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Journal of Advanced Research Design

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ISSN: 2289-7984


# Heave Response Amplitude Operator of Point Absorber Wave Energy Converter in Low Wave Energy

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**ARTICLE INFO**

***Article history:***
Received 5 March 2024
Received in revised form 7 November 2024
Accepted 16 December 2024
Available online 31 December 2024

***Keywords:***
Wave energy converter; point absorber; heave response amplitude operator; low wave energy

**ABSTRACT**

Point Absorber Wave Energy Converter (PAWEC) is a floater device that moves up and down with waves. The device absorbs the orbital motion of the wave and utilize the heaving motion to drive the generator, converting the mechanical energy to generate electricity. PAWEC has been famously used by researchers as it is easy for fabrication and installation. Most of the PAWEC prototype and research recently used wave data from European seas which have high wave energy. The objectives of this paper are to analyse the heaving performance of existing PAWEC design in low wave condition in Malaysia and its average of oscillation. There are three existing designs used i.e. Wavestar, Aquabuoy and Ocean Power Technology (OPT). Three wave conditions were considered in this research i.e. 0.03 m, 0.09 m and 0.15 m. The different bottom parameters of the floater play an important role such as curved, cone and flat for effective absorption to produce energy by converted it to electricity. The results show Wavestar and OPT design point absorber Heave Response Amplitude Operator (HRAO) is improved to absorb in low wave height compared to Aquabuoy by average HRAO efficiency 33% and power output of 4(Mw). This analysis highlights the extensive research being done to bring point absorbers closer to technical maturity, paving the way for commercialization and mass production for low wave energy in Malaysia.

## 1. Introduction

Renewable energy is defined by the International Renewable Energy Agency (IRENA) as energy extracted from nature that can be replenished indefinitely [1]. Renewable energy is energy generated from natural resources that does not emit carbon dioxide ($CO_2$) into the atmosphere and does not require the use of fuel to generate electricity. Renewable resources include natural sources such as

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https://doi.org/10.37934/ard.123.1.261271

waves, tidal currents, wind and sunlight. Using these sources reduce the world's reliance on oil and gas while also reducing greenhouse gas emissions from electricity production and consumption. The most advanced forms of ocean energy are ocean wave and tidal current energy, which are predicted to contribute significantly to global warming [2].

Wave energy is a clean and renewable energy that is reliable, realistic, sustainable and economical which can replace all current fuel sources used by the people of this planet. Among the different forms of renewable energy, wave energy has a range of benefits, including the density is higher than that of other renewable energy sources such as solar and wind energy [3]. It was claimed that the intensity is about 2–3 kW/m2 for wave energy, 0.4–0.6 kW/m2 for wind energy and 0.1–0.2 kW/m2 for solar energy [4]. Wave energy resources are enormous, when compared to the electricity consumption as seen by Qiao *et al.,* [5]. CO2 emissions associated with wave energy generation have been claimed to be very low when compared to those associated with non-renewable energy generation, smaller than those associated with solar energy generation and rather comparable to those associated with wind energy generation [6]. Wave conditions can be well predicted ahead of the time. The predicted incoming waves can be used for operational planning [7]. Wave energy converters (WECs) can generate power up to 90% of the time, while wind and solar energy converters can generate power only up to 30% of the time [8].

To date, there have been over 1000 Wave Energy Converter (WEC) design patents filed around the world. There are about 200 different WEC devices in various stages of production and testing at the moment [9]. However, the device's efficiency and performance in low-sea-state conditions remain low. Most current developments are based on extracting wave energy from European seas, where wave height and period are much larger than in Malaysian seas. The wave energy industry in Malaysia is currently in its infancy, with just a few units. Most of the figures on show are still in the early stages of growth, with some undergoing feasibility studies. Early theoretical experiments on a heaving point absorber converter showed that the device's oscillation frequency should match the frequency of the incident waves in order for it to be an effective absorber [10].

Currently existing prototype point absorber prototype are divided into three categories. They are floating freely, fixed to the seabed and integrated to structure. The floating-point absorber is PowerBuoy, Wavebob, Aquabuoy and Swedishbuoy.

