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PHYSICAL MODELLING OF NATURAL COASTAL PROTECTION SYSTEM: CONTRIBUTION OF GREEN MUSSELS TO THE EFFECTIVENESS OF NATURAL COASTAL PROTECTION SYSTEMS

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Abstract: Indonesia is an archipelago with a long coastline which provides many economic, social, and cultural advantages. Therefore, it is necessary to protect coastal areas from erosion. Mangroves as a form of natural coastal protection, are economically and environmentally feasible in many coastal areas. However, before mangroves can grow into strong trees which require 2 years of plantation, the ocean waves will damage them. To solve this problem, a natural coastal protection system using main natural protection (mangroves) as well as a temporary artificial structure (bamboo poles with green mussels) is proposed. This study aims to quantify wave height reduction using various mangroves and bamboo pole configurations. The laboratory experiments were conducted in a wave flume using physical models of mangroves as the main natural protection and bamboo poles with green mussels as the temporary artificial structure. Various wave conditions, including extreme waves, were generated during the laboratory test. This paper focuses on wave transmission over the natural coastal protection system to determine the most effective configuration of bamboo poles with green mussels. The results show that the most effective configuration model is to use 50 mm between the poles' columns and rows and mm breakwater width of 800 mm.

Keywords: Natural coastal protection, mangroves, green mussels, temporary structure.

Introduction

Indonesia is the largest archipelago in the world with Indonesia's oceans accounting for 76% of its total area of 7.9 million km² (Frederick & Worden, 2011) as well as a total coastline of 99,083 km (Setiawan, 2022). Therefore, Indonesia has enormous potential for coastal and marine resources including food, vegetation such as mangroves and coral reefs, and minerals. Some factors that cause coastal erosion include human activities such as mangrove deforestation and the expansion of artificial ponds towards the sea. Other factors of erosion are caused directly by the environment, such as the energy from ocean waves. Overcoming this problem can be done by constructing coastal protection, which can reduce the transmitted wave energy within the coastal area.

Cultivating mangroves as a natural method effectively protects the coast from erosion and wave damage (Mark Spalding, 2014). Extensive research has been carried out on the performance of mangrove forests in protecting the coastlines (Husrin *et al.,* 2012; Johnson *et al*., 2018; Rao *et al.,* 1999; Schmitt *et al*., 2014; Strusińska-Correia *et al*., 2014; Hashim & Catherine, 2013; Yuanita *et al.,* 2018; 2019; 2020 2021). However, in using mangroves as coastal protection, young trees are vulnerable to the force of ocean waves. Therefore, it is necessary to protect the mangroves for a better opportunity to develop properly (Yuanita *et al*., 2021). One solution to overcome the damage to young mangrove forests is to build a temporary permeable structure such as a bamboo pole breakwater. Bamboo pole breakwaters can minimise wave energy while still allowing sedimentation to occur (Armono *et al*., 2022). For additional structural and economic support, the green mussel is proposed. Green mussel aquaculture that uses bamboo stakes is commonly found in Indonesia's coastal areas (Rejeki *et al*., 2021). This structure can protect mangrove plants until they mature. Cultivating the embedded green mussels can also increase residents' income around the coast and make the sea water clearer due to their natural abilities as a filter. In this study, the performance of green mussels on the effectiveness of temporary breakwaters is analysed using physical experiments. This experiment determines the most effective breakwater design based on the effectiveness of bamboo pole breakwaters and green mussels.

Materials and Methods

The methodology of this study is presented in Figure 1. The research starts by conducting a literature review of previous studies. Before making the test object, the scale is determined first. Then, the wave scenarios are determined according to the ocean conditions in Indonesia (Yuanita *et al.,* 2021) and the capability of the wave maker used. After that, the scenarios of the test object and the variation of the waves are determined for certain scenarios. Before performing the modelling simulation, the wave probe is calibrated first, and its accuracy is checked before the simulation is run. When

