Experimental study on the influence of draft relative due to wave transmission energy coefficient on hanging sheet pile breakwater

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Abstract. Rubble mound breakwater is recently become the most widely used breakwater, consist both of natural and artificial stone. It required a large dimension of structure so that the investment costs become more and more expensive. One of the solutions that can be implemented is Hanging Sheet Pile breakwater. Unfortunately, the performance of this type of breakwater has not been known yet. Performance of this breakwater represented by wave energy transmission coefficient (KEₜ). Therefore, this study aims to examine the effect of relative draft (s/d) and relative wave height (H/s) to KEₜ. This study conducted in Ocean Technology Laboratory of Universitas Hasanuddin. The parameters studied are structure dimensions and wave parameters. Wave parameters consist of wave height (H) and wave period (T), while the structure parameter is the draft structure (D). The result of this study shows that the greater value of both incident wave steepness (Hi/gT²) and structure relative draft (s/d), then the smaller of KEₜ value will be achieved. Also, the greater relative H/s, the smaller KEₜ will be achieved. For all cases of study, the transmission coefficient ranges from 0.122 – 0.786.

1. Introduction
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. These breakwaters have disadvantages due to its large dimensions and development costs. One potential type of breakwaters to be developed in order to reduce building dimensions and large development costs is the Hanging Sheet Pile. This type of breakwater is similar to a vertical pole breakwater. The first research on pole breakwater was conducted by Wiegel and reported that the transmission coefficient was only influenced by the distance between the cylindrical pole and the cylinder diameter [1]. Hayashi and Kano conducted a study of cylindrical pole breaks that focused on moment distribution on cylinder poles and wave transmission through breakwaters [2]. Hayasi and Kano then conducted and developed the theory about the effect of water spray through cylindrical pole breakwater. Furthermore, they also conducted experiments to verify the solutions developed earlier, and they reported that there is a difference between the developed analytical solutions with experimental results. Hayashi and Kano reasoned that this happened because the dissipation of energy in front of cylindrical poles, had been neglected. Furthermore, Hayashi et al revised the results of their research applying the assumption of waves in the shallow water, and then comparing
it with the experimental results. Hayashi et al. Reported that there was a lag between theory and experimental results and also reported that the greater the distance between the cylinders the greater the waves are transmitted. Truit and Herbich conducted a model test to determine the transmission of waves on vertical cylindrical poles and by varying the distance of the cylinder pile, their diameter and also with using irregular waves [3].

Truit and Herbich compared their research results with theories developed by Hayashi et al and reported that experiments have value closely with analytical solutions. Truit and Herbich therefore concluded that the formula developed by Hayashi et al yielded a corresponding result for irregular waves. Furthermore, Truit and Herbich investigated the effect of wave height and water depth on wave transmission and reported that wave parameters are important parameters affecting wave transmission, but the wave breaking geometry also plays an important role in wave transmission phenomena.

Herbich and Douglas continue the previous research that has been done by Truit and Herbich by conducting a study of vertical cylindrical pole breakwaters made two lines in the direction of wave propagation [4]. Results obtained from a two-row vertical cylindrical split are compared with one-line vertical cylindrical pole breakers. Herbich and Douglas reported that two-row vertical cylinders can reduce 15% of the transmission wave for the value of b/D = 0.2, where b is the distance between the cylindrical gaps while D is the diameter of the cylinder. For b/D = 0.1, a wave breaker with two vertical cylinder lines can reduce the transmission wave height by 10%. Herbich and Douglas also examined the effects of wave periods, wave heights and water depth and reported that the transmission waves increased with increasing of water depth due to wave heights (d/H) and transmission waves decreasing with increasing wave steepness (ratio between wave height and wavelength, H/L). Kukano and Liu examined the spread of waves through a single vertical cylindrical pole through theoretical development to solve the vertical cylinder spreading effect on the waves by modelling the flow around the vertical cylinder [5]. Kukano and Liu consider the energy dissipation between the cylindrical poles consisting of two shapes of pole, i.e. rectangular and round. Kukano and Liu reported that the results of his research can be trusted for certain cases, but further research is needed by varying the shape of vertical piles and wave characteristics. Mani and Jayakumar examined the transmission of waves on cylindrical poles hanging in one line [6]. Mani and Jayakumar vary the cylinder loads submerged in water (s), the spacing between the cylinder pole (b) and the wave parameters (height and period) and report that for b/d = 0.22 and y/h = 0.46, can reduce the coefficients transmission up to 0.5. For H/gT^2 greater than 0.008, breakwaters can reduce up to 50% and for H/gT^2 between 0.005 to 0.008 breakwaters can reduce up to 40% of the incident wave.

