SEMARAK ILMU PUBLISHING

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

Wave Force on Breakwater with Multiangle Oblique Waves during Monsoon Season

Mohd Amin Hakim Ramli[1,*], Shahida Ishak[1], Muhammad Adli Mustapa[1], Rohaizad Hafidz Rozali[1], Kamarul Nasser Mokri[1], Iwan Zamil Mustaffa Kamal[2], Effi Helmy Ariffin[3], Yaseen Adnan Ahmed[4]

1 Maritime Engineering Section, Universiti Kuala Lumpur, Malaysia Institute of Marine Engineering Technology, 32200, Lumut, Perak, Malaysia
2 Asian Marine Design Centre, Universiti Kuala Lumpur, Malaysia Institute of Marine Engineering Technology, 32200, Lumut, Perak, Malaysia
3 Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030, Kuala Terengganu, Malaysia
4 Maritime Safety Research Centre, Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, 100 Montrose St, Glasgow G4 0LZ, United Kingdom

ARTICLE INFO

Article history:
Received 15 April 2024
Received in revised form 23 July 2024
Accepted 4 August 2024
Available online 30 August 2024

Keywords:
Breakwater; oblique wave; wave energy converter; wave force

ABSTRACT

A breakwater is a structure constructed near a coastline to safeguard the area from the force of waves and reduce erosion. Waves exert hydrodynamics forces on the structure by applying pressure momentum. It functions as a barrier that absorbs the energy zone waves, thereby producing calmer zones behind it. To withstand the impact of waves, breakwaters can be constructed from a variety of materials, including concrete slabs, rocks, and steel. The magnitude of force obtained from a wave pressure acting on a breakwater refers to the deformation of the structure resulting from force impact. The objective of this study is to analyse the wave force acting on a breakwater using computational fluid dynamics software that simulates the high wave condition operating on the breakwater. The location of the case study is the Universiti Malaysia Terengganu coastal protection which is facing South China Sea. When waves breach on the breakwater during the monsoon season, impact forces result in increased local pressure and dynamic loading. The wave characteristics of 5°, 15°, 35°, and 75° oblique waves were simulated to evaluate the impact of forces on the breakwater structure. The results illustrate the forces exerted on the breakwater by waves with varied characteristics, wave angles, and the occurrence of deformation-related phenomena. The simulation results show that as the oblique wave angle increases, the pressure force also increases simultaneously. The highest wave force acting on the breakwater is at the oblique wave angle of 75° with 5457.22 N and 105.76 kPa pressure.

1. Introduction

The waves contain enormous quantities of energy. A detached breakwater is usually needed to protect a port’s water area, wharf, and other structures from the direct effects of massive waves in the open sea. Wave energy is reduced by the breakwaters through three distinct mechanisms: wave reflection, fracturing, and vortex generation [1]. As port structures have improved in recent years,

* *Corresponding author.*
E-mail address: mohdamin@unikl.edu.my

https://doi.org/10.37934/arfmts.120.2.2938

favourable natural harbour conditions have been replaced by open seaport locations. Additionally, the construction of breakwaters has been limited by a severe hydrodynamic climate. Types of a breakwater are headland, detached, attached, nearshore, emerged, submerged, and floating breakwater. The type of breakwater that is widely applied so far to protect the beach and harbour pool is the rubble mound breakwater, both with natural and artificial stone [2,3]. It dissipates the incident wave energy by forcing them to break on a slope and it does not produce wave reflection. The advantages of rubble mound breakwater are (1) potential to accommodate small changes seabed or coastal. (2) potential to dissipate wave energy, thus reducing load on structure and tendency on scour. (3) low cost on construction, maintenance, and adaptation especially for structures in limited water depth. In this study, the objective of the research is to analyze the pressure or the impact of the oblique waves acting on the breakwater as recommended by Zhao *et al.,* [4] for further study. It also includes fundamental research on wave structure interaction and protection strategies from extreme sea states to improve structure credibility.

In comparison to solar and wind energy, wave energy is among the many forms of renewable energy that possess several advantages, including a greater density [5]. Wave energy is estimated to have a magnitude of 2-3 kW/m^2, wind energy of 0.4-0.6 kW/m^2, and solar energy of 0.1-0.2 kW/m^2 [6]. In contrast to the electricity consumption that was verified by Qiao *et al.,* [7] the wave energy resources are tremendous. Carbon dioxide (CO_2) emissions from wave energy generation are reportedly negligible in comparison to those of nonrenewable energy sources, being smaller than those emitted by solar energy generation and roughly equivalent to those emitted by wind energy generation [8]. Wave conditions can be forecasted far in advance. The projected inbound waves can be utilized to plan operations [9]. Wave energy converters (WEC) have the capability to generate electricity with a 90% success rate, in contrast to the 30% success rate of wind and solar energy converters, as mentioned by Sheng *et al.,* [10].

