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Wave Energy Potential Using OWC (Oscillating Water Column) System at Pantai Baron, Gunung Kidul, DI Yogyakarta, Indonesia

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ABSTRACT

The southern coast of Yogyakarta province in Indonesia has large potential for wave energy, where the most ideal location is Pantai Baron. This research was conducted to study the potential wave energy using OWC (Oscillating Water Column) at Pantai Baron. Wave height and wave periods are needed to find the potential wave energy that can be generated. Wind, fetch and bathymetry data will be used to determine wave height in deep sea. Refraction and shoaling calculation will be used to calculate wave height in shallow depth area. Wave height after refraction-shoaling combine with tidal data will be used to determine optimum position for OWC system. Wave height, wave incoming direction, total efficiency for OWC system and capacity factor will be used to calculate potential wave energy that can be produced. Average wave height on deep sea is 1.08 m, wave period is 9.73 sec and incoming wave dominant is from east. Optimum depth of system OWC is -5.0 m below MSL. Average wave height after refraction and shoaling effect is 1.1 – 1.2 m. Potential wave energy that can be generated is 3.9 – 5.6 MWh per year per 1 OWC system with chamber width is 2.4 m.

1. Introduction

The southern coast of Yogyakarta is an area directly facing the Indian Ocean, so it has a large enough potential for wave energy. The potential for wave energy in the south of Yogyakarta reaches more than 30 kW/m [1,2]. One of the ideal locations to build a Wave Power Plant is Pantai Baron [3]. To convert ocean, wave energy into electrical energy requires a converter machine. This converter machine functions as a converter of ocean wave energy to be used as a power to drive a turbine. There are several other type of converters that have been researched and used. One of the most excellent conversion machines based on the criteria of Reliability, Safety, Performance, Durability, Serviceability, Cost and Interference with Navigation is the OWC system [4].

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The calculation of the potential for ocean wave energy to become electrical energy using OWC at Pantai Baron has not been done much. To determine the potential for wave energy requires specific wave height data at the research location. Specific research on the potential for wave energy at Pantai Baron has been carried out, where the wave height used uses the height of deep sea waves, even though the OWC is placed in a shallow sea [5]. To obtain accurate potential data, it is necessary to calculate the wave height that will occur in shallow seas, where waves propagate from the deep sea to the shallow sea. Other non-specific studies were conducted at southern coast of Yogyakarta [2,6] and there were also studies that did not use OWC for their converter machines [1].

This research will discuss about the potential for wave energy using OWC at Pantai Baron, where the waves used are medium to shallow sea waves. Several efficiency coefficients are also used in this study. Research on the potential of ocean wave energy into electrical energy using OWC at Pantai Baron, where data using shallow ocean waves have never been used in previous studies. The data used is wind data recorded by Baron Techno Park, BPPT, for 3 years, from 2017 to 2019. Calibration of wave height is based on the point of breaking wave location from satellite maps. It is hoped that the results of this study can be used to further determine the economic potential and the possible types of building structures that will be used.

2. Methodology

2.1 Wave Energy

The formula to calculate electrical power and energy that can be generated from the energy wave group [7,8] using the OWC system are

$$P_{OWC} = \frac{\rho g^2}{64\pi} H^2 T w \eta_{OWC} \tag{1}$$

$$E_{OWCTotal} = Cf x 8760 x P_{OWC} \tag{2}$$

where P_{OWC}: Electric power by OWC system (Watt), $E_{OWC\ Total}$: Electrical energy by OWC system (Wh per year), ρ: density of sea water (kg/m^3), g: earth's gravitational force (m/s^2), H: wave height (m), T: wave period (sec), w: chamber width (m), Cf: Capacity factor.

$$\eta_{OWC} = \eta_p \eta_t \eta_g \tag{3}$$

where η_{OWC}: total efficiency of the OWC system, η_p: chamber efficiency, η_t: turbine efficiency, η_g: generator efficiency

The total efficiency of the OWC system is the product of the efficiency of the chamber, the efficiency of the turbine and the efficiency of the generator system. The efficiency of the chamber is the potential for ocean wave power that can be absorbed by the chamber in the OWC system. Turbine efficiency is the efficiency of the turbines used by the OWC system. Meanwhile, the efficiency of the generator is the efficiency of the generator used by the OWC system [9]. The total efficiency of the OWC system according to several studies ranges from 0-20% of the total potential energy produced by waves, depending on the wave height and period [9–13]. The total efficiency of the OWC system for each height and wave period can be seen in Table 1. Based on several studies, the CF (capacity factor) of the OWC system is 0.1 – 0.4 [14–16].

