

Hydraulic Investigation of the H-type Floating Breakwater

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Abstract—Floating breakwaters are commonly used for wave protection of onshore and offshore facilities in the last decade. The majority of the floating breakwaters developed in the past are solid-type structures that have fixed drafts and may be highly reflective to the incoming waves. In this study, the H-type floating breakwater is proposed to serve as a wave attenuator instead of a wave reflector. The buoyancy of the breakwater is controlled by the placement of sandbags in the chamber embedded within the main body of the structure. The study aims to investigate the hydraulic properties of the H-type floating breakwater in random waves via a physical modeling. The hydraulic characteristics of the breakwater are quantified by the reflection and transmission coefficients as well as the energy dissipation coefficient. The experimental results have shown that the H-type floating breakwater is hydraulically efficient and provides high wave attenuation capability when subjected to short-period waves.

Keywords—floating breakwater; wave transmission; wave reflection; energy dissipation

I. INTRODUCTION

In recent years, the use of floating breakwaters for providing protection from wave disturbance has become prevalent in recreational harbours, marinas and fishing ports that do not require a high level of wave attenuation. For recreational harbours, coastal swimmers and surfers prefer to have acceptable wave condition to suit their sporting activities; and for marinas and fishing harbours, creation of complete still water conditions in the shelter regions may not be a necessity. Due to extensive application potentials in various sectors, floating breakwaters are still being one of the most studied structures in coastal engineering.

Floating breakwaters are essentially barriers afloat at the sea surface where the energy flux is maximal in intermediate waters. They permit water circulation and fish migration beneath the structures. The presence of floating breakwaters cause less interruption to nearshore sediment transports; hence, posing less impact to the adjacent shoreline and environment. Floating breakwaters intercept the incident waves mainly by reflection and energy loss mechanisms, and are found to be most effective when used at locations where wave conditions are less severe.

Various efforts have been made by different researchers to identify the most optimum floating breakwater design that is capable of providing the desired hydraulic performance, *i.e.* adequate wave attenuation. With respect to the geometrical effect of the breakwaters, McCartney [1] classified them into four types namely box-, pontoon-, mat-, and tethered float-types. The box- and pontoon- types are generally good wave reflectors; whilst the mat- and tethered float-types are efficient energy dissipaters. Effort has been made to increase the hydraulic performance of the box-type floating breakwaters by incorporating supplementary parts to the rectangular bodies, *e.g.* installation of wave-wall at the seaward side of the breakwater [2], keel and porous plate attachment at the bottom of the breakwater [3,4] as well as insertion of pneumatic chambers between the rectangular floating blocks [5].

The mat-type floating breakwaters are relatively smaller than the box-type and are formed by interlace of scrapped tires, logs and more recently floating pipes [6] and pre-fabricated blocks [7]. The wave suppression ability of these breakwaters primarily depends on the surface area coverage and the configurations. Floating breakwaters that are made of a single or multiple plates are widely studied by researchers due to their simplicity in design and cost effectiveness [8,9,10]. The plate-type floating breakwater can also be used to retard the current velocity by attachment of polyethylene nets at close intervals beneath the plate [11]. Some other innovative floating breakwaters with exclusive features are the Y-frame floating breakwater [12], cylindrical floating breakwater [13], sloping floating breakwater [14] and semicircular floating breakwater [15].

Wave reflection around the man-made structures is one of the key concerns in the design of ports and harbours. Excessive wave activity resulted from reflected waves in front of the breakwater is often undesirable as it may pose navigation hazard to the small floating vessels and scouring problems at the bottom. The majority of the abovementioned floating breakwaters suppress waves mainly by reflection; hence, they may not be suitable to provide wave protection at the sensitive sites. Therefore, this present study explores the development of a good anti-reflection floating breakwater.

II. THE H-TYPE FLOATING BREAKWATER

In this research, the H-shape floating breakwater was developed. Figure 1 shows the schematic view of the floating breakwater. The breakwater model was made of marine plywood and subsequently coated with fiberglass for greater durability and water-proof ability. The breakwater model has dimensions of 1.00 m width, 1.44 m length and 0.5 m height. The two ‘arms’ at the top of the main body is created to facilitate wave breaking at the structure; whereas the two ‘legs’ at the bottom is to enhance the weight of the breakwater barrier against wave actions. As breakwater immersion depth is an important parameter controlling the hydrodynamic performance of the floating breakwater, a ballast chamber located within the breakwater body, as shown in Fig. 1, has been designed for adjustment of buoyancy or immersion depth of the breakwater with respect to still water level. A 2 x 9 matrix wooden grid system was developed for the placement of sandbags for weight control of the breakwater. The ballast chamber was covered by transparent lid made of Plexiglas. The gap between the breakwater body and the transparent lid was tightly sealed by adhesive tapes so as to prevent the seepage of water to the ballast chamber.

