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THE DIMENSION EFFECT OF ROUGH PIPE ARRANGEMENT ON WAVE TRANSMISSION AND WAVE REFLECTION AS POROUS BREAKWATER STRUCTURE

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ABSTRACT

Waves that propagate through a form of porous breakwater structure below the water surface will be transmitted. The structural model of the porous breakwater is designed with a position perpendicular to the wave arrival direction at the wave generating flume, which functions in addition to reducing the incident wave's energy and minimizing wave reflection. This study aims to determine the effect of variations in the length of the pipe model, the diameter of the pipe model and the height of the pipe model structure. Laboratory experiment research by varying the length of the pipe arranged in such a way that the friction plane hole in the model is in the same direction as the incoming wave with variations in water depth (d_1=30 cm; d_2=33 cm and d_3=36 cm) and variations in pipe diameter (D_1 = 15 cm, D_2 = 10 cm and D_3 = 7,5 cm). The results showed that the structure's length and height with a much smaller diameter decrease the transmission wave, and the reflection wave is relatively constant.

Keywords: dimensions of rough pipe arrangement, coefficient of transmission, coefficien of reflection.

INTRODUCTION

The building of the coastal structure serves to anticipate and control abrasion, maintaining the coastline by reducing the energy of the coming waves that hit the coast (Syamsuri *et al*, 2019). Conventional emerged rubble mound breakwaters are commonly built to protect ports and marinas from direct wave action (Park, 2017).

With increased high-valued developments in the coastal region, engineers must design innovative coastal protection structures that can provide adequate harbor tranquility with minimum visual impact (Kamath, 2018). Submerged breakwater as the main structure of coastal engineering to protect coast is widely laid on the seabed because of its significant wave-dissipation performance (Triatmodjo, 2011). To design a reliable breakwater that will withstand severe environmental conditions, accurate prediction of hydrodynamic interactions with multi-bodied structures must be considered (Koley, 2019).

The breakwater structure has recently undergone research developments, one of which is the porous breakwater structure developed by Quin (Quin, 1972) by trying to reduce the wave force hitting the front of the breakwater. Porous breakwaters have varied models that are expected to minimize wave reflections and reduce wave transmission, an upright and impermeable building will reflect large waves than sloping and permeable buildings (Triatmodjo, 1999). In addition, if the wave passes through an obstacle with a rough plane surface, then the wave energy will decrease as the rough plane surface increases, the larger the rough surface to the wave energy passing through it then the wave transmitted will decrease by reducing the wave energy (Triatmodjo, 2011). With mentioned basics, our research maximized the dimensions of rough pipe arrangement as a porous breakwater structure by increasing the magnitude of the friction areas dimensions on the surface of the pipe wall to analyze the model parameters against the length of the pipe and the diameter of the pipe, so it is expected to be more effective in reducing the waves that come. In addition, this study developed coastal buildings as porous breakwater structures that are effective, efficient, and economical by reducing materials as wave dampers.

The purpose of this study is to review the potential area of friction of rough pipe arrangement dimensions as a porous breakwater against wave height reduction (Triatmodjo, 1993).

LITERATURE STUDY

Wave Characteristics

Wave characteristics are grouped by the ratio between wave height (H) and wavelength (L). This grouping is known to be small-amplitude waves and finite-amplitude waves. Small amplitude waves of water particles move in a trajectory and have a circular or elliptical closed orbital motion called linear waves. Stokes' theory of the particle's orbit is not closed, i.e. nonlinear waves have an orbit that continues to the next orbit, causing the flow of water mass in the direction of wave alignment (Koraim, 2014).

When the wave spreads, the water particles move in a small vertical circle and remain in position as the shape and energy of the wave progress. Water particles on the surface move in a large circle and form wave peaks at

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the top of circles and wave valleys at the lowest trajectory. Below the surface, water moves in circles that get smaller to a depth greater than half the wavelength (Koraim, 2014). Figure-1(a) indicates the orbital movement of closed particles at small amplitude waves, and Figure 1(b) opened orbit of water particles according to Stokes's theory as follows (Dean, 1984) :

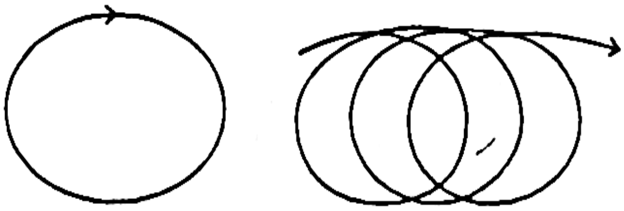

Figure-1. a) Closed Particle Orbit; b) Opened Particle Orbit.

