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Experimental Study of Wave Reflection on A-Jack Armor Unit on Seawall Structure

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***Abstract*— In planning the construction of a seawall, it is necessary to consider several things, such as incoming waves, types of defensive units, and economic factors. So planning for the type and size of the armor unit used, it is expected that the structure will only experience minimal damage. In addition, there are other considerations, such as wave reflection by the structure. In the port area, a structure with low wave reflection is needed to keep the anchored pool calm. In this study, experimentally, the effect of the reflection coefficient on the seawall structure with the A-Jack armor unit was carried out. The experiment was held in a wave flume with regular waves with variations in height (0,10 – 0,175 cm) and periods (1,4 seconds and 1,6 seconds) of waves with three variations of a structural slope, namely 1:1, 1:1,5, and 1:2. The reflection coefficient analysis was carried out using the two-point methods which were recorded with a wave probe. Based on experiments, it is known that the steeper the slope of the structure will result in a more significant increase in reflection. To improve the accuracy of the spectral variations of the incident and reflected waves, it is necessary to record with three-wave probes because the two-wave probe method has several weaknesses and is prone to interference in analyzing the data obtained.**

Keywords— A-Jack armor unit, seawall, structural slope, wave reflection,

I. INTRODUCTION

Approximately 71% of the earth consists of oceans and forms 1.634.701 km of coastline in coastal areas [1]. Coastal areas are often used for various things, such as a place to live, a place of recreation, to a place to work. This coastal area will experience changes due to various things, both due to natural and human activities. Some coastal area modifiers are caused by nature, such as sea level rise, waves, and sediment transport along the coastline, to surge overwash, an event when large waves pick up and leave material in coastal areas. On the other hand, some changes in coastal areas caused by humans include land subsidence due to the extraction of resources below the surface, disruption of sediment transport, development in coastal areas that cause an increase in wave energy concentrations, and the use of materials in coastal areas [2].

Coastal protection structures generally solve erosion and sedimentation problems in coastal areas. There are various coastal protection buildings with entirely different functions and limitations. The structure can be in the form of a floating breakwater or a fixed breakwater. Researchers have widely developed floating breakwaters [3 - 12]. This structure has the advantage that the structure can be used at sea depths of more than 10 feet [3]. Soft subgrade conditions [4] and this floating breakwater structure cause minimal disturbance to water circulation, sediment transport, and fish movement and migration, effectively reducing waves with fewer than 2 meters [13]. These structures are easy to move and re-install with different formations to other locations [3, 5, 14], not causing scour [4]. However, this structure is ineffective in reducing wave height in short waves with a wave period of 6 seconds and a frequency of 1.6 radians per second. If the mooring system fails, it will result in overall structural failure [12]. This structure also requires higher maintenance costs than fixed breakwaters [13].

Fixed breakwater-type coastal protection can be in the form of seawalls, bulkheads, and revetment structures that prevent landslides and protect the land from waves but are limited to protecting the land directly behind it. The coast guard functions as a damper to reduce wave energy. Determination of this type is generally limited to the price required for its construction. Other fixed breakwater structures include groins, jetties, and breakwaters [2]. In determining and designing the type of breakwater used, it is necessary to examine various aspects of the needs and the environment, wavelength, depth, placement, design, and direction of wave arrival. Design analysis is needed so that the structure can meet requirements such as no runoff so that the design can be classified as meeting structural and functional safety [2]. In addition, there are other things to consider, such as how the structure affects the waves. It is known that the waves that hit the structure will experience three conditions, namely reflection, dissipation, and transmission waves. By knowing the behavior of the wave, it will be possible to determine the magnitude of the wave parameters and the shape of its structure. As in the anchored pool area, a structure that can create calm water conditions is needed, so a structure with a high level of reflection is needed.

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Beach protection can also be done naturally with mangrove trees. Mangroves can grow almost along coastlines in the tropics and subtropics. However, they cannot grow naturally under current solid conditions, while the wave energy must be reduced. Therefore, sedimentation and erosion can be predicted before mangrove rehabilitation [16, 17].

