Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

Laboratory Assessment of A Fixed Box-Type Breakwater as Temporary Coastal Protection Against Wave Actions

Ilmi Fatihah Sazali[1], Nuryazmeen Farhan Haron[1*]

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

*Corresponding author: nuryazmeen@uitm.edu.my

Received: 22 November 2023/ Accepted: 08 March 2024/ Published online: 29 March 2024

Abstract

Coastal areas are vulnerable to the erosive forces of waves, particularly during storm events. Temporary coastal protection measures are often necessary to mitigate damage while permanent solutions are being developed. This study investigates the effectiveness of a fixed box-type breakwater as a temporary measure against wave action. Laboratory experiments were conducted to assess the performance of the breakwater under varying wave conditions. The wave attenuation performance of the proposed breakwater was tested in a series of early experiments in a two-dimensional (2D) wave flume under various conditions, including frequency and wave periods for different models (FB_1 without membrane, FB_2 with a single 46cm membrane, FB_3 with 46cm and 56cm double membranes, and FB_4 with a single 56cm membrane). Additionally, the flexible membrane's length was examined, along with other derived breakwater designs such as rectangle boxes and boxes joined by a single flexible membrane. Results indicate significant wave attenuation behind the breakwater, suggesting its potential efficacy in protecting coastal areas. According to the findings, the fixed breakwater (FB_3 model) might successfully reduce waves by about 50% in moderately longer waves with a wave period of 2s. This article presents the methodology, experimental setup, results, and implications of the study, highlighting the suitability of fixed box-type breakwaters as a viable temporary coastal protection solution.

Keywords: Coastal protection; Fixed box-type breakwater; Laboratory assessment; Wave actions; Temporary measures

1. Introduction

Coastal erosion presents a significant threat to infrastructure, habitats, and communities worldwide. While permanent coastal protection measures like seawalls and revetments are effective in the long term, they often require substantial time and investment for planning and construction. Consequently, temporary solutions are crucial to mitigating the impact of waves and erosion. Fixed box-type breakwaters have emerged as potential temporary measures due to their ease of installation and effectiveness in dissipating wave energy. They serve as low-cost substitutes for conventional breakwaters, particularly in coastal and nearshore regions undergoing multifunctional development. When coastal areas face low wave energy, fixed breakwaters become a viable alternative. Previous studies have highlighted the advantages of free surface breakwaters over bottom-founded ones, including their easy rearrangement, relocation, and minimal environmental impact (Cebada-Relea et al., 2023; Fouladi et al., 2023; Guo et al., 2022; Ji et al., 2022).

Early research focused on enhancing wave attenuation through single box or pontoon-type structures. To improve wave attenuation, combined systems consisting of main structures (e.g., box or pontoon) and accessory parts (e.g., frame structures, flexible structures) were developed, leveraging the strengths of both types of

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

breakwaters (Paotonan et al., 2022; Yang et al., 2018; Diamantoulaki & Angelides, 2010; Kee, 2005; Koutandos et al., 2004). Additionally, research by Uzaki et al. (2011) and Ji et al. (2018) explored alternative combination forms, such as main boxes coupled with vertical or horizontal plates. Flexible membrane materials have gained attention due to their portability, affordability, and ease of deployment.

While numerical analyses of flexible membranes have been conducted (Cebada-Relea et al., 2023; Chen et al., 2022; Chen et al., 2023; Cui et al., 2022; Diamantoulaki & Angelide, 2010; Ji et al., 2023; Kee, 2005; Li et al., 2020; Park & Kim, 2023; Sun et al., 2022; Wei & Yin, 2022; Yin et al., 2023), experimental studies, especially for combined breakwater types, remain limited. Quantitative information on the hydraulic behavior of such breakwaters is also scarce, emphasizing the need for further research. This paper presents findings from a laboratory investigation to assess the effectiveness of a combined fixed box-type breakwater in reducing transmitted waves, aiming to provide insights into its suitability as a temporary coastal protection solution.

2. Research Method

2.1 Construction of Breakwater Models

Laboratory experiments were conducted in a wave flume to assess the effectiveness of the fixed box-type breakwater. The breakwater was constructed according to specified dimensions and placed within the flume. A series of wave conditions, including varying wave heights and periods, were generated to simulate different coastal scenarios. Measurements of wave height and energy dissipation were recorded both upstream and downstream of the breakwater to evaluate its performance.

The breakwater model used in this study is derived from the box-type breakwater design. According to Wu et al. (2022), Figure 1 displays the schematic diagram of the box-type breakwater. The model of this breakwater consists of a sturdy wooden structure with a height that prevents the wave height from exceeding it.

