INDONESIAN JOURNAL OF MULTIDISCIPLINARY SCIENCE

P-ISSN: 2808-5957
E-ISSN: 2808-6724
ijoms.internationaljournallabs.com

WAVE ENERGY CONVERTER SYSTEM ANALYSIS PERFORMANCE WITH PITCH MOTION IN VARIOUS DIMENSIONS AND DRAFT FOR APPLIED IN INDONESIA SEA

Muhammad Fahmi
Master's Program in Ocean Engineering
Faculty of Civil and Environmental Engineering Institut Teknologi Bandung, Indonesia
Email : fahmisalmin@gmail.com

ARTICLE INFO

Date Received : 03 August 2022
Revision date : 13 August 2022
Date Approved : 18 August 2022

Keywords: *wave energy converter; pitch; power take off; renewable energy; ocean energy; indonesia sea.*

ABSTRACT

In Indonesia, national electricity consumption is expected continue to rise every year. One solution to meet the needs of electrical energy is to use clean energy that is sustainable to environment. Seeing Indonesia as an archipelagic *country, One of renewable energy that could develop is ocean energy (Wave Energy Converter). Wave Energy Converter can be converted into electrical energy through a converter in the form of a floating structure. The structure will respond to the external force of the ocean waves into the pitching motion. The pitch movement will move a series of tools which are then channeled into a generator to produce electrical energy. The structure is said to be effective if it produces a large enough performance value. In this study the structure is modeled with various drafts and dimensions to obtain the most optimal hydrostatic parameter values. Furthermore, from this value, it is possible to estimate the amount of electrical energy that can be generated by adding a uniformed PTO damping value for each structure. From the results of the study, it was found that each structure with the same PTO damping value of 5×10^4 kNm has a different performance value in each wave period. From the results of the analysis, it is found that the greater the value of mass and radiation damping, the greater the energy generation and performance of the structure. The structure that has the best performance is structure-6 with a Performance value of 72.12% at a wave period of 9 seconds which match with North Sumatera mean wave period.*

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INTRODUCTION

Being an archipelagic country, Indonesia mostly consists of approximately 17,504 islands, 108,000 km long coastline and a total sea water area of 6,400,000 km^2. Thus, it

is crucial to explore the possibility of extracting energy from the ocean and one of them is wave energy (Idris & Gammaranti, 2018). Based on the RUPTL from PT PLN, national electricity consumption in 2022 is estimated to reach 1,147 kWh/capita and will continue to increase to 1,501 kWh/capita until the end of 2027. From this data, it is predicted that electricity consumers will get an average growth of 6.86%/year for the next 10 years.

In addition to the increase in electricity consumers, environmental pollution due to energy processing is a major issue in influencing current global climate changes. Carbon emissions caused by power plants that are not clean energy are one of the biggest contributors to the extreme climate changes. The graph of the increase in carbon emission can be seen in Figure 1 (D. Siswanto, 2019).

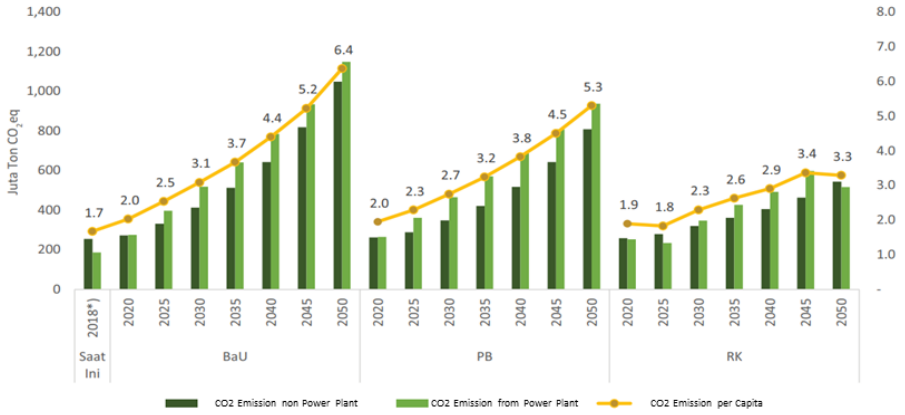


Figure 1. CO2 emission per capita by (Siswanto, et al., 2019).

