Hydrodynamic Performance of Heaving Motion on Cylinder and Conical Two-Body Point Absorber in Low Wave Energy

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Abstract. The motion response of floating wave energy converters (WEC) is crucial for study in the field of ocean energy harvesting. A well-known design for gathering ocean wave energy is the floating wave energy point absorber. It is commonly investigated theoretically using idealised one- and two-degrees-of-freedom dynamic models based on the system's number of free bodies. Using Computational Fluid Dynamics (CFD) software, this article evaluates the hydrodynamic damping of heaving motions on cylinder and conical two-body point absorber wave energy harvesters. The damping performance of both point absorber devices in the Sarawak zone was evaluated using a simulation run at low wave heights (0.25m-2.25m) and short wave periods (3.5s-9.5s). Both point absorber bodies are modelled to determine their heaving dynamic motion frequency under calm, medium, and strong wave conditions. This analysis reveals the extensive research being undertaken to advance point absorbers' technical maturity, ultimately paving the way for commercialization and mass production. The results reveal that a cylinder two-body point absorber with a Response Amplitude Operator (RAO) is more efficient than a conical point absorber at absorbing low wave heights.

1. Introduction
The oceans are teeming with waves that have the potential to contribute significantly to the global supply of emission-free electricity. Due to the vast amount of energy contained in the oceans, research into the design, production, and installation of wave energy conversion devices is accelerating [1]. Mustapa [2] developed a map illustrating the graphical distribution of annual mean power density around the globe to identify places with the greatest potential for wave energy development. Due to its high energy density, regularity, and widespread availability, wave energy is one of the most advanced forms of ocean energy and one of the most promising ocean renewable energy resources [3]. Numerical modelling and simulation are crucial in the development of wave energy converters because they allow for the cost-effective evaluation of a wide number of wave energy system design possibilities. Not only is wave energy available for 90% of the time at any particular area, but it is also far more efficient than other renewable energy sources such as solar and wind, which are often only available for 20% to 30% of the time [4]. Energy is extracted from point absorbers by the relative motion of a body moving in response to wave forcing and fixed or immobile structures. Budal and Falnes proposed the concept of harvesting ocean wave energy via a point absorber in 1975 [5]. Numerous scholars rapidly became interested in the concept, and substantial theoretical study was performed to establish its applicability and optimization. Another often used approach is to connect the free-floating buoy to another submerged body, resulting in a two-body arrangement. There are numerous advantages when compared to their single-body sibling. Two-body systems are simple to install since they do not require direct or rigid attachment to the seafloor, allowing them to be used in deeper water with higher available wave power [6].
Aquaboy and PowerBuoy are two prototypes of two-body point absorbers that are still in existence. Aquabuoys are buoyancy aids that assist them in remaining afloat. A huge cylinder known as the accelerator tube is located beneath the float. A piston holds the accelerator tube in the buoy's centre and is connected to the buoy's top and bottom by a tube pump. The relative flow between the piston and the buoy sweeps the tube pump, compressing the water in a Pelton turbine [7]. The PowerBuoy wave energy converter allows a floating buoy to freely sail up and down the wave's height, converting its motion to electricity via an electric generator [8]. The two-body point absorber is designed differently than the Aquabuoy and PowerBuoy prototypes. The Aquabuoy is cylindrical in shape, whereas the PowerBuoy is conical. This study contributes by examining the hydrodynamic heaving response of these two-body point absorbers under Sarawak wave conditions. The virtual model of the point absorber with cylinder and conical point absorber is created using Auto-desk Inventor, a computer-aided design (CAD) application. J.Kim [9] addressed the cylinder two body point absorber, whereas [10] examined a conical two body point absorber's numerical model. CFD software was used to evaluate the fluid problem associated with an existing point absorber device. The WEC system is examined in this study using only wave forces; currents and wind loads are not included. A floating WEC is often constructed in resonance with the encountered wave to maximise wave energy extraction [11].

Malaysia's government has set an audacious goal of boosting renewable energy's share of the country's energy mix (RE). Malaysia now generates approximately 2% of its electricity from renewable sources but wants to increase that to 20% by 2025 [12]. According to Omar [13] and Bahareh [14], the South China Sea contains enormous wave power potential. Sarawak was chosen as the venue for this study. According to preliminary assessments, Sarawak has an average energy potential for intermediate waves. This location provided the wave characteristics employed in this investigation, demonstrating an average energy resource for intermediate waves.

