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Experimental Study on Wave Attenuation Performance of Recycled Materials As Floating Breakwater

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***Abstract*—Wave modeling has become increasingly important in coastal engineering, particularly for understanding sea wave behavior and assessing the performance of protective structures. Researchers often employ flume wave makers, which allow precise replication of wave characteristics to study wave dynamics in controlled conditions. Floating breakwaters present a cost-effective alternative to conventional fixed structures, especially in areas with relatively mild wave climates, and are frequently used to protect harbors, marinas, and shorelines from erosion. In this study, the performance of three floating breakwater designs was evaluated, with each constructed from recycled plastic bottles to assess the feasibility of incorporating post-consumer materials in coastal infrastructure. The prototypes varied in submersion levels which 0% submerged, 50% submerged and 70% submerged. These models were tested under different wave conditions in amplitude and frequency, to determine their effectiveness in reducing wave height and transmission. The objective was to identify the configuration that offered the greatest wave attenuation under conditions representative of real coastal environments, thereby providing insight into the optimal design for practical application in sustainable coastal engineering.**

Keywords*—Wave, Floating breakwater, Wave transmission, Recycled materials.

I. INTRODUCTION

A breakwater is an offshore structure, typically built parallel to the shoreline, designed to reduce the energy of incoming waves before they reach the coast. Its primary functions are to dissipate wave energy and to promote the accumulation of sediment in the sheltered area between the structure and the shore, which in turn helps protect the coastline from erosion. As noted by Dai *et al*. [1], breakwater also known as wave attenuators are essential coastal engineering solutions for mitigating the effects of waves in nearshore environments. They are commonly constructed from large concrete caissons or quarried rocks placed on a rock mound foundation.

A study by Zhang *et al.* [2] underscores the advantages of floating breakwaters when compared to breakwaters anchored to the seabed. These advantages include reduced construction costs and less environmental impact. Additionally, floating breakwaters can help mitigate the effects of tidal variations and rising sea levels conducted a study in 2006 [3] that emphasized the importance of various wave characteristics, such as wave duration, steepness, and height, in determining the efficiency of floating breakwaters. They explored three distinct designs of floating breakwaters: single, double, and catamaran configurations. Furthermore, research conducted by PND Engineers, Inc. in 2015 indicates that floating breakwaters are particularly effective for managing smaller waves and durations. Additionally, they offer temporary moorage space, which can be beneficial in various coastal applications.

The knowledge gained from these research studies has significant implications for coastal engineering and sustainability efforts. It also opens the door for future exploration of utilizing recycled plastic bottles in the construction of floating breakwaters, which could have both environmental and cost-saving benefits. Moreover, this body of research can serve as a valuable resource for educational institutions, providing essential guidance and information for students pursuing academic studies in related fields.

II. LITERATURE REVIEW

A study by Yu *et al.* [4] focused on the issue of wave transmission through vertical plates, specifically

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examining scenarios involving one or two such plates. In the case of a single thin plate, the wave transmission behavior is relatively straightforward and predictable. As the wavelength increases, more wave energy passes through the plate, while less energy is reflected. However, when two vertical plates are involved, the wave interaction becomes more complex, making the analysis of transmission and reflection more challenging. Both analytical and experimental methods were used to identify the resonance conditions associated with transmitted and reflected waves. In related research, Liu *et al.* [5] investigated wave transmission between two vertical plates, where one plate allowed wave penetration and the other was impenetrable. Their study successfully addressed the complexities of wave behavior in such configurations, contributing valuable insights into the dynamics of wave-structure interaction.

Several studies have investigated the factors influencing the performance of floating breakwaters. Wang *et al.* [6] emphasized that their effectiveness is largely determined by width, incident wave angle, and mooring method. According to Loukogeorgaki *et al.* [7], a floating breakwater is considered effective when the wave transmission coefficient (KT) is less than 0.5. Supporting this, Wang *et al.* [6] noted that to achieve KT < 0.5, the ratio of breakwater width (B) to wavelength (L) must exceed 0.35. Ji *et al.* [8] further highlighted that greater wave heights (H) lead to increased motion responses and more energy dissipation in floating structures. Armono *et al.* [9] added that both wave period and water depth significantly influence wave transmission; as water depth increases, so does the transmission coefficient.

