Analytical Approach of Wave Transmission Coefficient through on Composite Hanging Breakwater

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Abstract. Conventional breakwater like a rubble mount is require large infestation, especially when that structure construct in deep water. Currently, innovations are needed to solve financial problems in building breakwaters. Composite hanging breakwater is proposed as a new solution in marine structure. Composite hanging breakwater made by both of stone and concrete or steel material consist of two-part are structural part and filler. Structural parts are piles, beams, and brackets made of concrete or steel. Filler material using of stone or other material. This structure has the advantage are cheaper than conventional breakwater, precast material, and the diameter of stone filler is relatively small. Until now, the performance of composite hanging breakwater is unknown. Commonly, the key performance indicator of breakwaters is wave transmission and represent by the waves transmission coefficient. Therefore, in this study, an analytical equation of wave transmission coefficient was developed using the conservation of energy concept. Based on this equation shows that the wave transmission coefficient is influenced by both structure and wave parameter. After the equation has been obtained, then it is compared with previous research. Research that has been used as a comparison includes research by Weigel (1960), Abul-Azm (1993), Liu and Abbaspour (1982), Abu-Azm (1993), Heikal (1997), Koraim (2005), Rage and Koraim (2010), and Koraim (2014). Wave parameter represents by waves steepness implicitly, and structure parameter is represented by the permeability of structure, relative length, and relative depth. The greater the value both of relative depth and length, the smaller value of wave transmission coefficient. The greater the value of structure permeability, the smaller the value of wave transmission coefficient. When the D/h is zero, the wave transmission coefficient is equal to one and when the D/h is equal to one, the transmission coefficient is close to or equal to zero. When the D/h value is less than 0.5, the K_t value in this present study is lower than the K_t value in previous studies for the same D/h value, and when the D/h value is greater or equal to 0.5 then the K_t value is close or the same with the previous study.

1. Introduction
One of the requirements for loading and unloading process at the port is that the wave height at the berth is small as possible. The problem is many port doesn’t meet the requirements. Especially if the port is facing directly to the open sea. Port exposed to the extreme waves require breakwaters to protect port basin. Recently, the type of breakwater have been widely used is conventional breakwater. This breakwater made by natural and artificial stone. The main problem in using this type of breakwater is high cost due to large dimension of structure, especially if structure is located at deep sea. In terms of overcoming the high cost of construction, one solution that can be used is hanging breakwater which is abbreviated as HB. As the name implies, this structure hangs on transvers and longitudinal beams that supported by piles. Because the damper of structure doesn’t reach the ground or hanged, than the volume
of structure relatively small compared with conventional breakwater. Because the dimensions are small so the cost is lower.

Based on a rough estimate made by Paotonan, 2015, it was found that for the breakwater placed at a depth of 20 m, the wave height and period of 3 m and 8 seconds, respectively, the draft and wave height ranges from 0.10 to 2.50 and the ratio between structure width and length waves between 0.028 to 0.045, the percentage of this breakwater costs to the conventional breakwater cost ranges from 3.83% to 12.89%. This means the financial benefits will be obtained if in using of hanging breakwater are quite large.

Structurally, the hanging breakwater consists of several main parts, namely the superstructure and foundation components. The superstructure consists of pile caps, transverse beams, longitudinal beams and energy-absorbing construction. While the foundation in the form of concrete or steel piles. The picture of the hanging breakwater can be seen in the Figure 1.

![Figure 1. Hanging breakwater](image)

The performance of breakwater is indicated by waves high behind the breakwater and named transmission wave. The value that indicates the hanging breakwater performance is the transmission coefficient. This value is the ratio between the wave height behind and in front of the breakwater. The research that is relatively close with this current research is research related to the wave transmission through hanging sheet pile breakwater and research related to the semi-immersed smooth solid walls, slotted or screen breakwater, and bodies supported on widely or closely spaced piles.

Research related to the wave transmission through hanging sheet pile breakwater has been conducted by Paotonan, et al [1] and [2]. This research is an experimental study was conducted in the laboratory and reported that the transmission coefficient ($K_t$) influenced by draft (D) and gap (b) of structures and wave parameters (both of high and period of waves). Both regular and irregular wave transmission coefficient through on hanging sheet pile as a breakwater indicates that the higher the wave steepness, the smaller the wave transmission coefficient [1]. The greater the ratio of draft and water depth (D/h), the smaller the value of transmission coefficient [1] and [2].

