Experimental Study on the Effect of Mooring Angle on Mooring Tension of Porous Saw Type Floating Breakwater

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Abstract: The floating breakwater is commonly used as an alternative solution to conventional fixed breakwaters and can be used effectively in coastal areas in environments with relatively small waves, poor soil conditions, deep-sea depth, and shore with intense erosion rate. Since it is a floating structure, a mooring system is used to maintain its position. This study aims to determine the mooring tension that occurs on each mooring rope with a physical model test. This research was conducted on the type of pontoon and porous saw. In this study, it was found that on a porous saw type, the greatest maximum tension occurred at the mooring angle 30º (3.98 N) while the smallest maximum tension occurred at the mooring angle 60º (0.73 N). The pontoon type also gives the same result where the 30º mooring angle gives the highest maximum tension (4.91 N) while the 60º mooring gives the smallest maximum tension (1.27 N). Besides, the porous saw type of floating breakwaters can provide smaller mooring tension than the pontoon type. The porous saw type can reduce mooring tension by 10% up to 15% at an angle of 30º - 60º.

1 INTRODUCTION

In recent years, a lot of efforts have been made to manage and utilize the coastal areas of Indonesia. Such as industry, trade, transportation, residential, and the tourism sector. Thus, in line with population growth and the increase of socio-economic development activities, the value of coastal areas continues to grow. Coastal areas, despite having high economic value, are vulnerable to many threats. One of the serious threats faced by coastal areas is abrasion which can cause coastal area reduction, due to the large amount of wave energy that comes directly to the coastal area without the wave energy being absorbed beforehand.

Because it is considered important to avoid negative effects due to abrasion, it is very necessary to build and install a coastal protection structure that can reduce wave energy towards the coast area. One of the coastal protection structures that can protect the shore area from abrasion and erosion is the breakwater. A breakwater is a structure built to protect the area behind it from a wave attack. There are two types of breakwaters. Fixed breakwater and floating breakwater, that are built depending on the water depth and tides condition where the structure is placed. Floating breakwater has several advantages than the fixed breakwater. Its efficiency is almost independent of tides and sea-level rise, its dependence on the environment is low, the impact of a floating breakwater to the environment is low, the cost of construction and decommissioning is low, the time required for installation is short, and it is possible to reset the module and/or to set the layout if there is a change in the future (Ruol et. al., 2012). However, since it is a floating structure, the anchor system is required which is placed at the bottom of the sea (Fousert, 2006). Figure 1 shows two types of floating breakwater schematically (Pianc, 1994).

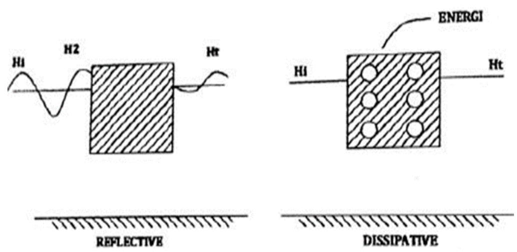

Figure 1: Two types of floating breakwater schematically.

There are so many types of floating breakwater, the most commonly used is the pontoon type which is connected and tethered to the seabed using a cable

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or chain. A floating breakwater is a floating structure that requires a mooring system to keep the structure stay in place (McCartney, 1985). One of the aspects that must be considered when designing floating breakwater is the mooring system of the structure. Moorings, whether constructed of piles or mooring lines and anchors, must hold a breakwater in place and a careful assessment of mooring forces during design storm wave attacks must be made to ensure the survival of the breakwater. Waves loading generally dictates the design of floating breakwater and its mooring system (Tsinker and Gregory, 1995). In this study, a physical model test will be carried out to find the maximum tension value on several types of floating breakwater then examine by comparing type. Two types are being considered: porous saw type, and pontoon type. This test will be carried out by varying the water level as a simulation of tidal conditions. In the test, the mooring angle will also be varied by referring to previous research so that the optimum results are obtained.

2 MATERIALS AND METHODS

2.1 Research Scenario

The floating breakwater model is tied by a mooring rope with a mooring angle α at water level D and placed in wave characteristics under significant wave height Hs and period T (see Figure 2). These four environmental parameters are independent variables that will be varied. The effect monitored and recorded in this test is the mooring rope tension as the response variable.