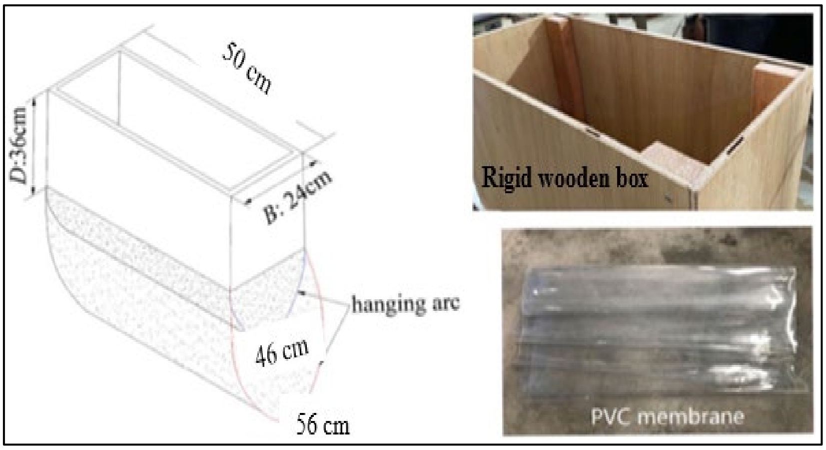


Figure 1. Scheme design and material used to build breakwater models

The rigid wooden box is connected to a steel frame structure that is installed on the flume wave maker by fixing it with a bolt connection. For box-type breakwater with a flexible membrane, two sizes of a flexible membrane are used, where the length of two membranes is 46 cm and 56 cm, respectively. The membranes are connected to the wooden box by hanging the arc on the below edges along the width direction and fastening it with tacks, as shown in Figure 2.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

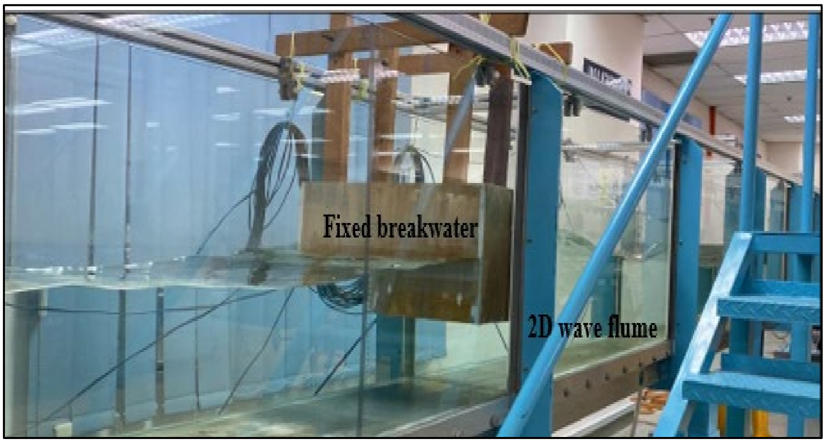


Figure 2. Fixed breakwater position in a 2D wave flume

2.2 Experimental Equipment

The entire experimental work was conducted within a 2D wave flume (Figure 3), where the breakwater was positioned at a distance of 8.2 meters from the wave paddle. The wave generation mechanism utilized a piston-type paddle installed at the upstream section of the wave flume to produce regular waves. The breakwater itself was installed at a near-central location in the wave flume, with a freshwater depth of 30 cm. Various combinations of wave amplitude and frequency were generated using this wave generator. The experimental waves followed the standard Joint North Sea Wave Project (JONSWAP) spectrum with a value of $\gamma = 3.3$. In the case of $\gamma = 3.3$, the spectrum is relatively steep, indicating a pronounced concentration of energy at the peak frequency. A total of eight experimental runs were conducted in the laboratory to evaluate the wave reduction.

Figure 3. 2D Wave Flume used in the laboratory assessment

2.3 Experimental Circumstances

To carry out the investigations, regular waves were generated at a fixed water depth of 30 cm. The frequencies used were 0.8 Hz and 0.5 Hz, corresponding to a wavelength of 0.08. The relative draft depth, represented as *d/h*, was set to 0.3. According to Sun et al. (2022), using a fixed breakwater with a relative depth of one-third of the water depth provides better wave attenuation properties.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

To analyze the reduction in wave height, measurements were taken before and after the submerged breakwater at four different locations. These locations were identified as CH_1, CH_2, CH_3, and CH_4, and probes were suspended in the flume to position them accordingly. CH_1 and CH_2 were positioned upstream of the breakwater to measure the incident wave, while CH_3 and CH_4 were placed downstream. A wave absorber was installed at the far end of the wave flume to reduce the transmitted wave after it passed through the breakwater. The specific measuring distances for CH_1, CH_2, CH_3, and CH_4 were 600 cm, 800 cm, 1224 cm, and 1424 cm, respectively, from the wave paddle. Additionally, the experimental runs were visually documented using still photographs and video recordings. A more detailed representation of the experimental setup is shown in Figure 4.