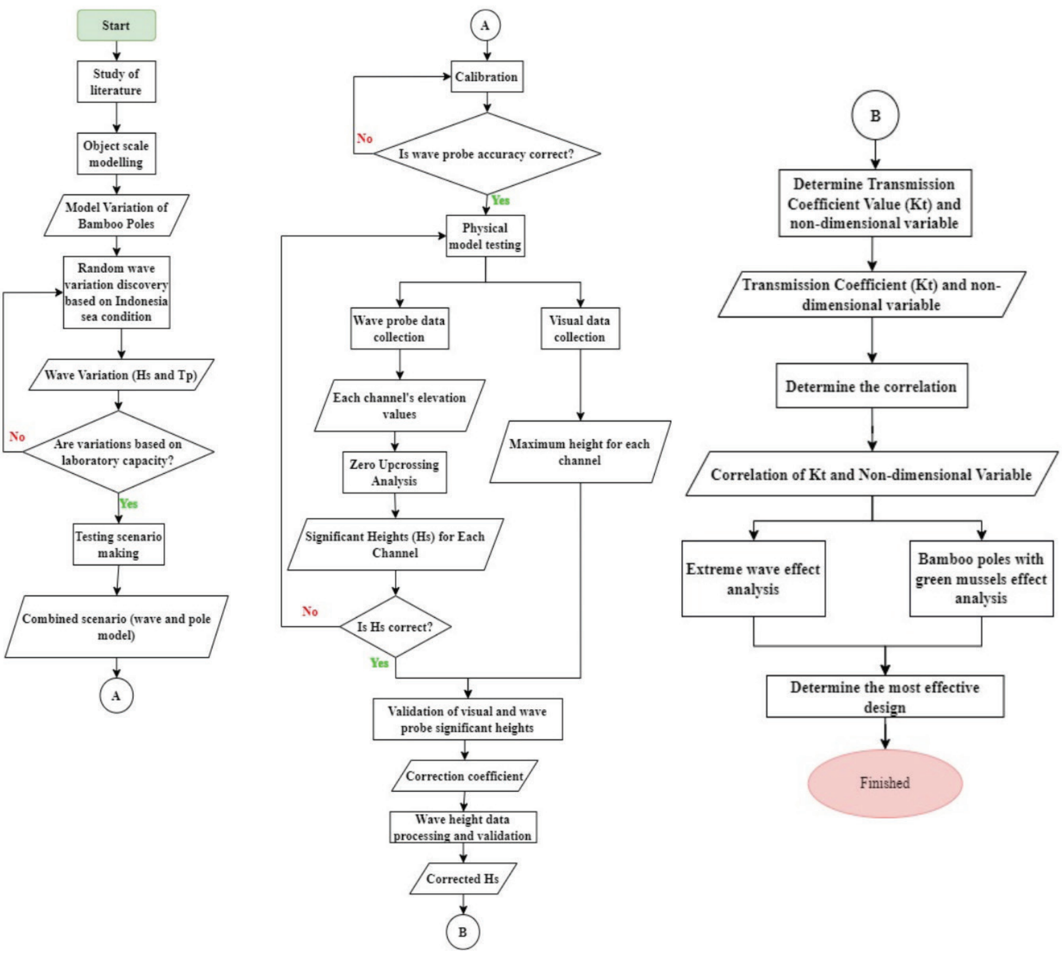

Figure 1: Study methodology

performing the simulation, data collection is conducted visually and by a wave probe. The data recorded by the wave probe on each channel will be processed using the zero up-crossing analysis method and the results will be validated with the input data on the wave maker. Then, the data from the zero up-crossing will also be validated through comparison with each channel's observed maximum wave height. This validation method is used since the wave probes accuracy is not completely optimal, and historical data from past experiments reveals that discrepancies between wave probe data and visual data of up to 10% can occur. The visual data is observed through recorded footage to ensure ease of cross-checking and accuracy of observations. The visual validation produces a correction coefficient with an appropriate significant wave height value. The wave height values are then converted into a spectrum, and another validation using the JONSWAP spectrum is also carried out. The JONSWAP spectrum is used because it relates to the random wave conditions of Indonesian waters. The objective of this validation is to investigate any extreme anomalies that occur within the wave spectrum compared to the theoretical JONSWAP spectrum. These anomalies can occur due to wave interference between incoming waves and waves reflected from the structures. To account for this, the anomalies are removed from the data, which results in the final corrected data being analysed. The transmission coefficient value is then calculated, and the non-dimensional parameters are determined to obtain the relationship between the two in each scenario. The non-dimensional parameters are obtained using the Phi Buckingham method. The Phi Buckingham method is used due to its output of non-dimensional variables from a set of dimensional variables. The non-dimensional analysed parameters enable the correlation analysis to be exclusive without external factors from different variables affecting the result. In this study, the analysis of the performance of green mussels on the effectiveness of temporary breakwaters and the effect of extreme waves is carried out. From this analysis, the most effective breakwater design can be determined.