Ocean Power Technologies created the PowerBuoy, which is made up of two parts: a floater an d a spar that serves as a second body. The structure consists of a cylindrical structure with one component that is relatively immobile as the bottom end and a second component that moves as the top end floating buoy inside a fixed cylinder due to wave motion. The rising and falling of the waves causes the relative motion of the two components, which is utilised to drive electromechanical generators or hydraulic energy converters [11]. Finevera Renewables developed the AquaBuoy, which is the third generation of two Swedish designs. The original and slanted IPS buoys employ wave energy to pressurise a fluid, which is then used to power a turbine engine. The vertical movement of the top floating buoy drives a large, neutrally buoyant disc enclosed in a long tube under the buoy, which acts as a water piston. The change in hose volume functions as a pump to pressurise the seawater and the water piston motion elongates and relaxes a hose carrying saltwater [12]. A full-scale prototype and a 1 MW pilot offshore in Makah Bay, Washington, have both been used to test the AquaBuoy design. As for fixed to bottom point absorber, they are Corpower by Corpower Ocean, CETO by Carnegie wave energy and Archimedes wave swing by teamwork technology BV.

Malaysia is a tropical region and the weather changes drastically as the monsoon season progresses. The Malaysian government has set an ambitious plan of increasing the percentage of renewable energy (RE) in the country's energy mix. Malaysia currently generates about 2% of its electricity from renewable sources, relatives to the total generation mix and aims to achieve a 20%

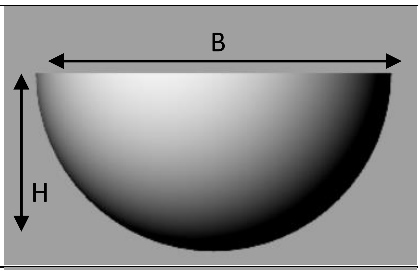
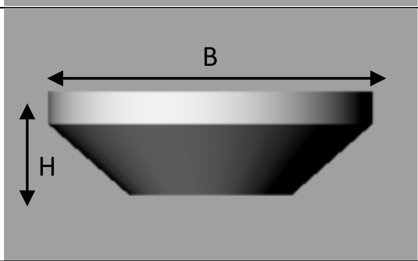
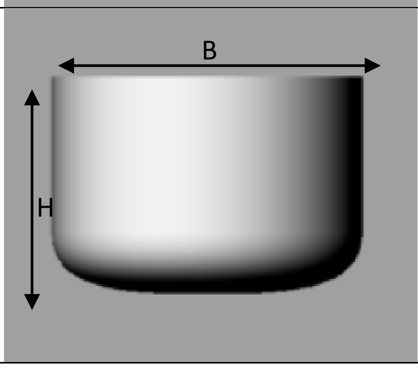
penetration rate by 2025 [13]. The current energy mix for Malaysia power generation is mainly provided by natural gas and coal. Based on Yaakob *et al.,* [14] and Kamranzad *et al.,* [15], the South China Sea has a huge potential for wave power. In this research, the location selected is Terengganu, Malaysia. Based on Yaakob *et al.,* [14], this location has the potential of wave energy resources. In general, the preliminary assessment indicates that Malaysia has an average energy resource for intermediate waves.

The main challenge in the development wave energy converter in Malaysian seas is that the wave height is relatively low [16,17]. The limitation of wave height in Malaysian seas poses a research challenge for the utilize wave energy converter in this region. However, once marine renewable energy is established, the resident in coastline is practical to the most direct impact [18,19]. The wave energy resource in Malaysia is relatively less effective compared to other resources, although it can still be harnessed by focusing on technology that are designed to operate in low wave conditions [20,21]. In this research, the simulation analysis using Flow-3D software for HRAO of point absorber in heaving motion with three wave condition were carried to analyse the hydrodynamic response in low wave characteristics.

## 2. Methodology

A three models of existing point absorber were used in this study. Table 1 shows the dimension of PAWEC and its bottom design type. Based on the design, the bottom part has different type i.e. curved, cone and flat bottom.

**Table 1**
Wavestar, Ocean power technology and Aquabuoy design details

| Design | Side view | Bottom type | Dimension (mm) |
|---|---|---|---|
| Wavestar |  | Curved | Diameter: 400<br>Height (H): 200<br>B/H ratio: 2 |
| Ocean Power Technology |  | Cone | Diameter: 400<br>Height (H): 100<br>B/H ratio: 4 |
| Aquabuoy |  | Flat | Diameter:400<br>Height (H): 280<br>B/H ratio: 1.42 |

### *2.1 Wave Condition*

Table 2 shows the wave condition at Kuala Terengganu. The data of the wave condition is from Yaakob *et al.,* [14]. The wave condition indicates as low (1), medium (2) and high (3) wave.