Recognized as a renewable marine energy source, wave energy has drawn interest due to its large reserve. However, the high cost of construction hinders the commercialization of wave energy production. By integrating wave energy devices with other coastal or offshore structures, cost sharing of infrastructures built for various purposes is a promising strategy for reducing the cost of marine renewable energy development [11]. Combining WEC with a floating breakwater is a potential strategy for commercializing wave power [12,13]. The sea wave slotcone generator (SSG) is a wave energy converter based on the overtopping concept integrated with breakwater [14]. Figure 1 shows the concept of SSG integrated with breakwater to absorb wave energy. As a wave runs up on the breakwater ramp, it will go through the chamber (slotcone) and pass through the turbine. Another integration concept is overtopping breakwater for wave energy conversion (OBREC) [15]. Figure 1 shows the concept of OBREC. The dissipation of wave breaking on the ramp through the chamber and rotates the turbine. Another method of absorbing wave energy by integrating with breakwater is oscillating water column (OWC). The wave will compress the air in the chamber then the high-pressure air will rotate the turbine.

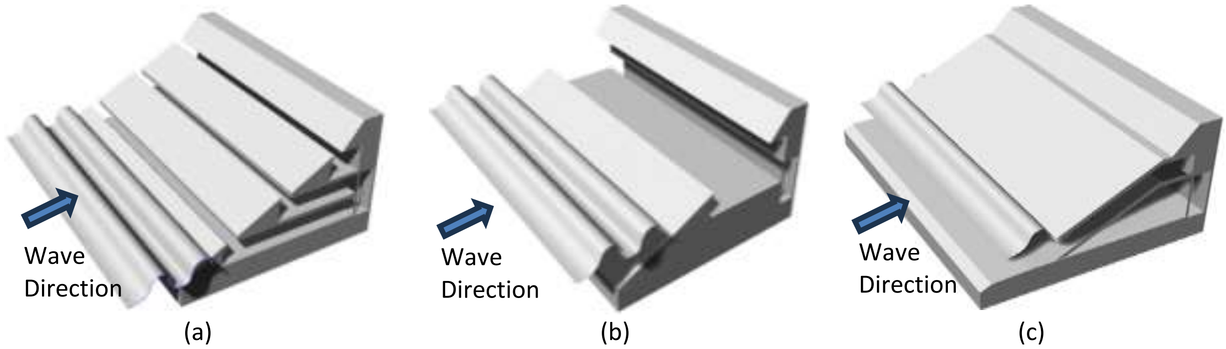

Fig. 1. (a) Sea wave Slot-cone Generator (SSG) (b) Overtopping Breakwater for Wave Energy Conversion (OBREC), (c) Oscillating Water column (OWC)

The quantity of wave overtopping on breakwater is highly subject to the angle of wave attack. Many studies have been done to understand the oblique waves behavior on breakwater. According to Han *et al.,* [16], the arc curvature exerted little influence on the maximal wave force in the previous sections. van Gent [17] proposed a guideline to account for the impact of oblique waves on wave overtopping at vertical caisson breakwaters with and without a recurved parapet. Jeya *et al.,* [18] presents the results of a comprehensive experimental investigation of the Quadrant Face Pile Supported Breakwater (QPSB) in two distinct water depths and three different oblique wave attacks. In the present study, a comprehensive descriptive parameter is sought to estimate forces acting on combining breakwater with wave energy.

During the monsoon season, the breakwaters may possibly be exposed to a significant amount of wave force. Therefore, the evaluation in terms of the wave force that makes contact on a breakwater becomes one of the essential parts in the design process. In principle, the force can be obtained by multiplying the pressure distribution to the surface area of a breakwater. According to previous studies, the magnitude of the wave force varies with the angle of oblique waves [19-21]. According to a new wave basin test, the stability of rubble mound breakwater generally increases with oblique waves [22]. This is because the influence of oblique waves varies depending on the wave angle and type of armour layer, and they significantly reduce the required armour size. The intensity of the waves force on the breakwater may be used as alternative energy by converting it into wave energy through wave energy converter system. According to Setyandito *et al.,* [23], the relative velocities which is the flow velocity during wave run up on slope surface increases with the height of the wave run. Wave energy will increase because of the increased discharge inside the perforated breakwater caused by this velocity increase. As a result, wave energy is generated at higher relative velocity.

