Dynamic Behavior Analysis of Porous Saw Floating Breakwater under Regular Waves

Sujantoko, E. B. Djatmiko, W. Wardhana, H. D. Armono and Wahyudi
Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

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Abstract: Porous saw floating breakwaters are floated and tethered breakwaters for coastal protectors with typical steep, deep, and relatively large choppy contours, designed with saw porous, to be able to absorb waves efficiently and effectively. A proposed numerical model was developed for the porous saw type, while the model for the pontoon and the saw type will be used as a comparative study. All types of the structure breakwaters were physically placed inside the flume tank in which the direction of waves was perpendicular (to the structure) with 3 cm height and 1.1 seconds of period conducted in 41 cm depth of water. The numerical model shows that the Response Amplitude Operators (RAO) only affect the sway, heave, and roll motions. The porous saw floating breakwater demonstrates the smallest RAO value among other types i.e. sway 0.66 cm/cm, heave 2.1 cm/cm, and roll 0.86 deg/cm. It means the porous saw type more advantages since the ability to absorb the wave. Moreover, some of the wave energy will be reduced when the wave passes through the structure. Therefore, the wave energy received by the structure and the mooring rope becomes smaller.

1 INTRODUCTION

In recent years, many sectors attempt to manage and utilize the Indonesian coastal region. Such as industry, trade, transportation, housing, and the tourism sector. As population growth and increasing socio-economic development activities, the "value" of the coastal region continues to grow. Coastal areas, despite their high economic value, are vulnerable to many threats. One serious threat encountered is abrasion, causes a reduction in coastal areas. It may happen because of the large amount of wave energy comes directly to the coast without any absorption beforehand.

Preventing the negative effects caused by abrasion, it is very important to build and install the coastal protection structures to reduce wave energy towards the coastal area. One of the coastal protection structures that protect from abrasion and erosion is a breakwater, a structure was built to protect the area behind it from the wave attacks. There are two types of breakwaters, namely fixed breakwater and floating breakwater, both are built depending on the normal water level elevation and tidal conditions in which the structure is placed. Floating breakwater offers the level of protection needed when working in deeper waters with exposure to natural resources that are stronger than conventional types of the breakwater. Floating breakwater applying the concepts of reflection, dissipation, and transformation to reduce wave energy so that it can weaken the up-coming wave to an acceptable level (Morey, 1998). This breakwater is a floating structure on a limited draft and depends on the interaction of building structures at the top of the water column. Moreover, another advantage of floating breakwater against the fixed breakwater, the efficiency does almost not depend on the tides and sea-level rise, then the impact to the environment is low, the cost of structure construction, installation and removal are low, short time for installation, and ability to reset the layout if there are changes in the future (Ruol et al. , 2012). However, as a floated structure, then a mooring system placed on the seabed (Fousert, 2006).

In general, floating breakwaters reduce the surface waves through the mechanism of reflection, destroying the movement of water particles and attenuation of viscosity. When the waves hit the structure, energy will be reflected, scattered, and partially muted by the structure. The greater the wave energy absorbed, the higher the intensity of the following structure's motion. Since most of the wave energy will be converted into motion energy. The

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amount of energy absorbed is largely determined by the magnitude of the cross-sectional area of the structure relative to the perpendicular direction of the incident wave. Therefore, a floating breakwater design with minimum cross-section and interaction effect is an important reference for producing designs with minimum responsiveness. Such conditions can be achieved with porous surface conditions.

Based on the concept of maximum energy dissipation due to reflections and minimum energy trajectories that pass through the structure, the floating breakwater research continues to develop to find better performance. The number of researchers has conducted a study on the floating breakwater with porous types, namely porous pontoon (Lee & Ker, 1997; Williams & Li, 1998; Wang & Sun, 2010), porous boxes (Stainissie & Drimer, 2003; Koutandos & Prinos, 2011; Zeng et al., 2018), porous plates (Chwang & Dong, 1984; Wang & Ren, 1993; Cho, 2016; Fang at al., 2018), porous cylinder (William et al., 2000; Zhao et al., 2010; Shih, 2012).

This research will study the porous floating breakwater. This type of structure also reduces extreme wave loads which can affect the performance of floating structures. In an impermeable form, the structure will receive the maximum wave force so that it will transfer the wave energy to the mooring rope. This undesirable condition since mooring ropes will receive large loads so that the structure remains stable receiving wave force. The response of structural motions as a result of wave loads will affect the performance of the structure, i.e. reflection and transmission of waves. Therefore, during the design stage, it is necessary to predict the structure's motion to produce a small wave attenuation. Numerical simulations will be carried out to determine the characteristics of the 6 degrees of freedom structure motions using the Ansys Aqwa Module.