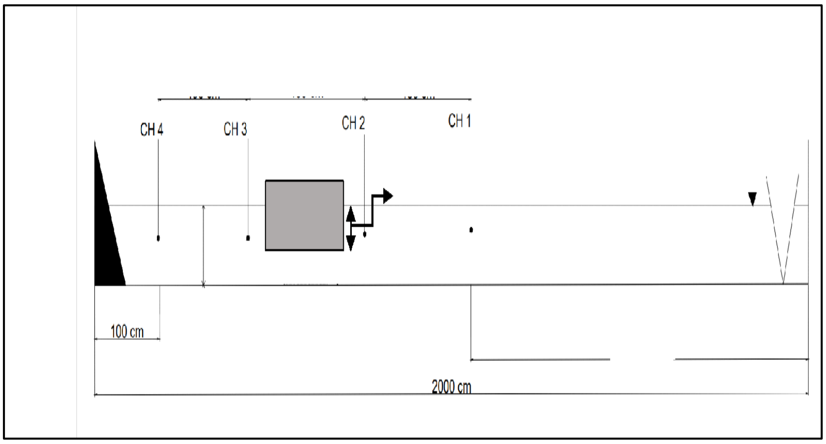


Figure 4. Position of probes in a 2D wave flume

2.4 Experimental Procedures

The production of waves and the analysis of wave dissipation in fixed breakwater models were conducted using software called High Resolution (HR) Merlin and HR Data AcQuisition (DAQ).

2.4.1 HR Merlin Wave Generation Program

HR Merlin, a wave generation software created by HR Wallingford Ltd., allows for the accurate simulation of various ocean conditions in wave basins, towing tanks, and wave flumes. This software effectively manages digitally filtered white noise to produce regular (sinusoidal) waves as well as random waves that replicate commonly observed wave spectra. Additionally, it offers capabilities for generating custom spectrum shapes, concentrated waves, and solitary waves. Figure 5 shows a visual representation of the wave generation process in HR Merlin.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

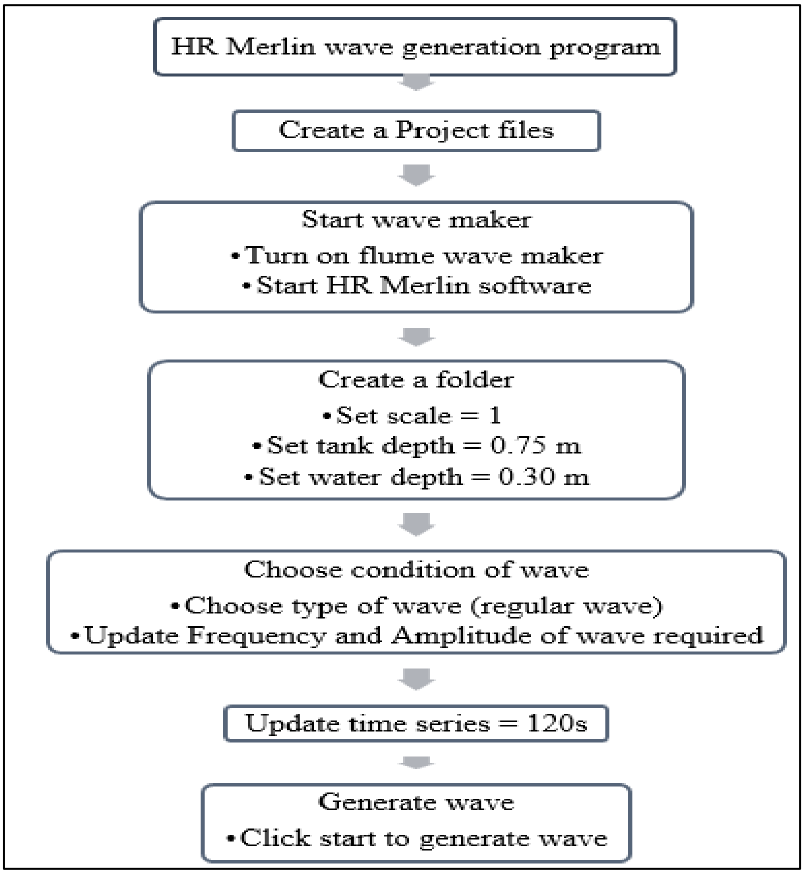


Figure 5. HR Merlin acquisition procedure

2.4.2 HR DAQ

HR DAQ is an integral part of a comprehensive suite of applications that simplifies the process of acquiring and analyzing data from various instruments. The software package includes several features, such as specialized calibration procedures for wave probes, real-time data collection capabilities, and a collection of analytical tools. Figure 6 illustrates the HR DAQ acquisition procedure.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

