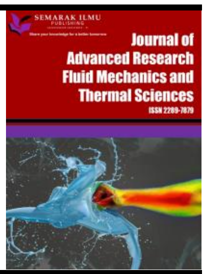
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 112, Issue 2 (2023) 33-42

SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Experimental Study on Wave Transmission Coefficient of Double Cylindrical Floating Breakwater in a Wave Basin

Andrew Yip Jun Kit[1], Sunny Goh Eng Giap[1,2,*], Mohammad Fadhli Ahmad[1,♣]

[1] Faculty of Ocean Engineering Technology and Informatics, University Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[2] Hydrology and Water Resources Research Interest Group, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

ARTICLE INFO

Article history:
Received 17 September 2023
Received in revised form 25 November 2023
Accepted 7 December 2023
Available online 31 December 2023

Keywords:
Floating structure; coastal protection; wave attenuation; wave transmission coefficient; coastal erosion

ABSTRACT

Floating breakwater is a better alternative than the conventional method. It is an effective coastal engineering unit used to protect coastal regions such as harbours and marinas from erosive waves. It has many other applications such as offshore renewable energy generation, infrastructure preservation, temporary structure, and provides a controlled environment for aquaculture activities. The floating breakwater such as the double cylindrical floating breakwater (DCFB) is claimed to have effective wave attenuation characteristics. A lab scale investigation was done by placing the DCFB in a controlled wave basin in with wave generator to generate wave and wave gauge to quantify the wave transmission coefficient. The wave transmission coefficient represents the effectiveness of the breakwater system in attenuating incoming waves, where an effective breakwater system will result in a low transmission coefficient value. In this study, the DCFB's effectiveness in terms of wave transmission coefficient was investigated with two different configurations where the spacing between the cylinders of the DCFB units are 0.2 m and 0.6 m respectively. Results show that the configuration of DCFB units with 0.5 m cylinder spacing are more effective in absorbing incoming wave height resulting in lower transmission coefficient. Furthermore, some prospective areas had been identified for future enhancement.

1. Introduction

Floating breakwaters are effective coastal engineering structures in reducing the effect of destructive ocean waves on coastal regions such as harbour facilities [1]. The double cylindrical floating breakwater (DCFB) is specifically designed with two rigid cylinders attached with a wall in between and a mesh cage attached below the unit [2]. The configuration is claimed to have effective wave attenuation [3]. Hence, exploring the DCFB unit on coastal protection from destructive ocean waves, including harbour safety, becomes important [4].

* *Corresponding author.*
E-mail address: sunnygoh@gmail.com
♣ *Corresponding author.*
E-mail address: fadhli@umt.edu.my

https://doi.org/10.37934/arfmts.112.2.3342

The DCFB structure performance can be properly understood using a quantification unit to represent its ability to mitigate incoming waves [5]. Wave transmission coefficient can be used to assess the relative amount of wave energy remaining after passing through the DCFB by quantifying the wave height changes after passing through the DCFB [6].

The response of the DCFB structure varies with different wave energies indicates that the structure is effective and has potential to attenuate incoming wave energy [7]. Thus, the quantification of wave transmission coefficient of the DCFB in a controlled lab scale experiment serves as an expansion of theoretical practice into actual coastal engineering and planning applications [8].

The study on DCFB is significantly beyond the interest of the academic values [9]. Coastal phenomenon such as storm surges, erosion and other coastal hazards are becoming more severe together with climate change [10]. Therefore, the introduction of DCFB into actual coastal applications can be seen as a desirable solution to the potential environmental hazards in coastal areas [11]. Determining the wave transmission coefficient under different environmental conditions are necessary to identify the most optimum DCFB design and arrangement to effectively protect coastal areas from potential wave damages [12]. Successful application of floating breakwater to mitigate coastal damage not only contribute to the progress in coastal engineering but also improves safety and sustainability of community environments [13].

The increase of human population living near to coastal area and extreme weather patterns due to climate change calls for a greener solution to coastal engineering approaches. The conventional approach of piling type breakwater system often impose change to the natural coastline, subsequently bringing ecological damage will not be sustainable in a long run. In this aspect, a floating breakwater system such as the proposed DCFB will have a better advantage. With proper design specification, floating breakwater systems will have a significant advantage over the conventional floating breakwater. However, to date, the opportunity of applying floating breakwaters in actual site conditions are not well documented. In many experimental studies, the effects of size and arrangement of the DCFB system on transmission coefficient is not fully understood [14].