The main challenge in the development wave energy converter in Malaysian seas is that the wave height is relatively low, where the average wave energy density of Malaysian sea facing the south China Sea is in the range of 1.41 kW/m to 7.92kW/m [24]. The limitation of wave height in Malaysian seas poses a research challenge for the utilize wave energy converter in this region. However, once marine renewable energy is established, the resident in remote island is practical to the most direct impact and it is achievable with abundant supports from government and private sectors it is worthwhile to research a more suitable form of wave energy converter in Malaysian seas [24,25]. Although Malaysia wave energy density relatively low, based on Lim *et al.,* [26] to capture the maximum amount of energy, efficient and dependable devices with a low significant wave height are required. A prior study by Kang *et al.,* [27] looked at the reaction of integration of breakwater and wave energy converter in Malaysian water and found that the power output techniques from the integration method might be improved even further in Malaysia water.

2. Methodology
2.1 Project Background

Figure 2 shows the coastal in Terengganu which is located at the Universiti Malaysia Terengganu (UMT). It was chosen due to its location as it faces the south China Sea which has a lot of energy potential for energy extraction and existing breakwater construction. There are three available breakwater structures at UMT beach. The length of the first breakwater, located at “A”, is approximately 258.33 meters. The length of the second breakwater “B” was 257.42 meters while the length of the third breakwater at “C” was approximately 165.63 meters. Its peak elevation is +6m, while the transition between the breakwater and the submerged terrain is 6 metres in height. For the purpose of the case study, breakwater "C" was chosen as a suitable position corresponding to the ideal place for energy extraction. When considering the direction of the wind, breakwater “C" offered improved accessibility and was positioned closer to allow the wind to blow straight against the breakwater construction, as compared to breakwaters “A” and “B.” Breakwater “A” and “B” were mainly for the protection of and shelter for the UMT coastline, as shown in Figure 2.

Fig. 2. Layout plan of the transition project

The structural section of breakwater "C" at the transition is illustrated in Figure 3. The rubble mound breakwater type consists of primary and secondary armor layers. The two-layer covered with rock and filled with 30 meters sand strengthen with high strength geotextile and supported with core material and bed down layer. The mean sea water level is perpendicular with the first armor layer which most of the wave force is focused while the second layer is to overcome the extreme weather which is during the monsoon season.

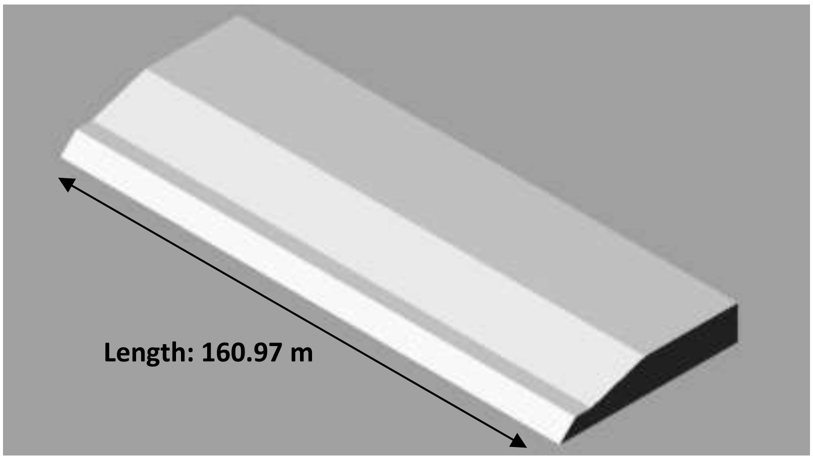

Fig. 3. Layout plan of the transition project

2.2 Model Design

Dimensions of geometric model scale is L_r 1:8.3; the time scale is $T_r = L_r^{1/2}$. The simulation dimension aligned with deepwater wave tank dimension. The wave tank size is 15m long, 10m wide, and 6 m depth. At maximal wave height, the wave-generating capacity is 0.5m and the wave period is between 0.02-4 seconds. The whole 160.97m breakwater was simulated with slope type armor with 18 degrees angle nearshore. Basis design of the breakwater "C" is shown in Figure 4 with scale of 1:8.3.