**Table 2**
Three wave condition for zone Kuala Terengganu

| Wave condition | Wave height (m) | Wave period (s) |
|---|---|---|
| 1 | 0.03 | 1.2 |
| 2 | 0.09 | 1.9 |
| 3 | 0.15 | 2.3 |

### *2.2 Wave Tank Experiment Setup*

The settings utilised in experiment work are similar to simulation setup. The reason for this is to reduce undesired errors that can affect experimental outcomes. In addition, the results were subsequently utilised to validate previous simulation efforts. The model of point absorber is placed on top of the wave absorber which is 25.3m from wavemaker as shown in Figure 1 and a close up perspective view of the model as in Figure 2. The wave tank size is 30m long, 10m wide and 6 m depth.

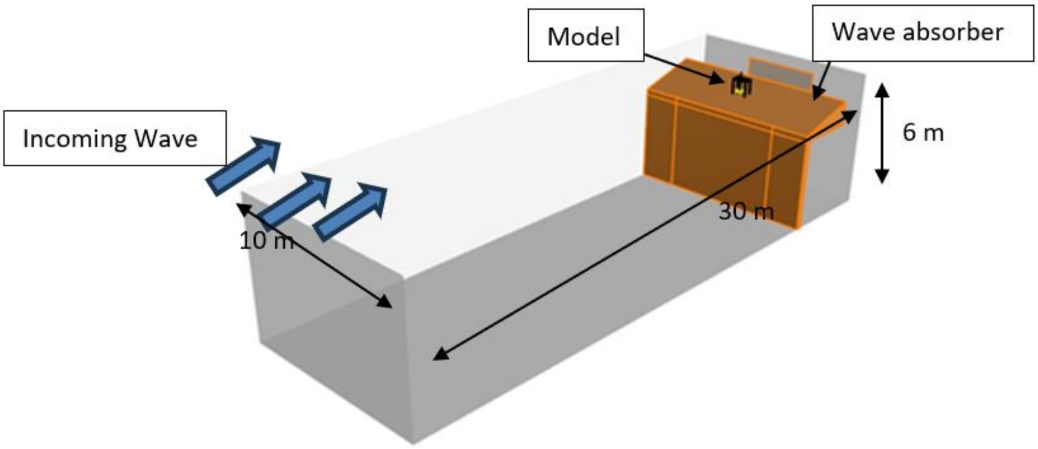



**Fig. 1.** Location of the model on the wave tank arrangement

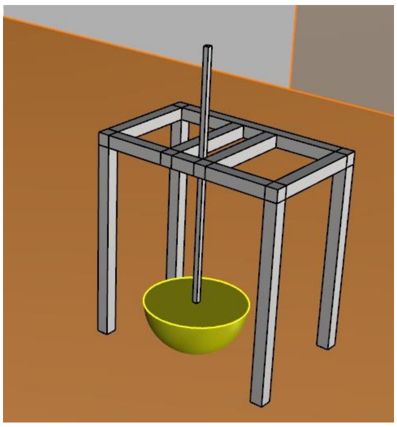


**Fig. 2.** Close up perspective view of the model

### 2.3 Boundary Condition

The boundary condition setup is shown in Figure 3. The dimension of the setup is similar to the hydrodynamic wave tank size at UniKL MIMET.