Rao and Satyananayana conducted a model study that focused on wave transmission through a two-row cylindrical pole breaker [7]. Rao and Satyananayana studied the effect of water depth, the steepness of the incident wave, the distance between the poles, and the distance between the pole-breaking pole lines to the wave transmission. Rao and Satyananayana also compared the solid type and hollow type of pole.

In conclusion the results of Rao and Satyananayana's research is the effect of water depth on the transmission of wave can be neglected both for breakwaters and perforated cylinders, the greater the wave steepness the smaller the wave transmission will be. The greater the inter-pole distance, the greater the transmission wave will be. The use of the breaker in a two-line pole, causes a decrease in the transmission wave. There is no difference between the two-line breakwaters for the hollow and solid poles; and the difference in continuing waves between the hollow and solid pole breakwater is negligible. The Koraim & Salem study undertakes to see the performance of a horizontal semi-circular split pipe supported by a vertical cylinder mantle in reflecting, transmitting and transmitting waves [8]. Koraim & Salem reported that the breakwaters would be effective if the semi-circular pipe is placed horizontally, the diameter of the semi-circle pole increases, the semicircular pole break splitting is 45°, the wavelength is greater than half the water depth, and the wavelength is greater than twice of water depth. Koraim [9] and Koraim, et al [10] examine the performance of hanging breakwaters made of L-shaped and C-shape bars that are laid flat with the support of vertical poles, through theoretical and experimental approaches for regular waves. The parameters studied were wavelength, L-shape and C-shape bars, the distance between L-shape and C-shape bars, diameter and spacing between vertical
supports. Koraim reported that the comparison between experimental results and theoretical predictions for the reflection, transmission and dissipation coefficients is excellent.

Paotonan conducts study on a pilecap type breakwater with an analytic approach to find the magnitude of wave height passing through the wave breaker represented by the value of the transmission coefficient \[1\]. This study also find that the construction cost of pilecap type breakwater is much cheaper than conventional breakwaters. Investment cost savings can be up to 72% more than conventional type breakwaters. Paotonan and Suyatno conducted research on stresses and deformations in sheet pile breakers by varying the gap width between sheet pile and constant wave parameters using ANSYS \[12\]. They also reported that the greater the width of the gap between the sheet pile, the less force, tension and deformation occur. The greater the stress, then the greater deformation will occurs, in nonlinear relationship. Previous research has not specifically examined the wave transmission on the breaking sheet pile. Therefore, this study focused to examine the effect of wave velocity \((H_i/gT^2)\) and relative depth \((s)\) of sheet pile breakwaters to wave energy transmission coefficient \((KE_t)\).

2. Theoretical Basis

The waves that travel from the deep sea to the coast and are blocked by buildings, some of their energy is reflected, some transmitted and others are dissipated. The magnitude of the reflected wave energy, dissipated and transmitted depends on the characteristics of the coming wave (period, height, and water depth), the type of building (smooth or rough surface, water pass or waterproof) and building geometry (slope, elevation and width of building height). The illustration of fluid interaction with sheet pile breakwaters can be seen in Figure 1.

![Figure 1. Illustration of fluid interaction with sheet pile breakwaters](image)

Figure 1 shows that \(H_i, H_r, H_d\) and \(H_t\) are the incident, reflection, dissipation & transmission wave height respectively. In the context of wave energy, the illustration in Fig. 1 can be formulated as follows;

\[ E_r = E_i + E_d + E_t \]  

(1)

If both sides of Eq. 1 divided by \(E_i\), then;

\[ \frac{E_r}{E_i} + \frac{E_d}{E_i} + \frac{E_t}{E_i} = 1 \]  

(2)

Based on linear wave theory, wave energy is formulated with;

\[ E = \frac{\rho g H^2}{8} \]  

(3)

If eq. 3 is substituted to eq. 1, the equation will be;

\[ \left( \frac{H_r}{H_i} \right)^2 + \left( \frac{H_d}{H_i} \right)^2 + \left( \frac{H_t}{H_i} \right)^2 = 1 \]  

(4)

or

\[ (K_r)^2 + (K_d)^2 + (K_t)^2 = 1 \]  

(5)
By measuring the wave height in front of the model \(H_i\) and the wave height behind the hanging sheet pile \(H_t\) model, the wave energy transmission coefficient \(KE_i = (K_i)^2\) can be calculated. The energy transmission coefficient of this wave will be influenced by two non-conventional parameters of wave steepness and relative draft; and can mathematically written as follows:

\[
KE_i = f \left( \frac{H_i}{gT^2} \right)\frac{s}{d}
\]

(6)

3. Experimental Setup
This research was conducted in the Ocean Technology Laboratory, Faculty of Engineering, Universitas Hasanuddin; through physical experiment using flume tank equipped with sophisticated wave generator. The wave generator used is a piston type wave maker consisting of actuators and electric motors. The wave flume is 24 meters long, with 1 meter width and 1.22 meters of height of probes. The model is placed inside a wave flume and reinforced with a wood and iron base. The sketch and laying of models within the wave flume can be seen in Fig. 2, 3 and 4.