Bamboo Pole with Green Mussels and Mangrove Model Scenarios

The scale used in this modelling is 1:10. The bamboo pole model uses cylindrical iron rods with a diameter of 12 mm and a length of 120 cm, which is placed on a perforated multiplex wood measuring 1.2 m x 2.4 m. Two multiplexes were used with one mounted on a 25 cm high iron frame and one mounted on the top of the bamboo pole model to prevent the rods from swaying. The green mussel model uses a wool thread wrapped around the rod. The mangrove model uses a similar one from previous research (Yuanita *et al*., 2019; 2020; 2021), which are cylindrical iron rods with a diameter of 10 mm and a length of 120 cm. For the bamboo pole model, nine configuration variations were used, as shown in Table 1.

Table 1: Variation of bamboo pole breakwater model scenarios

Variations (mm)	**Configuration Code**								
	SA1	**SA2**	**SA3**	**SA4**	**SA5**	**SA6**	**SB1**	**SB2**	**SB3**
Columns Distance	50	50	100	100	50	150	50	100	150
Rows Distance	50	100	50	100	150	150	100	100	150
Distance to mangroves	1400	1300	1300	1300	1300	1300	700	700	700
Breakwater Width	800	900	900	900	900	900	1500	1500	1500
Total Poles	383	225	219	115	158	53	360	184	83

Configurations of the Systems and Waves

The scenarios used in this study vary in system configuration, bamboo pole configuration, and wave parameters. The water depth used is 65 cm, with a beach height of 25 cm. Eleven wave parameters were used, which can be seen in Table 2. Tests were carried out with four system configurations, which can be seen in Table 3 with illustrations in Figure 2. Wave steepness was modified based on a dimensionless analysis as follows:

$$s_0 = \frac{H}{gT^2}, \quad (1)$$

Results and Discussion

Dimensional analysis using the Phi Buckingham method was carried out to obtain the relationship between parameters that affect the damping of energy and wave height due to the bamboo poles and green mussels' breakwater. The resulting non-dimensional parameters are $\frac{H_t}{H_i}$ (wave transmission coefficient), $\frac{JB}{H_s}$ (distance between breakwater rows), $\frac{JK}{H_s}$ (distance between breakwater columns), $\frac{Bw}{H_s}$ (breakwater width), and $\frac{H_s}{gT_p^2}$ (wave steepness).

The validation and correction of the data from the recording of the wave probe is carried out to ensure that the data is valid for the analysis. The results of the data correction from both visual data and the JONSWAP spectrum can be seen in an example of the wave spectrum comparison as shown in Figure 3.

Transmission Coefficient

In this study, the transmission coefficient is described on the breakwater structure with initial wave height (H_i) on CH_2, transmitted wave

Table 2: Variations of wave significant height (H_s) and peak period (T_p)

Wave Code	Wave Variation		
		H_s (m)	T_p (s)
1	0.0060	0.1500	1.6000
2		0.1000	1.3000
3		0.0800	1.1700
4	0.0030	0.1500	2.2600
5		0.1000	1.8400
6		0.0800	1.6500
7	0.0005	0.1500	5.5300
8		0.1000	4.5200
9		0.0800	4.0400
10	0.0015	0.1500	3.1600
(11) Extreme	0.0020	0.3000	4.0000

Table 3: System code

System Code	System Configuration
P	System configuration of only a beach
M	System configuration of a beach and mangroves
MT	System configuration of a beach, mangroves, and bamboo poles
MK	System configuration of a beach, mangroves, and bamboo poles with green mussels

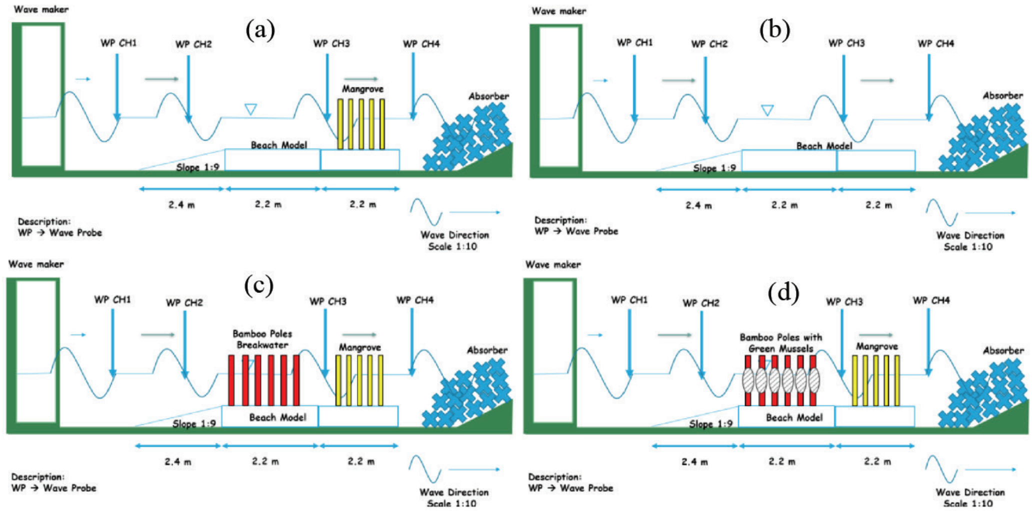

Figure 2: Model Configuration profile: Beach P Scenario (a), with Mangrove M Scenario (b), with Bamboo Poles MT Scenario (c), and with Green Mussels MK Scenario (d)