Clean energy or renewable energy is an effective solution in dealing with these two issues. Looking at the geographical location of Indonesia which is directly adjacent to the Indian and Pacific oceans, the potential for ocean energy should be able to be utilized and developed in Indonesia (Idris & Gammaranti, 2018). The mean wave period data in Indonesia shown in

Figure ***2*** (Triasdian et al., 2018) and the distribution of wave energy potential in Indonesia can be seen in Figure 3 (Purba et al., 2015).

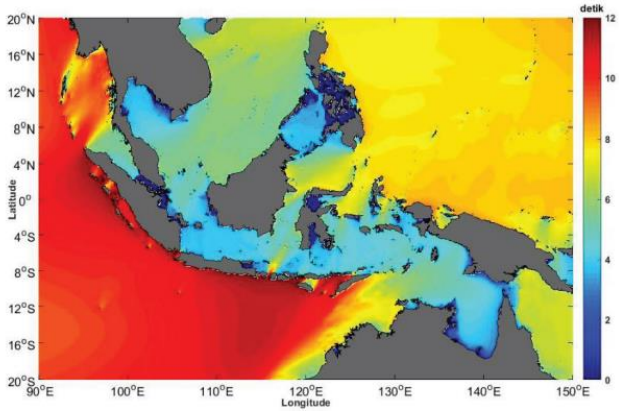


Figure 2. Mean wave Period Average from 1991-2011 by (Triasdian et al., 2018).

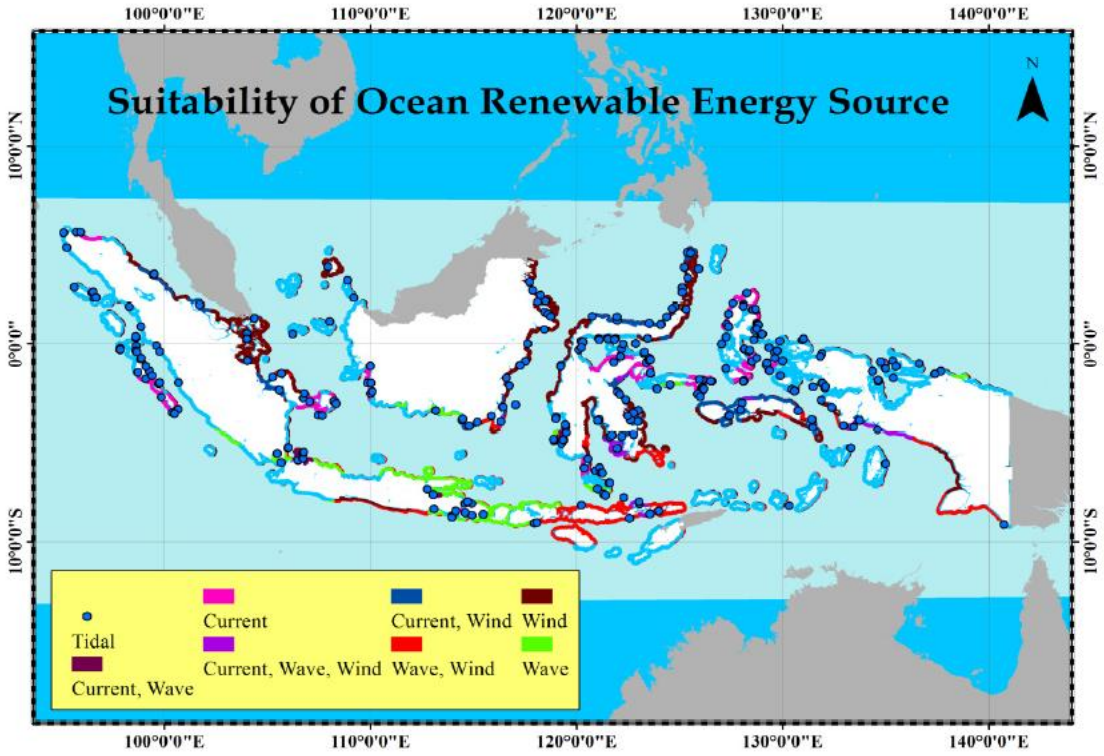


Figure 3. Potential of Wave Energy in Indonesia by (Purba et al., 2015).