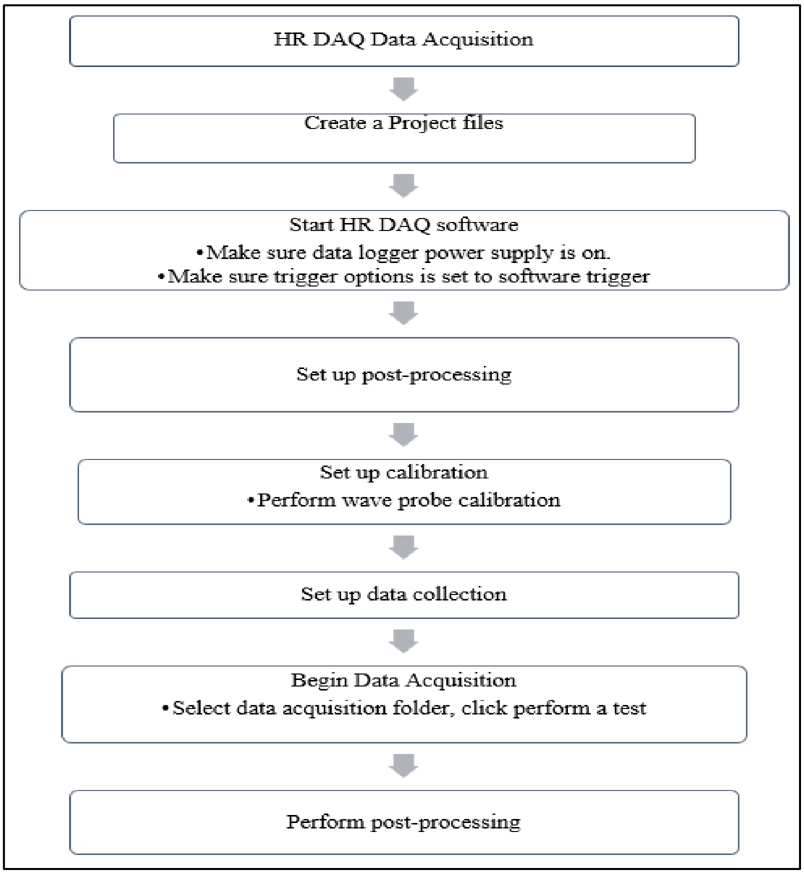


Figure 6. HR DAQ acquisition procedure

3. Results and Discussion

Below are the findings from the laboratory analysis of the fixed breakwater model using 2D Wave Flume.

3.1 Fixed Box-Type Breakwater Performance

The data in Table 1 shows how much of a wave reduction the fixed breakwater achieved. The wave reduction efficiency was determined by comparing the wave heights before and after reaching the breakwater. The calculation of the percentage difference was performed using the following formula (Equation 1):

$$\text{Wave height reduction (\%)} = \frac{Height\ before\ model - Height\ after\ model}{Height\ before\ model} \times 100 \quad (1)$$

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

Table 1. Percentage wave reduction data

Model	Period (s)	Amplitude (m)	Frequency (Hz)	H before breakwater at CH_2 (m)	H after breakwater at CH_3 (m)	Percentage difference (%)
FB_1	2	0.08	0.5	0.217	0.144	33.64
	1.25	0.08	0.8	0.228	0.171	25.00
FB_2	2	0.08	0.5	0.213	0.119	44.13
	1.25	0.08	0.8	0.244	0.173	29.10
FB_3	2	0.08	0.5	0.178	0.074	58.43
	1.25	0.08	0.8	0.264	0.158	40.15
FB_4	2	0.08	0.5	0.196	0.211	7.65
	1.25	0.08	0.8	0.257	0.263	2.33

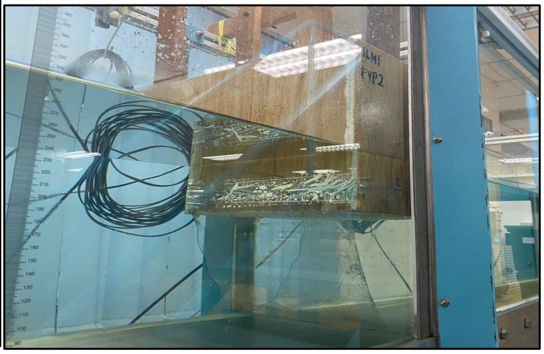
3.2 Significance of Wave Height Reduction of Fixed Breakwater Models based on Different Wave Frequency, *F*

