic and monochromatic. This approximation is appropriate, since irregular waves can be considered as a superposition of regular waves and therefore the dynamics of the system would still be governed by the same mechanisms and the present analysis remains valid when considering deployment in a real environment.

In addition to the studied parameters, further investigation regarding the inclusion of irregular waves in the analysis would be of most interest, since it would allow studying the influence of different sea states and an optimal device configuration could be established for different wave climate combinations. Including viscous effects and their variation with body shape would be useful in a more accurate power extraction forecast. Finally, combining the capture factor with other performance assessment factors would allow a deeper insight over the parameters influencing the behaviour of the converter studied.

**References**