Many OWC systems are installed in onshore areas, where in shallow sea areas a wave transformation will occur and then it will break. The result of breaking waves will result in a loss of energy from the ocean waves where the energy loss due to breaking waves is about 15% [17].

In addition to breaking waves, what is certain to happen is tides, so at low tide the chamber may not be filled with sea water, so it will result in energy loss from ocean waves. Tides are a sinusoidal function, where the water level will vary. Changes in water level will also affect energy losses in the OWC system, but this is not too significant when compared to changes in ocean wave characteristics [18].

Table 1
OWC efficiency for given wave height and periode [10]

Wave height, Hs (m)	4.25					9.1	8.4		
	3.75				11.5	10.7	8.5		
	3.25			13.3	13.3	11.2	10.1		
	2.75		11.1	14.1	13.4	11.7	10.2	8.5	
	2.25		11.5	15.5	14.8	12.5	11.0	8.3	
	1.75	4.2	10.3	15.2	14.8	12.4	11.0	8.0	6.3
	1.25	2.8	8.9	11.3	13.9	12.9	10.4	8.0	
Te (s)		6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5

2.2 Wave Hindcasting

Wave forecasting uses a method that is quite widely used, namely the SPM 1984 method. This method was choosen because it is the simplest method for determining ocean wave forecasting in the deep sea [19]. This method uses 3 equations to predict the height and wave period with inputs in the form of fetch length, duration and wind speed. The result of this wave forecast is the wave height and wave period [20].

The propagating waves have energy. When the incident wave comes with a certain angle of incidence from deep water to shallow water, the wave will experience refraction and shoaling. In the process of refraction, the wavefronts moving in the water with straight and parallel contours will tend to be parallel to the contours, or in other words, the angle of incidence of the waves will decrease. Refraction events can also result in changes in wave height [21].

In the course of the wave from deep water to shallow water, there is a change in speed, which becomes slower. This change, apart from causing a change in direction, also results in an enlargement of the wave height, which is called shoaling. During its propagation, the wave can no longer "contain" the energy of the wave. This "energy destruction" process takes the form of a breaking wave where the criteria are $H / h \approx 0.78$ (H = wave height and h = water depth) [22].

To determine wave height along the coast, the Ref / Dif program [23] is used, which is a program for modeling wave refraction and diffraction. The data used are wave height, wave period, incident direction and bathymetry. The output of this program is the height and direction of the waves at a certain point.

2.3 Tide

The next important factor is tides, this is used to determine the ideal OWC position, so that at low tide, the mouth of the OWC is still inundated by sea water and sea waves still occur. In addition, it must be ensured that at low tide there are no breaking waves. Tides are also used to design the structure of the OWC so that the turbine does not sink at high tide. Forecasting the important water level is using the Least Square method.

3. Result and Discussion

3.1 Location

The research location is Pantai Baron, where 3 points were selected, namely BO1-BO3. The research location can be seen in Figure 1. This location was choosen was based previous research, where Pantai Baron 3 points selected. The research prioritizes the selection of a global location that compares various factors at several points on the southern coast of Yogyakarta [3].

3.2 Data

3.2.1 Bathymetri map

The bathymetry map comes from BIG [24], where the bathymetric map of Pantai Baron can be seen in Figure 1.