Ocean energy can be classified into 4 types there are wave energy, tidal energy, ocean current energy and ocean thermal energy. One of the wave energy types are Wave Energy Converter (WEC) that is designed to extract wave energy into electrical energy (M. A. Siddiqui, 2015), while Power Take Off (PTO) is used to carry out the transformation of structural oscillations to convert existing wave energy into electrical energy that is ready to be distributed. The Figure 4 below are the types of PTO that can be applied to the WEC system (Pecher & Kofoed, 2017).

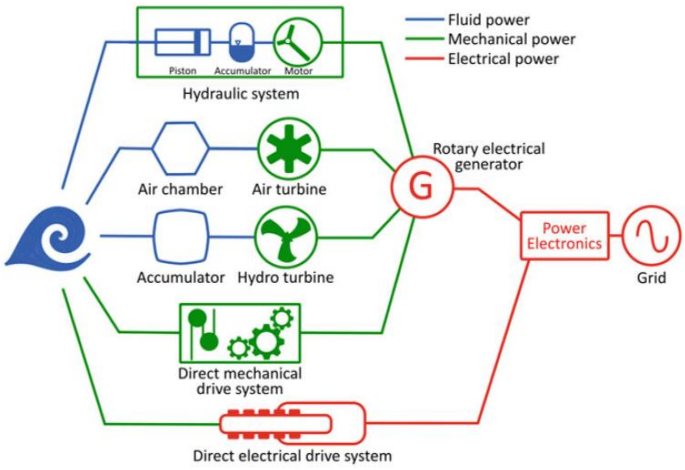


Figure 4. Types of Power Take Off System by (Pecher & Kofoed, 2017).

The objectives of the following research are to Analyzing hydrodynamics parameter in optimizing the performance of the Wave Energy Converter that utilizes pitching motion and knowing the best performance for several wave period of the potential for wave energy converter from several structural designs and applied the structure to Indonesia sea base on the natural period of structure.

METHOD

Physical modelling of resources is both time consuming and costly, therefore numerical assessment of resources is desirable to bring down both timescales and overall project costs. The method used in the following research is numerical simulation using hydrodynamic software to calculate the floating structure parameter hydrodynamics (G. Zhen, 2015). In the following research, a structure with a geometric shape that is close to the salter duck shape will be used as shown in Figure 5. The shape of the structure will be simulated with different structural parameters that shown in Table 1.

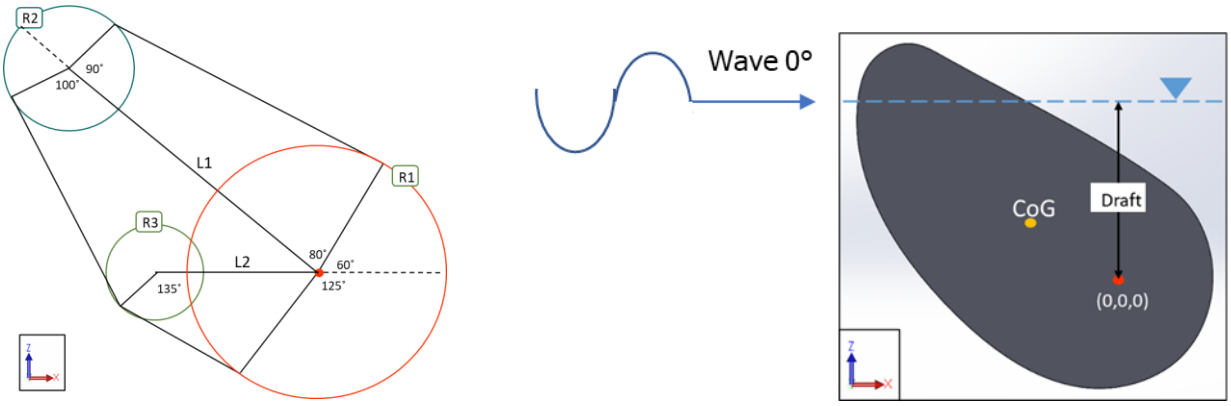


Figure 5. Parameter of Floating Structure

Table 1. Parameter of Floating Structure.