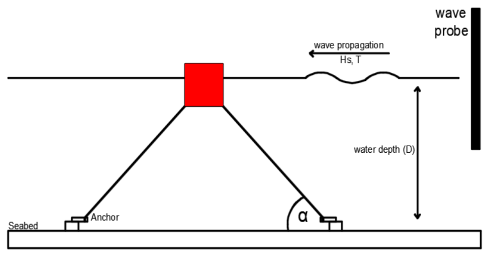


Figure 2: Layout sketch of floating breakwater physical model tests.

2.2 Floating Breakwater Design

The material used in the floating breakwater prototype is K300 concrete with a concrete density of 2300 kg/m3. The thickness used is 0.2 m. The porous saw type floating breakwater has the same basic dimensions (length 10 m, height 3 m and width 3 m) and also use the same material as the pontoon type. There is a slight difference between the two models where the porous saw has a pore which is penetrated the structure from the front to the back. There is also a triangle shape lined up in the front of the structure.

In the porous saw type floating breakwater, pipes are used so that the front and rear sides of the breakwater are perforated. The pipe used has an outside diameter of 20 cm using High-Density Polyethylene (HDPE) material with a density of 960 kg/m3. The two breakwater types above float with a 2-meter 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 two models requires the thickness of the porous saw type floating breakwater to be 0.18 m or 0.02 m smaller to keep both drafts are the same. The reduction was caused by the loss of buoyant force due to a hole in the floating breakwater.

2.3 Test Modelling and Scaling

Tests are carried out in the laboratory so a model is needed from both the structure and the environmental conditions. in this test a 1:50 scale of length was used. Figure 3 and 4 show image of both type of floating breakwaters to be tested.

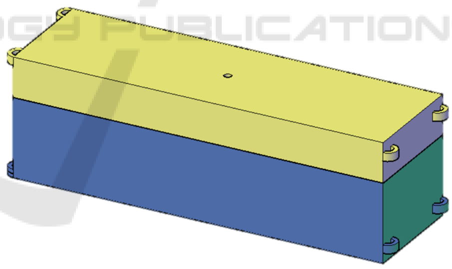


Figure 3: Floating breakwater type pontoon.

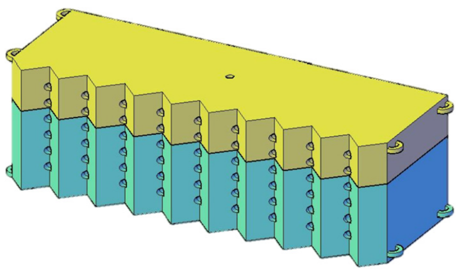


Figure 4: Floating breakwater type porous saw.

Table 1: The model scale of environmental condition tested (scale 1: 50 for D and Hs, 1 : √50 for T).

Parameter	Prototype	Model
Water level elevation (D)	21,5 m	41 cm
	21,5 m	43 cm
	22,5 m	45 cm
Wave height (Hs)	1,5 m	3 cm
	2 m	4 cm
	2,5 m	5 cm
Wave period (T)	7,8 s	1,1 s
	9,2 s	1,3 s
	11,3 s	1,6 s

The mooring angle (α) are at 30º, 45º and 60º.

2.4 Physical Model Tests Layout Setting

Several factors important for conducting the experiments include physical model design, the structure layout, and the measurement equipment used in Wave Flume Laboratory. These factors help researchers better understand the experiments. A Wave Probe is placed to record the wave height and wave period. In this test, an 35 cm artificial seabed was built at the bottom of the Wave Flume. This seabed used to adjust the designed water level scenario. Since the Wave Flume only works if the test was carried out at a water depth between 41 - 45 cm. Figure 5 depicts a sketch of the top and side view of the layout test.

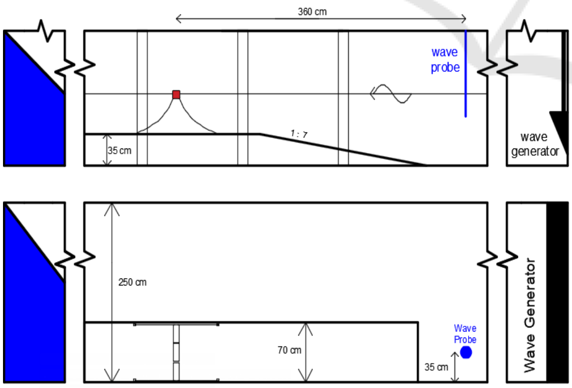


Figure 5: Model sketch layout of the test.