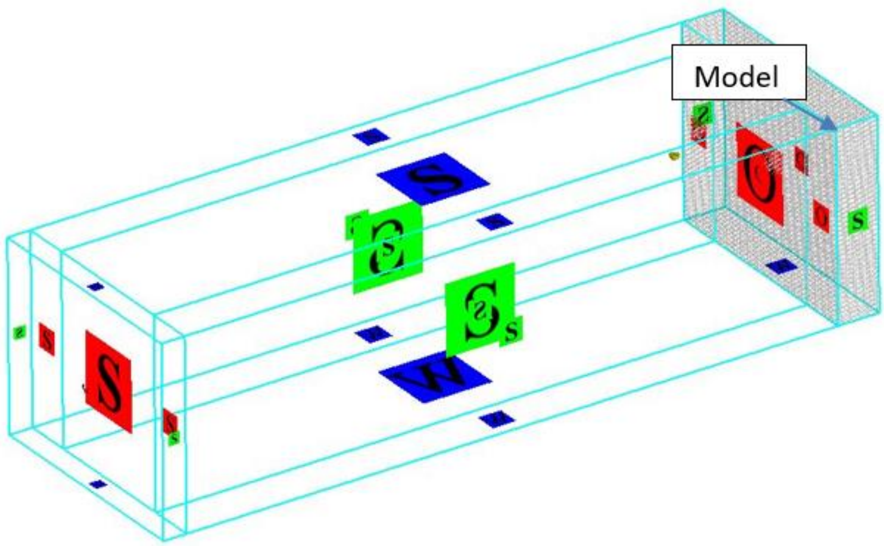



**Fig. 3.** Boundary condition setup in computational fluid dynamic software

Each side of the boundary condition is shown in a Table 3. The water level for all conditions were set at 5.72m.

**Table 3**
Boundary condition justification

| Boundary Condition | Justification | Symbol |
|---|---|---|
| Wave | Incoming wave | WV |
| Symmetry | Sidewalls of boundary | S |
| Outflow | The outflow of the fluid Bottom floor | O |
| Wall | | W |

### 2.4 Location of Probe

The location of the probe is located at the centre of the point absorber device. This to capture the oscillation of the device in a vertical motion as in Figure 4.

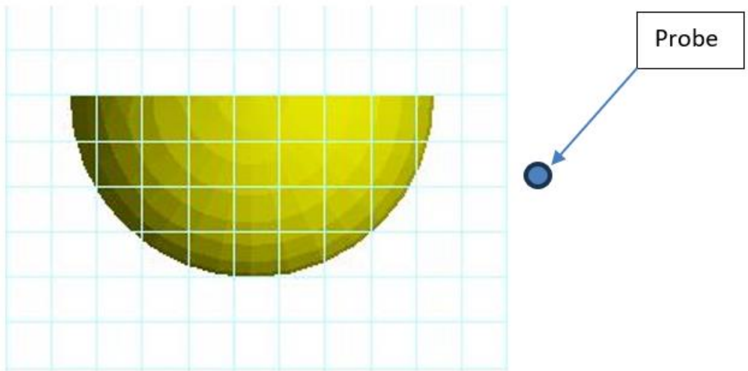



**Fig. 4.** Location of probe

*2.5 Grid Dependent Study (GDS)*

The GDS study is suitable for reducing or minimizing the impact on computational performance of the number of grid sizes. For each of the designs, there are four case studies with different mesh size to find the optimum size. Most optimum grid line size was determined as the graph starts showing consistent trend in results as in Figure 5.

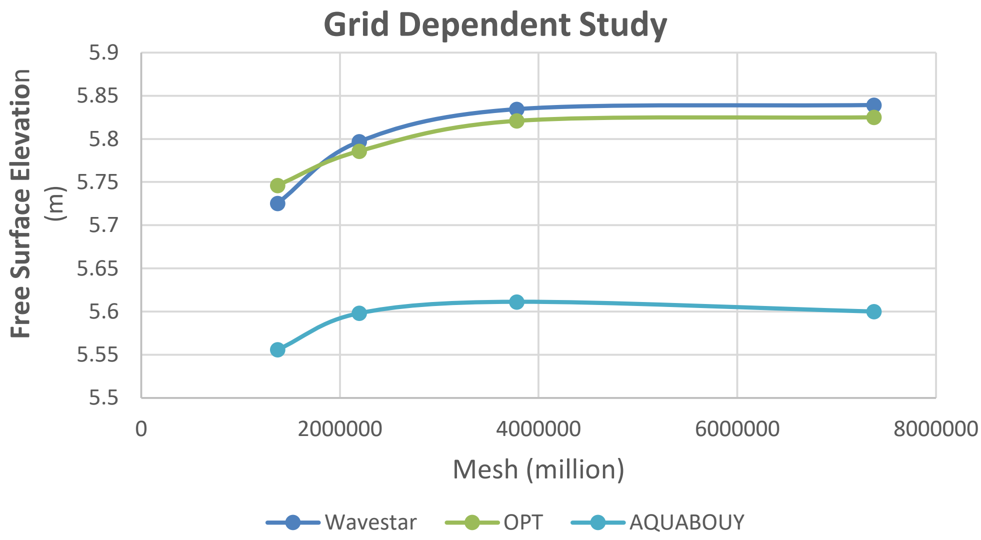



**Fig. 5.** Grid dependent study

## 3. Results

The results of HRAO from CFD simulation software for all wave condition is shown in Figure 6 to Figure 8. The oscillation of the device considers after five cycles of the wave because at this point the devices are starting to absorb the wave. There are sixteen waves were considered in this study.