2 METHOD OF RESEARCH

2.1 Floating Breakwater Design

The material used in the floating breakwater model is High-Density Polyethylene (HDPE) with a density of 960 kg/m^3. Figure 1 shows the pontoon, porous saw, and saw type floating breakwater have the same dimensions (length 20 cm, height 6 cm and width 6 cm). The types are slightly different, the porous saw type has a pore, which is penetrated the structure from the front to the back and there is also a triangle shape lined up in the front of the structure.

In the porous saw type, the pipes are used so that the front and rear sides of the breakwater are perforated. The pipe used has an outside diameter of 0.4 cm. These three breakwater types above are floats with a 4 cm draft. The pore in the porous saw type floating breakwater is take up to 5% area of the overall area in the side of the structure. The difference between these three models requires the thickness of the porous saw type floating breakwater to be 0.36 cm to keep drafts are the same. The reduction was caused by the loss of buoyant force due to a hole in the floating breakwater.

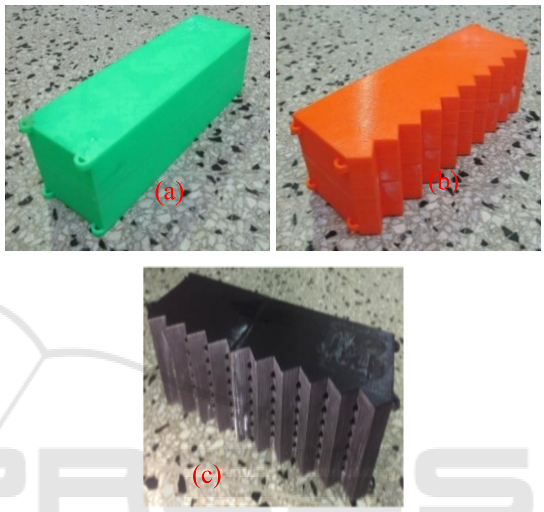

Figure 1: Floating breakwater (a) type pontoon, (b) saw and (c) porous saw.

2.2 Hydrostatic Parameters

A series of floating breakwater models arranged in 3 directions longitudinal to the width of the flume tank. The hydrostatic parameters in this numerical simulation are used as a basis for measuring the model validation. Based on the dimensions of the floating breakwater model, it can be determined the volume of the types of a pontoon, saw, and porous saw respectively 2266.58 cm^3, 2487.5 cm^3, and 2274 cm^3. The mass of the floating breakwater can be determined by multiplying the volume by the density of HDPE so that the mass of the floating breakwater type of pontoon, saw, and porous saw is 1457 gr, 1592 gr, and 1535 gr respectively. The third dimension of this structure is designed to have a draft of 4 cm.

The initial step before developing a numerical model is calculating the center of gravity for each structure. The value of the gravity center in the floating structure is very important to determine the stability of the floating breakwater. The center of gravity calculation is done by dividing floating breakwater into several parts. Then, determining the value of inertia and the radius of structure gyration. Complete data on hydrostatic parameters are shown in Table 1.

Table 1: Hydrostatic data floating breakwater.

Hydrostatic Parameters	Pontoon	Saw	Porous Saw
Vol. Displ. (cm^3)	2266.6	2487.5	2274
Massa (gr)	1457	1592	1535
Ixx	3822	4498.9	4387.6
Iyy	40812	44553.75	44546.85
Izz	43197	47276.3	47253.4
Kxx	1.62	1.68	1.64
Kyy	5.29	5.29	5.29
Kzz	5.45	5.45	5.45
WPA (cm^2)	360	372	372

2.3 Validation of the Hydrostatic Model

Numerical simulations to determine the response of floating breakwater motion are performed by computational fluid dynamics with the ANSYS/ AQWA hydrodynamic simulation software. Figure 2 shows the layout of the model scenario with the direction of the incident wave perpendicular to the structure.

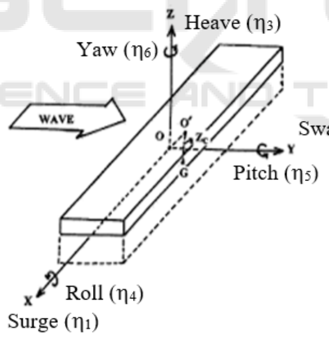

Figure 2: Degree of freedom of floating structures (Das & Das, 2005).

Before conducting the structural motion analysis, the floating breakwater model must be validated to find out the floating breakwater by the conditions in the analytical calculation. Important hydrostatic parameters that will be used for the validation of this model are the volume displacement and water plane area. Based on The American Bereau of Shipping (1998), the validation is a maximum of 2% and for other provisions a maximum value of 1%. The calibration results of the model are shown in Table 2 and 3.