Parameter			Remarks
R-1	m	100%	Radius of circle as a reference
R-2	m	50%	Radius of circle to the reference (R-1)
R-3	m	40%	
Wide	m	400%	Wide of Structure to the reference (R-1)
L-1	m	250%	Length of head structure to the reference (R-1)
L-2	m	125%	

In the following study the structure will be made into five different dimensional variations with the point of the reference at (0,0,0) being the midpoint of R-1 which is also used as a comparison parameter against other parameters. Structure-2 has R-1 is 2 meter and continues to increase by one meter up to Structure-6 which has R-1 value is 6 meters. The optimization of the performance of this device requires a systematic investigation of the effect of several variables (Lucas et al., 2009).

For the calculation of the Wave Energy from the structure, it is required the value of PTO damping. The PTO damping value has a different optimum value for each structure. For this study the value of PTO damping will used 5×10^4 kNm for all structures (G. C. Soares, 2015).

In the numerical simulation, a conventional boundary element method which based on the potential flow is applied (the relevant potential theory can be found in (Falnes & Kurniawan, 2020), (Faltinsen, 1993), (McCue, 2016). The hydrodynamic analysis will calculate on the frequency domain (ω). The magnitude of the RAO (ξ_j) with high a wave amplitude of 1 meter can be calculated by the following equation (1):

$$\xi_j = \frac{M_E}{\left[-\omega^2\left(I_{ij} + A_{ij}\right) + i\omega\left(B_{ij}\right) + C_{ij}\right]} \tag{1}$$

Meanwhile, the solution to the equation for the moment of power take off will be influenced by the radiation damping of PTO and the equation for moment external PTO (M_{pto}) is obtained as follows equation (2):

$$M_5^{pto} = -B_{55}^{pto}\dot{\theta}_5 = -i\omega B_{55}^{pto}\xi_5 \tag{2}$$

From equation (2), we get the following dynamic equation of pitching motion on a floating structure with PTO damping as follows equation (3):

$$[-\omega^2(I + I_{55}) + i\omega(B_{55} + B_{55}^{PTO}) + C_{55}]\xi_5 = M_5^{ex} \tag{3}$$

From equation (3) it can be seen that the value of the pitch (RAO) with the addition of PTO damping and 1 meter wave amplitude at each wave frequency can be calculated by the following equation (4):

$$\xi_5 = \frac{M_5^{ex}}{-\omega^2(I + I_{55}) + i\omega(B_{55} + B_{55}^{PTO}) + C_{55}} \quad (4)$$

where I_{55}, B_{55}, and C_{55} are the added mass, damping coefficient and the stiffness coefficient (Sheng & Lewis, 2012). Meanwhile, to get the average power absorber PTO (P_{PTO}) that can be generated by the WEC structure can be used the following equation (5):

$$P_{PTO} = \frac{1}{2}\omega^2 B_{55}^{PTO} |\xi_5|^2 \quad (5)$$

After obtaining the PTO value from the WEC structure, the performance of the WEC structure can be known by comparing the amount of WEC power with theoretical Wave Power (P_{in}) as shown in equation (6) where the ρ is the density of seawater (Margheritini & Kofoed, 2019). The comparison between PTO absorber to wave power that multiplied by the width of the structure, it is commonly called the Capture Width Ratio (CWR) or performance. The performance of the WEC structure can be calculated using the equation (7) (Wu et al., 2017):

$$P_{in} = \frac{\rho g A^2 \omega}{4k} \quad (6)$$

$$CWR = \frac{P_{PTO}}{P_{in}\, W} \quad (7)$$

RESULT AND DISCUSSION

Modeling and Analysis Results

In the following chapter, the results of the hydrodynamic modeling of the structure will be analyzed with the output in the form of potential energy that can be generated by the PTO of the structure.

Response Amplitude Operator

The results for the RAO value are a three-dimensional graph consisting of the wave period (s), the direction of the incident wave (˚) and the magnitude of the pitch motion (˚/m) (Shi et al., 2019). The wave period is modeled in the range of 2 to 63 seconds with a frequency interval of 0.03 rad/s in the range of 0.1 to 3.2 rad/s. The direction of the incident wave against the structure is set at 45° intervals from 0° to 360°, with a wave amplitude set at 1 meter using regular wave theory.

Figure *6* shown the RAO results of each structure.