*3.1 HRAO*
*3.1.1 Wave condition 1*

Figure 6 shows the HRAO of the PAWEC in a calm wave. The Aquabuoy design performed 40% better than OPT and Wavestar. With the small wave height and wave period, the flat bottom design absorbed wave energy better by 0.02 m difference. Figure 9 exhibits the average HRAO of a point absorber in wave condition 1.

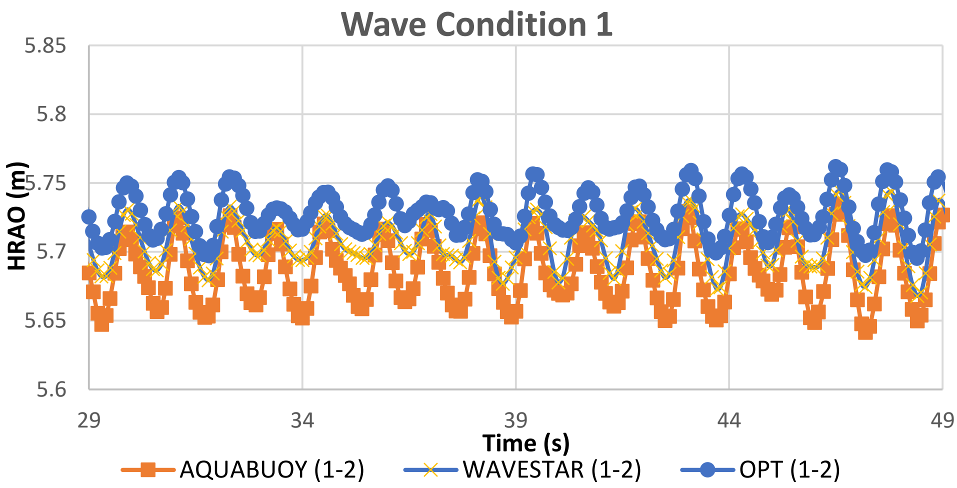



**Fig. 6.** HRAO of a point absorber in wave condition 1

### *3.1.2 Wave condition 2*

In a medium wave (Figure 7), OPT responded approximately 0.3 m of the heaving motion slightly better compared to Aquabuoy and Wavestar. Figure 10 exhibits the average HRAO of a point absorber in wave condition 2.

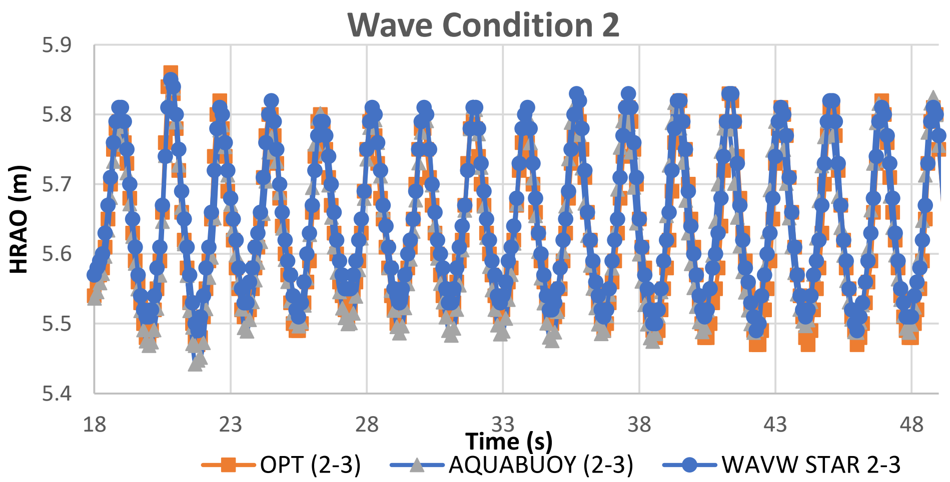



**Fig. 7.** HRAO of a point absorber in wave condition 2

### *3.1.3 Wave condition 3*

In a strong wave condition, OPT and Wavestar design promising response to the wave which shows 0.4m stroke compared to 0.3m for Aquabuoy (Figure 8). It showed that slimmest bottom response higher stroke in strong wave and absorbed frequency response to the wave frequency. The floating device reacted better in this sea state which show higher RAO response compared to wave condition 1 and 2. Figure 10 exhibits the average HRAO of a point absorber in wave condition 3.