DCFB systems can be applied for many coastal protection purposes such as small craft harbours and marinas, or even as shoreline erosion control [15,16]. These examples indicate the potential of DCFB as part of an integrated coastal management system. The DCFB system is less intrusive in the shoreline environment as compared to conventional breakwaters and does not cause significant modification on the natural system [17]. It also has the ability to adapt to different wave conditions and can be designed to meet specific application needs, such as offshore renewable energy generation, infrastructure preservation, recreation, temporary structure, and create controlled environment for various aquaculture activities [18-29]. This study investigates the wave transmission coefficients of TCFB with different sizes and arrangements.

The ability of DCFB to mitigate incoming waves is the focus of this investigation. The primary aim is to have an in-depth comprehension on the structure and its functions, as well as to evaluate the structure performance by investigating the wave transmission coefficient. The current study has two objectives: firstly, to quantify the wave transmission coefficient of DCFB with different spacing between the cylinders (0.2m and 0.5m respectively) [12]; and secondly, to compare the wave transmission coefficient of DCFB systems without gap between the DCFB units and with a 0.5m gap between the DCFB units. The experiment was carried out in a wave basin with a wave paddle to generate waves and wave gauges to quantify the wave transmission coefficient.

2. Materials and Methodology

A three units of DCFB cylindrical floating breakwater (DCFB) were placed in a series, one after another, as shown in Figure 1. Figure 1 shows a physical unit of the DCFB for this study with the two rigid floating cylinders attached with a wall in between and a mesh cage at the bottom. In wave basin experiment, as shown in Figure 2 and Figure 3, wave was generated from wave maker and was transmitted along the wave basin towards the sand beach. Wave gauge (WG) 1 was used to measure incoming waves, WG2 was to measure waves reflected from DCFB and WG3 was to measure transmitted waves. In the first objective, DCFB with different sizes were tested. For the second objective, DCFB were arranged 0.5 m apart from one another (Figure 4) and the results were compared to the results from the first objective to determine the effects of different arrangement towards wave transmission coefficient.

Fig. 1. Double cylindrical floating breakwater used in this study

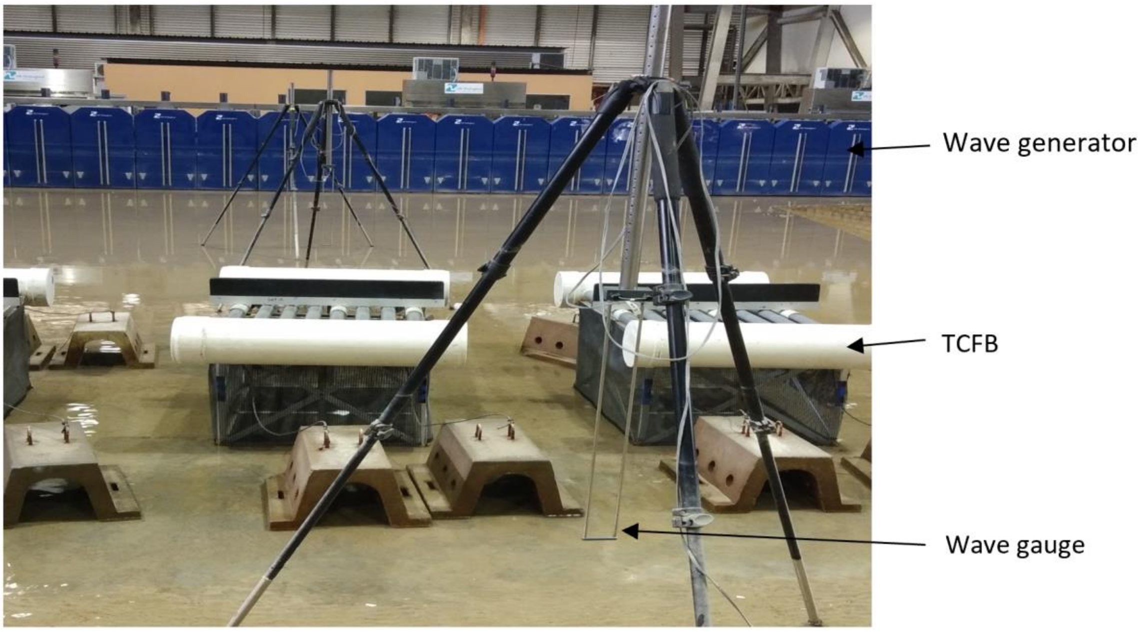


Fig. 2. The physical setup of the three units of twin cylindrical floating breakwater, showing pairs of floating cylinders to form a floating breakwater and the position of wave generator and wave generators