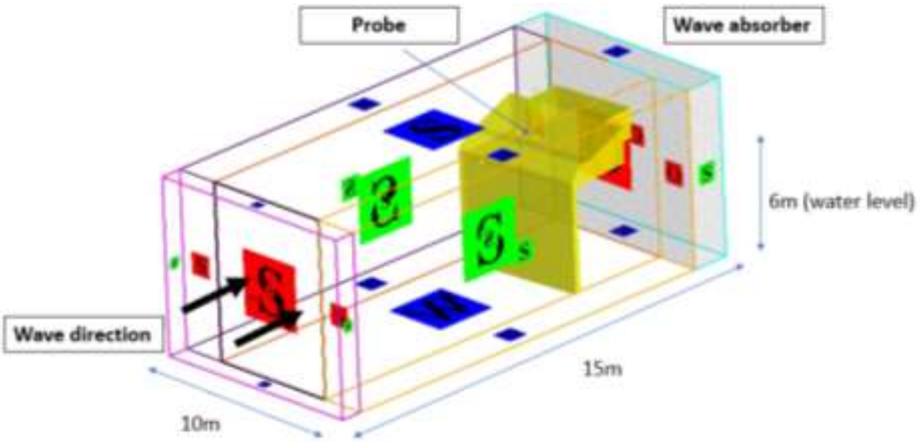

Fig. 4. Boundary condition setup in computational fluid dynamic software

2.3 Boundary Condition

Based on a model scale, the initial condition for the fluid in the computational domain was set to be at rest with the depth of 6 meters of water with 15 meters long, 10 meters wide and 7-meter depth. Then, each corner of the computing domain was given a boundary condition. The input domain was set to wave boundary type WV (wave direction) for the purpose of supporting the location of the generated wave in this research. The computing domain's boundary was then set to wall type W along the bottom. For along the side and top are denoted as S for symmetry. The outflow boundary type of the rear computational domain denoted by O, was specified. In addition, continuative boundary type C was applied to each nested mesh region. The purpose is to allow the solver to continually measure the wave interaction effect that occurs at different nested mesh areas.

Figure 5 shows the conclusive configuration of computational domain limits. The probe measures the wave force acting on a breakwater attached to the breakwater at mean water level. To justify the reflect of the influence of the wave force, a water level of 6.0 meter was selected for the simulation.

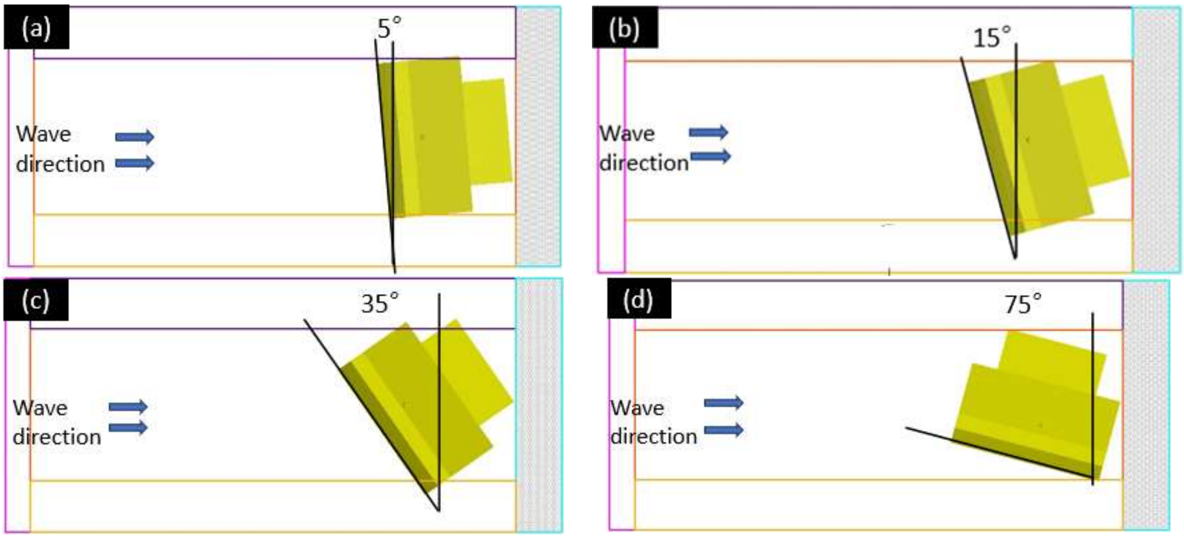

Fig. 5. (a) 5°angle, (b) 15°angle, (c) 35°angle, and 75°angle setup top view

2.4 Oblique Wave Angle and Wave Data

Figure 6 depicts the four angles 5°,15°,35°, and 75° that were selected between the wave incidence direction and the axis of the breakwater. The selection process takes into account the wave frequency distribution in the open sea and gives due consideration to the most unfavourable waves. As for wave simulation there is only one wave selected as the highest wave was recorded at this area. The wave height is Hs:0.3meter with wave period of Tp:3.1seconds.

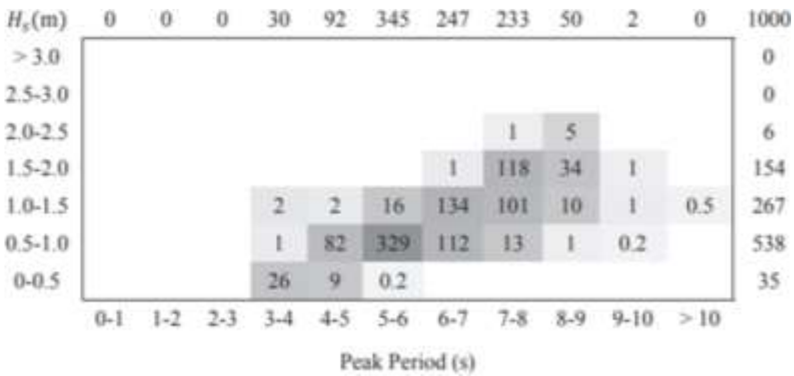

Fig. 6. Wave condition at UMT coastline [22]

3. Results

The simulation was carried out to investigate the impact of wave pressure on the breakwater subjected to multiangle oblique waves within 30 seconds timeframe. The simulation is being carried out using computational fluid dynamics software and the wave data shown in Figure 7, is the annual wave scatters diagram for Terengganu, Malaysia.