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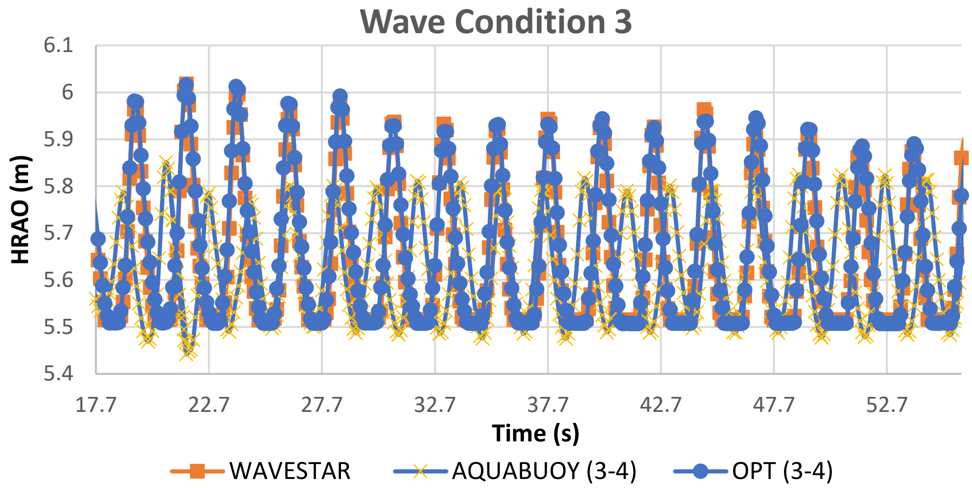