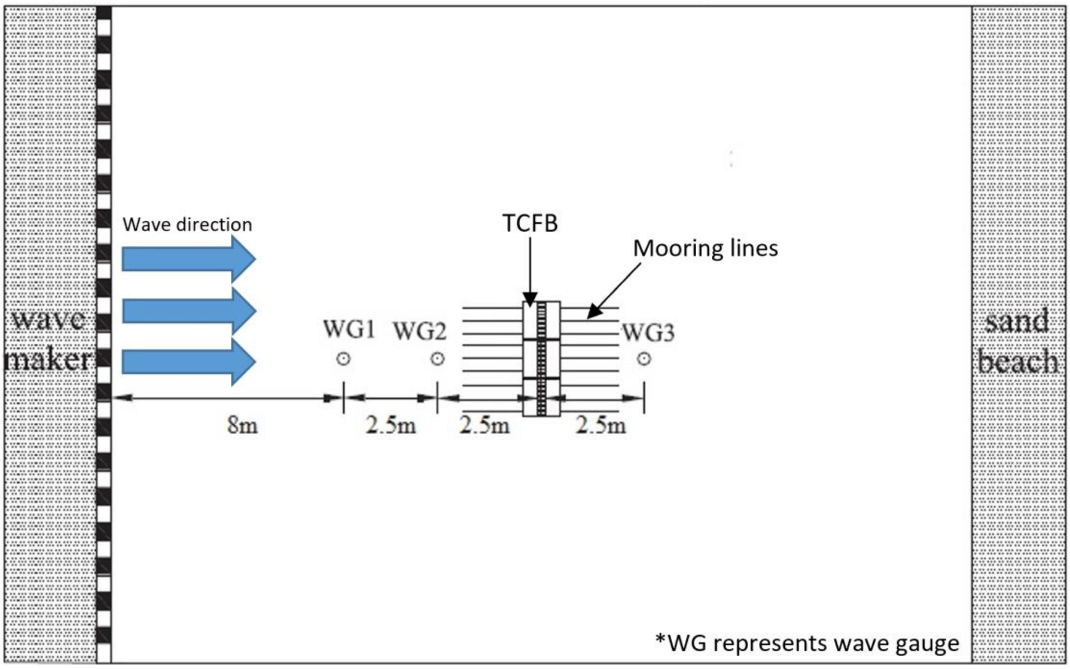


Fig. 3. Three units of double cylindrical floating breakwater located in series

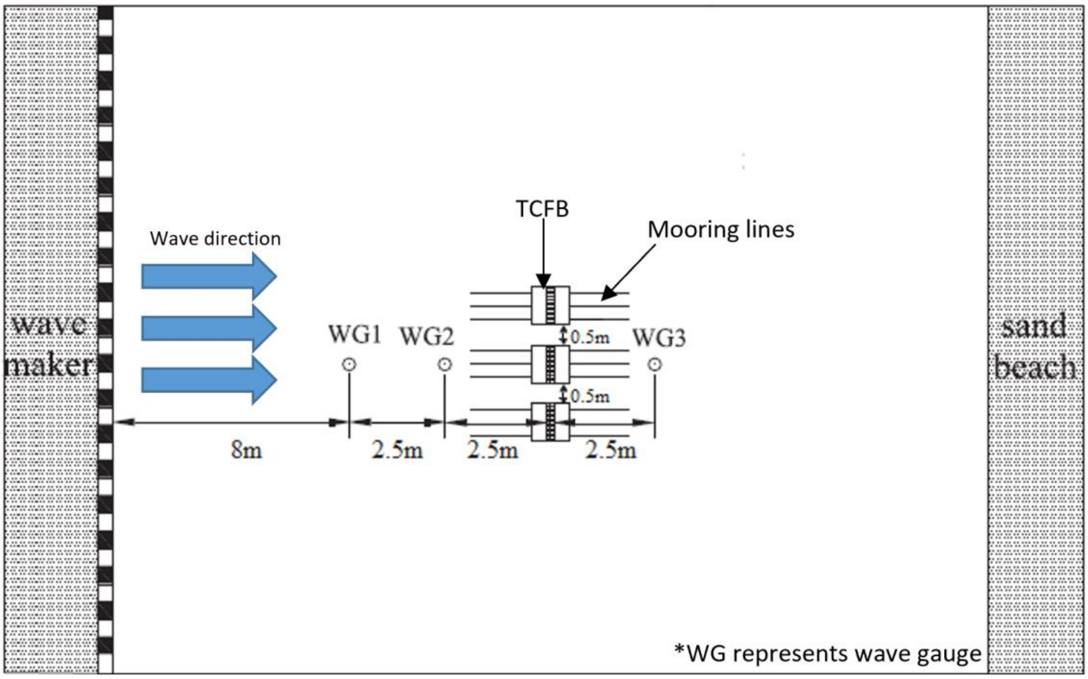


Fig. 4. Three double cylindrical floating breakwaters spaced 0.5m between each other

To quantify the effectiveness of the DCFB, the wave transmission coefficient (K_t) was used to calculate the ratio of transmitted wave height and incident wave height. The formula was given by [30-33]:

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

where H_t is the transmitted wave height, and H_i is the incident wave height.

