The Analytical Solution of Waves Transmission Coefficient on Semi Fixed Floating Breakwater

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Abstract. One type of breakwaters that can be used to protect port basin is floating breakwaters. The use of floating breakwaters is suitable for relatively large water depths. In deep waters, the floating breakwaters volume is smaller than rubble mounds breakwater. Consequently, floating breakwaters are cheaper than rubble mounds breakwater. Unfortunately, a practical approach to analysing the performance of floating breakwater in reducing wave height is unknown. Floating breakwater performances indicated by wave transmission coefficient. Therefore, in this study an analytical wave transmission coefficient was formulated. The simple formula can be used to estimate high of wave at behind of floating breakwater. Based on these equations, the wave transmission coefficient influenced by the wave parameters and structural parameters. Wave parameters represents by wave high, wave period, water depth and wave length while structure parameters represents by both of width and draft of structure. Wave transmission coefficient also influenced by the wave frequency and having motion frequency.

1. Introduction
Indonesia as the largest archipelagic country in the world has around 17 thousand islands with a coastline length reaching 95,181 kilometres. Geographically Indonesia's position is very strategic to trade traffic because it is located between two continents and two oceans. This condition needs to be supported by inter-island transportation facilities and infrastructure, including adequate ports to support trade activities and maintain the sovereignty of Indonesian maritime affairs. Port basin should be protected by wave disturbance to guarantee that the both of loading and unloading ships activities are safety. There are requirements of wave high at the pier so the ship can tie up safely as shown at Table 1.

Table 1 shows that the greater the dimension of ships or boats the greater significant wave high that required at pier and vice versa. Marina ports, significant wave high at berth maximally 0.15 m. For the large ships significant wave high is required reach 1.70 m. Significant wave high at berth that greater than 1.70 m is not required for all ships.
**Table 1. The maximum significant wave high required at pier**

| Ship Types                  | $H_s$ at pier |
|-----------------------------|--------------|
| Marinas                     | 0.15         |
| Fishing boats               | 0.40         |
| General Cargo (<30,000 DWT) | 0.70         |
| Bulk Cargo (<30,000 DWT)    | 0.80         |
| Bulk Cargo (30,000-10,000 DWT) | 0.80-1.50   |
| Oil Tanker (<30,000 dwt)    | 1.00         |
| Oil Tanker (30,000-150,000 DWT) | 1.00-1.70   |
| Passenger Ship              | 0.70         |

One of an alternative solution to protect port basin is floating breakwater. Unfortunately, the simple solution to identify floating breakwater performance not understood. Therefore in this research derivate the new formula to calculate wave attenuation coefficient after wave reach at the lee of structure. The large floating structure was introducing firstly by Edward R Armstrong who initiated a sea drone as an aircraft runway on the sea. The developed of floating breakwater has increased significantly in the recent years. A lot of research related to floating breakwaters has been done previously researches [1-5]. Floating breakwater has many advantages compare with fixed breakwater, namely flexible, movable and can be rebuild in deferent layout [6], chipper than fixed breakwater and easily in construction [7]. There are many types of floating breakwater has identify by [8], are box type, pontoon type, mat type, tethered float type. Although floating breakwater has advantage, but this type of breakwaters are not effective in areas with high or fast-moving waves. In heavy storms these breakwaters are subject to failure, and if they come detached from their moorings they can become a danger. Floating breakwaters have the advantage of being detachable when not in use, but the labour costs to replace the breakwater can be high when compared to a fixed breakwater. Pontoon type is the most widely used in recent years. Commonly, floating breakwater will be effective if the wave high is less than 5 feet or about 1.5 m [9], as shown in the following figure.

![Figure1. The affectivity of floating breakwater as a function of wave high](image)

Rectangular pontoon as a floating breakwater widely used in recent years and usually built segmented that connected by flexible connector and tethered to the bottom using cable or chain. The binding of floating breakwater to the bottom should be strongly so that cannot be moves. The use of mooring system on floating breakwater must pay attention several aspects including failure both of mooring system and floater must not occur and interaction both of mooring and floater must be safely.
2. Methodology

This research was analytical approach or analytical solution of wave propagation through on floating breakwater. Wave that propagate on floating breakwater or floating object, a part of its energy will be reflected, transmitted and attenuated by turbulence and friction both of fluid and floating structure. Base on conservation of energy concept, the amount of incoming wave energy will be same with the sum of reflected, dissipated and transmission wave energy and can be formulated as:

\[ E_i = E_r + E_d + E_t \quad (1) \]

where \( E_i, E_r, E_d \) and \( E_t \) are incoming wave energy, reflected wave energy, dissipation wave energy and transmission wave energy respectively. The performance of floating breakwater is wave transmission coefficient (\( K_t \)). The smaller value of wave transmission coefficient, the better the floating breakwater perform in reducing the wave height. Wave transmission coefficient is the ratio between wave high at behind of floating breakwater (\( H_t \)) with wave high at the front of floating breakwater (\( H_i \)) and mathematically written as:

\[ K_T = \frac{H_t}{H_i} \quad (2) \]