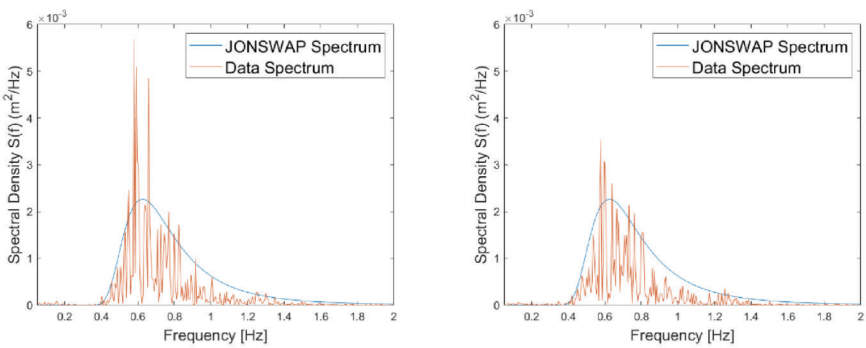

Figure 3: JONSWAP Wave Spectrum P-1 before (Left) and after (Right) Outlier Deletion

height (Ht) on CH_3, and the protection system with H_i on CH_2 and H_t on CH_4. An example of calculating the transmission coefficient (K_t) after waves passing structure (Structure K_t) and passing protection system (System K_t) is presented in Figure 4.

The relationship between K_t and dimensionless wave steepness () is inversely proportional, where the greater the steepness, the smaller the K_t value, and the more effective the coastal protection. An example of this relationship is illustrated in Figure 5.

The performance of green mussels is determined by comparing the results of the reduction percentage in the wave height values of the breakwater structure and protection system in the MT and MK scenarios (excluding the extreme wave condition). However, in the case of breakwater structure values, certain scenarios encounter issues with CH_3 data, specifically MT-SA4, MT-SA5, MT-SB2, MK-SA2, and MK-SA3. As a result, the values used can be taken from the average difference between MT and MK other than those scenarios, except for MT-SB2, because only two wave scenarios are problematic. The value used is the average of the rest of the wave scenarios. The protection system values have no problems so that they can be directly used. Figure 6 shows that green mussels increase the effectiveness of the breakwater and system. It is also seen that

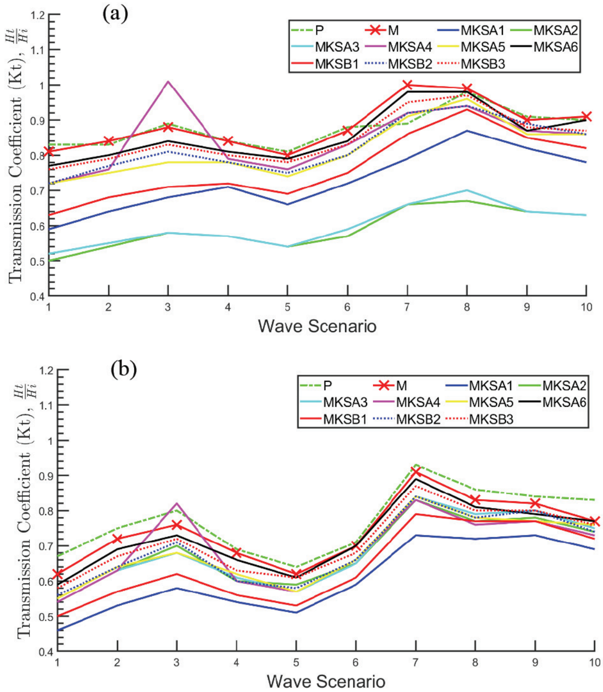

Figure 4: Comparison of Structure K_t (a) and System (b) for all green mussel scenarios