Hanging breakwaters are similar to floating breakwaters. The difference is that the hanging breakwater is static while the floating breakwater moves with the movement of the waves. Therefore hanging breakwaters are relatively effective compared to floating breakwaters for the same structural dimensions. Floating breakwaters can also be made semi-fixed by limiting movement in the horizontal direction and allowing the structure to move in the vertical direction. Through an analytical approach conducted by Paotonan, et al it is obtained that the transmission coefficient is influenced by wave and
structure parameters. Wave parameters represent by wavelength, $\lambda$, wave period, $T$ and water depth, $h$ while structure parameter represents by the length of the structure, $L$, structures, $B$, draft, $D$, shape of bodies, natural period, the mass of structurer, $m$, added mass, and damping coefficient, [3]. Although the equation in research [3] has not been validated with laboratory and field data, physically the formula has represented all the influential parameters. The equation cannot be applied to the hanging breakwater because the structural response is not the same as the floating breakwater response. Therefore, in this study, research was carried out to formulate a suitable equation for hanging breakwaters.

In addition to the research mentioned above, other studies have been carried out by previous researchers. The efficiency of the semi-immersed walls was experimentally and theoretically studied by many researchers [4], [5], and [6]. These researchers carried out experimental studies to determine the efficiency of this type under regular waves. The different theoretical models based on the Power Theory, the Eigen Function Expansion Method, the Boundary Integral Equation, and the Reynolds Average Naiver Stokes Equations for this model have been investigated by [7] and 8]. The hydrodynamic performance of a vertical wall with permeable lower parts (horizontal slots) experimentally and theoretically under normal regular waves has been studied by [9]. The Hydraulic characteristics of pile-supported L-shaped bars used as a screen breakwater have been investigated by [10].

2. Methodology

This research has been carried out to formulate wave transmission through hanging breakwaters. The derivation of the formula has started by assuming that when the incident wave hits the structure, the incident wave force, $F_i$ will be equal to the sum of the reflected wave force, $F_r$, the wave force due to underflow, $F_u$, and the transmitted wave force, $F_t$. This assumption is shown in Figure 2.

Based on Figure 2 waves force on hanging breakwater can be formulated mathematically as equation (1) below:

$$F_i = F_r + F_u + F_t$$

(1)

In the case of formulating the wave through the hanging breakwater, the first step is to formulate the wave pressure on the hanging breakwater. Based on the linear wave theory, the wave pressure is formulated as follows:

$$p = -\rho g z + \rho g \frac{H_i \cosh (h+D)}{2 \cosh kh} \cos(kx - \omega t)$$

(2)
The first term on the right side in equation (1) is hydrostatic pressure and has been neglected in the development of the formula because it acts in all directions and cancels out each other. Therefore only the second term was considered, namely dynamics effect by waves. Equation (2) can be simplified as below:

\[ p = \rho g \left( \frac{H_i \cosh(h+D)}{2 \cosh h} \right) \cos(kx - \sigma t) \]

Wave pressure will be maximum when the value of \( \cos(kx - \sigma t) \) is equal to 1. Then, the equation (3) above can be written as Equation 4 below:

\[ p = \rho g \left( \frac{H_i \cosh(h+D)}{2 \cosh h} \right) \]

Based on Figure 2 and Equation 4, the distribution of wave pressure on the hanging breakwater can be idealized as shown in Figure 3:

![Figure 3. Wave pressure distribution on hanging breakwater](image)

The wave pressures \( p_1, p_2, p_3, p_4 \) in Figure 3 can be seen in Figure 4. After formulating the wave pressure, the next step is to formulate the wave force on the structure. Based on Figure 3 and Equation 4, the wave force can be formulated by multiplying the pressure and depth per unit width. The results of the development of the formula for each force (\( F_i, F_r, F_u, \) and \( F_t \)) acting on the hanging breakwater based on the wave pressure distribution can be seen in Figure 4. By substituting \( F_i, F_r, F_u, \) and \( F_t \) into Equation 1 and then simplifying carry out, the following equation 5 is obtained:

\[ \frac{D}{h} \beta \left( \frac{\cosh k + \cosh(k-D)}{\cosh k + 1} \right) + \left( 1 - \frac{D}{h} \right) \left( \frac{\cosh(h-D)+1}{\cosh h + 1} \right) + \frac{H_t}{H_i} = 1 \]