The laboratory assessments were conducted on two different wave frequencies, namely, F =0.5 Hz and F = 0.8 Hz. This allows for a more comprehensive assessment of their performance and effectiveness. Waves with different frequencies have distinct characteristics and energy distributions, which can affect how breakwaters interact with and mitigate the waves, and it becomes possible to evaluate the breakwater's behavior under varying wave conditions. Figure 7 shows the effect of relative structure height on wave height reduction for two different wave frequencies and different models (FB_1, FB_2, FB_3, and FB_4). The type of wave was a regular wave. The discussion is based on data mainly from Channel 2 (CH_2) and Channel 3 (CH_3).

(a) FB_1 without membrane

(b) FB_2 with single 46 cm membrane

(c) FB_3 with 46 cm and 56 cm double membranes

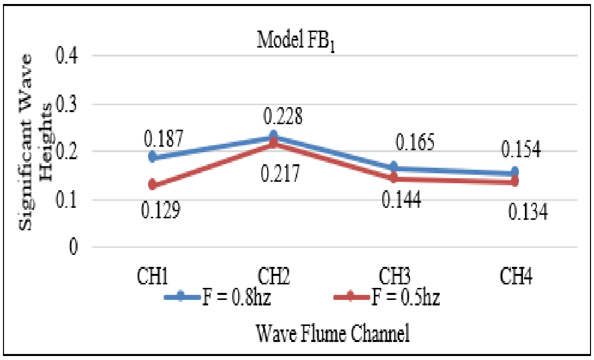


(d) FB_4 with a single 56 cm membrane

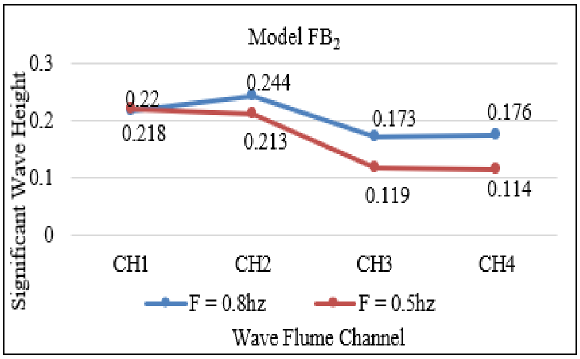
Figure 7. Different fixed breakwater models

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

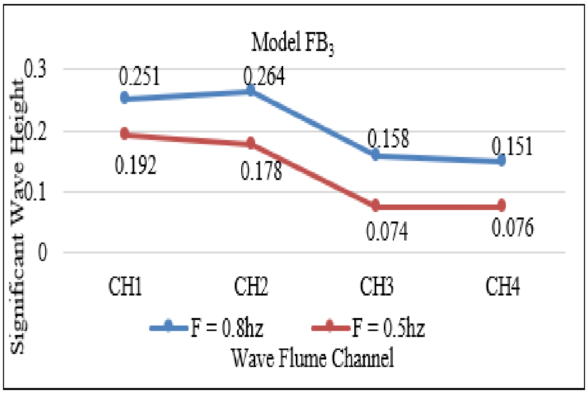
Based on the assessment, the graph of significant wave height against channels was conducted as in Figure 8 for different fixed breakwater models. The graph in Figure 8a indicates that the wave height peaked higher at F = 0.8 Hz at a height of 0.228m compared to the wave height at F = 0.5 Hz, which reached 0.217m. However, a reduction in wave height can be seen after waves hit the fixed breakwater at F = 0.8 Hz, where the height was reduced from 0.165m to 0.154m at CH_4, showing a percentage reduction of 33.33%. On the other hand, at F = 0.5 Hz, the wave height was reduced to 0.144m at CH_3 and continued to be reduced to 0.134m at CH_4. At this frequency, the wave height can be decreased by 50.69%. Meanwhile, the graph (Figure 8b) shows that the wave height peaked higher at F = 0.8 Hz at a height of 0.244m compared to the wave height at F = 0.5 Hz, which reached 0.213m. However, the wave height at 0.8 Hz was only reduced to 0.173 m, which is 41.04%. On the contrary, at F = 0.5 Hz, the percentage reduction is about 78.99% at 0.119m. Figure 8c illustrates that the wave height peaked higher at F = 0.8 Hz at a height of 0.264m compared to the wave height at F = 0.5 Hz, which reached 0.178m. The waves could be seen to behave successfully in terms of their reduction in wave height. Lastly, Figure 8d shows the wave heights, which were not successful in terms of their reduction at CH_3 as they increased to 0.263 m and 0.211 m subsequently. The waves could be seen to start reducing at CH_4, at 0.224m for 0.8 Hz. However, the wave height at 0.5 Hz remains at 0.196 m, similar to its height at CH_2.