3. Results and Discussion

Initially, the water level was around 0.3 m, when the water level was at rest. When the wave maker was turn on, a wave amplitude 0.3 m was generated above at peak and below at trough of the water level at rest. Figure 5 clearly showed a wave height of 0.6 m (peak minus trough) was generated in the wave basin that heading towards the DCFB. After the incident wave height (WG1) hits the DCFB the wave of lower height was seen leaving the DCFB (WG3), which then direct towards the sand beach. The contact of the incident wave with the DCFB result in energy loss, which the size of DCFB and the arrangement of DCFB results in absorption of a certain amount of energy. The overall effect resulted in a portion of energy leaving the DCFB transmitted at a lower wave height. On average, the transmitted wave height was seen to carry about 0.1 m amplitude, which was equivalent to 0.2 m (two times the amplitude). The rise and fall of the wave height corresponded well between the incident and the transmitted waves. A lower transmitted wave height than the incident was the reason of having less than unity wave transmission coefficient, which was commonly observed by other researchers [31-35].

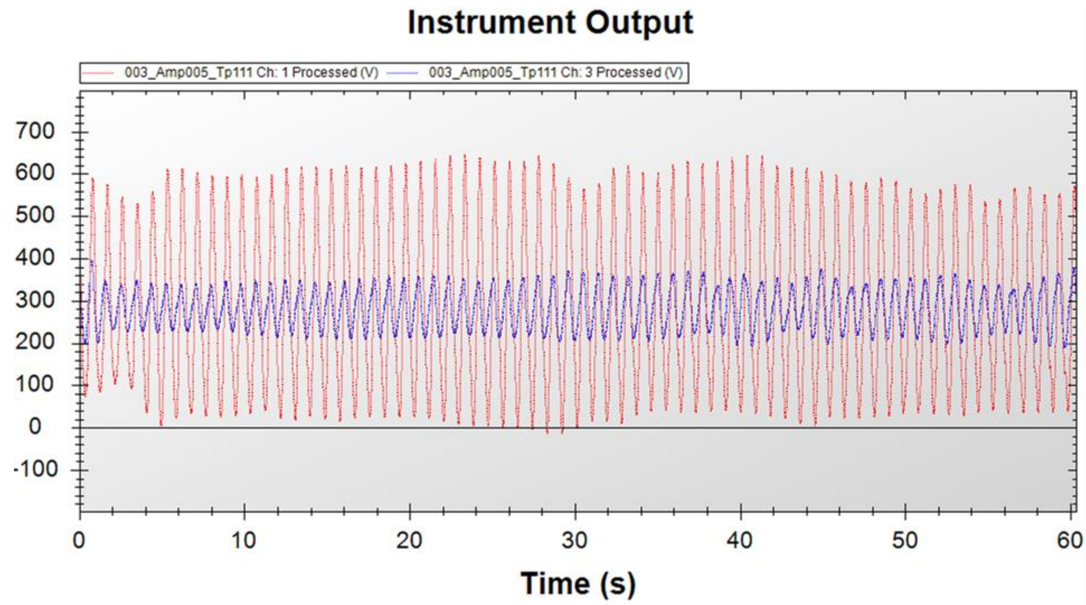


Fig. 5. The heights of the incident wave heading towards double cylindrical floating breakwaters and transmitted wave after the breakwaters. Note the red line refers to incident wave height (WG1), and the blue line refers to transmitted wave height (WG3)

The DCFB was further analysed for wave transmission coefficient. The coefficient indicates the ability of the DCFB structure, that come in direct contact with the wave, to absorb the incident energy before releasing the energy as transmitted wave. A high wave transmission coefficient indicates the structure is unable to absorb the energy, and vice versa. In Figure 6, the transmission coefficient was found to increase with the increasing ratio of wavelength (L) and breadth of the floating breakwater system (B), which is similarly to those reported by Ji *et al.,* [35]. The observation indicates that subjecting the system to a low frequency wave (or high wavelength), as in high L/B ratio, a large amount of energy would be transmitted across the DCFB structure without much resistance. The increasing wave transmission coefficient was found at greater rate of increment, in the range of a low L/B from 1.25 to 1.9, but as the L/B increases to high value range from 1.9 to 3.1, the wave transmission coefficient (K_t) was found to increase at a lower rate. A similar trend was observed when raising the wave height from 0.1 to 0.15 and 0.2 m, that the wave transmission coefficient was found to increase. The corresponding response of DCFB structure to incident wave height of 0.1, 0.15, and 0.2 m has a response of increasing ratio of K_t/(L/B) at 0.43, 0.51, and 0.65, respectively. Thus, either one or both increment the incoming wave height and wavelength, it reduces the ability of the DCFB structure to dampen the wave energy. It was also important to point out that the damping characteristic was only valid right before wave transmission coefficient reached the value of unity. As evident in the Figure 6, the wave transmission coefficient when rose above the unity value, the DCFB structure would appear as enhancing the transmitted wave height, which greater than the incident wave height. As the reason is currently clear, the movement of the structure magnify the wave amplitude after the DCFB structure could be partly responsible for the enhancement of transmitted wave height.