This paper will analyze the behavior of wave reflection on the sea wall with the armor unit a jack. Based on the structural function, sea walls are grouped into constructions parallel to the shoreline. This building directly limits the land area with seawater and is used to protect muddy or sandy beaches. The seawall consists of the foot construction, the sheath, the berm, and the top of the structure. The selection of variations in the protective layer varies, such as natural stone, bamboo, concrete blocks with specific shapes, and porous structures [18-21]. Using natural stone may be possible if the work site is close to the source of stone of the required size and weight. At the same time, concrete blocks have the advantage of flexibility in adjusting the required strength level. On the other hand, structures made of bamboo structures are generally constructed after conditions have been met at the site. The protection system can minimize wave energy reduction while sedimentation can still occur.

This research was conducted experimentally to determine the earlier wave reflection with the a-jack type of protective layer unit. Experiments were conducted with variations in the height and period of regular waves on the wave flume. In this paper, the researcher analyzes the effect of wave reflection due to the structure's placement and angle of inclination and then compares it with other protective layer units.

II. METHOD

2.1 Experiment Scenario

The 1:20 scale A-Jack model experiment (Figure 1) was carried out in a 2-D wave flume (20m x 2m x 1.5m) in the Department of Marine Engineering, Institut Teknologi Sepuluh Nopember (ITS), Indonesia. Based on the dimensions of the wave flume and the chosen model scale, during the experiment, the water depth was set at 0.70 m. The wave generator generates waves at one end and the wave absorber at the other to dampen the reflected wave energy. All normal wave flume operations are controlled by a control computer equipped with an analog-digital converter interface. This tool will convert analog data into digital data (Figure 2). Wave probe one is located 10.2 m in front of the seawall model and 0.75 m between wave probes 2 and 3 (Figure 3), which are used to determine wave reflection. Seawalls are arranged in three slope variations, namely 1:1, 1:1.5, and 1:2, and three layers. The core layer uses sandbags, the middle layer uses crushed stone, which weighs 1:10 the weight of the A-Jack model, and the outer layer is the A-Jack protective layer unit. A jack consists of 2 layers arranged randomly.

2.2 Experiment Test

The impact of regular wave forces on the seawall with the jack-barrier unit was tested at a water depth of 14 m under actual conditions in the field—wave height 2.0 - 3.5 m, with a wave period of 6.3 s and 7.2 seconds. Based on the model scale in the laboratory, the model wave period is 1.4 s and 1.6 s, and the model wave height is 0.01 - 0.175 m.

2.3 Calibration of Wave Probe

Wave probe calibration needs to be done to ensure that the data measured on the computer matches the voltage the wave probe uses when measuring changes in water level elevation. Calibration is done by recording the electrical voltage that is read when the wave probe is placed at the zero point, and then the wave probe is moved as far as 7 cm four times up and down. Calibration is carried out routinely to maintain the accuracy of the recorded data, both before and after the experiment.

2.4 Wave Reflection Analysis

When a wave hits an object, it will be reflected either entirely or only partially. In its application in the real world, wave reflection needs to be reviewed, especially on the protection structure at the port. If the level of absorption of wave energy in the structure is too low, it can cause the condition of the anchored pool to become unsettled and disturb the ship at anchor. The level of the structure's ability to reflect the wave is determined by the reflection coefficient parameter, namely the ratio of the reflected wave's height to the incident wave's height.

$$K_r = \frac{H_r}{H_i} \tag{1}$$

Where a reflection coefficient K_r, a reflected wave height, H_r (m), and an incident wave height, H_i (m).

In a physical experiment, the level of the structure's ability to reflect waves can be estimated by several methods. The two-probes method was used to record the reflected and incident waves (Figure 4), as investigated by Goda and Suzuki [22]. In this test, the closest wave probe is placed 0.2L from the structure or about 80 cm, while the distance between the wave probes (Δl) is 75 cm.

Furthermore, to estimate the reflection coefficient in an experiment, Goda and Suzuki use the equation to get an incident wave height and a reflection wave height, namely:

$$\begin{cases} \eta_I = a_I \cos(kx - \sigma t + \varepsilon_I) \\ \eta_R = a_R \cos(kx - \sigma t + \varepsilon_R) \end{cases} \tag{2}$$

Where η_I and η_R are the surface elevation of the incident and reflected wave, k wave number, σ the angular frequency, ε_I and ε_R are a phase angle of the incident and the reflection wave.