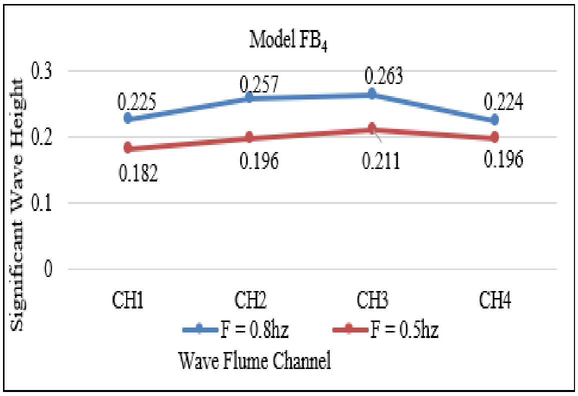
(a) FB_1 without membrane



(b) FB_2 with single 46 cm membrane



(c) FB_3 with 46 cm and 56 cm double membranes



(d) FB_4 with a single 56 cm membrane

Figure 8. Graph of significant wave height against wave flume channel for different models

Based on the analysis conducted above, shows that the fixed breakwaters behave more efficiently when the frequency of waves is set to 0.5 Hz. The frequency of waves is indirectly proportional to their wave period, T (Equation 2).

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

$$T = \frac{1}{F} \tag{2}$$

Therefore, we can acquire the wave period by using this formula. The wave period for F = 0.5 Hz is 2.0 s, while the wave period for F = 0.8 Hz is 1.25 s. As per the findings of a study conducted by Magdalena & Jonathan (2022), it was observed that there is a consistent trend of higher wave transmission as the wave period becomes longer.

When the frequency of the incident waves differs significantly from the natural frequency of the fixed breakwater, less resonance occurs. In such cases, the breakwater is less likely to experience amplified responses and can effectively reduce wave heights. These types of waves are called long waves and are typically generated by distant weather systems, such as storms or strong winds over large bodies of water. Long waves can travel great distances across the ocean and can be observed as the rhythmic rise and fall of the water's surface. They have wavelengths greater than 1.73 times the water depth and periods usually ranging from a few seconds to several minutes (Li et al., 2020).

This could be seen from the analysis of significant wave heights in the graphs above (Figure 8), where the percentage of wave height reduction is higher at T = 2.0s. It is important to note that the response of a fixed breakwater may vary depending on the wave period, which is inversely related to the frequency, where longer wave periods typically correspond to lower frequencies. For example, in the case of Model 4 (FB_4), the wave height reduction could only be seen at the final channel, CH_4. This could be caused by the long flexible membrane, which may dissipate particle movements through the obvious swing motions, causing the wave height to increase after encountering the Fixed breakwater**.**

3.3 Effectiveness of Models in Reducing Wave Attenuation

The graph in Figure 9 shows the percentage of wave reduction of fixed breakwater models for different wave periods of 1.25s and 2s that were tested in this laboratory assessment. Based on the graph, the lowest percentage of wave reduction occurs at FB_4, which is 7.65% for the 2s period and 2.33% for the 1.25s period. This is due to the long flexible membrane swinging the motion of waves, which causes the energy to be pushed forward, hence increasing the wave height after passing through the fixed breakwater. However, FB_4 shows sufficient efficiency at CH_4, albeit not as distinctive as the other three models. The best performance of wave reduction happened at FB_3, with a reduction percentage of up to 58.43% for the long wave (2 s period) and 40.15% for the 1.25 s period. This aligns with past findings that stated that fixed breakwater with membrane efficiency could increase up to 50% and more compared to FB without membrane (Li et al., 2020). Meanwhile, FB_1 with 33.64% for the 2s period and 25% for the 1.25s period shows that without the aid of a membrane, the fixed breakwater could still manage to reduce the wave heights before the wave hits the fixed breakwater. On the other hand, at FB_2, the percentage increases to 44.13% for the 2s period and 29.10% for the 1.25s period. This indicates that the flexible membrane is successful in acting as a wave absorber and dampening the wave energy as it passes through.