Scattered diagram above depicts the possibility of occurrence annually. The data was used to compute Terengganu's total yearly energy output at the conclusion of this study. The data were obtained from Yaakob 2016. Referring to the wave scatter diagram, the highest wave height Hw was recorded to 2.5 meter with period of Tp 8.5 seconds was assumed to be during monsoon season.

The wave pressure is measured by positioning the probe on the surface of breakwater at the water level. The pressure time series for various wave angles of 5°, 15°, 35° and 75° are shown in Figure 7. The Goda Eq. (1) is applied in this study to validate the pressure obtained. Based on the assumption of a trapezoidal pressure distribution, one of the most widely acknowledged techniques for computing wave forces on caissons was established by Goda (1974; 2010) (Figure 1(a)). The utmost pressure predicted by the formulae at the level of still water, P_1, is directly proportional to the wave height, H, and can be expressed as follows:

$$P_1 = \frac{1}{2}(1 + \cos\beta)(\alpha_1\lambda_1 + \alpha_2\lambda_2\cos^2\beta)\rho g h$$

where β is the angle of wave incidence, ρ is the density of the water, g is the acceleration due to gravity, λ_1 and λ_2 are modification factors for structure geometry, and α_1 and α_2 are wave pressure coefficients.

From pressure time series data in Figure 7, the maximum pressure is observed to occur at around T=10 s. This occurs during the third wave due to the combination of wave 1 and wave 2 that produced greater pressure resulting from the kinetic energy and momentum of the wave. The maximum value for each wave angle from the simulation and Goda Equation is represented in Table 1. The highest value of pressure obtained is 105.76 kPa which contributed to the maximum force of 5457.22 N at the 75° wave angle attacked. The study of the impact of wave force on the breakwater is essential to avoid structure failure and erosion on the coastline.