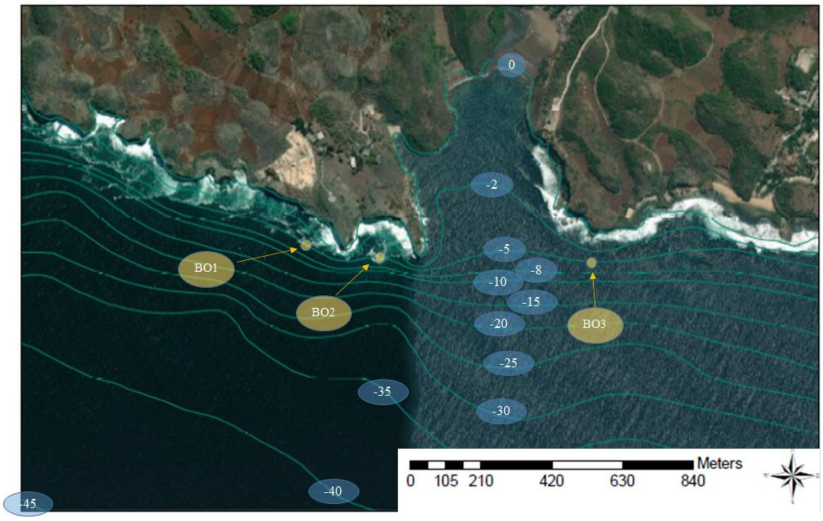

Fig. 1. Research location at Pantai Baron, Kabupaten Gunung Kidul

3.2.2 Wind

The wind data comes from Baron Technopark, where the data is from 2017 until 2019. Wind data can be seen in the form of waindrose in Figure 2.

3.2.3 Fetch

The fetch for the southern coast of DI Yogyakarta tends to be the same, because the location is not too far when compared to the distance of the fetch. The fetch map for the southern coast of DI Yogyakarta can be seen in Figure 3. From the calculations, it is found that the effective fetch comes from the east, southeast, south, southwest and west.