During the propagation of waves from the deep sea to the shallow sea, the orbits of the particles change shape. The particle displacement orbit is circular at all depths in the deep ocean. In transitional seas and shallow seas, the paths of particles are elliptical-the greater the depth, the flatter the ellipse. And at the base, the motion of the particles is horizontal. If the wave orbit passes through the dimensions of the pipe model of the porous breakwater structure, there will be a change in the wave characteristics that requires a complete and accurate analysis (Zhao, 2021). It is necessary to decompose the incident wave into two components, according to the incidence angle and the permeability of the two breakwaters that form the gap (Yu, 1997).

Parameters of Porous Breakwater Structure

Wave reflection occurs when the incoming wave hits a wall or barrier, such as a breakwater. A superposition occurs where the height of the incident wave and the reflected wave will be greater than the height of the initial incident wave. The superposition wave height event was recorded in the experiment at the base of the model front (Goda, 1976).

The ability of a building to reflect waves is given by the reflection coefficient, which is the ratio between the height of the reflection wave (H_r) and the height of the incoming wave (H_i) (Metallinos, 2016). The different layers of the breakwater consist of rubble of different sizes and having different structural properties. The wave reflection parameter is usually expressed in terms of the reflection coefficient (K_r) which is defined as follows:

$$K_r = \frac{H_r}{H_i} = \sqrt{\frac{E_r}{E_i}} \quad (1)$$

Where the reflection energy $Er = \frac{1}{8}\rho g Hr^2$ and the energy of the incoming wave is $Ei = \frac{1}{8}\rho g Hi^2$ with ρ is the density of the liquid and g is the acceleration of gravity. The K_r value ranges from 1.0 for total reflection to 0 for no reflection.

Wave transmission (H_t) is the height of the wave transmitted through the obstacle and is measured by the transmission coefficient (K_t) calculated by the following equation:

$$K_t = \frac{H_t}{H_i} = \sqrt{\frac{E_t}{E_i}} \quad (2)$$

Where the energy of the transmission wave is $E_t = \frac{1}{8}\rho g H_t^2$. Incoming wave height ($H_i$) and the height of transmission wave (H_t) is the average wave height of the maximum and minimum measured wave heights before and after crossing obstacles, respectively. While the reflection wave height (H_r) is half of the difference between the maximum and minimum wave heights measured before crossing the obstacle.

According to Horikawa (Horikawa, 1978) that the amount of wave energy dissipated/damped (K_d) is the energy of the incident wave minus the energy of the transmitted and reflected waves (Paotonan, 2006):

$$K_d = 1 - K_t - K_r \quad (3)$$

As a wave propagates under frictional conditions, the wave height will decrease exponentially. The wavelength will decrease with friction, causing a decrease in the speed of wave propagation. Thus increasing the coefficient of friction will reduce the wave height (Ruey-Shah, 2015). Choosing different percentages of porosities makes it possible to achieve maximum energy dissipation with minimum transmitted energy (El Saie, 2019).

METHODOLOGY

Experimental research is conducted in the laboratory using a porous breakwater model an arranged in rows and columns so that the holes in the pipe model face the direction of the incoming waves. The length, width and height of the porous breakwater model are set according to the design plan.

This research uses a glass-walled wave channel equipment with a steel frame equipped with a generator to move the flap as a wave generator from the front of the model and a wave damping device located at the rear end of the flume where the length of the flume is 15 m, the width of the flume is 0.3 m and the effective height flume 0.8 m. Here are 3 variations of the length of the pipe model and 3 variations of the pipe diameter as shown in Figure-2. Below:

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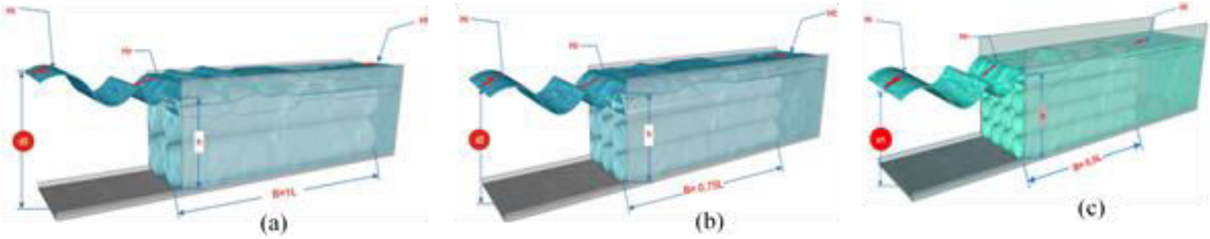

Figure-2. Pipe length variation (B) and pipe diameter (D). a). B_3 = 1,0L and D_1=15 cm; b). B_2 = 0,75L and D_2 = 10 cm; c) B_1 = 0,5L dan D_3 = 7,5 cm.