Since a new feature of the floating breakwater has been proposed in this study, this research is undertaken to identify the hydraulic characteristics of the breakwater when subjected to irregular waves in a wave flume.

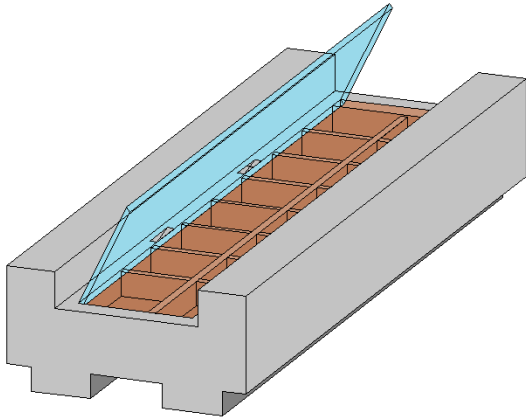


Fig. 1. The H-type floating breakwater – Test model

III. EXPERIMENTAL SET-UP AND PROGRAM

The laboratory tests were conducted in a 25 m long, 1.5 m wide and 1.5 m deep wave flume in the Offshore Engineering Laboratory of Universiti Teknologi PETRONAS, Malaysia. The walls of the wave flume were constructed using reinforced concrete and three panels of Plexiglass embedded at each side wall to ease the observations and monitoring of the experiments. The flap-type, active absorption wave generator developed by Edinburgh Design Ltd, UK was capable of generating both regular and random waves. At the down wave

end of the flume, passive wave absorbing ‘beaches’ were installed to reduce the reflection of incident waves from the end wall of the wave flume during the experiment. The test model was anchored to the flume bed by a 4-taut leg mooring configuration. Six resistance-type wave probes were used to record the water surface elevation at different locations in the flume as shown in Fig. 2. Three wave probes were placed at the front of the test model for the measurement of incident and reflected waves induced by the breakwater. The other three probes were stationed at the lee of the test model for to record the transmitted and reflected waves from the wave absorber. Decomposition of wave components from wave series was conducted by the 3-point method [16]. These probes were carefully calibrated regularly before and after the experiments to avoid measurement errors.

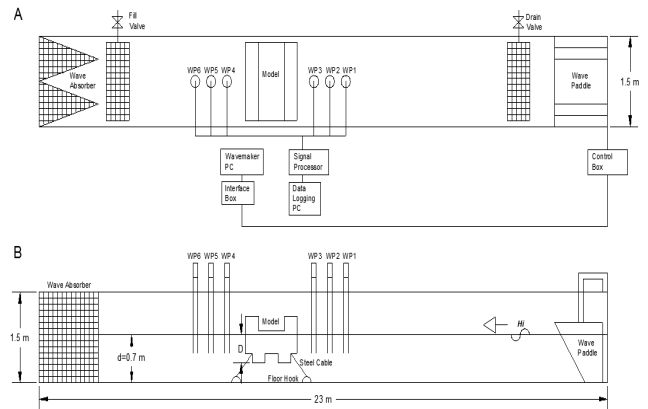


Fig. 2. Laboratory set-up: Plan view (top) and side view (bottom)

The model was tested in a water depth of 0.7 m subjected to random waves described by JONSWAP spectrum with a peak enhancement factor of 3.3. The test model was immersed at depths of 0.08, 0.12 and 0.16 m from still water level, which corresponded to the breakwater draft-to-water depth ratio D/d of 0.114, 0.171 and 0.228, respectively. The model was tested in waves with peak period ranging from 0.8 to 1.4 s with an interval of 0.2 s, and wave steepness H_{m0}/L_p of 0.04, 0.06 and 0.07 (for short-period waves) for each wave period.