2.5 Equipment Calibration

The equipment to measure water elevation is Wave Probes, while Load Cells used to measure mooring tension. Both types of equipment are calibrated to see the equipment's condition whether it is still in good condition to be used in this test or not.

a. Wave Probe calibration

In general, the following steps required in the Wave Probe calibration process is explained below:

1. The Wave Probe is positioned where the tip of the Wave Probe touches the surface of the water. The voltage shown on the control computer will change slightly and the voltage will be recorded 3 times which will be averaged.
2. The Wave Probe then moved 20 cm deeper into the water. The voltage results are then recorded again 3 times and averaged. This process repeats until it reaches a depth of 80 cm from the tip of the probe. The illustration can be seen in Figure 6.

After the calibration process is carried out, the values obtained from each water depth are then arranged into a graph. Figure 7 shows the results of the Wave Probe calibration before and after the experiment. From the graph, it can be seen that there is no significant change and the value of the coefficient of determination is close to 1 (0.999) which indicates that the stability of the Wave Probe is still very good.

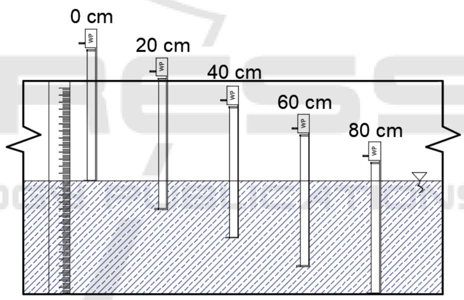


Figure 6: Wave Probe calibration process.

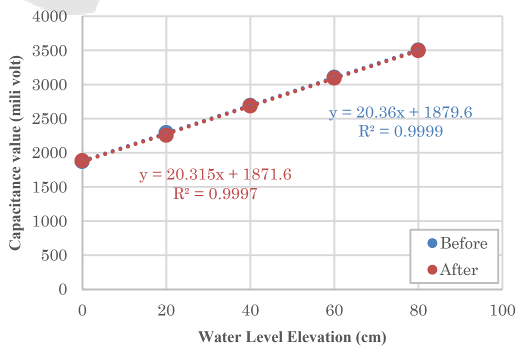


Figure 7: Wave Probe calibration graph.

b. Load Cell calibration

Four Load Cells with a capacity of 5 kg are being installed at the end of the bottom of the floating breakwater. Calibration is carried out by weighing five different loads i.e. 1000 grams, 500 grams, 200 grams, 100 grams, and 50 grams. The load is weighed using a digital scale beforehand so the actual weight of each load used is already known. The recorded load show on the computer will be compared to the actual weight of each load. The Load Cell used in this experiment can be seen in Figure 8.

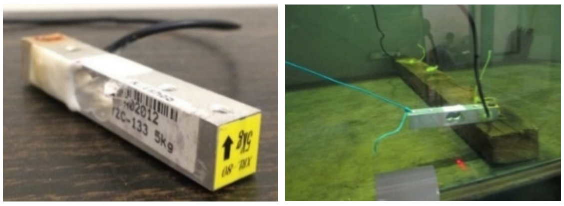


Figure 8: Load Cell with a capacity of 5 kg.

Calibration is done by changing the load on the Load Cell using a rope freely. Figure 9 shows the calibration results of each Load Cell used to validate the results of tension mooring recorded when the test takes place.

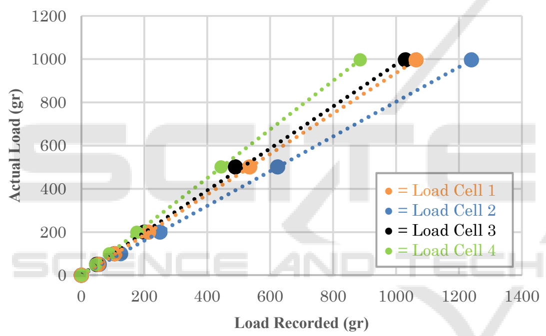


Figure 9: Load Cell calibration graph.

Figure 9 shows that each Load Cell has a different calibration value. Therefore, during data processing data, each Load Cell has a different regression equation. All regression equations (see Table 2) have the determination coefficient (R^2) really good (close to 1). These regression equations used as the correction factor for the load shown by the recorded computer.

Table 2: Load Cell calibration equation.

