

Hydrodynamic performance of cylindrical floating breakwater in waves

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ABSTRACT

Attenuating waves by simple prismatic structures are increasingly recognised for coastal protection. Yet, evaluating their performance as good attenuators inevitably requires a reliable approach to adequately capture the dynamic interaction between waves and structure. This paper presents a prediction on hydrodynamic properties of pile-restrained cylindrical floating breakwater using computational fluid dynamics (CFD) approach. Several parameters for the effects of relative width (W/L) and relative draft (d/H) of the floating breakwater on the coefficient of transmission, reflection, and energy dissipation have been simulated using Flow3D. A wave boundary is assigned to give an insight into the regular and random wave effects to the parameters used in the simulation. The result revealed that the wave absorbing effect of CFB is apparently good, especially in high regular waves that considerably suppress the wave transmission. The higher energy dissipation than reflection characteristics suggests that the breakwater behaves effective as wave dissipator, especially for short waves. This attributed to the stiffness effect and in-plane damping across the vertical cage. From the practical views, the installation of the breakwater system into floating bridge or docks with limited rolls is satisfactory for perimeter protection specifically in the coastal zone of peninsular Malaysia.

Keywords: Coastal protection; wave attenuation; cylindrical floating breakwater; computational fluid dynamics.

INTRODUCTION

Floating breakwaters are engineering structures commonly used as wave attenuators for coastal facilities. The ability of the structures to cope with sea level rise and increasing storminess makes them a smart solution for shoreline protection alternative to hard approaches such as armouring and traditional breakwaters. Their utilisation is enhanced by the existence of specific environmental design parameters, such as poor foundation and/or deep water conditions, water circulation and/or aesthetic considerations [1], as well as by their multiple advantages, for example, reduced environmental impact, transportation simplicity, relocation potential, flexibility for future extensions, relatively short duration of installation, "inherently base isolated" characteristic, existence of reduced requirements for foundation and lower construction cost for large water depths and soft bed scenarios [2]. Owing to this, floating breakwaters are given more attention among researchers in the area of coastal and harbour research. Recently, there has been an increasing interest in simple structures like pontoons or cylindrical floating breakwaters

(CFB) [3-5]. Among the advantages of using these inflatable breakwaters include the flexibility for either temporary or permanent use, transportability, cost-effectiveness, or ease of construction and installation. Meanwhile, the versatility of these structures is increasingly recognised, especially for marine culture renders it favourable and economical. Some specific studies in this type of the breakwater involve several parametric studies that mostly using linear/non-linear two-dimensional (2D) analyses or small-scale facilities [5-8]. The results showed that the transmission and reflection characteristics of a floating breakwater system are a function of complex design parameters between the structural configurations and waves. The wave transmission is generally decreased with increasing relative width and draft of the breakwater while unusually increased under large response of the structure.

Despite numerous studies and promising results by many authors, unsatisfactory wave attenuating effect of the floating breakwater in long waves make them remain a topic of studies by many researchers. In this regard, many cost-effective floating breakwaters have been introduced to manipulate its relative width and draft specifically to attenuate up- and down waves [3, 9-11]. Several hydrodynamic parameters were properly investigated while most studies have been in small-scale facilities for a regular wave condition and, this mainly targeted to obtain transmission coefficient below than 0.5. Since the efficiency of pontoons/cylindrical floating breakwaters is a function of complex design parameters between waves and structures, the current technology is still very limited and yet the presented approaches by authors seem inadequate particularly to capture the nonlinear dynamic phenomena of the moving structure. This is critical in most of the real problems of random wave encountered so that the complicated flow and turbulence patterns, as well as the force fields induced by different wave attacks, can be accurately predicted while not ignoring large motions of the breakwater. Therefore, this paper presents a prediction on hydrodynamic performance of cylindrical floating breakwater (CFB) under irregular and regular wave forcing via computational fluid dynamics (CFD) approach [12-14]. The numerical study focuses on transmission, reflection and dissipation coefficients and motion response of the breakwater. In this innovative procedure, the CFB model is properly developed in CAD and then integrated with CFD techniques using appropriate model set-ups. The simulations work by integrating the equation of motions for fluid-structure problem in three-dimensional (3D) analyses rather than making use of the simple linear 2D approach. The structure is thus, modelled very much like in the real world or in the physical laboratory testing, by constructing and organising individual three- dimensional elements and the computational grid is fitted so as to provide enough computational nodes within the flow paths. The motion response of the structure is only described in heave degree of freedom (DOF) mimicking like a pile-restrained floating breakwater [15, 16]. Several wave parameters are specifically associated with sea state condition of Peninsular Malaysia background by the South China Sea has been considered in the present study.