III. RESULTS AND DISCUSSION

3.1 The Effect of Iribarren's Number on the Reflection Coefficient

The Iribarren number describes its effect on the reflection coefficient in the reflection analysis. The Iribarren number itself is a non-dimensional parameter

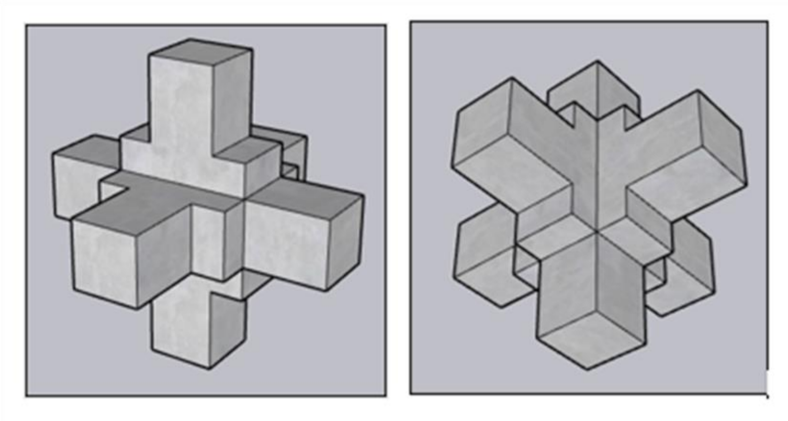

Figure 1. The A-Jack model with a scale of 1:20

Figure 2. Experimental equipment

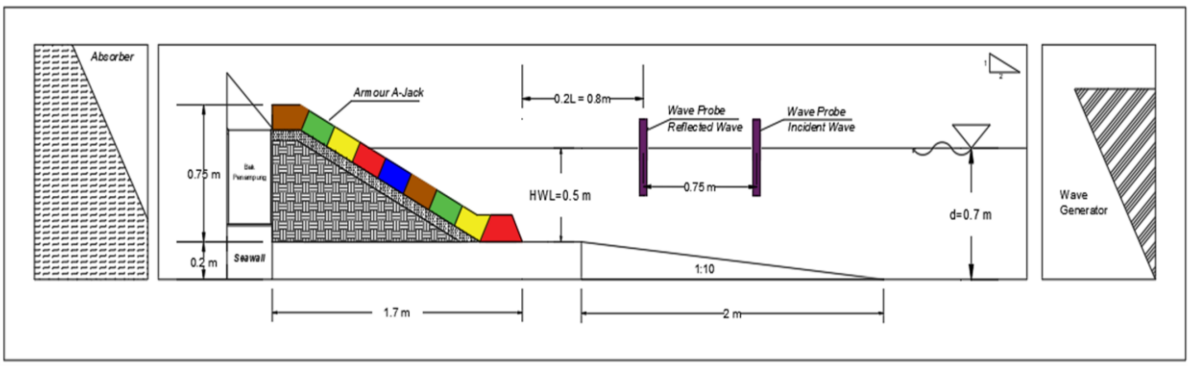

Figure 3. Experiment scheme on the seawall in wave flume

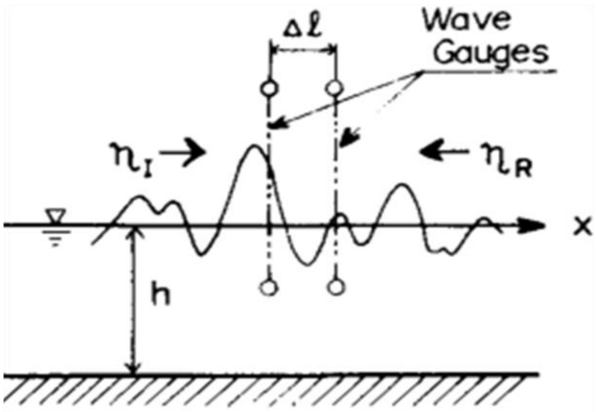

Figure 4. Wave probe configuration [22]

used to describe the impact of waves on coastal protection structures, which can be written as:

$$\xi = \frac{\tan\theta}{\sqrt{2\pi H/gT^2}} \tag{3}$$

Where θ is structure slope, H and T are height and wave period.