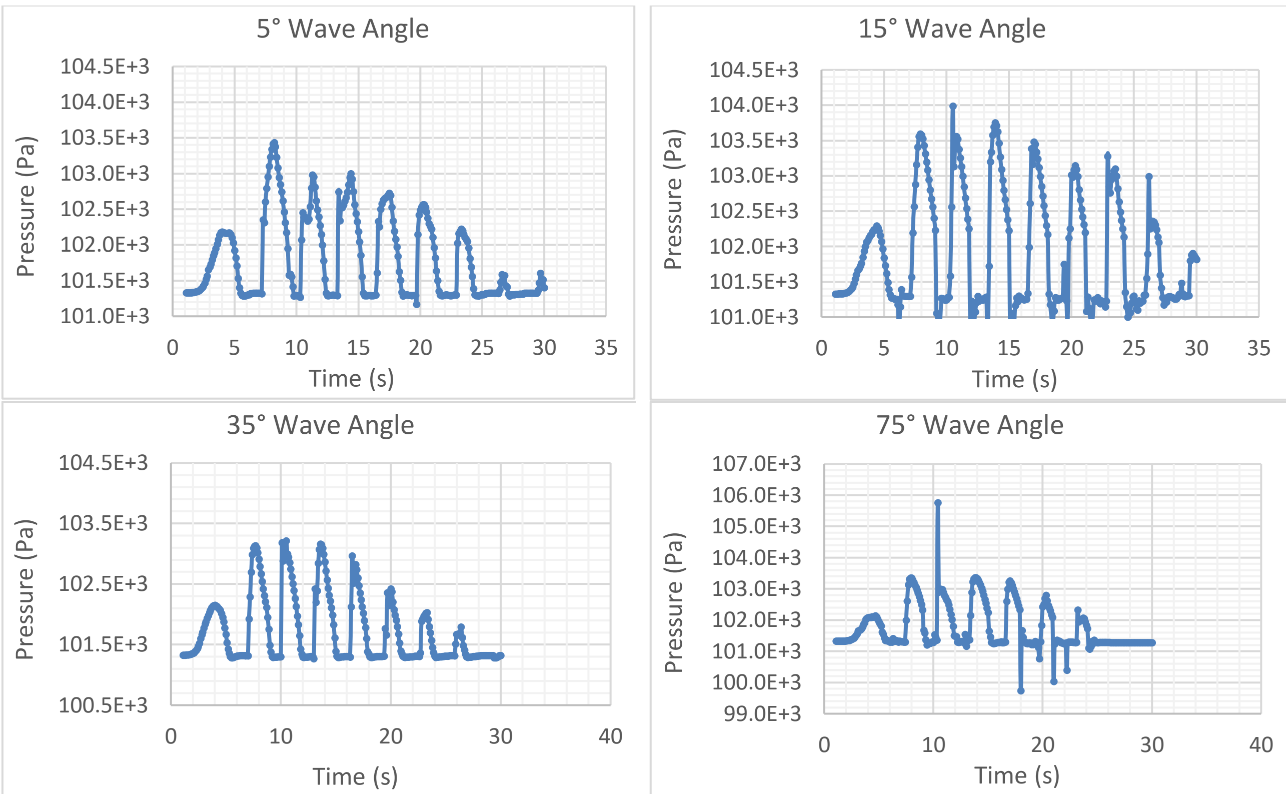

Fig. 7. Pressure versus time for all oblique waves

Table 1
The simulation and calculated values of maximum force and maximum pressure

Wave Angle	F_{max} (kN) (Simulation)	F_{max} (kN) (Calculated Value)
5°	15.39	15.16
15°	5.365	5.292
35°	2.334	2.829
75°	5.457	5.457
Pressure	P_{max}(kPa)	P_{max}(kPa)
5°	103.43	102.06
15°	103.98	102.56
35°	103.21	103.02
75°	105.76	105.76

4. Discussion

Based on the simulation results presented above, it is determined that the subsequent study conducted during the simulation should incorporate the following enhancements and additions: (1) This study only considered a singular dynamic condition of waves; however, natural conditions also involved the influence of tidal current, and at the breakwater transition, vortices and backflow were easily formed. (2) With respect to the impact of water level, a single water level was taken into account. Difference breaking forms and breaking positions of incidence of waves will result from the difference in water level. (3) In order to validate the simulation results, it recommended to conduct the experiment of model scale in wave tank in order to obtains more reasonable design value.

The simulation results were compared with Goda Equation, and it is observed that the experimental value is varies with calculated value by a factor of 1.00 to 1.01 times as shown in Figure 8 and Figure 9. The breakwater experiences the initial pressure of 101.3 kPa and this value remains regardless of the wave angles. Comparing the experimental values of pressure, the maximum pressure is consistent for all wave angle T=10 seconds. When the incident angle is 75°, the breakwater encounters the highest value of 105.76 kPa pressure. The experimental wave pressure is greater than the predicted Goda formula for different incident wave angle. Based on the calculated value, the angle of wave incidence is proportional to the wave pressure and wave force, as anticipated by the Goda formula.

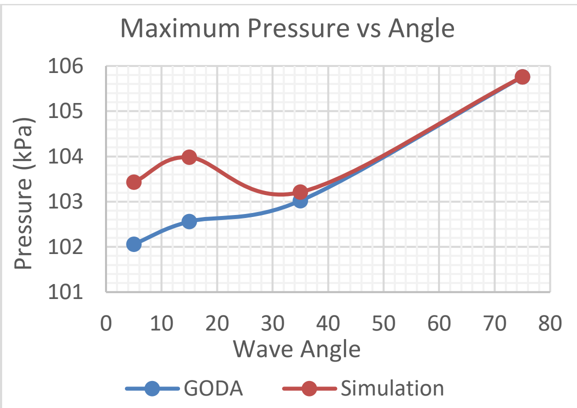

Fig. 8. Maximum pressure versus angle of attack

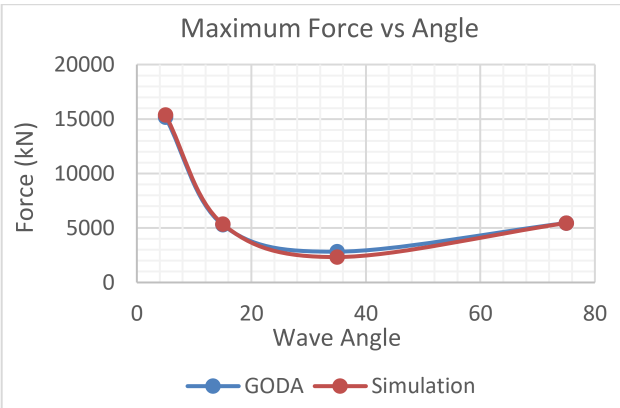

Fig. 9. Maximum force vs angle of attack

At the initial stage of breakwater design, the structural safety and physical model tests should be conducted at the greatest extent possible to validate more reasonable design values. Thus, the importance of knowing the maximum value of wave pressure and wave force is one of the main factors in designing the breakwater so that it can withstand this impact. Other than that, this input may also contribute to the design of wave energy converter device integrate with breakwater from the wave energy.