**Fig. 8.** HRAO of a point absorber in wave condition 3

### *3.2 Average HRAO*

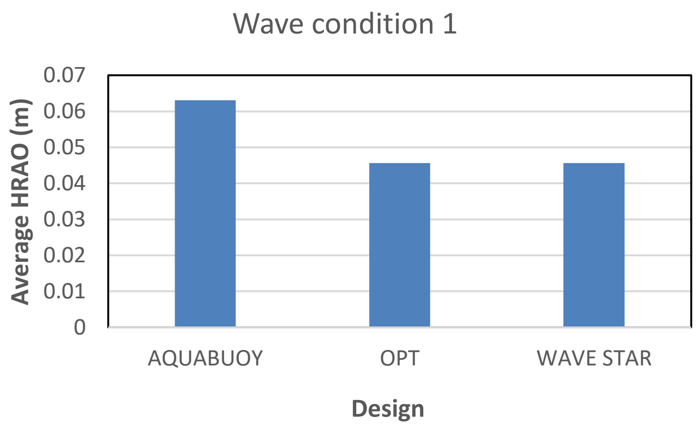


**Fig. 9.** HRAO of a point absorber in wave condition 1

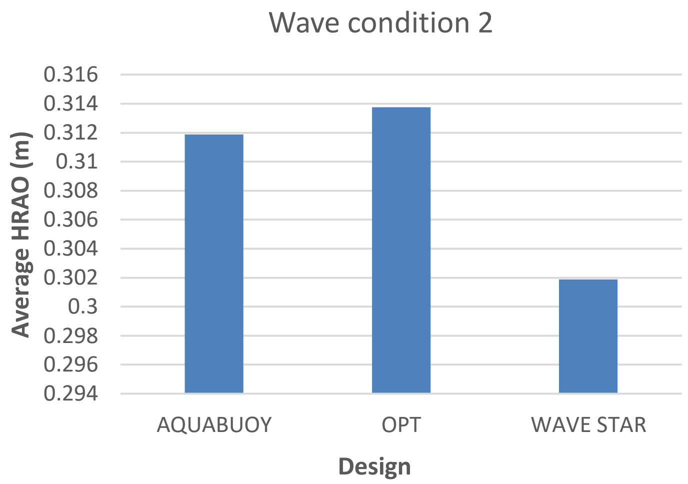


**Fig. 10.** HRAO of a point absorber in wave condition 2

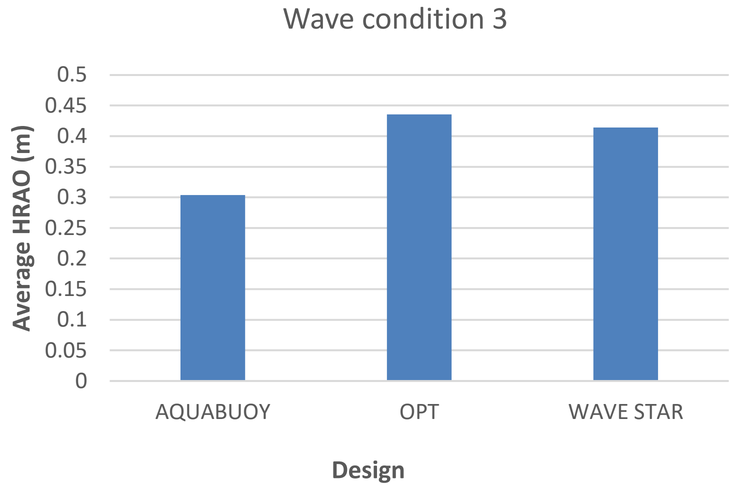


**Fig. 11.** HRAO of a point absorber in wave condition 3

### *3.3 Power*

The device was pulled in still water to full displacement and then released while the time history of the device is recorded. For the model, this section displayed the power estimated by calculation. PAWEC moved up and down with the change in mass above it. As a wave crest approaches, the water mass increases above the float, thus pushing it down. The forces acting on the float may be modelled *via* newton equation. The equation below shows the calculation estimate the power generated in this research. Eq. (1) shows the mass of water acting on the float device. The power transferred equation is shown in Eq. (2). It is simply multiplied by the velocity of the float, where the velocity is the stroke length divided by the half of the wave period. Figure 12 exhibits the annual power estimation for the all the wave conditions.

$$F_{water} = (\rho_{water} H A_{float}) g \quad (1)$$

$$P_{generated} = F_{water}( 2L_{stroke} / T) \quad (2)$$

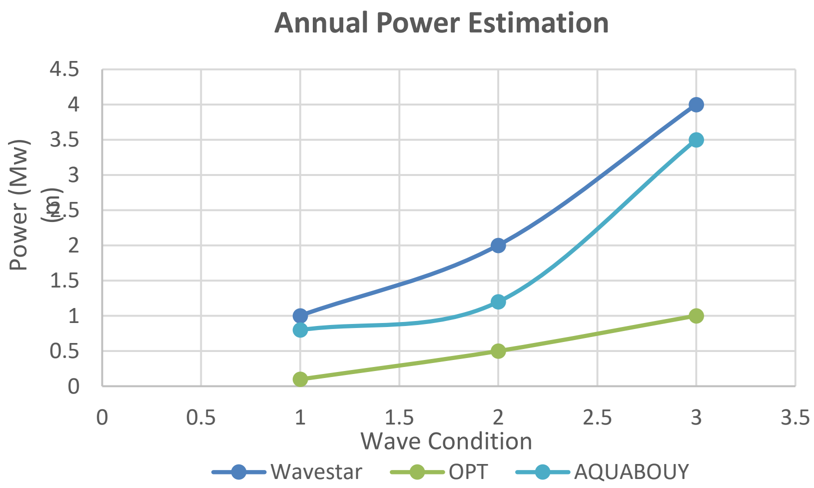


**Fig. 12.** Annual power estimation

## 4. Conclusions

The absorption of the wave force produced by the three wave conditions on a three-difference point absorber has been studied using computational fluid dynamics software. Two designs of PAWEC which are cone and curved bottom have been proposed to improve in low wave energy. The final study of PAWEC design has been carried out and the results show improvement compared to flat bottom. In this study, the least performed is flat bottom. The flat bottom performed better in wave condition 1, but it is very low energy. The outstanding design is cone bottom with HRAO are 0.04m, 0.4m and 0.3m in all three wave conditions. The results show that cone and curved produced high HRAO than the flat bottom. Thus, these two designs are proven to be more efficient and able to increase the performance of PAWEC at low wave height, especially in Kuala Terengganu coastline. At the initial stage of point absorber design, the structural safety and physical model tests should be conducted at the greatest extent possible to validate more reasonable design values. Other than that, this input may also contribute to the design of PAWEC for Malaysia waters.

## Acknowledgment
The authors would like to express their gratitude and thanks to Universiti of Kuala Lumpur for funding this research under Short Term Research Grant (STRG) no. 21024.

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