As is known in the Iribarren number, changes in the slope of the structure also impact changes in the reflection coefficient (Figure 5). Based on the results of this test, it can be seen that as the Iribarren number increases, it will cause an increase in the reflection coefficient. At a slope of 1:2, 1.5 and 1:1 have a reflection coefficient range between Kr = 0.56 – 0.81 with an average of 0.7, Kr = 0.62 - 0.86 with an average of 0.76, and Kr = 0.75 – 0.93 with an average of 0.85, respectively.

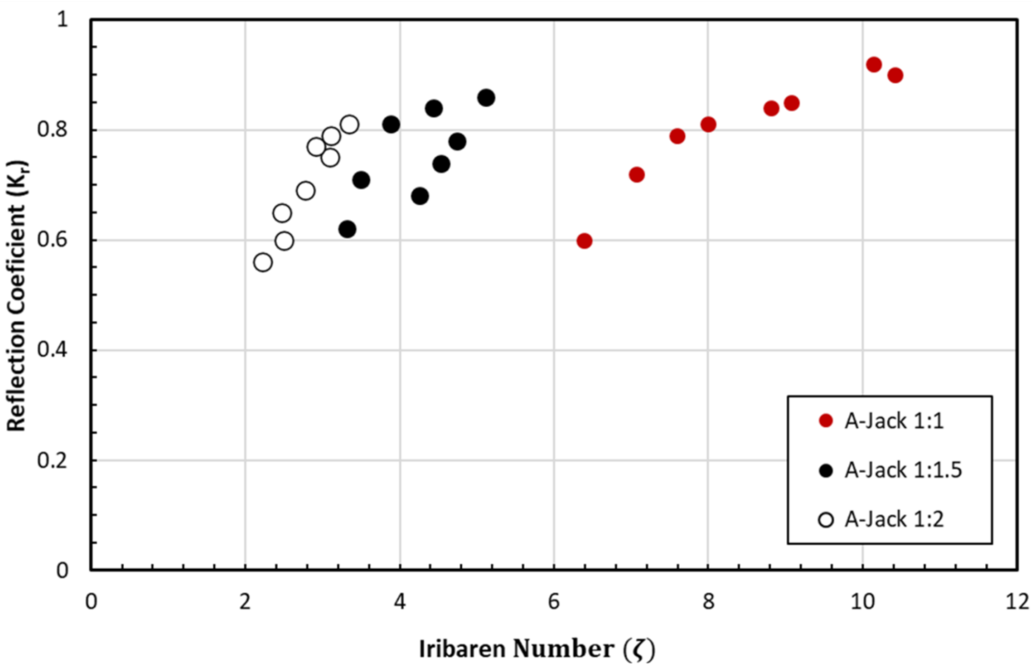

Figure 5. Relationship of Iribaren number to the reflection coefficient

3.2 A-Jack Reflection Coefficient Comparison with Other Protective Structures

After testing the wave reflection on the seawall with the armor unit A-Jack with variations in the slope of the structure, it is necessary to compare it with other models to prove the accuracy of the tests carried out. In this study, the research that will be used as a comparison is the research conducted by Allsop & Hettiarachchi [23], Pratola et al. [20], and the research conducted by Zanuttigh and van der Meer [24] with armor unit models.

Pratola et al. studied a structure with a slope of 1:1.3 where each unit weighs 0.891 kg with MAYA armor units. Meanwhile, the research conducted [23] was carried out on a structure with a structural slope of 1:2 with armor in the form of dolos and cobs, and the study used an armor unit with variations in the porosity level of the outermost layer installed (Figure 6). The results of the test analysis with other studies with different armor units are shown in Figure 7.