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 3 Issue 1 (March 2024), 133-144
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v3i1.133--144

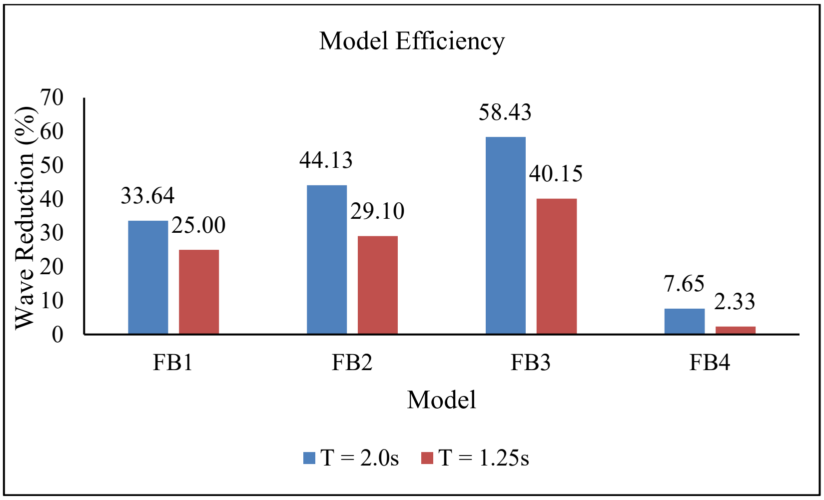


Figure 9. Graph of percentage of wave reduction of Fixed breakwater models for different wave periods

4. Conclusion

This study employed the practicality of enhanced fixed breakwater with the membrane in the context of wave attenuation by investigating the performance of the fixed breakwaters in reducing wave heights through a laboratory experiment. The observation of four breakwater models (FB_1, FB_2, FB_3, and FB_4) by analysing the visual photographs and recording wave height before and after passing through the breakwater helps as an indicator of the functionality of the fixed breakwaters. Also, a statistical analysis conducted on the performance of fixed breakwaters shows that fixed breakwater is more practical in long-wave regime periods ($T = 2.0$s) with a reduction of wave heights up to 58.43%. In addition, the results revealed that the addition of flexible membranes successfully promotes high wave dissipation behaviour by more than 50% compared to fixed breakwater without membrane.

Laboratory assessment of a fixed box-type breakwater as a temporary coastal protection measure against wave action demonstrates its effectiveness in attenuating wave energy. The results of this study provide valuable insights into the potential applications of fixed box-type breakwaters in coastal engineering and highlight their importance as part of an integrated coastal protection strategy. Future research should focus on refining breakwater design and evaluating their performance under field conditions to validate their efficacy as temporary coastal protection measures.

The findings of this study have important implications for coastal protection strategies, particularly in areas prone to erosion and storm damage. Fixed box-type breakwaters offer a viable temporary solution to mitigate the impact of waves while permanent measures are developed and implemented. Further research is warranted to optimize breakwater design and assess their performance in real-world coastal environments.

Acknowledgements

We thank the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia, for providing facilities to achieve our objectives in our research.

Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

References

Cebada-Relea, A. J., López, M., Claus, R., & Aenlle, M. (2023). Short-term analysis of extreme wave-induced forces on the connections of a floating breakwater. *Ocean Engineering*, *280*(May). https://doi.org/10.1016/j.oceaneng.2023.114579

Chen, J., Zhang, J., Wang, G., Zhang, Q., Guo, J., & Sun, X. (2022). Numerical simulation of the wave dissipation performance of floating box-type breakwaters under long-period waves. *Ocean Engineering*, *266*(P4), 113091. https://doi.org/10.1016/j.oceaneng.2022.113091

Chen, Y. kun, Liu, Y., Meringolo, D. D., & Hu, J. ming. (2023). Study on the hydrodynamics of a twin floating breakwater by using SPH method. *Coastal Engineering*, *179*(August 2022), 104230. https://doi.org/10.1016/j.coastaleng.2022.104230

Cui, J., Chen, X., Sun, P. N., & Li, M. Y. (2022). Numerical investigation on the hydrodynamic behavior of a floating breakwater with moon pool through a coupling SPH model. *Ocean Engineering*, *248*(February), 110849. https://doi.org/10.1016/j.oceaneng.2022.110849

Diamantoulaki, I., & Angelides, D. C. (2010). Analysis of performance of hinged floating breakwaters. *Engineering Structures*, *32*(8), 2407–2423. https://doi.org/10.1016/j.engstruct.2010.04.015

Fouladi, M. Q., Bahmanpouri, F., Rezazadeh, S., Kollolemad, F., Mashayekhi, M., & Viccione, G. (2023). Investigating the sidewall's effects on π-shaped floating breakwaters interacting with water waves by the scaled boundary FEM. *Ocean Engineering*, *284*(December 2022), 115200. https://doi.org/10.1016/j.oceaneng.2023.115200