Due to the versatility and compact size of point absorber wave energy converters, they have garnered considerable attention, and related research is ongoing [15]. However, low wave energy conversion efficiency is a typical issue in wave energy converter applications, and it is therefore important to improve wave energy conversion efficiency or lower production costs. Although the study is mostly computational fluid dynamics (CFD), it includes a heave response analysis to emphasise the effect of the device's motion reaction on the results.

The purpose of this paper is to compare the performance of cylinder and conical type two-body point absorbers in heaving motion under three wave situations encountered in the Sarawak zone, using simulated data generated by Computational Fluid Dynamics software.

2. Methodology

A thorough investigation of the entire system is required to obtain a reliable description of WEC's heaving reaction. This research is necessary because the accuracy of the anticipated heaving response is dependent on and affected by the physical attributes and numerical parameters utilised in the design. The research methodically explores a WEC system composed of a cylindrical and conical two-body floating WEC. The following sections will examine the models for the major system components, including the boundary condition, water and wave loading, and the approach for interpreting the simulation results.

2.1. Model of a Wave Energy Converter

In accordance with Fig 1, the components of both point absorber systems were introduced. These components' physical and numerical models will now be built. Fig. 2 and 3 illustrate how both models' boundary conditions are configured (WV: wave flow, O: outflow, S: Symmetry C: Continuative). The apparatus floats horizontally in the x- and y-axes on the surface of an infinitely large body of water. It has a finite depth represented by h and a negative z-direction. While the mooring lines are omitted from this study, the point absorber is allowed to move in response to the waves. The ratio for the cylinder model in this research was 1:6.67 and for the conical model was 1:8.33.
2.2. Water and wave loading

Table 1 summarises the environmental conditions based on the wave height (m) and period (s). Water is defined mathematically as an incompressible, inviscid, and irrotational fluid. As a result, the theory is based on potential flow, with velocity components entirely determined by the gradient of a harmonic velocity potential. Additionally, under the premise of small wave amplitudes, restrictions are applied in accordance with Navier Stokes theory. The point absorber is solely subjected to wave loads in this study; currents and wind loading are not considered. Typically, a floating WEC is tuned to the encountered
wave in order to extract the most amount of wave energy possible. The examination concludes with three distinct wave situations. Wave conditions 1, 2, and 3 respectively denote a calm wave, a medium wave, and a forceful wave. The simulation makes use of a 1:15 ratio.

Table 1. Environmental condition of the case study

| Wave condition | Wave Height, $H_w$ (m) | Wave Period, $T_s$ (s) |
|----------------|-------------------------|------------------------|
| Wave condition 1 | 0.25                    | 3.5                    |
| Wave condition 2 | 0.75                    | 5.5                    |
| Wave condition 3 | 2.25                    | 9.5                    |

2.3. Wave energy converter
The device is modelled in accordance with the geometry, mass, and damping properties specified in Table 2. These proportions match to those of a float at the water’s surface. At still water, the geometric centre of the cylinder intersects the free water surface. As a result, this point serves as the origin of the global coordinate system. The cylinder's mantle and bottom plate contain the majority of its mass. This concentration is employed in static settings to maintain the buoy in a stable balance with a positive metacentric height. Finally, a one-degree of freedom (DOF) damping is incorporated into the model to account for linear power take-off (PTO) damping.

Table 2. Dimension of cylinder and conical two-body point absorber

| Diameter | Cylinder (m) | Conical (m) |
|----------|--------------|-------------|
| Diameter | Outer:11     | Outer:11    |
|          | Inner:1      | Inner:2     |
| Depth    | 7.8          | 12.6        |
| Draft    | 6            | 7           |

3. Results
This section summarises the results of the simulation approach. Internal buoy motion, in particular, is reduced more than outward buoy motion approaches the resonance frequency. This is due to the fact that the internal buoy is lighter than the exterior buoy. The relative heave motion, which is directly proportional to the generation of electric power, is one of the most crucial components of this two-body WEC system.