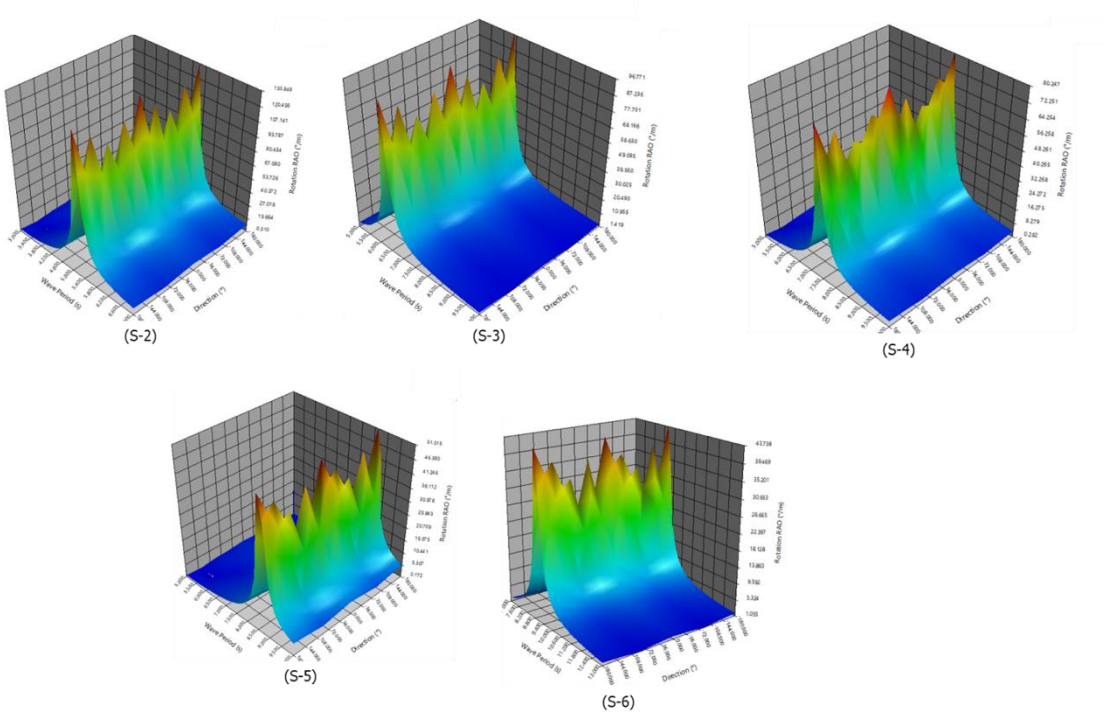


Figure 6. RAO from Each Structure Without PTO Damping.

From the results of the RAO analysis, it was found that the greater the mass of the structure, the smaller the pitch motion produced by the structure. It can be seen that structure-2 has the largest pitch motion while structure-6 has the smallest pitch motion with the optimum direction of the wave coming from 0°.

Meanwhile, for RAO with the addition of PTO damping, it was found that the greater the mass of the structure, the greater the pitch motion produced by the structure. It can be seen that structure-2 has the smallest pitch motion while structure-6 has the largest pitch motion when the structure is added with PTO damping. The following is a comparison chart of the RAO structure with the addition of PTO damping when the wave direction is 0° or wave coming to the head of structure.