Load Cell	Calibration Equation	Determination Coefficient (R^2)
1	$y = 0{,}9369x - 0{,}4691$	1
2	$y = 0{,}8026x + 0{,}6541$	1
3	$y = 0{,}9728x + 3{,}6322$	0,9992
4	$y = 1{,}1252x + 0{,}2195$	1

3 RESULTS AND DISCUSSION

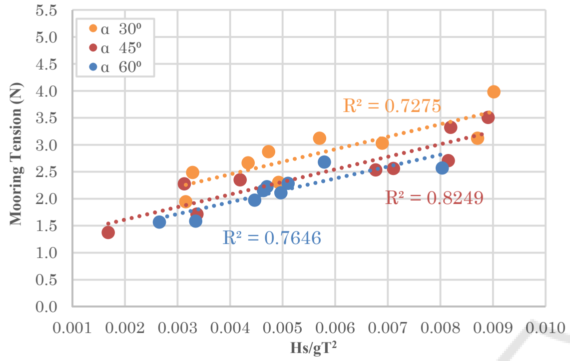
After all, preparations are completed, mooring tension data is collected every 2 minutes for each test, with an increment of 0.5 seconds. The recorded mooring tensions from each Load Cell recorded in four different columns then converted into kilograms (kg). The maximum tension was selected among data have been collected for analysis.

Preparation before analysis was conducted by grouping the data based on a combination between water level elevation and mooring angle. The total combination is 9 maximum tension with different Hs and T values. In this test the variables Hs and T are merged into one parameter, the parameter is known for wave steepness parameters (Hs/gT2). Each group of data is then arranged into a graph that shows the relationship between mooring tension and wave steepness parameters, Hs/gT2. In addition, linear regression was also performed on each group of data to simplify the comparison between data groups.

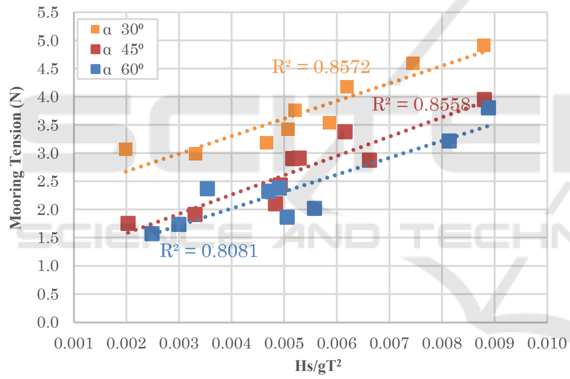
3.1 The Effect of Mooring Angle

Based on the data recorded from the physical model test carried out with variations in the mooring angle, a various maximum mooring tension value was obtained indicating that there is the influence of the mooring angle on the mooring tension of the floating breakwater. Figure 10 shows the effect of the mooring angle used in this test on the maximum mooring angle on the floating breakwater type porous saw and pontoon at a water level elevation of 45 cm. It can be seen in Figure 10, the greatest maximum mooring tension occurs at the 30º mooring angle on both the floating breakwater type; porous saw, and pontoon. On a porous saw type, compared to an angle of 30º, an angle of 45º and 60º have a smaller maximum mooring tension value of 15% and 20% respectively. While the pontoon type, the angle of 45º and 60º have the smallest maximum mooring tension value of 34% and 45% respectively to the angle of 30º. At the water level elevation of 41 cm and 43 cm, the same phenomena happen where the greatest maximum mooring tension occurs at an angle of 30º and the smallest maximum mooring tension occurs at an angle of 60º.

Some researchers have examined how the effect of the mooring angle on mooring tension. Wei, et al. (2011), examined the effect of the mooring angle on the interaction between the floating breakwater and the wave, and one that was tested was the effect on the mooring force. From the test, it is known that there is an increasing mooring tension when the mooring angle decreases from 90º to 0º especially when the mooring angle is below 30º. They added, even though the 60º angle gives the lowest mooring tension value, the motion of the structure is less stable. The results show that the sway, heave, and roll motions are high when the large angle is used, especially when the angle reaches 60º. The result of this study is not contradictory to the result obtained in Wei, et al. (2011).