In Figure 6, the spacing between DCFB structures was designed to have 0.2 m size between the floating cylinders, but between the TCFB units there was no gap. In Figure 7, the size between the floating cylinders have been increased to 0.6 m, while the gap between the DCFB units was increased to 0.5 m. The experimentation in Figure 6 was based the condition as layout in the in Abdullah *et al.,* [12]. The experimentation set up in the Figure 7 was to explore the possibility of improving the wave transmission coefficient by increasing the size between the floating cylinders and to introduce a gap between the TCFB units. The apparent difference between Figure 6 and Figure 7 was that the former examined on the wave transmission coefficient from less than unity to greater than unity, while the latter only focussed on the wave transmission coefficient that was less than unity. If the wave transmission coefficient (K_t) was examined until the value of unity for DCFB with size of 0.2 m (Figure 6), the K_t/(L/B) was found to be 0.41, 0.92, and 2.17 corresponding to wave height (WH) of 0.1, 0.15, and 0.2 m, as in Figure 6. Increasing K_t/(L/B) with the L/B ratio implies the reducing ability of the TCFB structure to absorb the wave energy as the incoming wavelength increases. Whereas in Figure 7, the K_t/(L/B) was found to be 1.76, 0.95, and 0.52 for WH of 0.1, 0.15, and 0.2 m, respectively. Thus, decreasing K_t/(L/B) with the L/B ratio implies the increasing ability of the DCFB structure to absorb the wave energy as the incoming wavelength increases. Since the former was based on DCFB structure size of 0.2 m with no gap, and the latter was based on a size of 0.6 m with 0.5 m gap; hence, increasing the DCFB size and gap were evident to the increase of energy absorption ability of the breakwater system.

In addition to study described above, there are more investigations in the planning stage which are to enhance the research and development to improve the energy damping ability of the DCFB structure. For instance, increasing the mass of the structure. Having a heavier floating breakwater would increase the inertia of the unit that would reduce the response of the floating unit to the incoming fluctuating wave energy. Shape and design improvement, for example, using a slope slide could allow the incoming motion water to rise and fall on the slope surface; thus, dampen the effect of the incoming wave impact. Damping device would be another area of consideration, for instance, fender such as rubber bumper on the side of the structure that in direct contact with the incoming wave would increase impact absorption to result in more unit structure stationary. Active control system is another area of improvement, for example, using active ballast to modify unit mass distribution within the structure could counter the structure motion caused by the incoming wave. Additional studies in the future are related to the mooring system that can affect the movement of the structure.

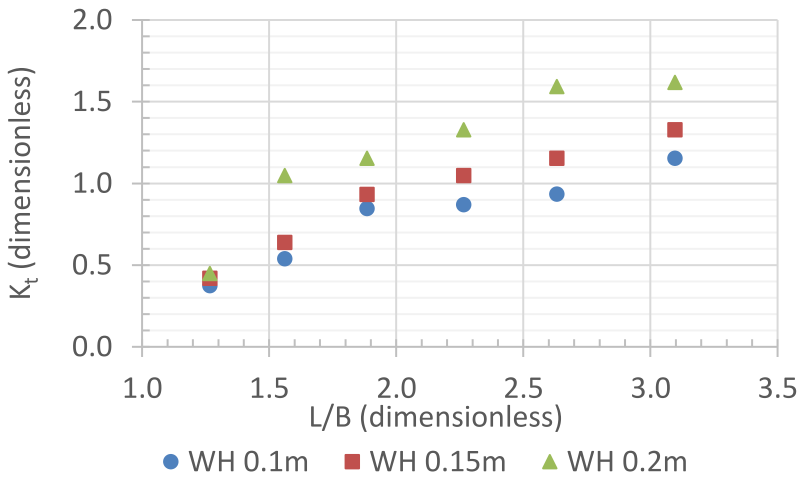


Fig. 6. Transmission coefficients of double cylindrical floating breakwaters (DCFB) in waves with size of 0.2 m between floating cylinders of the DCFB unit, without gap. Note that WH refers to wave height, K_t refers to the wave transmission coefficient, L is the wavelength, and B is the breadth of the floating breakwater system