METHODS AND MATERIALS

CFD MODELING

For the purpose of the present study, the Flow-3D solution was applied to describe the fluid and solid dynamics. Basically, the solver is based on RANS (Reynolds Averaged Navier-Stokes) equations that use an approach to solve the equation of fluid flow that is uniquely well-suited for free surface hydraulics problems. The solution of the equation of motions of fluid flow for control volume was carried out on a staggered and structured

finite difference grid. Upon solving, the scalar quantities, such as temperature and pressure were computed at cell centres while vector and tensor quantities were computed at cell faces. In fact, this approach provides a very stable and convenient way of computing derivatives. For fluid interface advection through the computational grid, the RANS equations were combined with the Volume of the Fluid method (TruVOFTM) to track the location of the true fluid surfaces. The viscosity and turbulence options were also activated with Newtonian viscosity being applied to the flow along with the selection of an appropriate turbulence model. Once the Flow-3D digital model was completely prepared, some selected simulations were performed with different activated turbulence models.

Regular Wave Theory

Based on the Airy's linear wave theory and assumptions, the regular wave equation for the free surface elevation $\eta(x,t)$, the velocity potential $\varphi(x,z,t)$, and velocity components in x and z directions u(x,z,t) and w(x,z,t) are rewritten as [17],

$$\eta = A\cos(kx - \omega t + \phi) \tag{1}$$

$$\varphi(x, z, t) = xU + \frac{A\omega \cosh[k(z+h)]\sin(kx - \omega t + \phi)}{k \sinh kh}$$
(2)

$$u(x, z, t) = U + \frac{A\omega \cosh[k(z+h)]\cos(kx - \omega t + \phi)}{\sinh kh}$$
(3)

$$\mathfrak{w}(x,z,t) = \frac{A\omega \sinh[k(z+h)]\sin(kx-\omega t+\phi)}{\sinh kh}$$
(4)

where ω is the angular frequency, k is the wave number and ϕ is the phase shift angle. The dispersion equation in terms of wave speed $c = \omega/k$ is given by

$$(c-U)^2 = \frac{g}{k} \tanh kh \tag{5}$$

Random Wave

The results for an irregular wave climate on the ocean surface can be interpreted by using a wave spectra model. A commonly used spectrum in oceanographic work is the Pierson-Moskowitz (P-M) spectrum [2, 17],

$$S(\omega) = \frac{\alpha g^2}{\omega^5 \exp[-\beta (g/U\omega)^4]}$$
(6)

where g is gravitational acceleration, ω is wave circular frequency $\lim_{s \in P} \operatorname{and} U$ is wind velocity at the standard height of 19.5 meters above sea level. The peak frequency of the spectrum described by equation (13) is

$$\omega_p = \left(\frac{4\beta}{5}\right)^{0.25} \left(\frac{g}{U}\right) \tag{7}$$

from which the windspeed can be obtained corresponding to that peak frequency. It is shown that the wave spectrum, $S(\omega)$ can be converted to a line spectrum of wave height as

$$H_i = 2[2S(\omega_i)(2\pi\Delta f_i)]^{0.5}$$
(8)

where, Δf_i is the frequency bandwidth corresponding to the spectral estimate $S(\omega_i)$ centred at ω_i .