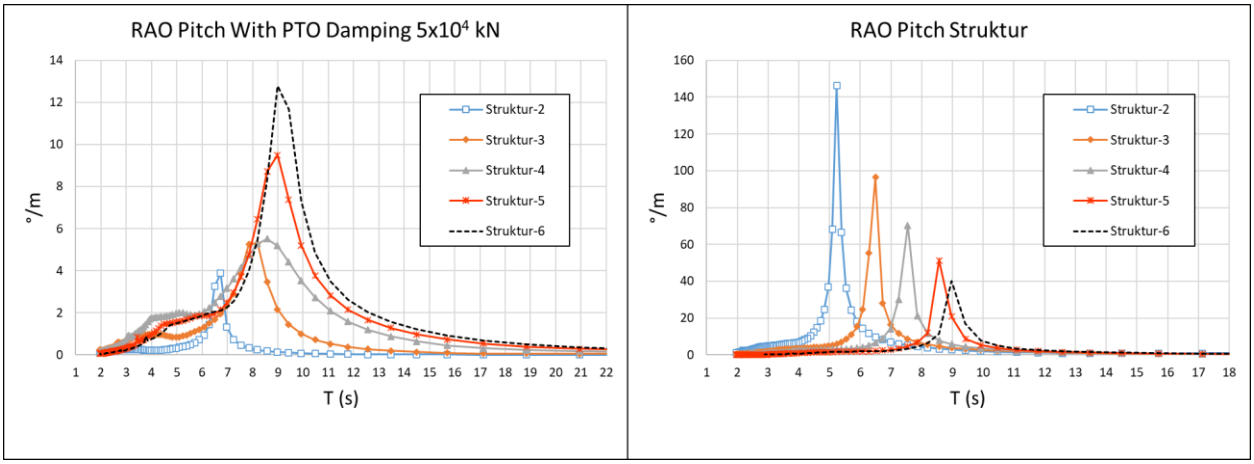


Figure 7. Graphics RAO of Structure 2 to 6.

From Figure 7 it can be seen that the pitch motion when the structure is in a free-floating condition it will be reduce by the addition of PTO damping, this happens for all structures with small or large mass. For a structure with a small mass, the pitch motion value will decrease significantly, while the larger the structure mass, the decrease in pitch motion will be smaller. The result of analysist the RAO graph of pitch motion which previously tended to decrease with increasing structural mass during free-floating conditions would change to tended to increase with increasing structural mass when added PTO damping to the structure.

Coefficient of Added Mass and Radiation Damping

To be able to compare the added mass and radiation damping values of each structure into one graph, a standard non-dimensional graph is used for these two parameters (Kurniawan, 2013). Figure 8 is shown the value of the coefficient added mass of each structure.

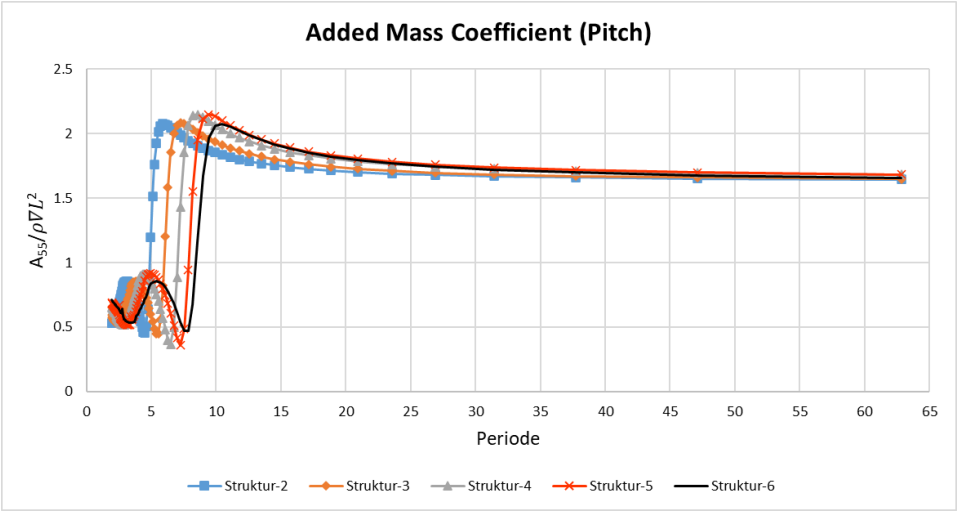


Figure 8. Coefficient Added Mass Pitch of Structure.

From Figure 8 it can be seen that the value of the coefficient added mass of each structure has the same pattern and the value is not too much different, only the mass of the structure that affects the peak position of the coefficient added mass of each structure. It can be seen that the greater the mass of the structure, the peak position of the coefficient added mass is in the high wave period, while if the mass of the structure is small, the peak of the coefficient added mass is in the short period. Meanwhile, the graph of the damping coefficient value of each structure shown in Figure 9.