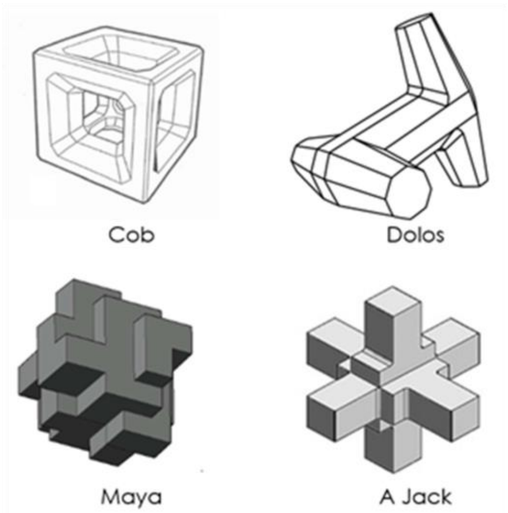

Figure 6. Various types of armor units for coastal protection structures

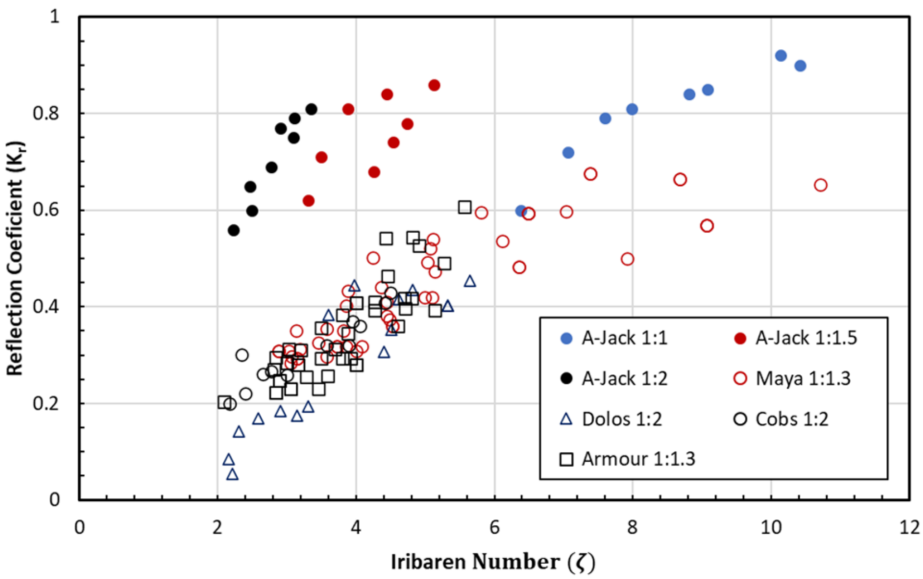

Figure 7. The relationship between the Iribarren number and the reflection coefficient for various types of outermost layers of coastal protection structures

Based on Figure 7, it can be concluded that all research conducted has similarities in the effect of the Iribarren number on the reflection coefficient. The increase in the Iribarren number is directly proportional to a structure's more significant reflection coefficient. In a similar Iribarren number range, the A-Jack type armor unit has a higher reflection coefficient than other armor units in the Iribaren number range 2 - 4. The armor unit in this study [24] has a reflection coefficient range of 0.2 – 0.4.

In this study, the Dolos and Cobs shape in the same Iribarren number range had a reflection coefficient of 0.05 – 0.44 and 0.2 – 0.35, respectively. In the MAYA armor unit, the reflection coefficient is in the range of 0.28 – 0.43. Meanwhile, the armor unit A-Jack currently being studied has a reflection coefficient range of 0.56 – 0.81.

In addition to comparing the various forms of armor units and different structural forms, comparing the impact of changes in the structure's slope on the reflection coefficient was also carried out with other studies. Based on Figure 8, in other studies, there are similarities in the relationship between the structure's slope, where the steeper a structure will increase the reflectance of the waves.