Turbulence Model

In free-surface flow studies particularly involving large waves like breakwaters and ship models, the flows are highly turbulent, which is why accurate turbulent modelling is important. In the simulation, the turbulence model based on Group (RNG) methods has been used for all simulation since it accounts for low Reynolds number effects [18-20] and is the most accurate and robust model available in the software that could simulate the best real-world problems[17]. Basically, this approach applies statistical methods to the derivation of the averaged equations for turbulence quantities, such as turbulent kinetic energy and its dissipation rate; in addition, to explicitly derive the equation constants in the model. The two transport equations for the turbulent kinetic energy k_T and its dissipation ε_T are rewritten as:

$$\frac{\partial k_T}{\partial_t} + \frac{1}{v_f} \left\{ u A_x \frac{\partial k_T}{\partial_x} + v A_y \frac{\partial k_T}{\partial_y} + \mathfrak{w} A_z \frac{\partial k_T}{\partial_z} \right\} = P_t + G_t + \text{Diff}_{kt} - \varepsilon_T \text{ Eq.}$$
(9)

$$\frac{\partial \varepsilon_T}{\partial_t} + \frac{1}{v_f} \left\{ u A_x \frac{\partial \varepsilon_T}{\partial_x} + v A_y \frac{\partial \varepsilon_T}{\partial_y} + \mathfrak{w} A_z \frac{\partial \varepsilon_T}{\partial_z} \right\} = \frac{CDIS1 \cdot \varepsilon_T}{k_T} \left(P_t + CDIS1 \cdot G_t \right) + \text{Diff}_{\varepsilon} - CDIS2 \frac{\varepsilon_T^2}{k_T}$$
(10)

where, P_t is the turbulent kinetic energy production, G_t is the buoyancy production term whereas Diff_{kt} represents the diffusion term of kinetic energy. For the additional transport equation in Eq. (5), the CDIS1, CDIS2, and CDIS3 are all dimensionless parameters for the model and $\text{Diff}_{\varepsilon}$ is the diffusion of dissipation.



Figure 1. Boundary condition in the computational domain.

Computation Domain and Meshing Generation

Prior to simulation, a numerical wave flume was deliberately built in FLOW-3D's geometry model. In addition, the geometry of the floating structure was drawn in CATIA (Computer-Aided Three-dimensional Interactive) and exported in a stereolithographic (STL) format. The STL images were then directly imported into Flow-3D to create a complete digital model where the appropriate mesh could be generated. Mesh and cell size are critically important that need to be applied appropriately as they can affect both

the accuracy of the results and the simulation runtime/memory. Thus, for the present wave-structure problem, the multi-block gridding was properly considered in the simulations in such a way that the nested blocks were embedded within containing block to locally increase the meshing resolution[21, 22]. By this technique, the cell count can be greatly reduced while maintaining resolution in order to capture the important features of the geometry as well as sufficient flow details. Using appropriate set-up, the effective domains for this CFD simulation in intermediate or infinite water depth are successfully employed and depicted as in Figure 1.

| Description | Distance with respect to origin point | Туре | Condition |
|------------------|---------------------------------------|----------|-----------|
| X _{min} | 12.0 <i>d</i> | Wave | Far field |
| X_{max} | 12.0 <i>d</i> | Outflow | Far field |
| Z_{min} | 1.00 <i>d</i> | Symmetry | Far field |
| Z_{max} | 0.60 <i>d</i> | Symmetry | Far field |
| Y_{min} | 0.40 d | Symmetry | Far field |
| Y_{max} | 0.40 <i>d</i> | Symmetry | Far field |

Table 1. Computational domain and boundary setting conditions.

Referring to Table 1, the wave boundary condition is assigned for the upstream while the outflow boundary condition for the downstream and symmetrical type for all other open boundaries is to minimise the effects of friction loss and surface tension. Here, the random and linear wave theories have been used in the solution corresponding to simulation parameters. In this mode, the wavemaker generates wave attacks into the computational domain according to the wave theories and basically requires input parameter as wind speed, w_s and wave amplitudes (A_w) with wave periods (T) for random and regular waves. The meshing generation of the cylindrical floating breakwater model was created in FLOW-3D software. The suitable mesh element for the domain discretisation was properly examined in order to maintain numerical accuracy and steadiness in the computational results regardless of longer CPU time. In a mesh independent study, five different total numbers of cell meshing in computational domain ranging from 300,000 to 6,000,000 were applied to one of the validation test conditions (d/H = 2.0500, W/L = 0.3209). The simulation was carried out up to t = 40 s with a sampling frequency of 20 Hz and the free surface elevations were predicted recurrently until finish time. Using the essential hydraulic data, the coefficients of transmission, K_t , reflection (K_r) and energy dissipation, (K_d) were properly determined in post-analysis.