Dai *et al.* [1] pointed out that floating breakwaters minimally disturb natural water movement, making them an environmentally friendly solution. Their ease of installation, repositioning, and removal further enhances their practicality. As a result, floating breakwaters have become a popular and versatile option for coastal and harbor protection, available in a wide range of configurations. Cheng *et al.* [10] explored a new double-row floating breakwater design aimed at improving hydrodynamic performance and wave attenuation. Their experimental comparison between a cuboid pontoon combined with a cylindrical airbag (Pontoon-Airbag) and a traditional single pontoon model showed that both configurations effectively reduced the wave transmission coefficient, with the Pontoon-Airbag system showing improved attenuation performance.

Floating breakwaters made of pontoons, airbags, concrete caissons, and quarried rock have effectively attenuated waves, yet each exhibits significant drawbacks [11, 12]. Pontoons entail high manufacturing and maintenance costs due to corrosion and biofouling; airbags suffer from puncture, ultraviolet degradation, and fatigue; concrete caissons are heavy, expensive to construct and transport, and require extensive seabed preparation; and rock breakwaters demand vast material volumes, incur high transport costs, and can disrupt benthic habitats [11]. In contrast, recycled plastic bottles present a sustainable, low-cost, and lightweight alternative, offering buoyancy while mitigating marine litter and supporting circular economy principles.

III. METHODOLOGY

The study was conducted in the laboratory in School of Civil Engineering, UiTM Shah Alam. The laboratory was in Block 1, Level 2 and in Hydraulic Laboratory. The instrument that was used to conduct the experiment was flume wave maker as shown in Fig. 1. The depth of the flume wave maker tank is 0.75 m, meanwhile the width of the tank itself is 0.5 m and the length is 20 m.

Fig. 1. Flume Wave Maker.

A. Development of Floating Breakwater

The primary construction material for the floating breakwater in this study was recycled plastic bottles. The structure was assembled by connecting 24 bottles using raffia string and double-sided tape. Three different designs were tested, each representing a different level of submergence: fully floating (0% submerged), half-submerged (50%), and three-quarters submerged (75%). Figure 2 presents a detailed side-view schematic of the floating breakwater positioned inside the flume tank while Fig. 3 shows the schematic diagram for three different conditions of density placed in the flume.

Fig. 2. View from every side of the development floating breakwater model.

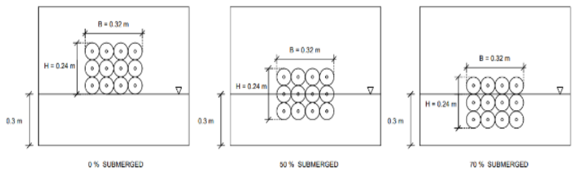

Fig. 3. Schematic diagram for three different conditions of density.

B. Experiment

Capacitance wave probes were used to measure the wave heights from offshore and after the breakwater. The experimental tests were undertaken over a 180s monitoring period and each test was repeated five times. All data were recorded by computer using SOLTEQ Flume Wave Maker data acquisition system. The research utilized a flume measuring 0.5 m in width, 20 m in length, and a maximum depth of 0.75 m. The flume was equipped with glass walls for most of its working section and was situated within the Hydraulic Laboratory of the Faculty of Civil Engineering at Universiti Teknologi MARA, Shah Alam. To generate waves, a wave paddle was installed at one end of the flume, controlled by a laboratory computer. Additionally, a wave absorber was present at the opposite end of the flume to dissipate any wave energy reflecting into the system. Figure 4 (a) & (b) illustrate the schematic diagram of the experiment in flume (front and top view).