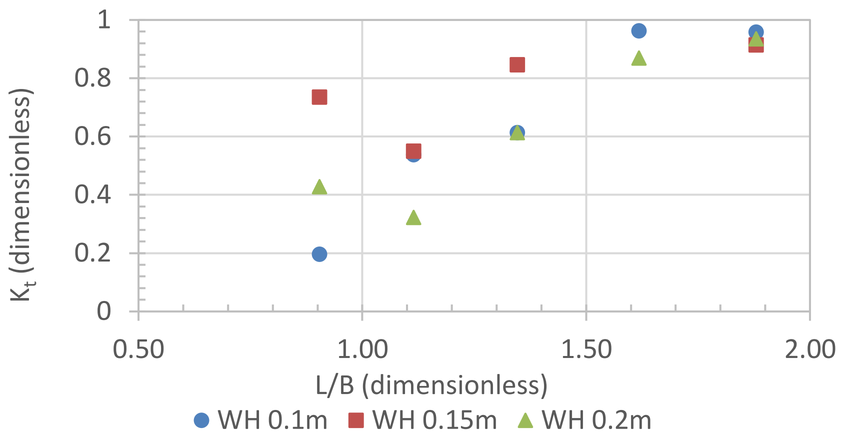


Fig. 7. Transmission coefficients of double cylindrical floating breakwaters (DCFB) in waves with size of 0.6 m between floating cylinders of the DCFB unit, with gap of 0.5 m between DCFB units. Note that WH refers to wave height, K_t refers to the wave transmission coefficient, L is the wavelength, and B is the breadth of the floating breakwater system

4. Conclusion

The double cylindrical floating breakwaters (DCFB) were fabricated and experimental in an indoor controlled environment that one side was wave generator and the other was sand beach used to absorb the transmitted wave. The wave heights 0.1 to 0.2 m were generated and direct towards the DCFB s that the first experiment was investigated with a spacing size between floating cylinders of 0.2 m with no gap. While the second experiment was investigated with spacing size of 0.6 m between floating cylinders with 0.5 m gap between DCFB units. The wave heights were measured using wave gauge located before and after the DCFB, that the ratio of transmitted wave height and incident wave height was taken as wave transmission coefficient, which used to indicate the efficiency of the DCFB structure unit in damping the incoming wave to result in lower transmitted wave height. Results in experiment one showed the wave transmission coefficient could be less than unity when the DCFB units were effective in absorbing the incoming energy of the wave, but as the incoming wavelength continued to increase, the transmitted wave height was found to be enhanced to result in the increase of the wave transmission coefficient to greater than unity that signifies a greater transmitted wave height than the incoming wave height. While focussing on the experimental conditions with wave transmission coefficients less than unity, the DCFB in second experiment with the gap of 0.5 m spacing sizes between structure units was found to exhibit a better damping effect than in experiment one. Furthermore, an improve version of the DCFB is currently in the planning stage, and more improvement can be achieved, for instance, the structure mass, shape and design improvement, damping device, and active control device.

Acknowledgement
This research was funded by a Geran Translasional (Vot 53304) Rekabentuk Selinder Terapung Pemecah Ombak Untuk Perlindungan Garisan Pantai (Design of Cylindrical Floating Breakwater Shoreline Protection).

References

[1] Chen, Yong-kun, Yong Liu, Domenico D. Meringolo, and Jia-ming Hu. "Study on the hydrodynamics of a twin floating breakwater by using SPH method." *Coastal Engineering* 179 (2023): 104230. https://doi.org/10.1016/j.coastaleng.2022.104230

[2] Ji, Chun-Yan, Xiang Chen, Jie Cui, Zhi-Ming Yuan, and Atilla Incecik. "Experimental study of a new type of floating breakwater." *Ocean Engineering* 105 (2015): 295-303. https://doi.org/10.1016/j.oceaneng.2015.06.046

[3] Cheng, Xiaofei, Chang Liu, Qilong Zhang, Ming He, and Xifeng Gao. "Numerical study on the hydrodynamic characteristics of a double-row floating breakwater composed of a pontoon and an airbag." *Journal of Marine Science and Engineering* 9, no. 9 (2021): 983. https://doi.org/10.3390/jmse9090983

[4] Sun, Bin, Hao Zhang, Cheng Li, and Zhiwei Li. "Research Progress and Prospect of Wave Attenuation Performance and Integration of Wave-Energy Converter of Floating Breakwater." *Journal of Environmental Engineering* 149, no. 4 (2023): 03123001. https://doi.org/10.1061/JOEEDU.EEENG-7118

[5] Cheng, Yong, Shiqi Dai, Saishuai Dai, Chunyan Ji, Maurizio Collu, Zhiming Yuan, and Atilla Incecik. "Energy conversion and hydrodynamic analysis of multi-degree-of-freedom wave energy converters integrated into a semi-submersible platform." *Energy Conversion and Management* 252 (2022): 115075. https://doi.org/10.1016/j.enconman.2021.115075