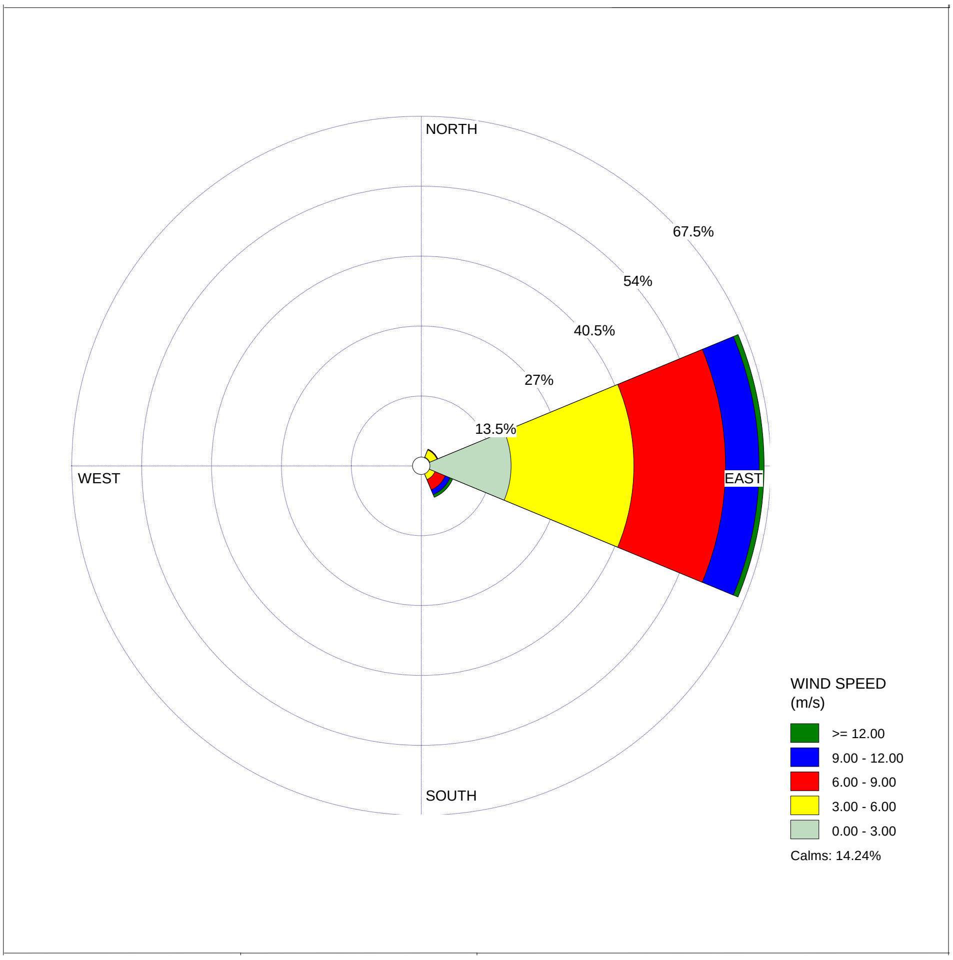

Fig. 2. Windrose Pantai Baron

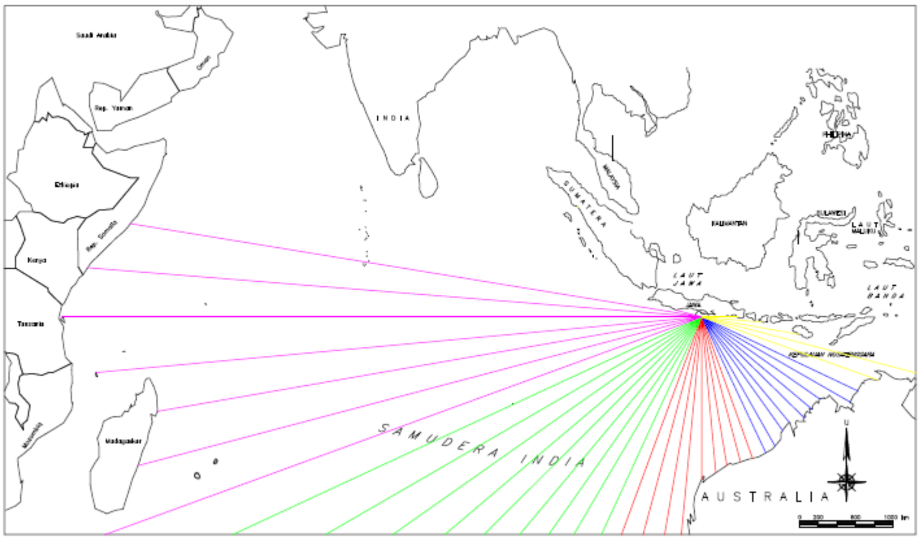

Fig. 3. Fetch Pantai Baron

3.3 Discussion
3.3.1 Wave hindcasting calculation

The results of hindcasting wave height using the SPM 1984 method based on wind data from Pantai Baron can be seen in the form of waverose in Figure 4. Based on the hindcasting results, the dominant wave height from the east with an average wave height of 1.08 m and a wave period of 9.73 seconds. The average wave height from only the east is 1.0 m with a wave period of 9.61 seconds and an occurrence frequency of 90.9%, for the average wave height from only the southeast is 1.75 m with a wave period of 13.35 seconds and an occurrence frequency of 9.1%, while the average is high. the wave from only the south is 1.45 m with a wave period of 11.76 seconds and an occurrence frequency of 0.1%.