Some of the materials used in the research are porous breakwater models, namely the arrangement of rough PVC pipes that are assembled with the size of the model width (P) = 30 cm (adjusted to flume width), and model height (h) = 29 cm and 30 cm (adjusted to pipe diameter).

Model length = (B_1 = *94,5 cm*, B_2 = *141,75 cm*, B_3 = *189 cm*), pipe diameter (D_1 = 15 cm, D_2 = 10 cm, D_3 = 7,5 cm). Figure-3. Shows the variation of water depth in the following three porous breakwater models:

Figure-3. Variation of water depth a) d_1 = 1.0h (0.29 m); b) d_2 = 1.1h (0.32 m); c) d_3 = 1.2h (0.36 m).

Prior to data collection, the water depth (d) was set with 3 variations, namely d_3 = 1.2h (0.36 m); d_2 = 1.1h (0.32 m) and d_1 = 1.0h (0.29 m), and determine the variation of the wave period, namely T_1 = 1.0 seconds, T_2 = 1.1 seconds and T_3 = 1.2 seconds, where h is the model's height (29 cm and 30 cm). The model's position is parallel to the direction of the incoming wave on the wave channel flume and is in the right position so that it is effective in measuring the height of the incident wave and the height of the reflection wave at the base of the model.

RESULTS AND DISCUSSIONS

Analysis Coefficient of Transmission and Coefficient of Reflection

Several test parameters were varied to know the wave response to the porous breakwater structure. For example, the length of the pipe model and the diameter of the pipe model are varied structures. At the same time, the wave height, wave period, and water depth are also variable wave parameters. The following are the results of the analysis of the calculation of the coefficient of transmission and wave coefficient of reflection as representative of various variations of data collection experiments (Syamsuri *et al*, 2021):

a) Coefficient of Transmission (K_t)

The analysis for the value of the coefficient of transmission is the comparison between the height of the transmission wave and the height of the incident wave. The following is one of the results of the calculation analysis on 1LD7.5 K_0, namely H_t = 1.0948 cm and H_i = 5.6528 cm, so that:

$$K_t = \frac{Ht}{Hi} = \frac{1.0948}{5.6528} = 0.1937$$

b) Coefficient of Reflection (K_r)

The analysis for the coefficient of reflection value is the ratio between the height of the reflected wave and the height of the incident wave. The following is one of the results of the calculation analysis on 1LD7.5 K0, namely H_r = 1.9624 cm and H_i = 5.6528 cm, so that:

$$K_r = \frac{Hr}{Hi} = \frac{1.9624}{5.6528} = 0.3472$$

c) Coefficient of Dissipation (K_d)

The analysis for the value of the coefficient of dissipation is the magnitude of the incident wave energy minus the transmitted and reflected wave energy.

The following is one of the results of the calculation analysis on 1LD7.5 K_0 by using K_t = 0.1937 and K_r = 0.3472, so that:

$$1 = K_t^2 + K_r^2 + K_d^2$$
$$K_d = \sqrt{1 - (Kt^2 + Kr^2)}$$
$$K_d = \sqrt{1 - (0.1937^2 + 0.3472^2)}$$
$$K_d = \sqrt{1 - (0.0375 + 0.1205)}$$
$$K_d = \sqrt{0.842}$$
$$K_d = 0.9176$$

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Coefficien of transmission calculation (K_t), coefficient of reflection (K_r) and coefficient of dissipation (K_d) is the result of analysis of data retrieval of transmission wave height, reflection wave height, and dissipation wave height. Furthermore, it will be included in the comparison graph of the effect of the relative length of the model on K_t and K_r to get the results of the analysis of changes in transmission and reflection.