[6] Cheng, Yong, Chun-yan Ji, Xue-kang Gu, Fa-li Huo, Jie Cui, and Zhi-Ming Yuan. "Hydrodynamics of a dual-module pontoon-net floating breakwater system: Numerical simulations and prototype tests." *Journal of Hydrodynamics* 33, no. 5 (2021): 915-927. https://doi.org/10.1007/s42241-021-0081-1

[7] Shen, Yu-sheng, Jun-ning Pan, Yi-ren Zhou, and Xing-gang Wang. "Experimental study on wave attenuation performance of a new type of floating breakwater with twin pontoons and multi porous vertical plates." *China Ocean Engineering* 36, no. 3 (2022): 384-394. https://doi.org/10.1007/s13344-022-0034-7

[8] Ruzzo, Carlo, Sara Muggiasca, Giovanni Malara, Federico Taruffi, Marco Belloli, Maurizio Collu, Liang Li, Giulio Brizzi, and Felice Arena. "Scaling strategies for multi-purpose floating structures physical modeling: State of art and new perspectives." *Applied Ocean Research* 108 (2021): 102487. https://doi.org/10.1016/j.apor.2020.102487

[9] Konispoliatis, Dimitrios N., and Spyridon A. Mavrakos. "Theoretical analysis of a vertical cylindrical floater in front of an orthogonal breakwater." *Fluids* 5, no. 3 (2020): 135. https://doi.org/10.3390/fluids5030135

[10] McCarthy, James J., ed. *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change*. Vol. 2. Cambridge University Press, 2001.

[11] Burcharth, Hans F., Barbara Zanuttigh, Thomas Lykke Andersen, Javier L. Lara, Gosse Jan Steendam, Piero Ruol, Philippe Sergent et al. "Innovative engineering solutions and best practices to mitigate coastal risk." In *Coastal Risk Management in a Changing Climate*, pp. 55-170. Butterworth-Heinemann, 2015. https://doi.org/10.1016/B978-0-12-397310-8.00003-8

[12] Abdullah, S. F., A. Fitriadhy, M. Hairil, and A. Jusoh. "Hydrodynamic performance of cylindrical floating breakwater in waves." *International Journal of Automotive and Mechanical Engineering* 14, no. 4 (2017): 4715-4729. https://doi.org/10.15282/ijame.14.4.2017.10.0371

[13] Teh, H. M. "Hydraulic performance of free surface breakwaters: A review." *Sains Malaysiana* 42, no. 9 (2013): 1301-1310.

[14] Saengsupavanich, Cherdvong, Effi Helmy Ariffin, Lee Shin Yun, and Dunstan Anthony Pereira. "Environmental impact of submerged and emerged breakwaters." *Heliyon* (2022). https://doi.org/10.1016/j.heliyon.2022.e12626

[15] Sujantoko, Sujantoko, Eko Budi Djatmiko, Wisnu Wardhana, and Is Naldi Gemilang Firmasyah. "Numerical Modeling of Hydrodynamic Performance on Porous Slope Type Floating Breakwater." *NAŠE MORE: Znanstveni Časopis za more i Pomorstvo* 70, no. 2 (2023). https://doi.org/10.17818/NM/2023/2.1

[16] Neelamani, Subramaniam, and Alanoud AlRagum. "Hydrodynamic Performance of Floating Pontoon Type Breakwater With Skirt Walls and Different Porosity." In *International Conference on Offshore Mechanics and Arctic Engineering*, vol. 85901, p. V05BT06A009. American Society of Mechanical Engineers, 2022. https://doi.org/10.1115/OMAE2022-80202

[17] Díaz, Hugo, José Serna, Javier Nieto, and C. Guedes Soares. "Market needs, opportunities and barriers for the floating wind industry." *Journal of Marine Science and Engineering* 10, no. 7 (2022): 934. https://doi.org/10.3390/jmse10070934

[18] Ren, Junqing, Peng Jin, Yingyi Liu, and Jun Zang. "Wave attenuation and focusing by a parabolic arc pontoon breakwater." *Energy* 217 (2021): 119405. https://doi.org/10.1016/j.energy.2020.119405

[19] Kamarlouei, M., J. F. Gaspar, Miguel Calvario, T. S. Hallak, Mário JGC Mendes, F. Thiebaut, and C. Guedes Soares. "Experimental analysis of wave energy converters concentrically attached on a floating offshore platform." *Renewable Energy* 152 (2020): 1171-1185. https://doi.org/10.1016/j.renene.2020.01.078

[20] Wang, Jun, and Peter D. Lund. "Review of recent offshore photovoltaics development." *Energies* 15, no. 20 (2022): 7462. https://doi.org/10.3390/en15207462