**Figure 2.** Sketch of the breakwater

**Figure 3.** Model position inside the flume
Figure 4. Sketch of Hanging Sheet Pile Breakwater position inside wave flume

Depth of water used is \( d = 0.6 \) m. The wave period (\( T \)) was varied 5 times, i.e. 0.8 seconds, 1.2 seconds, 1.6 seconds, 2 seconds and 2.4 seconds. While the wave height (\( H \)) was varied as much as 5 times per period change (\( T \)) above, i.e. 0.032 m, 0.064 m, 0.096 m, 0.128 m and 0.160 m. Variable draft of sheet pile set \( s_1 = d \), \( s_2 = 0.75 \)d and \( s_3 = 0.50 \)d or relative draft \((s/d)\) consisting of 0.50; 0.75 and 1.00. The distance between the sheet pile at the width of the flume was set \( b = 0.005 \) m (0.5 cm).

4. Result and Discussion

By varying wave height, \( H \), the wave period, \( T \), at a water depth of 0.60 m, and varying the structure draft \((s)\) that immersed in water and also specifying the gap width or spacing of the sheet pile, \( b = 0.005 \) m, and measuring of the wave height in front and behind the model, then \( H_i \) as incident wave height, and wave transmission height, \( H_t \), can be calculated. Totally there are 8 probes used in this study, i.e. 4 in front of the model and 4 behind the model. When wave comes in, \( H_i \) is calculated using data on the probe placed in front of the model. While the transmission wave height, \( H_t \) is calculated using the data on the probe placed behind the model. The formula for calculating \( H_i \) and \( H_t \) is as follows.

\[
H_i = \frac{H_{\text{max}} + H_{\text{min}}}{2} \quad \text{(Front)}
\]

\[
H_t = \frac{H_{\text{max}} + H_{\text{min}}}{2} \quad \text{(Back)}
\]

With knowing \( H_i \) and \( H_t \), KE\(_t\) values then can be calculated. Based on the incident wave height data, transmission wave height, wave period and full structure and water depth the steepness of wave, \( H_i/gT^2 \) and relative load \((s/d)\) can be calculated. The value of \( T \), \( H_i \), KE\(_t\), \( H_i/gT^2 \) and \( s/d \) can be seen in Table 1. Using the two values of non-dimensional parameters, KE\(_t\) values are presented in graphical form. The effect of \( H_i/gT^2 \) to KE\(_t\) value can be seen in Fig.5 to 7.

Figure 5. Effect of \( H_i/gT^2 \) on KE\(_t\) for \( s/d = 0.50 \) and width slit \((b) = 0.005 \) m
Figure 6. Effect of $H_i/gT^2$ on $KE_t$ for $s/d = 0.75$ and width slit (b) = 0.005 m

Figure 7. Effect of $H_i/gT^2$ on $KE_t$ for $s/d = 1.00$ and width slit (b) = 0.005 m