5. Conclusion

The impact of the wave force produced by the multiangle obliques wave on a breakwater has been studied using fluid dynamics computational software. The study was based on high wave conditions during the monsoon season at a coastal protection area facing the South China Sea. A model simulation with a scale of 1:8.3 was employed due to the limited number of research findings developed regarding the transition zone between stability and wave force, as well as the inherent difficulty in obtaining design parameters. Since the wave carries energy, it is expected to produce a high impact due to its pressure on the surface area of the breakwater. The multi-wave action of 5°, 15°, 35°, and 75° were simulated to determine the wave pressure and wave force and the value was then validated with the Goda Formula.

It can be concluded that the wave force acting on the breakwater was directly proportional to the incident wave direction angle. At the 75° wave angle, maximum pressure and maximum force are 105.16 kPa and 5457.22 N, respectively. Since these maximum values can be estimated, the information can be utilized to determine the type of materials that are appropriate for the breakwater's construction because these maximum values are estimable. This is a way of ensuring that the structure can sustain that kind of force. As previously indicated, this may also be advantageous for the integration of wave energy converter devices with breakwater construction.

Acknowledgment
The authors would like to express their gratitude and thanks to Universiti of Kuala Lumpur for funding this research under Short Term Research Grant (STRG) no. 21024.

References
[1] Alturfi, Uday Abdul Sahib M., and Abdul-Hassan K. Shukur. "Investigation of Energy Dissipation for Different Breakwater Based on Computational Fluid Dynamic Model." *CFD Letters* 16, no. 1 (2024): 22-42. https://doi.org/10.37934/cfdl.16.1.2242

[2] Temel, Ali, and Mustafa Dogan. "Time dependent investigation of the wave induced scour at the trunk section of a rubble mound breakwater." *Ocean Engineering* 221 (2021): 108564. https://doi.org/10.1016/j.oceaneng.2020.108564

[3] Kit, Andrew Yip Jun, Sunny Goh Eng Giap, and Mohammad Fadhli Ahmad. "Experimental Study on Wave Transmission Coefficient of Double Cylindrical Floating Breakwater in a Wave Basin." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 112, no. 2 (2023): 33-42. https://doi.org/10.37934/arfmts.112.2.3342

[4] Zhao, X. L., D. Z. Ning, Q. P. Zou, D. S. Qiao, and S. Q. Cai. "Hybrid floating breakwater-WEC system: A review." *Ocean Engineering* 186 (2019): 106126. https://doi.org/10.1016/j.oceaneng.2019.106126

[5] Prendergast, James, Mingfang Li, and Wanan Sheng. "A study on the effects of wave spectra on wave energy conversions." *IEEE Journal of Oceanic Engineering* 45, no. 1 (2018): 271-283. https://doi.org/10.1109/JOE.2018.2869636

[6] Wang, Lin, Athanasios Kolios, Lin Cui, and Qihu Sheng. "Flexible multibody dynamics modelling of point-absorber wave energy converters." *Renewable Energy* 127 (2018): 790-801. https://doi.org/10.1016/j.renene.2018.05.029

[7] Qiao, Dongsheng, Rizwan Haider, Jun Yan, Dezhi Ning, and Binbin Li. "Review of wave energy converter and design of mooring system." *Sustainability* 12, no. 19 (2020): 8251. https://doi.org/10.3390/su12198251

[8] Falcão, António F. O., and Joao C. C. Henriques. "Oscillating-water-column wave energy converters and air turbines: A review." *Renewable Energy* 85 (2016): 1391-1424. https://doi.org/10.1016/j.renene.2015.07.086

[9] Robertson, Bryson, Clayton Hiles, Ewelina Luczko, and Bradley Buckham. "Quantifying wave power and wave energy converter array production potential." *International Journal of Marine Energy* 14 (2016): 143-160. https://doi.org/10.1016/j.ijome.2015.10.001

[10] Sheng, Songwei, Kunlin Wang, Hongjun Lin, Yaqun Zhang, Yage You, Zhenpeng Wang, Aiju Chen, Jiaqiang Jiang, Wensheng Wang, and Yin Ye. "Model research and open sea tests of 100 kW wave energy convertor Sharp Eagle Wanshan." *Renewable Energy* 113 (2017): 587-595. https://doi.org/10.1016/j.renene.2017.06.019

[11] Tanaya, Toko, Nobuyuki Kinjo, Wataru Okada, Masato Yasuda, and Tomohiro Kuwae. "Improvement of the coral growth and cost-effectiveness of hybrid infrastructure by an innovative breakwater design in Naha Port, Okinawa, Japan." *Coastal Engineering Journal* 63, no. 3 (2021): 248-262. https://doi.org/10.1080/21664250.2021.1889823