Table 2: Validation of numerical models: volume displacement.

No	Floating Breakwater	Hydrostatic Parameters		
		Volume Displacement (cm^3)		
		Analytic	Numeric	Error %
1	Pontoon	1457	1457	0
2	Saw	1657	1657	0
3	Porous Saw	1663.79	1658.28	0.303

Table 3: Validation of numerical models: water plane area.

No	Floating Breakwater	Hydrostatic Parameters		
		Water Plane Area (cm^2)		
		Analytic	Numeric	Error %
1	Pontoon	360	360.01	0.0001
2	Saw	372	371.8	0.002
3	Porous Saw	372	371.8	0.002

3 RESULTS AND DISCUSSION

Numerical simulations of floating breakwater motion have been done at a depth of 41 cm, a wave period of 1.1 s and a wave height of 3 cm with the direction of the wave perpendicular to the structure. The results of numerical simulations are shown in figures 3-8.

The characteristic of surge motion in pontoons, saw and porous saw floating breakwater in the direction of waves perpendicular to the structure is very small and almost close to 0 (Figure 3). Saw type RAO is the biggest among other types because there is additional displacement in front of the structure. Generally in the surge motion, waves to the side do not have an effect on the occurrence of surge motions.

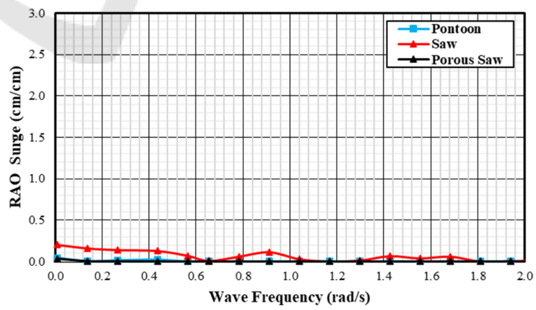

Figure 3: RAO Surge numerical prediction of various types of the floating breakwater.

Sway motion characteristics are almost the same as the surge motion where the maximum RAO value is at low frequencies (Figure 4). The highest RAO on the pontoon is 0.79 cm/cm. At the same frequency, the maximum RAO for saw-type floating breakwater is 0.98 cm/cm and porous saw-type RAO is 0.6

cm/cm. After that, the third RAO floating breakwater decreases gradually. Sway motion has a higher maximum value when compared to surge for side waves because side wave propagation has a great influence on sway motion.

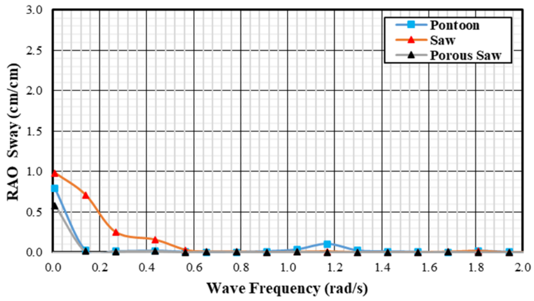

Figure 4: RAO Sway numerical prediction of various types of the floating breakwater.

Figure 5 shows the RAO heave motion is an example to explain dynamic systems that experience wave excitation. At low frequencies, the three RAO types of floating breakwater are 1.11 cm/cm, 1.08 cm/cm, and 1.13 cm/cm and gradually increase towards the resonant region at the natural frequency of 0.436 rad/s. the largest maximum RAO heave occurs in the saw type followed by porous pontoon and gergagi types respectively 2.85 cm / cm, 2.45 cm/cm, and 2.1 cm/cm. After crossing the peak, the RAO heave will decrease dramatically at high frequencies.

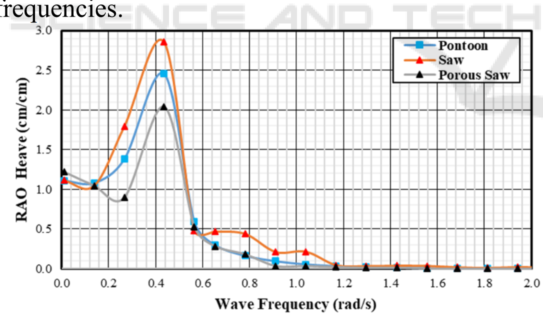

Figure 5: RAO Heave numerical prediction of various types of the floating breakwater.