Table 2. Mesh independent study on cylindrical floating breakwater (CFB) model.

| Case | Mesh type | Total number of cell meshing | K _t |
|------|------------|------------------------------|----------------|
| А | Hexahedral | 196608 | 0.796 |
| В | Hexahedral | 384000 | 0.565 |
| С | Hexahedral | 1572864 | 0.424 |
| D | Hexahedral | 3072000 | 0.415 |
| E | Hexahedral | 600000 | 0.420 |

The results of mesh independent study are depicted in Table 2. Overall, it shows that the result was converged to a specific coefficient as the total cells were increased and therefore the total cells of 1.5 million were adopted for the rest of the simulations since

further increments up to 3 or 6 millions of total cells were unnecessary on account of their insignificant influence into the computational results of K_t . Additionally, the Flow-3D solution includes a distinguishing routine using FAVORTM technique to realistically embed geometries and boundaries in the orthogonal meshes. The output geometry called FAVORed geometry would conveniently facilitate in judging on the adequacy of the chosen computational meshes as well as the resolution of the virtual model.

Parametric Study

Coefficient of Transmission, Reflection, and Dissipation

Different from traditional breakwaters, the wave attenuating mechanism of floating breakwater is perceived as either to reflect, dissipate or transmit the wave to leeside of the structure or the combinations of each (see Figure 2). Hence, the general performance of the structure can be evaluated via determination of the wave transformation characteristics consist of transmission, reflection and energy dissipation. This measurement is essential for the assessment of the effectiveness of floating structure as a breakwater.





For further analysis scheme of hydraulic data, the authors proposed two-probe method introduced by Goda and Suzuki (1977) [23] for separation between reflected waves (A_r) and incident waves (A_i) and also for transmitted wave (A_t) . The dimensionless parameters of transmission (K_t) , reflection (K_r) and energy dissipation (K_d) coefficients can be estimated as:

$$K_t = A_t / A_i \tag{11}$$

$$K_r = A_r / A_i \tag{12}$$

$$K_d = \sqrt{1 - {K_t}^2 - {K_r}^2} \tag{13}$$

Study Parameter

Figure 2 shows the problem of wave interactions with floating breakwater including governing parameters. In the present simulation, the combined geometrical and kinematical similarities were used for the scaling of wave parameters at the modelled water depth, h of 1 m. Table 3 summarises the ratio of breakwater draft to wave height (d/H) and breakwater width to the wavelength (W/L) of simulation parameters for test condition. For random waves, the wind data are appropriately selected associated with the sea state of the South China Sea. Here, five prevailing wind speeds were considered and the corresponding significant wave heights, H_s with peak periods, T_P were measured as shown in Figure 3. For comparison purposes, the regular waves were also used with

six similar wave heights and wave periods. For validation, several regular wave parameters were appropriately considered.

| 1) Random waves | | | 2) Regu | ılar waves |
|-------------------|-------|-------|---------|------------|
| Sea state (knots) | d/H | W/L | d/H | W/L |
| 27.213 | 1.577 | 0.080 | 1.577 | 0.095 |
| 23.326 | 2.733 | 0.086 | 2.050 | 0.168 |
| 19.438 | 4.100 | 0.111 | 2.733 | 0.168 |
| 15.551 | 8.200 | 0.266 | 4.100 | 0.321 |
| 11.663 | 8.200 | 0.396 | 8.200 | 0.266 |
| | | | 8.200 | 0.396 |

Table 3. Numerical test condition.