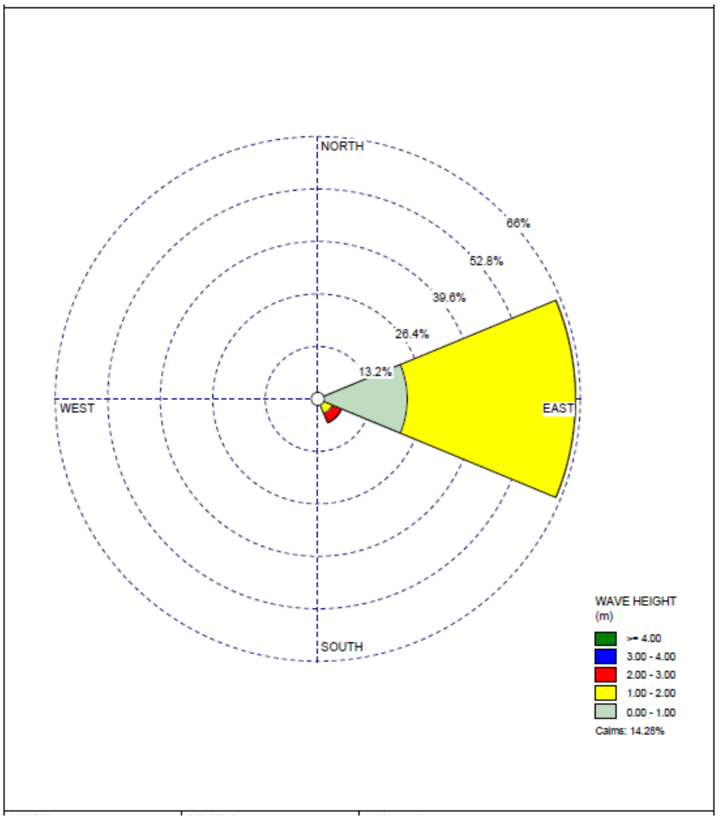

Fig. 4. Waverose Pantai Baron

3.3.2 Tide

The data used for forecasting is the tidal prediction data from PPI Baron on 29 October 2015 to 25 November 2015. The tidal data will then be predicted using the Least Square method to obtain data for 20 years. Forecasting data will be taken of important water level elevations for 20 years. The tidal forecasting data for Pantai Baron shows that distance between highest and lowest water tide is 230.75 cm [3].

3.3.3 Wave height at shallow depth area

Result of Ref/Dif modeling will be carried out for each direction of wave height, that are east, southeast and south. Map of the distribution of wave height can be seen in Figure 5 – 8. Based on Figures 5 - 8, it can be seen that the wave height at points BO1 - BO3 is higher than the wave height in the deep sea. This is caused by changes in sea depth (shoaling) and due to the effect of refraction, where there is a concentration of energy (convergent). The wave height of each location point can be seen in Table 2.

Changes in wave height that occur due to refraction and shoaling in the waters between the deep sea and the coast cause the waves to break at a certain wave height and depth. The location of the breaking waves for the Pantai Baron area can be seen in Figure 9. From this figure, it can be seen that by visual observation, the location of the breaking waves (marked with red line), it is in accordance with the actual conditions, because the actual breaking wave is marked with a white color on the water which indicates the foam resulting from the breaking wave. From this figure, most of the breaking waves occur at a depth of less than 5 m, so the OWC location at a depth of 5 m is quite safe.

Table 2
Wave height (m) at BO1 – BO3 points

Location	Total	Incoming Wave Direction		
		East	South East	South
BO1	1.1	0.97	1.98	1.89
BO2	1.21	1.07	1.76	1.81
BO3	1.21	1.13	2.20	2.09

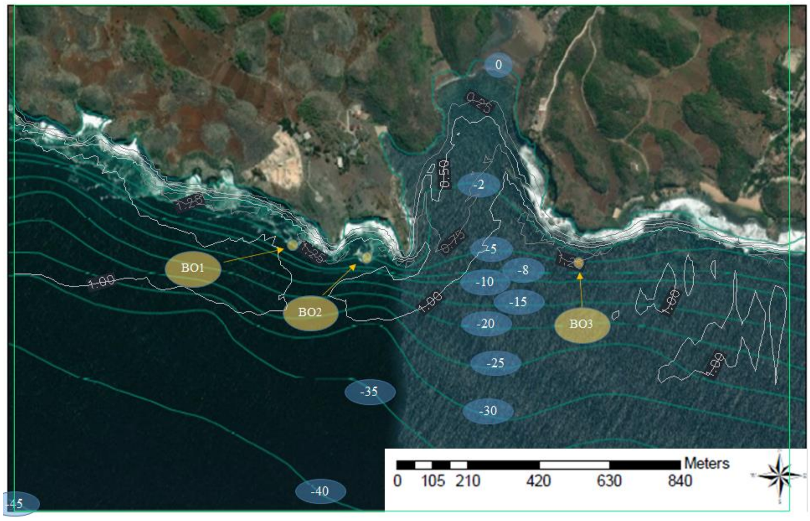

Fig. 5. Map of wave height Pantai Baron (H=1.08 m, T=9.73 sec, East)