[21] Peng, Wei, Yingnan Zhang, Qingping Zou, Xueer Yang, Yanjun Liu, and Jisheng Zhang. "Experimental investigation of a triple pontoon wave energy converter and breakwater hybrid system." *IET Renewable Power Generation* 15, no. 14 (2021): 3151-3164. https://doi.org/10.1049/rpg2.12214

[22] Nguyen, H. P., and C. M. Wang. "Heaving wave energy converter-type attachments to a pontoon-type very large floating structure." *Engineering Structures* 219 (2020): 110964. https://doi.org/10.1016/j.engstruct.2020.110964

[23] O'Shaughnessy, Kathryn A., Stephen J. Hawkins, Ally J. Evans, Mick E. Hanley, Paul Lunt, Richard C. Thompson, Robert A. Francis et al. "Design catalogue for eco-engineering of coastal artificial structures: a multifunctional approach for stakeholders and end-users." *Urban Ecosystems* 23 (2020): 431-443. https://doi.org/10.1007/s11252-019-00924-z

[24] Lim, Joseph. "Intensifying Food and Housing at Sea." *Oil Rig and Superbarge Floating Settlements* (2021): 19-60. https://doi.org/10.1007/978-981-15-5297-7_2

[25] Raju, Rahul Dev, and Madasamy Arockiasamy. "Coastal protection using integration of mangroves with floating barges: An innovative concept." *Journal of Marine Science and Engineering* 10, no. 5 (2022): 612. https://doi.org/10.3390/jmse10050612

[26] Vijay, K. G., S. Neelamani, T. Sahoo, K. Al-Salem, and C. S. Nishad. "Scattering of gravity waves by a pontoon type breakwater with a series of pervious and impervious skirt walls." *Ships and Offshore Structures* 17, no. 1 (2022): 130-142. https://doi.org/10.1080/17445302.2020.1827630

[27] Vo, Thi Thu Em, Hyeyoung Ko, Jun-Ho Huh, and Namje Park. "Overview of solar energy for aquaculture: The potential and future trends." *Energies* 14, no. 21 (2021): 6923. https://doi.org/10.3390/en14216923

[28] Sahoo, Haripriya, R. Gayathri, Mohamin BM Khan, and Harekrushna Behera. "Hybrid boundary element and eigenfunction expansion method for wave trapping by a floating porous box near a rigid wall." *Ships and Offshore Structures* (2022): 1-11. https://doi.org/10.1080/17445302.2022.2108227

[29] Claus, R., and M. López. "Key issues in the design of floating photovoltaic structures for the marine environment." *Renewable and Sustainable Energy Reviews* 164 (2022): 112502. https://doi.org/10.1016/j.rser.2022.112502

[30] Song, Won-Joon, John S. Popovics, John C. Aldrin, and Surendra P. Shah. "Measurement of surface wave transmission coefficient across surface-breaking cracks and notches in concrete." *The Journal of the Acoustical Society of America* 113, no. 2 (2003): 717-725. https://doi.org/10.1121/1.1537709

[31] Dong, G. H., Y. N. Zheng, Y. C. Li, B. Teng, C. T. Guan, and D. F. Lin. "Experiments on wave transmission coefficients of floating breakwaters." *Ocean Engineering* 35, no. 8-9 (2008): 931-938. https://doi.org/10.1016/j.oceaneng.2008.01.010

[32] Zhao, Xuanlie, Rong Xue, Jing Geng, and Malin Göteman. "Analytical investigation on the hydrodynamic performance of a multi-pontoon breakwater-WEC system." *Ocean Engineering* 220 (2021): 108394. https://doi.org/10.1016/j.oceaneng.2020.108394

[33] Li, Cheng, Haijia Zhang, Hao Zhang, Bin Sun, and Shaolin Yang. "Wave-attenuation and hydrodynamic properties of twin pontoon floating breakwater with kelp." *Applied Ocean Research* 124 (2022): 103213. https://doi.org/10.1016/j.apor.2022.103213

[34] Ning, De-Zhi, Xuan-Lie Zhao, Ming Zhao, Martyn Hann, and Hai-Gui Kang. "Analytical investigation of hydrodynamic performance of a dual pontoon WEC-type breakwater." *Applied Ocean Research* 65 (2017): 102-111. https://doi.org/10.1016/j.apor.2017.03.012

[35] Ji, Chunyan, Yong Cheng, Ke Yang, and Gaidai Oleg. "Numerical and experimental investigation of hydrodynamic performance of a cylindrical dual pontoon-net floating breakwater." *Coastal Engineering* 129 (2017): 1-16. https://doi.org/10.1016/j.coastaleng.2017.08.013