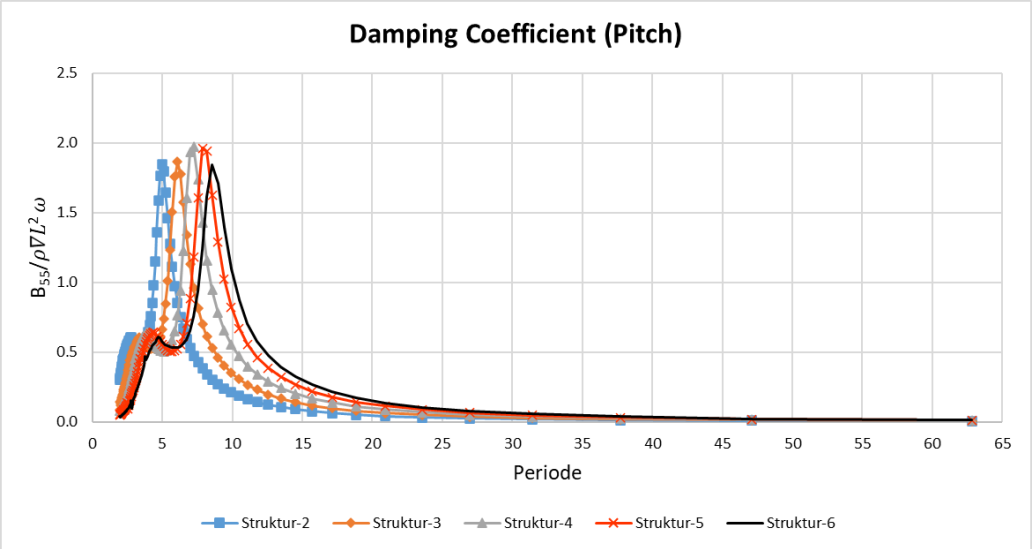


Figure 9. Coefficient Damping Pitch of Structure.

From Figure 9 it can be seen that the value of the damping coefficient of each structure has the same pattern and the value is not too much different. The mass of the structure affects the peak position of the damping coefficient of each structure. It can be seen that the larger the mass of the structure, the peak position of the damping coefficient is in the high wave period, while if the mass of the structure is small, the peak damping coefficient is at the low period.

Natural Period Comparison

Each structure will have a natural period value. The natural period seen at the peak of RAO motion graph from the structure, by knowing the natural period value it is expected that the structure will be able to resonance in that period. From the results of the hydrodynamic analysis of the structure the value of each natural period for pitch motion shown in **Table *2.*** Natural Period of Structure.Table 2.

Table 2. Natural Period of Structure.

Deskripsi	Unit	Structure				
		S-2	S-3	S-4	S-5	S-6

Mass	ton	192.6	650	1,538	3,004	5,200
Natural Period	s	5.2	6.5	7.5	8.6	9
Natural Period (with PTO)	s	6.7	7.8	8.2	9	9

It can be seen from Table 2 that for trend of natural period of the structure will increase when the mass of the structure gets bigger. Furthermore, the PTO damping also gives the impact to the natural period structure, with the value of PTO damping 5×10^4 kNm, the larger the mass of structure the less changer to natural period. For structure-6 that has a larger mass it is worth to absorb additional PTO damping of 5×10^4 kNm because there is no decreasing from the value of natural period.

Power Take Off and Performance

WEC performance analysis was carried out to see the efficiency of the power of PTO absorber to theoretical wave power. From the results of the PTO calculation, it was found that the highest PTO value was in the structure with the largest mass (Structure-6). While the smallest PTO is in structure-2 with the smallest mass compared to the other structures. The following is a comparison of the PTO from WEC structure with the direction of arrival wave is 0° with the range of wave period is 2 to 15 seconds as shown in Figure 10.