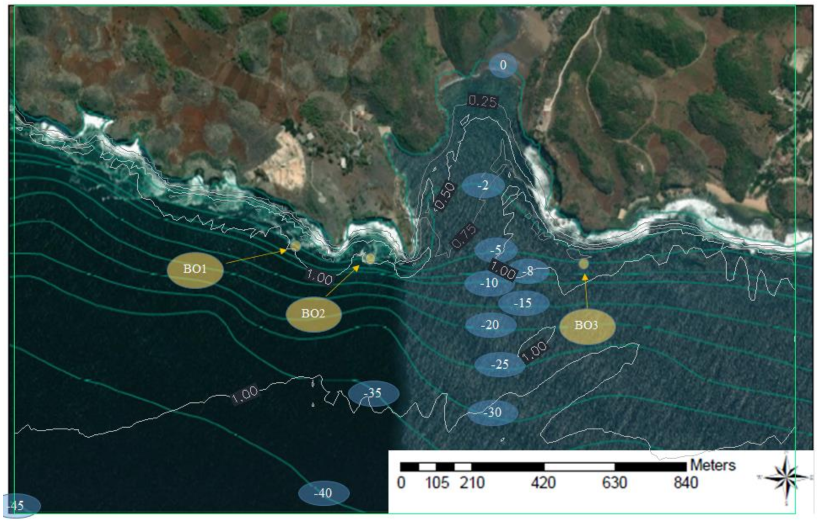

Fig. 6. Map of wave height Pantai Baron (H=1.02 m, T=9.61 sec, East)

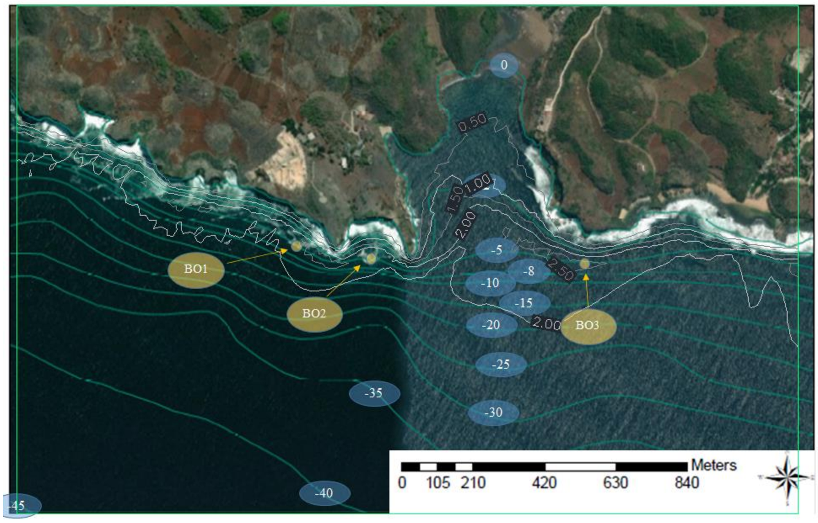

Fig. 7. Map of wave height Pantai Baron (H=1.75 m, T=13.35 sec, South East)

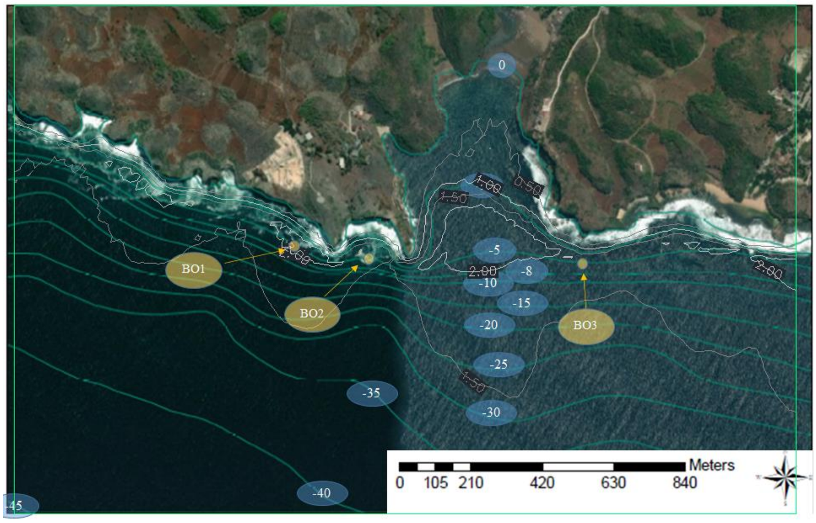

Fig. 8. Map of wave height Pantai Baron (H=1.45 m, T=11.76 sec, South)