Effect of model's relative length $\left(\frac{B}{h}\right)$ to K_t; K_r

Effect of model's relative length $\left(\frac{B}{h}\right)$ is the ratio between the length of the model (B) and the height of the model (h), has 3 variations of the length of the model (B) namely 1.0L = 189 cm, 0.75L = 142 cm and 0.5L = 95 cm (L is the wavelength) and 2 variations in model height (h) namely (h_1 = 29 cm dan h_1 = 30 cm) with 3 different water depths (d) (d_1=30 cm; d_2=33 cm and d_3=36 cm) to examine the effect of the relative length of the model $\left(\frac{B}{h}\right)$ to (K_t), and (K_r) on model 1.0LD; 0.75LD and 0.5LD. The results of the analysis of the calculation of the relative length of the model $\left(\frac{B}{h}\right)$ on K_t and K_r, one of them is on the 1LD7.5 model as follows:

$$\frac{B}{h} = \frac{189}{30} = 6.30 \qquad (4)$$

Where: B = length of pipe structure
h = model height

Figure-4. shows the relationship of the effect of the relative length of the $\left(\frac{B}{h}\right)$ model on the coefficient of transmission (K_t) in 3 variations of pipe diameter (D_1 = 15 cm, D_2 = 10 cm, D_3 = 7.5 cm), as follows:

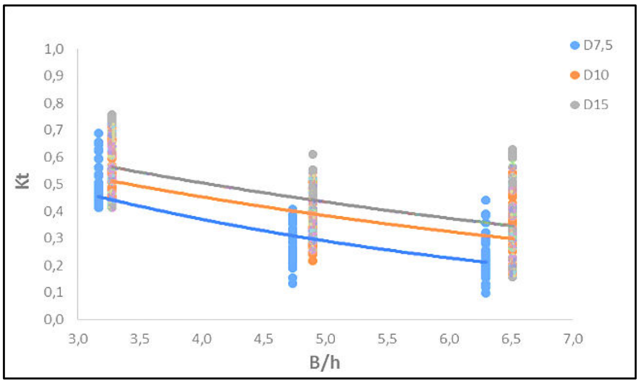

Figure-4. Relation between $\frac{B}{h}$ to K_t on D_1 = 15; D_2= 10; D_3 = 7.5.

Figure-4 show a decrease in the value of the coefficient of transmission (K_t) which is significant as the relative length of the model increases $\left(\frac{B}{h}\right)$, if B is getting longer and h is constant, then K_t decreases. Relation between $\frac{B}{h}$ and K_t on the three models with different pipe, diameters showed a significant decrease in the value of K_t. Because the smaller the pipe diameter and the longer the pipe indicates that the frictional area on the rough pipe wall is getting bigger. The smaller the diameter of the model, the circular wave-particle orbits that pass through the hole will experience a change in shape so that the waves that pass through the frictional hole experience a decrease in wave energy, resulting in the wave being transmitted/escaped decreasing, where the value of K_t at D15 = 0.35 – 0.58; D10 = 0.28 – 0.50; and D7.5 = 0.20 - 0.45.

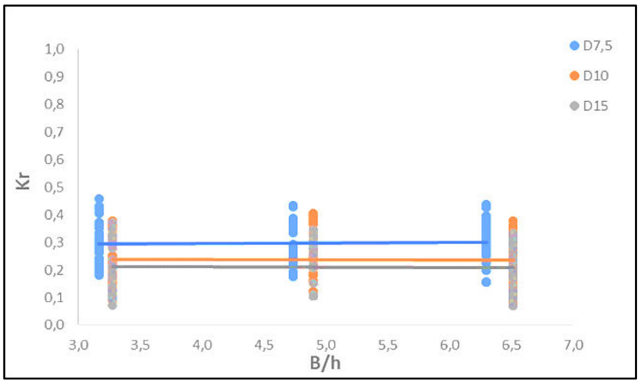

Figure-5. Relation between $\frac{B}{h}$ to K_r on D_1 = 15; D_2= 10; D_3 = 7.5.

Figure-5 shows the relative length relationship of the model $\left(\frac{B}{h}\right)$ to the coefficient of reflection (K_r) on the three models that have different lengths. This shows that the value of K_r did not experience a significant increase with increasing pipe length. The smaller the diameter of the pipe in the model, the greater the reflected field, so that the orbit of the wave particles that come on to the model will experience a greater reflection than the larger diameter because it has a smaller reflecting field, but in the three models with the same pipe diameter, different has a significant effect on the difference in the value of K_r on D7.5; D10; D15, where K_r for D15 = 0.20 – 0.20; D10 = 0.22 – 0.23; and D7.5 = 0.28 – 0.30.

CONCLUSIONS

The analysis results show that the transmission wave height and the resulting reflection wave height are strongly influenced by the length of the pipe, the height of the structure, and the diameter of the pipe. The longer the pipe and the higher the structure, the greater the friction field, which can reduce the height of the incident wave so that the transmitted wave decreases. While the height of the resulting reflection wave is influenced by the diameter of the pipe and the height of the model structure, the smaller the diameter of the pipe and the higher the structure, the resulting reflection wave increases even though the trend is constant.

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