IV. RESULTS AND DISCUSSION

Series of experiments were rigorously conducted in the wave flume to study the wave characteristics of the H-type floating breakwater against random waves. Fig. 3 presents the energy density spectra of an incident, reflected and transmitted waves for one of the test cases where the test parameters are $T_p = 1.0$ s, $H_{m0}/L_p = 0.04$ and $D/d = 0.228$. It is apparent from Fig. 3(a) that reflected wave energy (SZI) is much less than the incident wave energy (SZR) in front of the test model even though it is deeply immersed in water. Whereas, the reflected energy at the lee side of the test model, as shown in Fig. 3(b) is almost negligible due to the high efficiency of the wave absorber placed at the end of the flume in dissipating the energy of the incoming waves. In comparison with the incident wave energy in front of the model (see SZI in Fig. 3(a)), the

energy of the transmitted waves behind the model is approximately seven times smaller. Hence, the above test results show that the H-type floating breakwater is an efficient wave attenuator and a good anti-reflection structure when deeply immersed in water. This finding is to be verified by the outcomes of other tests conducted in different test environments. The overall hydraulic performance of the H-type floating breakwater is discussed in the following section.

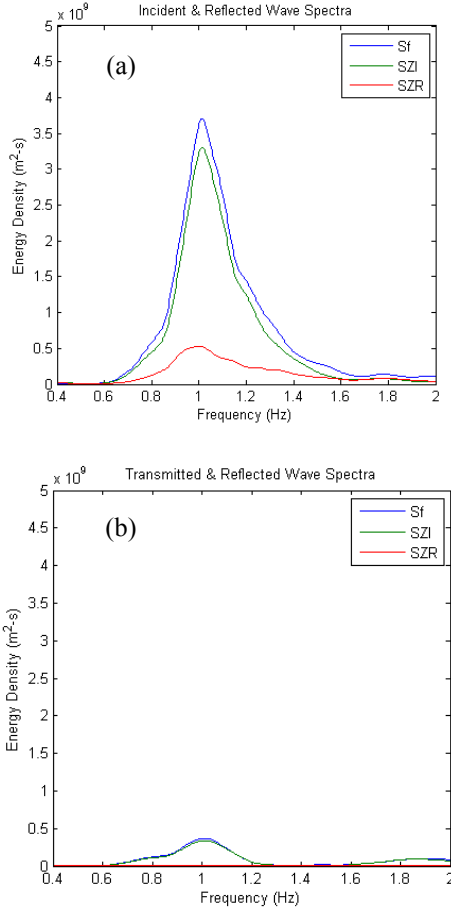


Fig. 3. Energy density spectra for incident, reflected and transmitted waves of $T_p = 1.0$ s, $H_{m0,r}/L_p = 0.04$ and $D/d = 0.228$: Wave measurement (a) at the front and (b) at the leeward side of the test model.

Hydraulic performance of floating breakwaters is commonly evaluated by energy coefficients, which comprises transmission coefficient (C_T), reflection coefficient (C_R) and energy dissipation coefficient (C_L^2):

$$C_T = \frac{H_{m0,t}}{H_{m0,i}} \quad (1)$$

$$C_R = \frac{H_{m0,r}}{H_{m0,i}} \quad (2)$$

$$C_L^2 = 1 - C_T^2 - C_R^2 = \frac{E_L}{E_i} \quad (3)$$

where $H_{m0,i}$, $H_{m0,r}$ and $H_{m0,t}$ are the incident, reflected and transmitted zeroth spectral moment wave heights, respectively. Note that the energy dissipation coefficient, which is mathematically derived as in (3), can also be represented in the form of energy, where E_i is the total energy of incident waves, E_L is the energy dissipated at the breakwater. Detailed derivations of the above energy coefficients are presented by Teh et al. [15].

A. Wave Transmission Coefficient

The wave energy coefficients C_T , C_R and C_L are plotted against the breakwater width B/L where B and L are the breakwater width and the wavelength corresponding to T_p , respectively. The geometrical ratio of B/L is a well accepted dimensionless parameter used in the design of coastal engineering structures. Since B is fixed in this study and the fact that L is the only independent variable that is governed by the change of wave period or wave frequency, the B/L is often termed as the relative wave period or the relative wave length.