Roll motion is almost the same as the characteristics of the heave motion (Figure 6). In the sub-critical region, the motion response represents the same condition in all types of the floating breakwater, then increases sharply in the resonant region and decreases significantly in the supercritical region. The natural frequency of the roll motion is 0.43 rad/s. The value of the highest response of roll motion on a saw is 11.86 deg/cm, followed by the pontoon type of 9.64 deg/cm, and the porous saw is 6.8 deg/cm.

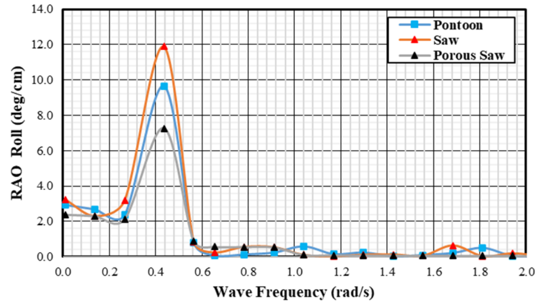

Figure 6: RAO Roll numerical prediction of various types of the floating breakwater.

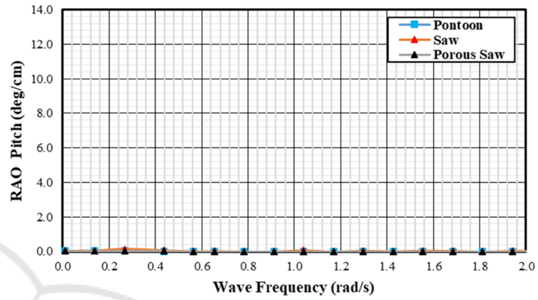

Figure 7: RAO Pitch numerical prediction of various types of the floating breakwater.

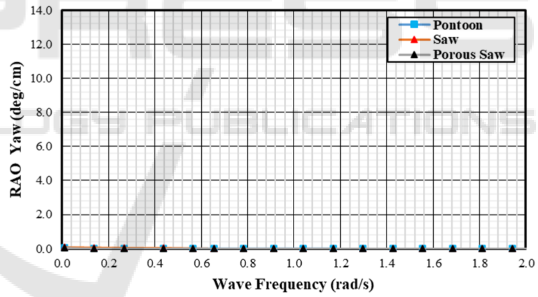

Figure 8: RAO Yaw numerical prediction of various types of the floating breakwater.

In pitch and yaw motions (Figure 7-8), it is not the same as roll motions which are both rotational mode motions. However, pitch and yaw motion intensity is not affected by side and bow waves, so that the value is 0 or close to 0 so there is almost no motions response.

Based on numerical simulations obtained floating breakwaters motion behavior. The condition of a free-floating structure without a mooring system will produce a vertical motion mode (heave, roll, and sway) which is more dominant than the horizontal motion mode (surge, pitch, yaw). This happens because all three modes of motion (vertical motion modes) have a stiffness factor due to harmonic wave excitation, the presence of this stiffness factor causes the damping factor value to be small so that when the motion reaches its resonant frequency, the change in motion characteristics will have a sharply increased part. Whereas the horizontal motion mode which does not have a stiffness factor during free-floating conditions will produce a relatively large damping factor so that the motion will be damped by the presence of the damping factor and the horizontal motion mode does not experience a sharp increase. If there is an increase in certain parts, then the increase in the curve is influenced by the coupling effect of other motions.

6 CONCLUSIONS

This paper compares the dynamic behavior of a porous saw type floating breakwater with another types. Numerical studies were carried out with computation fluid dynamics on models of these structures at a water depth of 41 cm, wave height of 3 cm, and a wave period of 1.1 seconds. some findings may be explained as follows:

- The surge, pitch, and yaw motion modes are not affected by side waves so the RAO value is very small and almost close to 0.
- The floating breakwater motion in the direction of incoming waves perpendicular to the structure only affects the motion sway, heave, and roll.
- Sway motion has a higher maximum value when compared to surge for side waves because side wave propagation has a great influence on sway motion. At the same frequency, the maximum RAO for saw-type floating breakwater is 0.98 cm/cm, tipe pontoon is 0.79 cm/cm and porous saw-type RAO is 0.6 cm/cm. After that, the third RAO floating breakwater decreases gradually.
- The largest RAO maximum heave motion occurs in the saw type followed by the type of pontoon and porous saw by 2.85 cm/cm, 2.45 cm/cm, and 2.1 cm/cm respectively. After going through the peak, the RAO heave will decrease dramatically at high frequencies.
- The highest peak value of RAO roll occurs at natural frequency 0.43 rad / s, in floating breakwater type of saw, pontoon, and porous saw of 11.86 deg/cm, 9.64 deg/cm, and 8.6 deg/cm respectively.

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