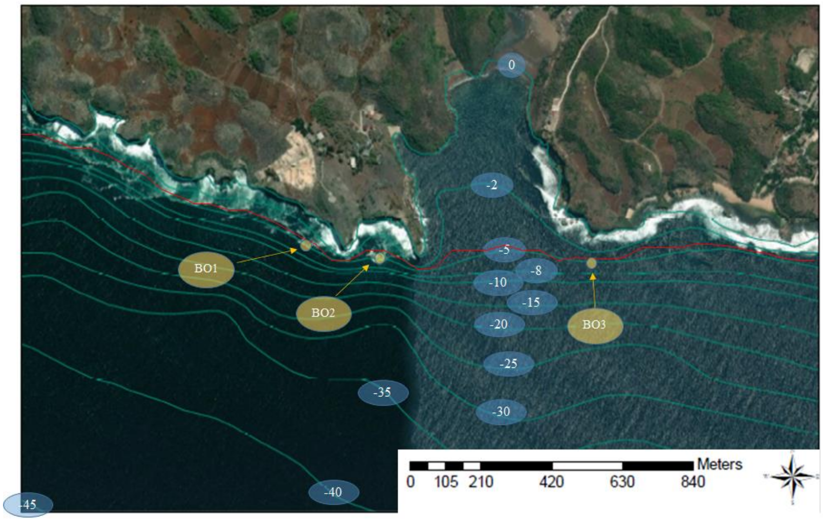

Fig. 9. Wave breaking line position (in red line)

3.3.4 Electrical power potential

Using the wave height at the BO1 - BO3 location, the potential for electrical power that can be generated can be calculated. Some of the parameters used are the chamber width (w) is 2.4 m [25], the efficiency of the OWC system which is used as a calculation based on *Bailey et al.,* [10] is 8% and the Cf value used is 0.4.

In this calculation, the tidal parameter is entered, where the bathymetry data used is in the MSL (Mean Sea Level) condition, so that in the low tide condition the chamber is still submerged by water, the sea depth is calculated minus the tidal value used. The important elevation values used are MLWL (Mean Low Water Level) and MLWS (Mean Low Water Spring), where the MLWL value is 0.59 m and MLWS is 0.95 m with the percentage of incidents, respectively, 6.9% and 0.25%.

The planned OWC system will be installed at a depth of 5 m relative to MSL. Based on the calculation, at that depth the height of the waves to break is 3.9 m. If the depth is reduced by MLWL and MLWS, the height of the breaking waves during MLWL and MLWS are 3.44 m and 3.16 m, respectively. From the results of the wave height distribution forecast above, at a depth of 5 m, it is possible that at the location of BO1 in MLWS conditions it will break with waves in the southeast incoming waves direction. According to Zhang and Yuan [17], the energy lost due to breaking waves is 15%, so for BO3 with a incoming wave direction from the southeast, the total energy loss is 0.0375%. The complete calculation of electrical energy for every 1 OWC system and direction to the chamber for all scenarios can be seen in Table 3.

The sketch of the position of the OWC system to the water level can be seen in Figure 10. The 2D sketch is the same for all BO1 - BO3 location points, because the OWC system for location points BO1 - BO3 is at the same sea depth. Based on the sketch, for the lowest receding conditions, the chamber will still be filled to the limit above the mouth of the chamber, this is to ensure that the air pressure due to the rise and fall of the water level is more effective and everything is channeled through the turbine, not out through the mouth of the chamber.

Based on Figure 10, it can be seen that the ups and downs of the waves, both at high tide and at low tide, are still effective enough to push or suck air in the chamber, because the water surface is still above the mouth of the chamber and below the turbine. At low tide conditions, the breaking waves have not occurred at the location points of BO2 and BO3, so that energy loss due to breaking waves does not occur. Whereas for the point of location BO1 the frequency of the breaking waves that occurred was less than 1%, so it was not significant.