Table 1. Value of $H_i$, $H_t$, $H_i/gT^2$ and $KE_t$ for various value of $s/d$

| T(S) | Hi  | Hi  | Hi  | Hi  | Ht  | Ht  | Hi/gT^2 | Hi/gT^2 | KEt  | KEt  | KEt  |
|------|-----|-----|-----|-----|-----|-----|---------|---------|------|------|------|
|      | s/d=1 | s/d=0.75 | s/d=0.5 | s/d=1 | s/d=0.75 | s/d=0.5 | s/d=1 | s/d=0.75 | s/d=0.5 | s/d=1 | s/d=0.75 | s/d=0.5 |
| 0.80 | 0.06 | 0.06 | 0.06 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.31 | 0.29 | 0.31 |
| 0.80 | 0.12 | 0.14 | 0.14 | 0.05 | 0.05 | 0.05 | 0.02 | 0.02 | 0.02 | 0.17 | 0.12 | 0.13 |
| 0.80 | 0.21 | 0.18 | 0.15 | 0.09 | 0.09 | 0.08 | 0.03 | 0.03 | 0.02 | 0.19 | 0.24 | 0.29 |
| 0.80 | 0.22 | 0.27 | 0.23 | 0.13 | 0.10 | 0.12 | 0.04 | 0.04 | 0.04 | 0.32 | 0.14 | 0.25 |
| 0.80 | 0.21 | 0.26 | 0.26 | 0.13 | 0.10 | 0.12 | 0.03 | 0.04 | 0.04 | 0.39 | 0.15 | 0.20 |
| 1.20 | 0.04 | 0.04 | 0.04 | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.35 | 0.21 | 0.24 |
| 1.20 | 0.08 | 0.08 | 0.09 | 0.04 | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 | 0.20 | 0.15 | 0.12 |
| 1.20 | 0.13 | 0.13 | 0.13 | 0.06 | 0.05 | 0.04 | 0.01 | 0.01 | 0.01 | 0.20 | 0.14 | 0.10 |
| 1.20 | 0.17 | 0.16 | 0.16 | 0.07 | 0.07 | 0.05 | 0.01 | 0.01 | 0.01 | 0.16 | 0.16 | 0.10 |
| 1.20 | 0.20 | 0.21 | 0.19 | 0.08 | 0.07 | 0.06 | 0.01 | 0.01 | 0.01 | 0.15 | 0.12 | 0.10 |
| 1.60 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.86 | 0.79 | 0.72 |
| 1.60 | 0.06 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.73 | 0.72 | 0.63 |
| 1.60 | 0.08 | 0.08 | 0.09 | 0.07 | 0.07 | 0.07 | 0.00 | 0.00 | 0.00 | 0.68 | 0.67 | 0.51 |
| 1.60 | 0.12 | 0.12 | 0.14 | 0.10 | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 0.72 | 0.60 | 0.44 |
| 1.60 | 0.15 | 0.18 | 0.21 | 0.12 | 0.13 | 0.13 | 0.01 | 0.01 | 0.01 | 0.66 | 0.57 | 0.37 |
| 2.00 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.73 | 0.74 | 0.58 |
Fig. 5 to 7 shows that an increasing wave steepness, \((H_i/gT^2)\), will cause a decreasing value of the transmission wave energy coefficient, \((K_{Et})\). This indicates that the steeper the waves come in front of the sheet pile breakwaters model, will cause a shrinking ratio of wave height behind and the front of the model. This phenomenon occurs because a wave with a large steepness occurs significant turbulence in front of the model and causing a decrease in wave height passing the model relative to the incident wave height. But note that the distribution of data for all is relatively large. For all the values of s/d are shown in Figures 5 to 7, for the \((H_i/gT^2)\) less than 0.01, the decreasing of \((K_{Et})\) due to the increasing of \((H_i/gT^2)\), is significant. Meanwhile on the value of \((H_i/gT^2)\) greater than 0.01, the increasing of \((H_i/gT^2)\) is relatively have a small effect on the changing of \((K_{Et})\).

The second objective of this study was to determine the draft relative effect (s/d) on the transmission energy coefficient. Therefore, by combining the graphs in Fig. 5 to 7 visualization of the effect s/d graphically can be done. The effect of s/d against \((K_{Et})\) for various values \((H_i/gT^2)\) can be seen in Figure 8.

**Figure 8.** Effect of s/d due to \(K_{Et}\) for several value of \(H_i/gT^2\)

Figure 8 shows that when experiments in no-model scheme, the energy transmission coefficient is close to 1. This means, there is no wave energy damping occurs. This can be seen on the flat \(K_{Et}\) graphical line as \(H_i/gT^2\) function at the same ordinate value of 1. Figure 8 also shows that the \(K_{Et}\) graph for the hanging sheet pile model with s/d 0.50 is above the \(K_{Et}\) graph for the model with s/d 0.75 and 1.00. This means that for the constant value of \(H_i/gT^2\), the greater value of s/d, the smaller of the \(K_{Et}\), will be, and it means the more effective the model for reducing the incoming wave energy. Nevertheless, the difference value of \(K_{Et}\) for model with s/d equal to 0.50 and 0.75, is relatively
small. Even for the value of $H/gT^2$ equal or greater than 0.01, the KE_t graphical line for s/d 0.50 and 0.75 is almost coincide. This means that when the value of $H/gT^2$ is greater or equal to 0.01, it will not be much benefit, although it enlarges the value s/d from the point of view of wave energy damping by the sheet pile breakwaters. The dissemination phenomena of KE_t as a considerable Hi/gT^2 function, may be caused by several things:

a. In certain wave simulations (high and large wave periods), the model becomes unstable and tends to move following the wave motion. So that in certain periods, the KE_t value increases as the resonant effect of the transmission wave and the reflection of the wave absorbers at the flume end

b. The wave absorber that is located at the end of the flume is less effective in reducing the reverse wave, which result an increasing wave height behind the model.

5. Conclusion
Based on the above discussions, the following concluded several things, namely:
1. The damping of wave energy through the hanging sheet pile breakwater is influenced by the draft structure (s), width of the structure gap (b), the incident wave height (H) and the wave period (T)
2. The greater value of wave steepness ($H/gT^2$) and the draft relative (s/d), then the smaller transmission energy coefficient (KE_t) will be.

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