The \( H_t/H_i \) term is the ratio between the height of the transmission wave and the height of the incident wave and is called the transmission coefficient. Equation (5) can be simplified as equation (15) as below:

\[ K_t = 1 - \left( \frac{D}{h} \beta \left( \frac{\cosh k + \cosh(k-D)}{\cosh k + 1} \right) + \left( 1 - \frac{D}{h} \right) \left( \frac{\cosh(h-D)+1}{\cosh h + 1} \right) \right) \]

In equation (6) above, the values of \( \beta, h, D, \) and \( h \) are structural permeability, water depth, structural draft, and wavenumber respectively. Physically when the value of \( D \) is equal to \( h \), then it should be \( K_t \) equal to 0, and when \( D \) is equal to zero the value of \( K_t \) should be zero. Based on these boundary conditions, it is found that equation (15) is not yet satisfied. Therefore, equation (6) must be modified so that the intended boundary conditions are met by adding the constant \( C \) for the 3rd term in Equation 6 the following:

\[ K_t = 1 - \left( \frac{D}{h} \beta \left( \frac{\cosh k + \cosh(k-D)}{\cosh k + 1} \right) + \left( 1 - \frac{D}{h} \right) \left( \frac{\cosh(h-D)+1}{\cosh h + 1} \right) \right) + e^{-CkD} \frac{D}{h} \]
3. Results
In equation 7 shows that when D/h is equal to 1, the value of K_t is equal to 1. However, when the value of D/h is equal to zero the value of K_t is still greater than 0. Although the value of K_t when D/h is not yet equal to zero, it is close to zero especially if the value of C is greater than 2. Thus equation (7) is
acceptable but requires validation with laboratory or field data. By using equation (7) and varying the ratio between D/h the table and graphs below are obtained.

Table 1. Calculations of $K_t$ Value on several values of C

| h (m) | l (m) | D (m) | β  | D/h | $K_t$  |
|-------|-------|-------|----|-----|--------|
|       |       |       |    |     | for C = 1 | for C = 2 | for C = 3 | for C = 4 | for C = 5 | for C = 6 |
| 15    | 10    | 44.1  | 0.00| 0.00| 1.00   | 1.00     | 1.00     | 1.00     | 1.00     | 1.00     |
| 15    | 10    | 0.0   | 1.50| 1.00| 0.1   | 0.96     | 0.84     | 0.74     | 0.65     | 0.58     | 0.51     |
| 15    | 10    | 0.0   | 3.00| 1.00| 0.2   | 0.90     | 0.71     | 0.57     | 0.47     | 0.39     | 0.33     |
| 15    | 10    | 0.0   | 4.50| 1.00| 0.3   | 0.83     | 0.61     | 0.46     | 0.36     | 0.30     | 0.26     |
| 15    | 10    | 0.0   | 6.00| 1.00| 0.4   | 0.76     | 0.52     | 0.38     | 0.30     | 0.25     | 0.23     |
| 15    | 10    | 0.0   | 7.50| 1.00| 0.5   | 0.68     | 0.43     | 0.31     | 0.25     | 0.22     | 0.21     |
| 15    | 10    | 0.0   | 9.00| 1.00| 0.6   | 0.60     | 0.36     | 0.25     | 0.21     | 0.19     | 0.18     |
| 15    | 10    | 0.0   | 9.75| 1.00| 0.65  | 0.56     | 0.32     | 0.22     | 0.19     | 0.17     | 0.17     |
| 15    | 10    | 0.0   | 10.50| 1.00| 0.7   | 0.52     | 0.28     | 0.20     | 0.17     | 0.15     | 0.15     |
| 15    | 10    | 0.0   | 12.00| 1.00| 0.8   | 0.43     | 0.21     | 0.14     | 0.12     | 0.11     | 0.11     |
| 15    | 10    | 0.0   | 13.50| 1.00| 0.9   | 0.34     | 0.13     | 0.08     | 0.06     | 0.06     | 0.06     |
| 15    | 10    | 0.0   | 13.80| 1.00| 0.92  | 0.32     | 0.12     | 0.07     | 0.05     | 0.05     | 0.05     |
| 15    | 10    | 0.0   | 14.70| 1.00| 0.98  | 0.26     | 0.07     | 0.03     | 0.02     | 0.01     | 0.01     |

Based on the values both D/h and $K_t$ in Table 1, then the relationship between D/h and $K_t$ for several C values is plotted in a graph as shown in Figure 5.