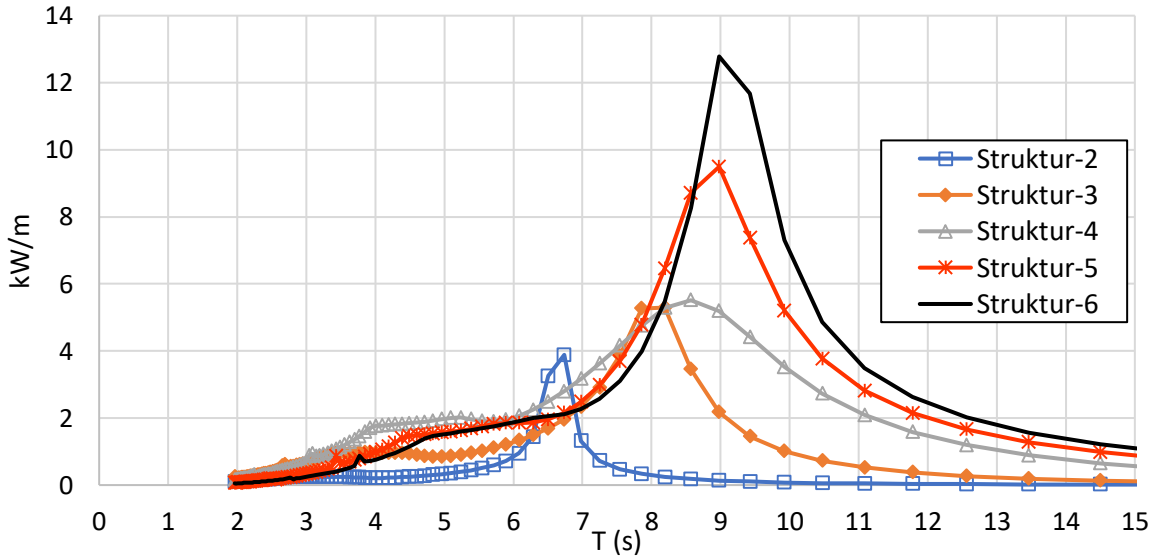


Figure 10. Power Take Off from Each Structure.

From the results of the analysis, it can be seen in Figure 11 that the highest CWR value is in structure-6 with value of 72.17% at wave period of 9 seconds. Structure-6 also has the highest PTO power compared to the other structures, which causes structure-6 to have the highest efficiency compared to the other structures. It is also seen that the CWR value of the structure is arise in the wave period range of 2 to 12 seconds.

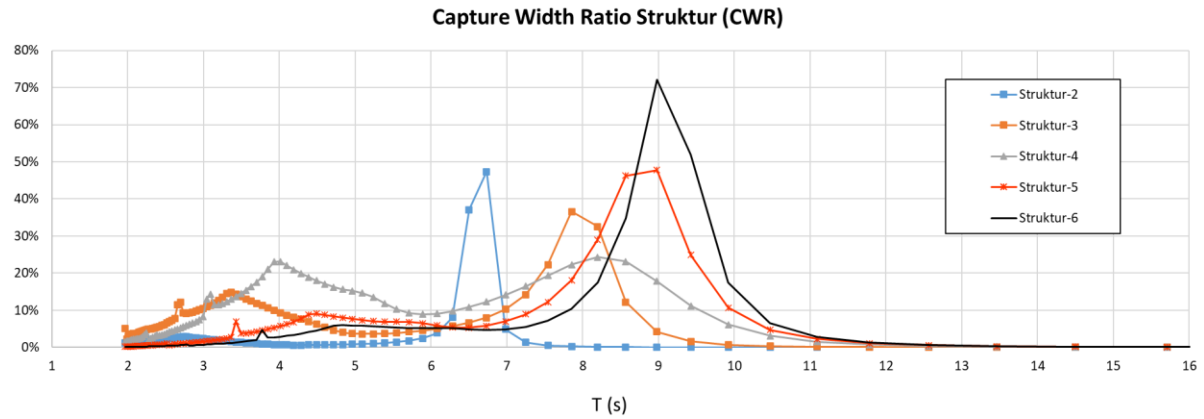


Figure 11. Performance from Each Structure.

CONCLUSION

The direction of the incident wave affects the pitch motion value of structure. The largest and optimal pitch motion is obtained from the direction of the incident wave 0° or the direction of the incident wave that is directly to the front of position of the structure.

From the analysis, it was found that when the condition of the structure was not given additional PTO damping, a structure with a small mass would have a large pitch motion, while a structure with a large mass would have a small pitch motion. However, when the structure is added with PTO damping (5×10^4 kNm) it will produce the opposite structural response.

In addition, it is also found that the value of mass and radiation damping will affect the value of PTO power absorber and the performance of the WEC structure. Another result is that the structure when given additional PTO damping can make changes in the value of the natural period or natural frequency from the structure. From the five structures, it was found that Structure-6 produced the most optimum CWR value of 72.17% at a wave period of 9 seconds, which matches North Sumatera's mean wave period.

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