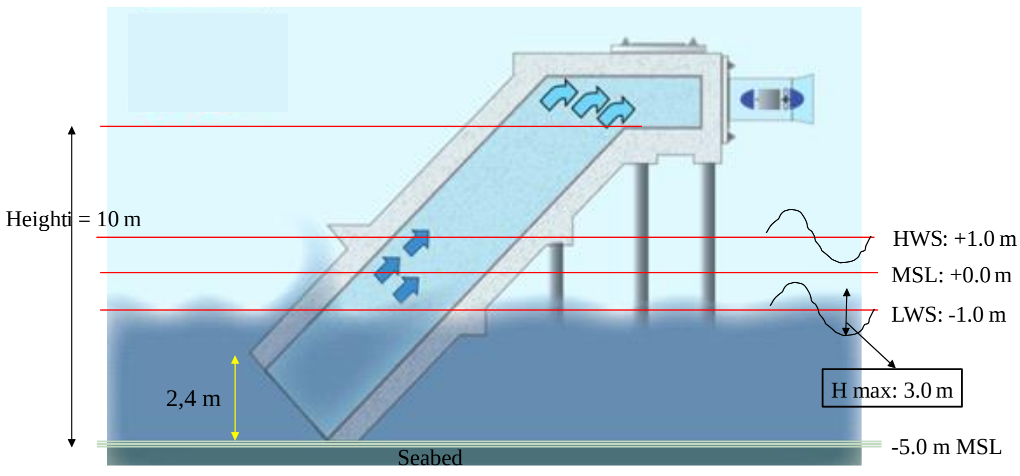

Fig. 10. 2-D sketch OWC system

Table 3
Electrical energy production calculation using 1 OWC system

Scenario	Location	Incoming Wave Direction	Wave Height (m)	Wave Period (second)	Frequency of Wave Incident	Electrical Power OWC System (Watt)	Total Electrical energy per Year (MWh/year)
1	BO1	East	1.10	9.73	100.00%	1109	3.89
2	BO1	East	0.97	9.61	90.85%	852	4.29
		South East	1.98	13.35	9.08%	4931	
		South	1.89	11.76	0.07%	3960	
3	BO2	East	1.21	9.73	100.00%	1342	4.70
4	BO2	East	1.07	9.61	90.85%	1037	4.55
		South East	1.76	13.35	9.08%	3896	
		South	1.81	11.76	0.07%	3632	
5	BO3	East	1.21	9.73	100.00%	1342	4.70
6	BO3	East	1.13	9.61	90.85%	1157	5.63
		South East	2.20	13.35	9.08%	6087	
		South	2.09	11.76	0.07%	4842	

Based on Table 3 above, when using the overall data from the waves that occur and the direction using the dominant direction, the location of BO3 produces the greatest electrical energy. The electrical energy that can be generated by the OWC system at the BO3 location is 4.7 MWh/year. Meanwhile, deep sea waves are calculated based on the percentage of each direction, so the BO3 location still produces the most electrical energy 5.63 MWh/year. The electrical energy generated by the OWC system at the BO3 location is 4.7 - 5.63 MWh/year. Overall, the electrical energy generated by OWC system at BO1 – BO3 location is 3.9 – 5.6 MWh/year.

4. Conclusion

The dominant wind at Pantai Baron comes from the east with an average wave height of 1.08 m and a wave period of 9.73 seconds. Meanwhile, waves only from the east have a wave height of 1.02 m, a wave period of 9.61 seconds and an occurrence frequency of 90.9%. The converter for converting wave energy into electrical energy is an Oscillating Water Column (OWC), which is placed at a depth of -5.0 m MSL. Three points were selected to calculate the potential, namely BO1-BO3. Simulation using Ref-Dif software is used to get the wave height at this depth, because of the effects of refraction and shoaling. It is found that the wave heights for the locations BO1-BO3 are 1.1 m, 1.21 m and 1.21 m. The OWC used uses a chamber width of 2.4 m, with an OWC efficiency of 8% and a Cf of 0.4. Based on calculations, the potential for electrical energy that can be generated at point BO3 by 1 OWC is 4.7 MWh / year. Overall, the potential electrical energy can be generated using 1 OWC system at Pantai Baron is around 3.9 – 5.6 MWh/year. Based on the potential of electrical energy that can be generated, the development of a sea wave power plant at Pantai Baron can continue to the next stage to design the safe structure for the designated area.

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