Figure 3. Estimation of wave parameters from the P-M spectrum.

| Tab | le 4. | Geometric | al and | structural | characterist | ics of | CFB | model |
|-----|-------|-----------|--------|------------|--------------|--------|-----|-------|
|-----|-------|-----------|--------|------------|--------------|--------|-----|-------|

| Characteristics | Value | | |
|-------------------------------------|-----------------|-------------------|-------|
| Descriptions | | Unit | |
| Length | l | m | 0.76 |
| Width | W | m | 0.50 |
| Height | D | m | 0.51 |
| Draft | d | m | 0.41 |
| Mass | m | kg | 20.82 |
| Roll inertia | I_{rr} | kg∗m ² | 3.87 |
| Pitch inertia | I_{yy} | kg∗m ² | 7.37 |
| Yaw inertia | I _{nn} | kg∗m ² | 4.61 |
| Centre of mass above bottom | C_{a} | m | 0.40 |
| | - <i>y</i> | | |
| Natural period of heave oscillation | T _h | S | 1.12 |

Simulation Condition

Model

In the simulation, the particular model of CFB was constructed based on a dimensional and geometrical similarity designed by Ji et al., 2005 [3]. The virtual model basically consists of two main cylinders, 0.2 m (diameter) connected along their perpendicular directions by nine close-spaced mini-cylinders (connectors), 0.02 m (diameter) thus jointly together forming the superstructure of the breakwater system. Apart from the main body, the flexible structure of mesh cage of 0.1 m wide and 0.4 high was designed hanging below the superstructure specifically to disturb the particle orbit of waves (see Figure 2). In addition, the rubber hollow balls which density is similar to water of 0.02 m diameter were put into the mesh cage to enhance the wave energy dissipation. The detailed geometrical and structural characteristics of CFB are presented in Table 4.

RESULTS AND DISCUSSION

Figures 4 to 9 show that the CFD simulations were successfully carried out to predict the transmission, reflection, and energy dissipation coefficients of the cylindrical floating breakwater (CFB) corresponding to aforementioned simulation parameters. The simulation results are appropriately discussed in the following sub-sections.

Verification of Numerical Model

It is at first indispensable to undertake a comparative survey in order to check the correctness of the CFD simulation with respect to the data published in the literature. The validation purpose for the present study has been based on experimental studies by Ji et al. (2015) for regular waves. From Figure 4, the CFD results show a downward trend of transmission coefficient, K_t as wave height increases similarly to experimental data. Meanwhile, the discrepancies between two results are from 1.29 to 22.45% as depicted in Table 5.



Figure 4. Transmission coefficients for T=1s.

Note that the simulated results are predicted lower than its counterpart. In particular, the CFD simulation results just remain stable at K_t around 0.5. This can be explained due to the difference in stiffness effects since the pile-restrained system was considered in the simulation. One of the reasons is because the pile-supported condition conduces to

enhance energy dissipation of the structure. This validation is important in the subsequent prediction for hydrodynamic properties of CFB.

| <i>H</i> (m) | K _t | | Discrepancy of K_t |
|--------------|----------------|-------|----------------------|
| | CFD | Exp. | (%) |
| 0.100 | 0.49 | 0.60 | 22.45 |
| 0.125 | 0.5 | 0.575 | 15.00 |
| 0.150 | 0.485 | 0.54 | 11.34 |
| 0.175 | 0.468 | 0.515 | 10.00 |
| 0.200 | 0.464 | 0.47 | 1.290 |

Table 5. Transmission coefficient of CFB at various wave heights.

Wave Transmission Coefficient

The wave damping performance of floating breakwater undersea wave force is estimated by its wave transmission coefficient, K_t . Figure 5 shows the change in coefficient of transmissions with various d/H and W/L for random and regular waves respectively. Generally, the similar trend could be seen from both results, especially when d/H > 2. Both figures present a minimum value of transmission approximately less than 0.3 at the smallest wave height and wave period considered (d/H = 8.2, W/L = 0.396). However, the prediction for random waves showed a peak K_t at highest wave height (d/H = 1.577) while for regular wave at d/H = 2.733. On top of this, a marked downward trend can be seen in Figure 5(b) for long and high waves (d/H < 3) in comparison to random wave figure. With increasing wave height, the performance of cylindrical floating breakwater (CFB) is marked good up to the 30% reduction of transmission than random wave case at the highest wave height. This forms a reasonable data as shown previously by the work from Ji et al., 2015 for regular waves. This can be attributed to the absorbing and added mass effect of CFB. Apart from wave breaking, the passing fluid force is proportionally reduced due to turbulence, friction loss and flow reversal across the mesh cage [5, 24]. In this case, the in-plane motion of CFB suggested to cause better damping and dispersing of more energy may be a reason for the declining trend.