[12] Zhang, Hengming, Binzhen Zhou, Jun Zang, Christopher Vogel, Peng Jin, and Dezhi Ning. "Optimization of a three-dimensional hybrid system combining a floating breakwater and a wave energy converter array." *Energy Conversion and Management* 247 (2021): 114717. https://doi.org/10.1016/j.enconman.2021.114717

[13] Cheng, Yong, Chen Xi, Saishuai Dai, Chunyan Ji, Maurizio Collu, Mingxin Li, Zhiming Yuan, and Atilla Incecik. "Wave energy extraction and hydroelastic response reduction of modular floating breakwaters as array wave energy converters integrated into a very large floating structure." *Applied Energy* 306 (2022): 117953. https://doi.org/10.1016/j.apenergy.2021.117953

[14] Buccino, Mariano, Daniela Salerno, and Mario Calabrese. "Structural response of seawave slotcone generators (SSG): Analysis of a nearshore device." In *ISOPE International Ocean and Polar Engineering Conference, pp. ISOPE-I*. ISOPE, 2018.

[15] Kralli, Vasiliki-Eleni, Nicolaos Theodossiou, and Theophanis Karambas. "Optimal design of Overtopping Breakwater for Energy Conversion (OBREC) Systems using the harmony search algorithm." *Frontiers in Energy Research* 7 (2019): 80. https://doi.org/10.3389/fenrg.2019.00080

[16] Han, Xinyu, Sheng Dong, and Yizhi Wang. "Interaction between oblique waves and arc-shaped breakwater: Wave action on the breakwater and wave transformation behind it." *Ocean Engineering* 234 (2021): 109252. https://doi.org/10.1016/j.oceaneng.2021.109252

[17] van Gent, Marcel R. A. "Influence of oblique wave attack on wave overtopping at caisson breakwaters with sea and swell conditions." *Coastal Engineering* 164 (2021): 103834. https://doi.org/10.1016/j.coastaleng.2020.103834

[18] Jeya, T. J. Jemi, V. Sriram, and V. Sundar. "Hydrodynamic characteristics of vertical and quadrant face pile supported breakwater under oblique waves." *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment* 236, no. 1 (2022): 62-73. https://doi.org/10.1177/14750902211031353

[19] Mares-Nasarre, Patricia, and Marcel R. A. van Gent. "Oblique wave attack on rubble mound breakwater crest walls of finite length." *Water* 12, no. 2 (2020): 353. https://doi.org/10.3390/w12020353

[20] Chang, Jen-Yi, and Chia-Cheng Tsai. "Wave forces on a partially reflecting wall by oblique Bragg scattering with porous breakwaters over uneven bottoms." *Journal of Marine Science and Engineering* 10, no. 3 (2022): 409. https://doi.org/10.3390/jmse10030409

[21] Martinelli, Luca, Piero Ruol, Chiara Favaretto, and Matteo Volpato. "Overtopping and stability of a rubble mound breakwater with Coreloc armour under oblique cyclonic waves." *Coastal Engineering Proceedings* 36 (2018): 9-9. https://doi.org/10.9753/icce.v36.structures.9

[22] van Gent, Marcel R. A. "Oblique wave attack on rubble mound breakwaters." *Coastal Engineering* 88 (2014): 43-54. https://doi.org/10.1016/j.coastaleng.2014.02.002

[23] Setyandito, Oki, Nizam Nizam, Andrew John Pierre, Gede Dharma Suputra, Yureana Wijayanti, and Martin Anda. "Numerical analysis of velocity magnitude on wave energy converter system in perforated breakwater." *International Journal of Renewable Energy Development* 11, no. 1 (2022): 27-33. https://doi.org/10.14710/ijred.2022.38535

[24] Yaakob, Omar, Farah Ellyza Hashim, Kamaludin Mohd Omar, Ami Hassan Md Din, and Kho King Koh. "Satellite-based wave data and wave energy resource assessment for South China Sea." *Renewable Energy* 88 (2016): 359-371. https://doi.org/10.1016/j.renene.2015.11.039

[25] Lim, Xin-Le, and Wei-Haur Lam. "Public acceptance of marine renewable energy in Malaysia." *Energy Policy* 65 (2014): 16-26. https://doi.org/10.1016/j.enpol.2013.09.053

[26] Lim, Xin-Le, Wei-Haur Lam, and Roslan Hashim. "Feasibility of marine renewable energy to the Feed-in Tariff system in Malaysia." *Renewable and Sustainable Energy Reviews* 49 (2015): 708-719. https://doi.org/10.1016/j.rser.2015.04.074

[27] Kang, Hooi Siang, Mohd Qisti Hakim Shaharuddin, Kee Quen Lee, Adelina Steven, Ummul Ghafir Md Arif, Nurhaslinda Khaliddin, and Chee Loon Siow. "Numerical analysis of point absorber for wave energy conversion in Malaysian seas." *Progress in Energy and Environment* 1 (2017): 25-39.