Figure 5. Relationship between D/h and $K_t$

Table 1 and Figure 5 shows that the greater the ratio between D/h, the smaller the $K_t$ value for all values of C. The value of $K_t$ in Figure 5 is purely influenced by the ratio between D/h or purely influenced by the structural draft. By varying the length of the structure and wave parameters are constant, the effect of the relative length $(L/\lambda)$ of the structure on to wave transmission coefficient is obtained as shown in Figure 6.
Figure 6. Relationship between \( L/\lambda \) and \( K_t \)

Figure 6 shows that the greater the value of \( L/\lambda \), the smaller value of the \( K_t \). The effect of \( L/\lambda \) on wave transmission coefficient in Figure 5 applies to the values both of \( D/h \) and \( \beta \) are 0.27 and 0.8 respectively. For other values both \( D/h \) and \( \beta \) have not been analyzed. The relationship between the two parameters above is close to exponential. From Figure 6 it is found that the greater the \( L/\lambda \) value, the smaller the wave transmission coefficient. Figure 7 below shows the relationship between the permeability of structure, \( \beta \), and wave transmission coefficient.

Figure 7. Relationship between \( \beta \) and \( K_t \)

Figure 7 above shows that the relation of structure permeability and wave transmission coefficient is linear relatively. The greater the value of structure permeability, the smaller the value of wave transmission coefficient. The relation of those parameters applies for values both of \( D/h \) and \( L/\lambda \) are 1.00 and 0.23 respectively. The influence of water depth and wavelength for structure parameter is constant has not been accommodated in the analysis. Therefore, in further research, the influence of these parameters will be studied. In addition, the formula that has been developed through an analytical approach must be validated with laboratory data going forward.

As an initial verification of the formula that has been developed, the calculation results are compared with previous research. Previous research that has been used as a comparator is research that has been carried out by Weigel (1960), Abul-Azm (1993), Liu and Abbaspour (1982), Abu-Azm (1993), Heikal (1997), Koraim (2005), Rage and Koraim (2010), and Koraim (2014). The wave transmission coefficient for the present study has been calculated using Equation 7. The results of the calculation of the
transmission coefficient, $K_t$ compared with the transmission coefficients from previous studies. The transmission coefficient is plotted on a graph as a function of $D/h$ as presented in Figure 8.

![Graph showing the comparison between present research and previous research](image)

**Figure 8.** Comparison between present research and previous research

Figure 8 shows that the $K_t$ value has been calculated using the present formula close to the $K_t$ value by previous studies for $D/h$ greater than or equal to 0.5. For the values of $D/h$, less than 0.5 the value of $K_t$ that has been calculated by the present formula is relatively small compared to $K_t$ by previous studies. The width of the structure in the direction of wave propagation for all previous studies is relatively small so the influence of the width of the structure is not significant. This is different from the current study where the influence of the width of the structure on the small draft of structure is significant so the $D/h$ value is smaller than 0.5 the $K_t$ value calculated by the proposed formula is smaller than the $K_t$ from the previous studies. The graph in Figure 8 applies to water depth, $h = 15$ m, wavelength, $\lambda = 44.12$ m, $h/\lambda = 0.34$, structure permeability, $\beta = 1$, structure length, $L = 10$ m, $C = 4$, and $D/h$ varies from 0 up to 1.0. The average percent error between the calculated transmission coefficient using the present formula and the transmission coefficient from previous studies for the value of the $D/h$ range is 43.4%. For the value of the $D/h$ range percent error is 24.5%.

4. **Conclusion**

Based on the theoretical development of the formula for calculating the transmission coefficient and the comparison of the current research results with previous studies, the following conclusions can be drawn:

1. Analytical solution of waves transmission through on hanging breakwater has been developed as shown in equation (7) and obtained that wave transmission coefficient through on hanging breakwater influenced by wave and structures parameters;
2. The greater the value of relative depth, relative length, and structure permeability than the smaller the value of wave transmission coefficient;
3. When the $D/h$ is zero, the waves transmission coefficient is equal to one and when the $D/h$ is equal to one, the transmission coefficient is close to or equal to zero;
4. When the $D/h$ value is less than 0.5, the $K_t$ value in this present study is lower than the $K_t$ value in previous studies for the same $D/h$ value, and when the $D/h$ value is greater or equal to 0.5 then the $K_t$ value is close or the same with the previous study.
5. Further research should be conducted to validate equation (7) by laboratory data.

5. **Acknowledgments**

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6. Reference

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