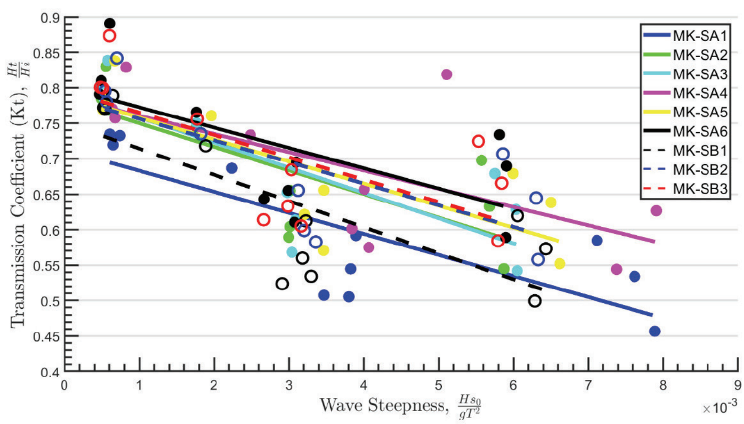

Figure 5: Comparison of System K_t for all scenarios

the denser the configuration of the bamboo pole, the more influential the green mussels, where SA1 and SB1, the two densest configurations, have larger differences in effectiveness between the MT and MK scenarios compared to the other configurations.

The most effective configurations in extreme conditions were the densest scenarios, SA1 and SB1, for configurations with or without green mussels. Overall, the highest wave reduction for structure and system under extreme conditions occurs for scenarios with green mussels' configuration, as shown in Figure 7. When directly comparing structure and system Kt, SA1 is the most effective configuration, as seen in Figure 8.

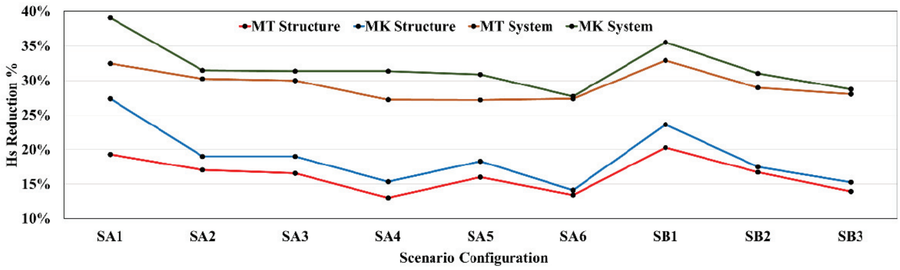

Figure 6: Comparison of H_s reduction between MT and MK scenarios

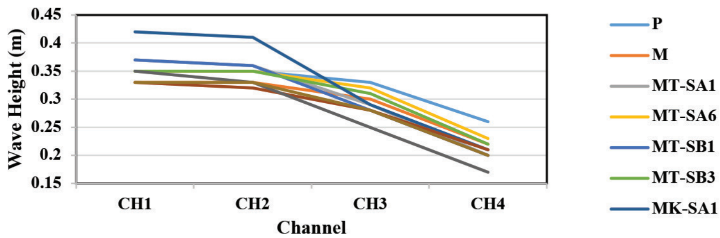

Figure 7: Comparison of Significant Wave Height transformation along the flume

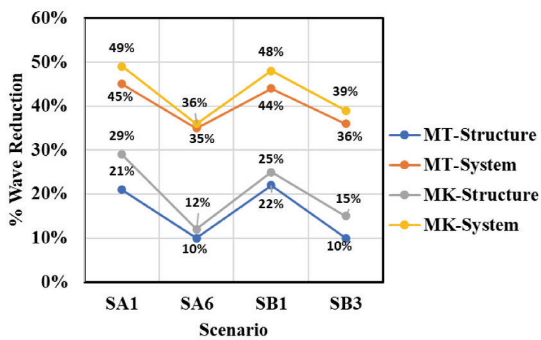

Figure 8: Comparison of percentage wave reduction between Structure and System

Conclusion

Physical modelling of a temporary breakwater has been carried out with a model scale 1:10 based on "Physical Models and Laboratory Techniques in Coastal Engineering" (Hughes, 1993). The bamboo pole model uses a cylindrical iron rod, and the green mussel model uses a woollen thread wrapped around an iron rod. There were 9 modelling configurations and 11 random wave scenarios used.

The research reveals that green mussels can affect the effectiveness of the bamboo pole breakwater structure and the natural coastal protection system by increasing wave reduction by an average of 2%-3%. Among the tested configurations, the most effective design based on the performance of green mussels and extreme conditions is the SA1 configuration, which increased the reduction percentage of H_s by 8% for the breakwater structure and 7% for the protection system. The SA1 configuration has a distance between columns and rows of 50 mm and a breakwater width of 800 mm. Notably, the findings also indicate that the natural coastal protection system proves more efficient in dealing with waves of comparatively greater steepness.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Acknowledgements

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