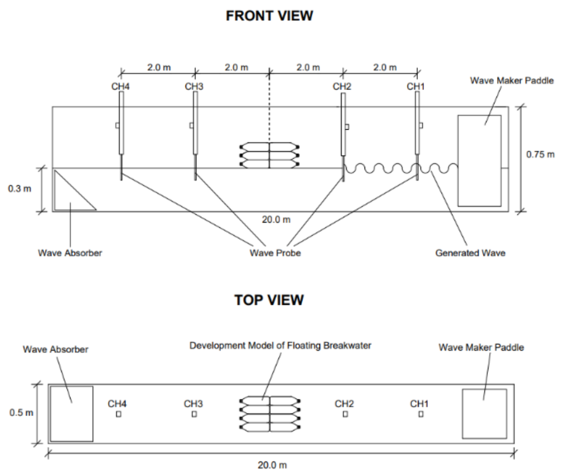

Fig. 4. (a) Schematic diagram of floating breakwater experiment for front view; (b) Schematic diagram of floating breakwater experiment for top view.

Figure 5 (a), (b) & (c) show the placement for three different model of floating breakwater inside the tank of flume wave maker, which were followed by no submerged (0%), ½ submerged (50%) and ¾ submerged (70%). All the floating breakwater model were tied up with the raffia strings to make it fix and to prevent the model from being moving when the incoming waves hits the model.

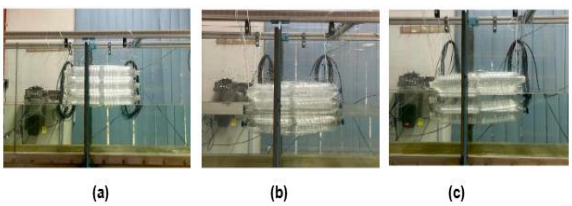

Fig. 5. Placement of the floating breakwater at different depths ((a) 0% submerged, (b) 50% submerged and (c) 70% submerged).

C. Data Analysis

In this research, data collection was carried out using a flume wave maker tank. The key parameter under investigation was wave height (measured in meters). To determine the wave height, a wave probe was employed. Additionally, the study involved collecting data on wave characteristics such as amplitude, frequency, and the duration required to generate waves in the flume wave maker, which was set at 180 seconds. For each density condition of the floating breakwater, three different sets of conditions were examined. Condition 1 involved an amplitude (A) of 0.03 meters and a frequency (f) of 0.3 Hz. Condition 2 featured an amplitude (A) of 0.06 meters and a frequency (f) of 0.5 Hz. Finally, condition 3 included an amplitude (A) of 0.09 meters and a frequency (f) of 0.9 Hz. Subsequently, the wave transmission coefficient was calculated after collecting the necessary data. The formula used to obtain the wave transmission coefficient was applied to the collected data as follows:

$$K_T = \frac{H_t}{H_i} \tag{1}$$

, where

K_T = Wave transmission coefficient

H_t = Transmitted wave height landward of the structure (after model)

H_i = Incident wave height at the toe of the structure (before model)

IV. RESULTS

The result obtained from the data produced by the generating waves of flume wave maker was discussed. The value of wave transmission indicates which design of floating breakwater will be the effective design to be used in reducing the wave transmission in the real coastal area. For this study, it only used the value of $H^{1/3,}$ which is known as the significant wave height.

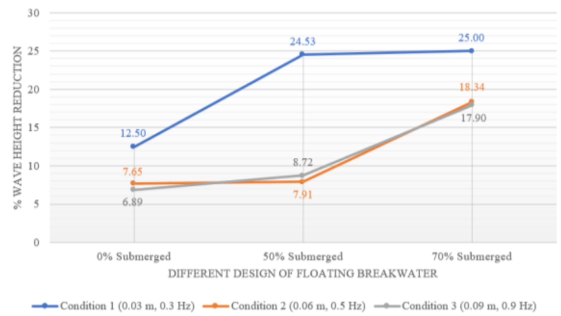

Fig. 6. Percentage of wave height reduction for different design of floating breakwater.