Guo, W., Zou, J., He, M., Mao, H., & Liu, Y. (2022). Comparison of hydrodynamic performance of floating breakwater with taut, slack, and hybrid mooring systems: An SPH-based preliminary investigation. *Ocean Engineering*, *258*(May), 111818. https://doi.org/10.1016/j.oceaneng.2022.111818

Ji, C., Bian, X., Huo, F., Guo, J., lian, Z., & Yuan, Z. (2022). Experimental study on hydrodynamic characteristics of a new type floating breakwater with opening pass and wing structure. *Ocean Engineering*, *259*(November 2021), 111923. https://doi.org/10.1016/j.oceaneng.2022.111923

Ji, C., Bian, X., Xu, S., Guo, J., & Huo, F. (2023). Numerical study on the hydrodynamic performance of floating breakwaters with complex configurations. *Ocean Engineering*, *273*(December 2022), 114032. https://doi.org/10.1016/j.oceaneng.2023.114032

Ji, C., Cheng, Y., Cui, J., Yuan, Z., & Gaidai, O. (2018). Hydrodynamic performance of floating breakwaters in long wave regime: An experimental study. *Ocean Engineering*, *152*(January), 154–166. https://doi.org/10.1016/j.oceaneng.2018.01.055

Kee, S. T. (2005). Submerged Horizontal and Vertical Membrane Wave Barrier. *Journal of Ocean Engineering and Technology*, *19*(2), 1–11.

Li, A., Liu, Y., Li, H. jun, & Fang, H. (2020). Analysis of water wave interaction with a submerged fluid-filled semi-circular membrane breakwater. *Ocean Engineering*, *197*(November 2019), 106901. https://doi.org/10.1016/j.oceaneng.2019.106901

Li, C., Zhang, H., Zhang, H., Sun, B., & Yang, S. (2022). Wave-attenuation and hydrodynamic properties of twin pontoon floating breakwater with kelp. *Applied Ocean Research*, *124*(February), 103213. https://doi.org/10.1016/j.apor.2022.103213

Magdalena, I., & Jonathan, G. (2022). Water waves resonance and its interaction with submerged breakwater. *Results in Engineering*, *13*(December 2021), 100343. https://doi.org/10.1016/j.rineng.2022.100343

Paotonan, C., Umar, H., Rahman, S., & Rachman, T. (2022). Analytical Approach of Wave Transmission Coefficient through on Composite Hanging Breakwater. *IOP Conference Series: Earth and Environmental Science*, *972*(1). https://doi.org/10.1088/1755-1315/972/1/012077

Park, J. C., & Kim, K. H. (2023). Analytical solutions for diffraction and radiation problems of an infinitely long floating compound breakwater with wide porous media. *Ocean Engineering*, *279*(April), 114548. https://doi.org/10.1016/j.oceaneng.2023.114548

Sun, B., Li, C., Yang, S., Zhang, H., & Song, Z. (2022). Experimental and numerical study on the wave attenuation performance and dynamic response of kelp-box type floating breakwater. *Ocean Engineering*, *263*(August), 112374. https://doi.org/10.1016/j.oceaneng.2022.112374

Sun, B., Zhang, H., Yang, S., & Li, C. (2022). Experimental investigation on the wave-attenuating performance and shape optimization of water ballast type floating breakwater. *Ocean Engineering*, *248*(February), 110848. https://doi.org/10.1016/j.oceaneng.2022.110848

Uzaki, K. I., Ikehata, Y., & Matsunaga, N. (2011). Performance of the wave energy dissipation of a floating breakwater with truss structures and the quantification of transmission coefficients. *Journal of Coastal Research*, *27*(4), 687–697. https://doi.org/10.2112/JCOASTRES-D-09-00070.1

Wei, K., & Yin, X. (2022). Numerical study into configuration of horizontal flanges on hydrodynamic performance of moored box-type floating breakwater. *Ocean Engineering*, *266*(P4), 112991. https://doi.org/10.1016/j.oceaneng.2022.112991

Wu, J. P., Mei, T. L., & Zou, Z. J. (2022). Experimental study on wave attenuation performance of a new type of free surface breakwater. *Ocean Engineering*, *244*(July 2021), 110447. https://doi.org/10.1016/j.oceaneng.2021.110447

Yin, Z., Ni, Z., Luan, Y., Zhang, X., Li, J., & Li, Y. (2023). Hydrodynamic characteristics of a box-type floating breakwater with restrained piles under regular waves. *Ocean Engineering*, *280*(December 2022), 114408. https://doi.org/10.1016/j.oceaneng.2023.114408