Fig. 4 displays the C_T of the H-type floating breakwater subjected to breakwater immersion depth ratios of $D/d = 0.114$, 0.171 and 0.229 in random waves of steepness tested ranges from 0.04 – 0.07. The C_T data show a maximum value of about 0.6, indicating that at least 40% attenuation of incident wave height would be anticipated for the H-type floating breakwater of $0.11 < D/d < 0.23$. Maximum wave suppression happens when the breakwater of $B/L = 0.5$ immersed at $D/d = 0.23$ is capable of dampening the incident wave height up to 70%. The figure also demonstrates a decrease of C_T with an increase in B/L , signifying that the breakwater restricts wave transmission more effectively in seas dominated by shorter period waves. The variation of C_T with respect to D/d is found to be remarkable, i.e. lower C_T values attained as D/d increases. In short, the H-type floating breakwater performs reasonably well as a wave attenuator when deeply immersed in water or/and adopted in wind-generated seas which are dominated by short period waves.

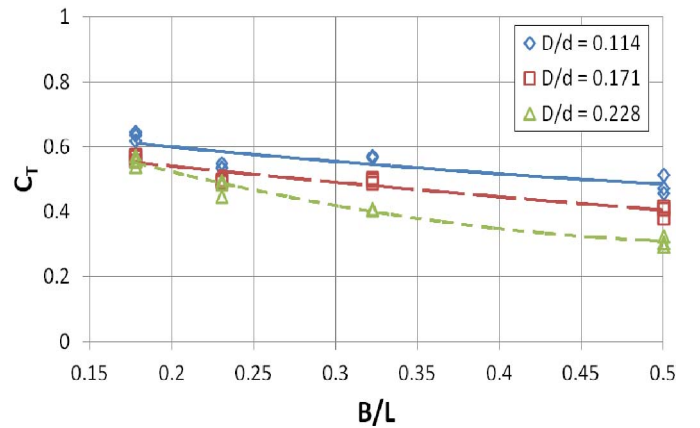


Fig. 4. Wave transmission coefficient C_T .

B. Wave Reflection Coefficient

Wave reflection performance of the H-type floating breakwater is quantified by the wave reflection coefficient, C_R . The higher the C_R values, the greater will be the wave reflection effect. Fig. 5 presents the relationship between C_R and B/L for the breakwater model in random waves. The general trend of the plots shows that the C_R plots of $D/d = 0.114$, 0.171 and 0.228 increase with the increasing B/L . This implies that the H-type floating breakwater becomes more reflective in shorter period waves. This finding is sensible as waves of shorter period are relatively small in length and the energies are largely intercepted by the frontal surface of the breakwater.

As $B/L > 0.3$, it is surprising to notice that the C_R of $D/d = 0.1714$ strike the highest values ($C_R = 0.5$). This is principally attributed to the fact that the breakwater immersed at $D/d = 0.1714$ provides the largest effective freeboard and draft for wave interception, resulting in high wave reflection. The C_R of higher relative breakwater draft ($D/d = 0.2286$) achieves the highest value at about 0.45 . This observation is sensible because the shallow freeboard of the breakwater permits more waves overtopping to take place at the upper column of the water, which in turn reduces the amount of wave reflection. As expected, the breakwater with shallow draft ($D/d = 0.1143$) provides the least C_R (about 0.3) due to the allowance of transmission of large amount of wave energy beneath the breakwater. The highest C_R value achieved by the breakwater is approximately 0.5 at $D/d = 0.171$. The C_R value, which is equivalent to 25% of the incident wave energy get reflected by the breakwater, is deemed to be relatively small as compared to the reflection caused by the conventional bottom-seated breakwaters as well as by some of the solid-type floating breakwaters [17].

The immersion depth of the breakwater is another important affecting influence to C_R of the H-type floating breakwater. It is surprising to notice that the C_R of $D/d = 0.171$ offers the highest values for the entire test range of B/L . This is principally attributed to the fact that the breakwater immersed at $D/d = 0.1714$ provides the largest effective freeboard and draft for wave interception and reflection. The C_R of higher relative breakwater draft ($D/d = 0.228$) achieves the highest value at about 0.45 . This observation is sensible because the shallow freeboard of the breakwater permits more overtopping waves to take place above the structure, which in turn reduces the amount of wave reflection. On another hand, the breakwater of a shallow draft ($D/d = 0.114$) provides the least C_R value at about 0.3 due to transmission of large amount of wave energy beneath the breakwater without much interception to take place.

In short, based on the experimental results the H-type floating breakwater can be regarded as a good anti-reflection structure and may be considered suitable to be adopted at sites where rough wave climate in front of the breakwater is undesirable.