Figure 6 illustrates the percentage of wave height reduction for the three different floating breakwater designs. The data shows that wave height reduction increases as the level of submergence (or effective density) of the breakwater increases. This trend is evident in Condition 1, where the fully floating breakwater (0% submerged) achieved a 12.50% reduction in wave height, the half-submerged design (50%) achieved 24.53%, and the three-quarters submerged design (70%) achieved the highest reduction at 25%. A similar pattern is observed in Conditions 2 and 3, where greater submergence consistently leads to greater wave height reduction. This indicates that the third design (¾ submerged or 70%) is the most effective in reducing wave energy. However, it was also noted that as wave amplitude and frequency increase, the percentage of wave height reduction decreases slightly, suggesting a reduced efficiency under more energetic wave conditions.

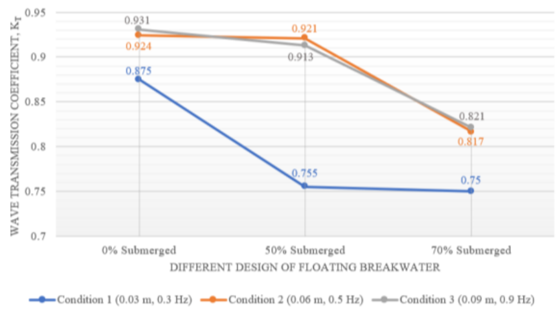

Fig. 7. Graph of wave transmission coefficient for different designs of floating breakwater.

Figure 7 presents the variation in wave transmission coefficient (K_T) for the three floating breakwater designs: fully floating (0% submerged), half-submerged (50%), and three-quarters submerged (70%). Among these, the ¾ submerged design consistently achieved the lowest K_T values across all tested wave conditions, indicating the highest effectiveness in reducing wave transmission. Specifically, for the ¾ submerged breakwater, K_T values were 0.750 in Condition 1, 0.817 in Condition 2, and 0.821 in Condition 3. In comparison, the fully floating (0% submerged) design showed significantly higher Kt values: 0.850 in Condition 1, 0.924 in Condition 2, and 0.931 in Condition 3. The half-submerged (50%) design also exhibited higher transmission rates than the 70% submerged model. These results indicate that deeper submergence leads to better wave attenuation, even under conditions of increased wave amplitude and frequency. While none of the designs achieved a Kt value below 0.5 as the threshold suggested by Loukogeorgaki *et al.* [7] for effective wave transmission reduction, all values still fall within a reasonable performance range. The lowest K_T observed in this study, 0.750, was recorded for the 70% submerged design under Condition 1, reinforcing its relative efficiency among the tested models.

V. CONCLUSION

The results of this study demonstrate that floating breakwaters constructed from recycled plastic bottles have strong potential for reducing wave energy in practical coastal engineering applications. Among the three designs tested, the ¾ submerged (70%) floating breakwater proved to be the most effective. Based on the calculations and analysis conducted, the 70% submerged design consistently showed lower wave transmission coefficients across various wave conditions differing in amplitude and frequency compared to the fully floating (0%) and half-submerged (50%) designs. Additionally, this design also achieved the highest percentage of wave height reduction in all three tested conditions.

Overall, the findings confirm that increasing the submergence level of a floating breakwater enhances its ability to dissipate wave energy. Therefore, the 70% submerged floating breakwater not only demonstrates the feasibility of using recycled materials but also stands out as the most efficient design in minimizing wave impacts.

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AUTHOR CONTRIBUTIONS

Nur Diyana Mohd Azhar: Literature Review, Experimental Design, Investigation, Testing, Data Analysis, Draft Writing, Review & Editing.

Zaizatul Zafflina Mohd Zaki: Conceptualization, Supervision, Resources, Technical Guidance, Investigation, Writing, Review & Editing.

CONFLICT OF INTERESTS

No conflict of interests was disclosed.

ETHICS STATEMENTS

Our publication ethics follow The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org/

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