Figure 5. Transmission coefficients for (a) random wave (b) regular wave.

This is also supported by the reduction of flow parameters observed in CFD simulation. In Figure 6, it is convenient to explain that the pressure field, velocity and surface elevation before and after the breakwater were increased as d/H decreased which can be traced by the red-yellow colours. Again, the differences in the above parameters between front and lee sides of the structure were growth with increasing wave height markedly for d/H = 1.577. Hydrodynamically, further reduction of these leeward forces relative to the seaward one directly reduces the transmission coefficient. Nevertheless, the random wave figure exhibits a reversed trend, as wave height increases the K_t increases reaching a peak value at approximately 0.76. One of the reasons for this phenomenon is due to the influence of chaotic processes occurring during propagation of the irregular wave. Yet, this could also be attributed to the large motions of CFB that in turn creating added wave disturbances to the leeside of the structure and thus considerably causing higher transmissions. The similar trend was predicted by Koutandos et al. [25] from heave motion floating breakwater in large-scale experimental studies. Of course, further study for more wave parameters is desired experimentally and numerically to confirm the above finding.



Figure 6. Wave absorbing effects of CFB in characteristics of (a) pressure pattern (b) velocity pattern (c) surface elevation pattern.

Beyond d/H > 3, it is interesting to note that the transmission coefficients are very similar between the figure for random and regular waves, especially for d/H = 4.1. The difference is merely negligible between the two results even the large distinct in wavelength (65% difference) are deliberately used as for comparison purpose. Nonetheless, this is favourable particularly for high and long waves to achieve K_t less than 0.5. Besides, a remarkable gap can also be observed for d/H = 8.2 with slight differences in wavelength (32%) for both graphs. This suggests that the wave period is another paramount parameter for small wave height that could control wave transmission. Overall, the results revealed that the floating breakwater has good performance rather in regular waves. However, the influence of the chaotic state in random wave propagations to the structure induces unique phenomena of wave transmission which is still comparable to and better than the regular wave figure, especially for d/H > 2. Therefore, for the selected simulation parameters, the present CFB has a satisfactory performance both in random and regular wave conditions.

Wave Reflection Coefficient

The study of wave reflection characteristic is important to understand the wave climate at the windward of the floating breakwater. The reflection should not be so high which can lead to a confusing sea state front of the structure that is dangerous for navigation, in particular. Figure 7 (a) and (b) depict the variations of reflection coefficients with various d/H and W/L for random and regular waves, respectively. The inclining trend of K_r can be observed from both figures with increasing d/H up to a respective maximum value of approximately 0.54 and 0.75 for random and regular waves. Although the significant slope can be seen in regular wave figure compared to its counterpart, it is rather mild. Afterwards, both figures show a slight declining trend of the reflection coefficient at the highest wave height (d/H = 1.577). The results entirely show that the higher the wave height the higher the coefficient of reflection. Nevertheless, the wavelength could control the reflection characteristics of the structure, especially in more long waves as evident for the case of W/L = 0.08 and W/L = 0.266. For example, in small and short waves (d/H = 8.2), the reflections of CFB are considerably low for both figures. For higher and longer waves, the K_r exhibits small growth in random waves while in regular waves increases sharply. This was clearly observed in the simulation due to the phenomenon of wave overtopping particularly for d/H = 1.577 and 2.050 as can be seen in Figure 6. Frequent overtopping induces wave breaking while increases windward reflection is one of the reasons for high K_r , especially at d/H = 1.577 markedly for regular wave figure. Therefore, the results reveal that the floating breakwater tends to work in the more reflective manner in high and regular wave conditions while under random waves, the CFB performs rather in consistent reflection with K_r around 0.5 even at high and long waves. This finding is further supported by the upward and downward trends of transmission coefficients for random and regular wave conditions, respectively (see Figure 5 (a) and (b)).



Figure 7. Reflection coefficients for (a) random wave (b) regular wave.