a) Porous saw

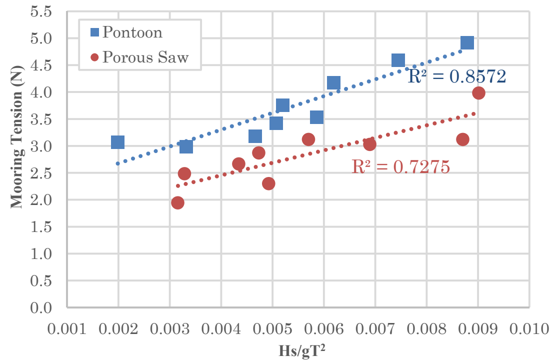


b) Pontoon

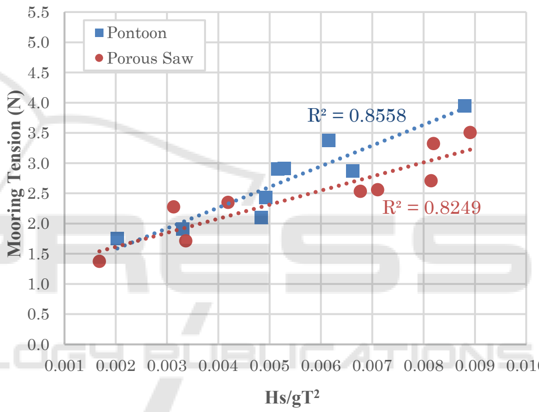
Figure 10: Mooring tension at water level 45 cm on floating breakwater type porous saw and pontoon.

3.2 Floating Breakwater Type Comparison

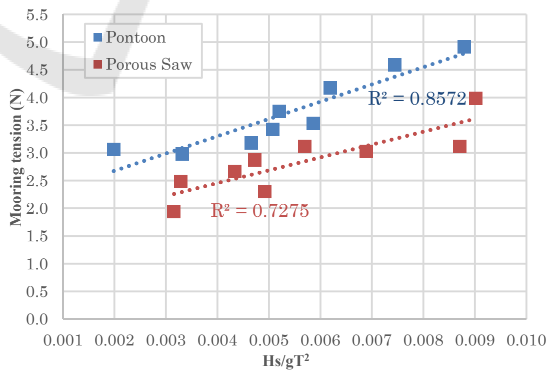
The testing of the floating breakwater mooring tension is carried out on two types of floating breakwater which are the porous saw type and the pontoon type so that there is a mooring tension difference experienced by the two types of floating breakwater tested. The comparison graph of the porous saw and pontoon type floating breakwater shows that a larger tension occurs on a pontoon type floating breakwater. Figure 11 shows a comparison of the two types of a floating breakwater at 45 cm water level elevation. It can be seen in figure 11 that the pontoon type floating breakwater produces a greater mooring tension than the porous saw type. This proves that porosity addition can reduce the mooring tension value. The mooring tension reduction also varies from 10% up to 15%.



(a) 30o



(b) 45º



(c) 60º

Figure 11: Comparison between both floating breakwater porous saw and pontoon types at various mooring angles.

There are some previous researchers also supported the results obtained in this study. One of them is Wilbur (1996), he carried out a study of perforated floating breakwaters and how they affected various aspects of the floating breakwater. One of the aspects that were studied is the mooring tension and transmission coefficient. In terms of the transmission coefficients, it is found that solid floating breakwater has a smaller transmission coefficient value indicates that solid floating breakwater can reduce waves better. But in terms of the mooring tension produced in the mooring lines, both the mooring line on the seaward side and shoreward side produces a smaller mooring tension value on the perforated floating breakwater.

Wilbur (1996) says that when a wave hits the structure of a floating breakwater, some of the waves are reflected, some pass away, and some others enter through the pore that is in the structure and that, of course, reduces the impact received by the mooring system. Marks continued, if the floating breakwater used is a solid structure, the greater reflection will occur on the side of the floating breakwater wall with a high resultant force. In the case of a perforated floating breakwater, the wave force will be transmitted to the mooring rope and also some of the wave force will direct the floating breakwater to move (oscillating) so that it forms a new wave behind the structure. This is certainly one of the disadvantages of using a solid floating breakwater rather than the perforated floating breakwater. Research conducted by Wilbur was also proven in this study where the tension produced by a porous saw type floating breakwater is lower than that of a pontoon floating breakwater.

4 CONCLUSIONS

Based on this study, several conclusions can be drawn from the physical model tests of mooring tension on the porous saw type floating breakwater including:

1. Based on variations in the mooring angle and water level elevation, the following conclusions are obtained:
   - The greater the mooring angle, the smaller the mooring tension experienced by the mooring line.
   - Based on the variations of the mooring angle, 30º, 45º, and 60º, it can be seen that the greatest mooring tension occurs at an angle of 30º with mooring tension differences at 45º and 60º of 15% and 20% smaller than an angle of 30º respectively.
2. Floating breakwater type porous saw type gives a smaller mooring tension than the pontoon type. The porous saw type can reduce mooring tension by 10% up to 15% at an angle of 30º - 60º.

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