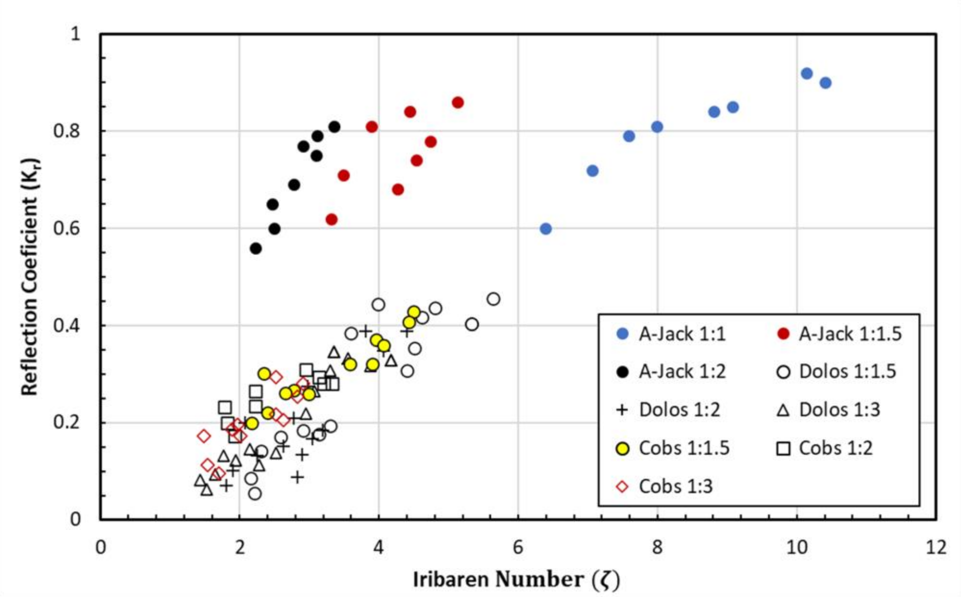

Figure. 8. The relationship between Iribarren number and reflection coefficient

The Dolos armor units with slopes of 1:1.5, 1:2, and 1:3 have the highest reflection coefficients of 0.45, 0.39, and 0.35, respectively. In the same study, the armor unit cobs at a slope of 1:1.5, 1:2, and 1:3 had the highest reflection coefficients of 0,43, 0,31, and 0,29. While the armor unit A-Jack, with a slope change of 1:1, 1.5, and 1:2, has the highest reflection coefficient of 0.92, 0.86, and 0.81.

The method used in this study is to use two wave probes to record changes in water elevation [22]. However, in a study conducted by Allsop & Hettiarachchi [23] and Pratola et al. [20], three-wave probes are used to record changes in water elevation. The recorded wave spectrum is analyzed to obtain the reflection coefficient. According to Mansard and Funke [25], the method with three probe waves can improve accuracy in the spectral variation of the incident and reflected waves. In contrast, the two-wave probe method has several weaknesses and is susceptible to interference in analyzing the data obtained.

IV. CONCLUSION

The results of wave reflection experimental studies on A-Jack protective layer units on seawalls with variations in slope show that the steeper the slope of the structure will result in a more significant increase in the reflection coefficient.

To improve the accuracy of the spectral variations of the incident and reflected waves, it is necessary to record with three-wave probes because the two-wave probe method has several weaknesses and is prone to interference in analyzing the data obtained.

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REFERENCES

[1] Ahmadian, A. S. (2016). Numerical Models for Submerged Breakwaters. In *Butterworth-Heinemann*.

[2] CERC (1984). Shore Protection Manual. Coastal Engineering Research Centre, Dept. of the Army Waterways Experiment Station, US Army Corps of Engineers, Washington.

[3] Hales, L. Z. (1981). *Floating Breakwater: State of the art Literature Review*. Technical Report No. 81-1. U.S. Army Coastal Engineering Research Center, Fort Belvoir.

[4] McCartney, B. L. (1985). Floating breakwater design. *Journal of Waterway, Port, Coastal and Ocean Engineering,* 111 (2), p. 304-318.

[5] Dai, J., Wang, C. M., Utsunomiya, T., Duan, W. (2018). Review of recent research and development on floating breakwaters. *Ocean Engineering,* 158, p. 132-151.

[6] Sujantoko, Djatmiko, E. B., Wardhana, W., Armono, H. D., Sholihin, Ali, M. F. (2019). Experimental study on the effect of mooring angle on mooring tension of porous saw type floating breakwater. *Proceeding* of *The* 7th *International Seminars on Ocean and Coastal Engineering, Environmental and Natural Disaster Management,* Surabaya, Indonesia, Nov 6-7, p. 94-99.