Wave Energy Dissipation Coefficient

Investigation on the energy dissipation characteristics is essential to understand the efficiency of the floating structure as a breakwater. In which, a breakwater can be

considered to be performing well if the energy dissipation capability is high. Figure 8 (a) and (b) show the change in coefficient of dissipation with various d/H and W/L for random and regular waves, respectively. Obviously, the similar trend can be observed for both figures. K_d increased steadily as the wave height decreased reaching a peak value with approximately 0.9 for shortwave. This phenomenon is mainly observed in simulation due to the increasing intensity of oscillating air-water vortices observed in the front submerged part of the breakwater. As shown in Figure 9, the turbulent intensity was developing and expanding with increased simulation time as indicated by the red and yellow-green colours. This is due to the fact that under short wave the simulated CFB moves vertically out of phase with the standing wave formed in front of the structure that consequently exerts forcibly a hydrodynamic opposite force with the incoming wave. Inherently, the significant motion of the structure relative to the higher natural frequency of oscillations than the wave periods creates stronger vortices of turbulence, especially in the upstream bottom part. This phase differences in angle between the vertical motion of floating breakwater and the standing waves was previously observed by Tolba, 1998 using video analysis [26]. Furthermore, it is convenient to explain that the increase in the turbulent intensity was basically proportional to the increased energy dissipations shown by yellow and red-blue colours in Figure 9. In other words, the hydrodynamic force dominated strongly relative to added mass and smaller internal elastic response effects since this floating structure tends to work in more dissipative manner.



Figure 8. Dissipation coefficients for (a) random wave (b) regular wave

Similarly, in high and long waves (d/H < 5), the energy dissipations are still higher in comparison to reflection coefficients for both tested wave conditions. As indicated previously by Figure 6, the vortices generated are thus expected to be stronger and more developed for both front and rear sides of the CFB than those in short wave. This ultimately reveals the functional effectiveness of the geometric configuration and mesh cage of the breakwater for wave parameters considered in present study. Therefore, this dissipation ability, especially in high and long waves can be considered as an advantage from an engineering point of view. Overall, the wave dissipation coefficients for the regular wave condition are slightly greater than the random wave counterpart at around 10%, especially when d/H > 2. In addition, the results showed that the dissipation coefficient only slightly decreases with increasing wavelength at the same wave height, especially when comparing both figures for d/H = 4.1 and d/H = 8.2. Therefore, it can be concluded from Figure 7 (a) and (b) that the floating breakwater is generally efficient in dissipating short and long waves under both random and regular wave forcing with comparable K_d results.



Figure 9. Characteristics of turbulent patterns on cylindrical floating breakwater for short waves.

CONCLUSIONS

In the present paper, wave-body interactions for a floating structure under random and regular waves were deliberately simulated via integration between CAD and computational fluid dynamics technique. The CFD model was based on fully RANS equations and RNG model. The equations were discretised based on the Volume of the Fluid method (TruVOFTM) and a sufficiently thin numerical grid was fitted to evaluate the fluid-structure interaction. The simulations were properly carried out to estimate the hydrodynamic properties of the cylindrical floating breakwater (CFB). It can be concluded that:

- The verification of the present approach and experiment model test was successfully carried out and formed a fair agreement with acceptable errors.
- For selected simulation parameters, the present model was able to capture the damping and added mass effects from the mesh cage of the cylindrical floating breakwater (CFB), especially in attenuating high and long regular waves.

- Results from both cases of regular and random waves indicate that transmission coefficient is very sensitive to wave period for small wave height.
- For a large draft of CFB (d/h > 0.2), the pile-supported CFB may perform in dissipative manner in wave absorbing mechanism with dissipation coefficients considerably greater than reflection one for both random and regular wave conditions.
- Considering the present data, it is highly suggested that the floating structure is satisfactory to be used for sustainable wave transformation and protection for the valuable coastal zone and coastal mangroves specifically in Peninsular Malaysia background by the South China Sea.
- Through an appropriate combining and tuning of modern CAD and CFD techniques, a relatively powerful and economical advantageous tool can be created to investigate the interaction between waves and floating breakwater.

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