3. Research Result

Based on strip theory \[10\], the wave induced force on rectangular float in linier wave theory is formulated as follow:

\[ F_{zR} = \frac{\rho g H B \lambda}{2 \pi} \left( e^{-2 \pi i/\lambda} + 1 \right) \sin \left( \frac{2 \pi L}{\lambda} \right) \cos(\omega t) \quad (3) \]

or

\[ F_{zR} = F_o \cos(\omega t) \quad (4) \]

still in \[10\], generally we can represent the heaving displacement of floating body by:

\[ Z = \frac{\left( \frac{F_o}{\rho g A_w} \right) \cos(\omega t + \gamma - \sigma_z)}{\sqrt{1 - \frac{\omega^2}{\omega_z^2} + \left( 2 \Delta \frac{\omega}{\omega_z} \right)^2}} \quad (5) \]

by substituting Equation (3) to Equation (5), obtained:

\[ Z = \frac{\left( \frac{HB\lambda}{2 \pi A_w} \left( e^{-2 \pi i/\lambda} + 1 \right) \sin \left( \frac{2 \pi L}{\lambda} \right) \cos(\omega t) \right) \cos(\omega t + \gamma - \sigma_z)}{\sqrt{1 - \frac{\omega^2}{\omega_z^2} + \left( 2 \Delta \frac{\omega}{\omega_z} \right)^2}} \quad (6) \]

For the maximum value of \( Z \) is written as:

\[ Z = \frac{\left( \frac{HB\lambda}{2 \pi A_w} \right) \left( e^{-2 \pi i/\lambda} + 1 \right) \sin \left( \frac{2 \pi L}{\lambda} \right)}{\sqrt{1 - \frac{\omega^2}{\omega_z^2} + \left( 2 \Delta \frac{\omega}{\omega_z} \right)^2}} \quad (7) \]
water plane area of the float body is multiplication both of length and width of body. Then Equation (7) can be written as:

\[
Z = \frac{H \lambda}{2 \rho d L} \left( e^{-2 \pi h/\lambda} + 1 \right) \sin \left( \frac{2 \pi L}{\lambda} \right) \left\{ 1 - \left( \frac{\omega^2}{\omega_z^2} \right)^2 + \left( 2 \Delta \left( \frac{\omega}{\omega_z} \right) \right)^2 \right\}^{-1/2}
\]  
(8)

Wave that propagate on floating breakwater a part of its energy will be reflected, transmitted and attenuated by turbulence and friction both of fluid and floating structure. The figure below describe wave through on semi fixed floating breakwater.

![Wave Propagation Diagram](image)

**Figure 2.** Illustration of wave propagation on semi fixed floating breakwater

When the wave comes from deep water and reach the floating breakwater, the incoming and transmitted wave’s energy are formulated:

\[
E_I = \frac{\rho g H_I^2}{8} \lambda B
\]

(9)

\[
E_T = \frac{\rho g H_I^2}{8} \lambda B
\]

(10)

On floating object, wave energy dissipation will be equivalent with wave energy that used to moves the object in the vertical direction or heaving movement and formulated as follows:

\[
Ed = \frac{\rho g}{8} \left[ \frac{H \lambda}{2 \rho d L} \left( e^{-2 \pi h/\lambda} + 1 \right) \sin \left( \frac{2 \pi L}{\lambda} \right) \left\{ 1 - \left( \frac{\omega^2}{\omega_z^2} \right)^2 + \left( 2 \Delta \left( \frac{\omega}{\omega_z} \right) \right)^2 \right\}^{-1/2} \right]^2 \lambda B
\]

(11)

By substituting Equations (9)-(11) to Equation (1), obtained:
\begin{equation}
\frac{\rho g H L^2}{8} \cdot \frac{\lambda B}{\lambda} = \frac{\rho g}{8} \left[ \frac{H L}{2\pi L} e^{2\pi i/\lambda} + 1 \right] \sin \left( \frac{2\pi L}{\lambda} \right) \left[ \left( 1 - \frac{\omega^2}{\omega_0^2} \right)^2 + \left( 2\Delta \times \frac{\omega}{\omega_0} \right)^2 \right] \ \ \ \ \ \ (12)
\end{equation}

By simplification of Equation (12) then obtained:

\begin{equation}
K_t = \frac{\lambda \left( e^{-2\pi i/\lambda} + 1 \right)^2 \sin^2 \left( \frac{2\pi L}{\lambda} \right)}{1 - \frac{4\pi^2 L \left( 1 - \frac{\omega^2}{\omega_0^2} \right)^2 + \left( 2\Delta \times \frac{\omega}{\omega_0} \right)^2}{(\Delta v)^2}} \ \ \ \ (13)
\end{equation}

Equation (13) shows that the Kt, influenced by both of wave and structures parameters. Wave parameters are incoming wave high and wave length. Structure parameters are structure width and draft of structures. The value of Kt also influenced wave and heaving motion frequency. As an important note, Equation (13) still needs a more comprehensively study in the future. Especially, validate of equation (13) with laboratory data should be conducted. Until now, researchers not recommended for anyone to use the Equation (13) directly because this equation should be validate using experimental data.

4. Conclusion
There are several conclusions which can be drawn from this study. They are:

- The Equation (13) as simple approximation to calculate wave transmission coefficient should be validated using of experimental or numerical investigation.
- Base on Equation (13), the transmission coefficient (Kt) influenced by structure and wave parameters.
- Wave parameters represents by wave length (\( \lambda \)), wave period (T) and water depth (h).
- Structure parameters represents by length of structure (L), structure width (B), draft (T), shape of bodies, natural period (TN), mass of structure (m), added mass (mv) and dumping coefficient (\( \Delta v \)).

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