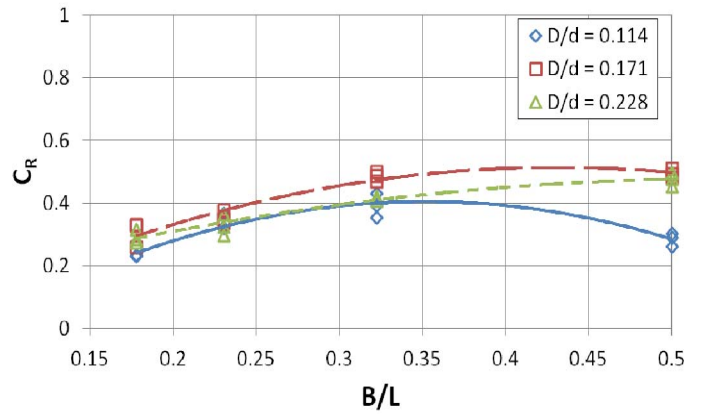
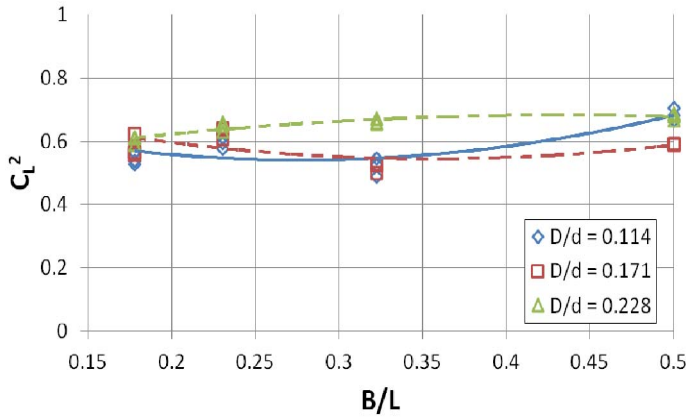


Fig. 5. Wave transmission coefficient C_R .

C. Energy Dissipation Coefficient

Wave energy dissipation of the H-type floating breakwater is measured by the energy dissipation coefficient, C_L^2 . As mentioned earlier, C_L^2 indicates amount of energy loss compared to the total energy of the incident waves. The higher the C_L^2 values, the greater will be the energy loss triggered by the H-type floating breakwater. Based on the observation during the experiments, some of the dominant mechanisms that trigger energy loss to the wave system were identified. These include wave breaking, wave run-up and run down, formation of eddies underneath the test model, and generation of sound and heat. Since these hydraulic processes are difficult to be measured physically, the loss of energy due to a breakwater is often quantified using (3) derived based on the Principle of Conservation of Energy.

Fig. 6 presents the C_L^2 of the H-type floating breakwater at $D/d = 0.114$, 0.171 and 0.228 . It is seen from the figure that the C_L^2 of the test models do not seem to be much affected by B/L . Approximately 10% of enhancement of energy loss at the floating breakwater would be anticipated as B/L increases from 0.18 to 0.50 . This signifies that the amount of lost energy at the breakwater is less dependent upon wave period; hence, it may not be economically viable to enhance the energy dissipation performance of the H-type floating breakwater by increasing the width of the structure. Considering C_L values achieved by the test model at different immersion depths ($0.7 < C_L < 0.5$), the H-type floating breakwater is proven to be an effective wave dissipater, particularly when it is deeply immersed in water.



V. CONCLUSIONS

Series of experiments were rigorously conducted in the wave flume to study the hydraulic characteristics of the H-type floating breakwater in random waves. The following conclusions were reached within the limitations of the test program:

- The ranges of energy coefficients of the H-type floating breakwater are presented in Table 1.
- Wave transmission of the breakwater can be limited by (i) increasing the width of the breakwater, B , (ii) installation at sites exposed to shorter period waves, and (iii) increasing the draft of the breakwater, D .
- Wave reflection becomes more dominant when the breakwater is subjected to shorter period waves.
- Breakwater of deeper immersion depth induces more energy loss to the incident wave during wave-structure interactions.
- The H-type floating breakwater is an effective wave attenuator, a good anti-reflection structure and a efficient energy dissipater.

Table 1: Ranges of C_T , C_R and C_L^2 at $D/d = 0.114, 0.171$ and 0.228 .

D/d	0.113	0.171	0.228
C_T	0.45 – 0.64	0.38– 0.57	0.29– 0.57
C_R	0.23 – 0.43	0.25– 0.51	0.27– 0.49
C_L^2	0.49 – 0.70	0.50– 0.64	0.58– 0.68

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