[7] Sujantoko, Djatmiko, E. B., Wardhana, W., Armono, H. D., Wahyudi (2019). Dynamic behavior analysis of porous saw floating breakwater under regular waves. *Proceeding of The* 7th *International Seminars on Ocean and Coastal Engineering, Environmental and Natural Disaster Management*, Surabaya, Indonesia, Nov 6-7, p. 236-24.1

[8] Sujantoko, Wardhana, W., Djatmiko, E. B., Armono, H. D., Putro, W. S., Almuzaki, R. H. (2021). Studi karakteristik gelombang pada floating breakwater tipe terpancang dan tambat. *Jurnal Teknik Hidraulik*, 12(1), p. 39-52.

[9] Sujantoko, Djatmiko, E. B., Wardhana, W., Hidayatullah, A. (2021). Analisa tegangan mooring pada floating breakwater tipe gergaji dengan pemodelan fisik. *Jurnal Teknik Sipil,* 28(3), p. 289-300.

[10] Sujantoko, Djatmiko, E.B., Wardhana, W. (2022). Experimental investigation of the performance of porous-slope floating breakwater. *International Journal on Engineering and Applications*, 10(2), p. 149-157.

[11] Sujantoko, Armono, H.D., Djatmiko, E. B., Putra, R. D. (2022). Stability analysis of concrete block anchor on steep-slope floating breakwater. *Fluids*, 7(8), 259.

[12] Sujantoko, Djatmiko, E.B. and Wardhana, W. (2022). Experimental study on mooring tension of porous-slope type floating breakwater. *International Journal on Engineering and Applications*, 10(5), p.345-352.

[13] Kelly, H. (1999), *Discussion about Floating Breakwaters*, Naval Facilities Engineering Command, Norfolk, Virginia.

[14] Tsinker, G.P. (1995). *Marine Structures Engineering: Specialized Application*. New York: An International Thomson Publishing Company.

[15] Murali, K., Mani, J.S. (1997). Performance of cage floating breakwater. *Journal of Waterway, Port, Coastal and Ocean Engineering 123 (4)*, p. 172-179.

[16] Salem, M.E.; Mercer, D.E. (2012). The Economic Value of Mangroves: A Meta-Analysis. Sustainability, 4, 359–383.

[17] Winterwerp, J.C., Erftemeijer, P.L.A., Suryadiputra, N., van Eijk, P., Zhang, L. (2013). Defining eco-morphodynamic requirements for rehabilitating eroding mangrove-mud coasts. *Wetlands*, 33, p. 515–526.

[18] Armono, H.D., Bromo, B.H., Sholihin, Sujantoko (2022). Numerical study of bamboo breakwater for wave reduction, *Fluids*, 7 (1), p. 1-13.

[19] Armono, H. D., Winarto, A., Sujantoko, Suastika, I. K. (2021). A laboratory study on wave transmission over hexagonal artificial reef, IOP Conference Series: Earth and Environmental Science. 799 (1), p. 1-9.

[20] Pratola, L., Rinaldi, A, Molfetta, M. G., Bruno, M. F., Pasquali, D., Dentale, F., Mossa, M. (2021). Investigation on the reflection coefficient for seawalls protected by a rubble mound structure. *Journal of Marine Science and Engineering*, 9, 937.

[21] Chen, H. B., Tsai, C. P., Chiu, J. R. (2006). Wave reflection from vertical breakwater with porous structure. *Ocean Engineering 33*, p. 1705–1717.

[22] Goda, Y., Suzuki, Y. (1976). Estimation of the incident and reflected waves in random wave experiments, *In Proceedings of the 15th International Conference on Coastal Engineering, ASCE,* Honolulu, Hawai, USA, pp. 828-845.

[23] Allsop, N. W. H., Hettiarachchi, S. S. L. (1989). Reflections from coastal structures. *Coastal Engineering 1988*, p. 782–794.

[24] Zanuttigh, B., van der Meer, J. W. (2008). Wave reflection from coastal structures in design conditions. *Coastal Engineering*, *55*(10), p. 771–779.

[25] Mansard, E. P. D., Funke, E. R. (1980). The measurement of incident and reflected spectra using a least squares method. *Coastal Engineering Proceedings,* 1 (17), *8,* p.154–172.