3.1. RAO response
The figures illustrates the RAO results acquired using CFD simulation software for a variety of wave conditions. The initial motion study of the WEC validated the simulation's existence of temporary start-up effects. After a period of time, the reaction attains the harmonic response predicted by the simulation when the point absorber's amplitude and period of motion responses were constant. To eliminate transitory start-up impacts, several simulation approaches were evaluated using harmonic data covering the time range 5–20 seconds (s). Figure 4 shows the heaving action of a cylinder and conical two-body point absorber in a calm wave. By 0.03 m, the cylinder two-body response was superior to the conical.
At wave condition 2, an intermediate wave, the point absorber's heaving motion appears to be successful, as depicted in figure 5. This results in a more harmonic heave response for both point absorbers. By 0.13m, the conical kind of two-body point absorber produced a greater heaving motion than the cylinder type. The cylinder form exhibited a positive reaction in a strong wave situation, with a 0.13m stroke of the point absorber compared to 0.03m for the conical type, as indicated in figure 6. It established that when a powerful wave occurs, the cylinder's two bodies expand and the absorbed frequency increases in proportion to the wave frequency. In comparison to the first and second wave circumstances, the floating device performed better in this sea state, demonstrating a larger RAO response.

![Fig 4](image1.png)  
**Fig 4.** RAO response of cylinder and conical two-body point absorber in wave condition 1.

![Fig 5](image2.png)  
**Fig 5.** RAO response of cylinder and conical two-body point absorber in wave condition 2.
3.2. Power produce estimation

When the system was tuned to the approaching wave swell, the device produced the highest power. The device's native frequency was set to match the incoming wave frequency throughout this tuning process. The natural frequency was estimated using decay testing. In still water, the device was dragged to full displacement and then released while its time history was recorded. This section summarised the model's calculated power. The float type's height and width varied in reaction to changes in the mass above it. The water mass above the float grows as the wave crest approaches, effectively pulling it down. To mimic the forces acting on the float, Newton equations can be employed. The calculation below explains how the quantity of power generated during this experiment was determined. Equation (1) represents the force produced on the float device by the mass of water; $F_{\text{water}}$ : force, $\rho_{\text{water}}$ : density of water, $H_{\text{float}}$ : height of floaters, $A_{\text{float}}$ : Area of floater and $g$ : gravity. The following equation depicts the power transmitted ($P_{\text{generated}}$) equation (2). It is simply multiplied by the float's velocity ($F_{\text{water}}$), which is equal to the stroke length divided by the half ($2L_{\text{stroke}}$) of the wave period ($T$).

$$F_{\text{water}} = (\rho_{\text{water}} H_{\text{float}} A_{\text{float}})g$$  \hspace{1cm} (1)

$$P_{\text{generated}} = F_{\text{water}} \left( \frac{2L_{\text{stroke}}}{T} \right)$$  \hspace{1cm} (2)

![Fig 6. RAO response of cylinder and conical two-body point absorber in wave condition 3.](image)

![Fig 7. Annual power estimation](image)
The power calculation for a cylinder two-body point absorber in each of the three circumstances is represented in Figure 7. In general, cylinder bodies outperform conical bodies. The greatest potential is found in cylinder two-body point absorber wave condition 3, with an estimated output of 115.5 Mw, followed by wave condition 2, with an estimated output of 60.39 Mw, and finally, wave condition 1, with an estimated output of 15.82 Mw. Additionally, under all wave conditions, the cylinder two-body point absorber has the ability to create a total average of 191.7 Mw of power.

4. Conclusion
The purpose of this project was to design a dual-action cylinder and conical wave energy converter capable of working in Malaysia’s shallow water. On the basis of the foregoing observations and discussion, it can be concluded that both dual-action wave energy converters are capable of generating electricity utilising small-scale waves in Sarawak. With a large draught and volume, a buoy provides radiation damping with a small amplitude and a narrow bandwidth. As a result, the buoy’s capacity is decreased to improve the buoy’s frequency-dependent hydrostatic properties at a particular water depth, hence improving the oscillating system’s performance. The volume of a cylindrical buoy with a considerable draw is reduced while the wetted surface is increased.

Cylinder point absorbers exhibit substantially more motion than conical point absorbers in this investigation. The cylindrical point absorber oscillated at an average height of 0.16 metre, while the conical point absorber oscillated at an average height of 0.11 metre. This mismatch can have a substantial effect on the ability of a point absorber to absorb wave energy. The larger the heave RAO, the more oscillations occurred in the WEC, which resulted in increased energy generation. As a result, cylinder point absorbers are advised because they have been demonstrated to be more efficient when used with Sarawak water.

Given that this research involves computer simulation of a dual-action wave energy converter, it is recommended that a three-dimensional model be generated using CFD modelling. Additionally, by incorporating complicated features such as a mooring system and a variable angle height at the converter's bottom, the dual-action wave energy converter can be employed to generate a smooth wave flow. Thus, these enhanced capabilities may contribute to the efficiency improvement of dual-action wave energy converters.

5. References
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