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THE BREAKWATER, FROM WAVE BREAKER TO WAVE CATCHER

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Abstract

The function of breakwater as a wave energy breaker needs to be changed into a coastal protection that can capture wave energy. Such Innovation is important for the maritime state that un-renewable energy was in critical deposit. This study examines the magnitude of the wave energy that can be captured through the slope breakwater over-topping. This research was conducted by physical model simulations at the Laboratory of Coastal Engineering, Department of Civil Engineering, Hasanuddin University. Physical model simulation 1:20 in geometric scale have been performed under regular wave conditions to simulate six types of structure model where differ in slope and height of free-board. The results showed an over-topping discharge (q) is significantly influenced by the parameters of the breakwater free-board relative to the wave height (R/H_i), the slope of the structure ($\tan \alpha$) and wave steepness (H_s/L_o). The result of over-topping discharge (q) equation was found smaller than the Van Der Meer result in the breaker parameter (z_p) less than 2, while in the z_p higher than 2, the rate of q is much larger than the Van Der Meer rate. The power efficiency achievement is about 7.4% on average for z_p smaller than 2, while the power efficiency for z_p higher than 2 is about 34% in average.

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1. Introduction

The rubble mound type of the breakwater is one of the famous and mostly used in the world as coastal defense structures. The breakwater serves to reduce incoming wave energy in protecting certain coastal areas from wave attack. Reduction wave energy through dissipating and/or reflecting whole or a part of the wave energy. The magnitudes of the wave energy are consist of energy dissipated (E_d), the reflected portion (E_r) and energy transmitted (E_t) that can be determined based on the law of energy conservation in which the incoming wave energy (E_i) is equal to $E_d + E_r + E_t$. The best rubble mound breakwater is the breakwater that can be dissipated a large portion of incoming energy and therefore the transmitted and reflected wave becomes small. Based on Hudson formula, a larger wave energy to dissipate, a larger weight (W) of grain of rubble mound materials will be required. This condition will be influenced the cost of construction.

This paper presents a partial result of research works related to the paradigm change of the functions of breakwater from the wave energy breaker to the wave energy catcher without reducing its main function as coastal protection structure. The capture wave energy to be utilized as a power resource. Catching the wave energy is done by creating a reservoir at the top crest of the structure that serves to capture the over-topping discharge through the wave run-up on the slope walls of structure. This mechanism will produce differential water level between reservoir and still sea water level as a pressure head. A pressure head and over-topping discharge are the important parameter for power generation.

2. Wave Energy & Power

Wave motion besides giving the movement of the water particles orbitally, also provide flux energy of waves. Wave energy is composed of two types, namely kinetic energy (E_k) and potential energy (E_p). The kinetic energy is caused by the orbital particle velocity in the wave motion. While the potential energy is due to the displacement of the water table due to wave motion. The total energy of the wave is combined kinetic energy and potential energy ($E = E_k + E_p$). From the basic energy formula both for kinetic and potential with the assumption of sinusoidal wave conditions, the wave energy can develop. Finally, we found the magnitude of E_k and E_p in the unity of wavelength and width are $1/16$ ($\rho g H^2 L$) and the total wave energy per unit crest width E (Sorensen, R., M., 2006) is:

$$E = 1/8 (\rho g H^2 L) \quad (1)$$

Where, ρ is the mass density of water (kg/m^3), g is the acceleration due to gravity (m/s^2), H is the wave height (m) and L is the length of wave that can be calculated by $L = gT^2/2\pi \tanh 2\pi d/L$. Wavelength in deep sea can be computed by $gT^2/2\pi$.

Wave power (P) is the wave energy per unit time transmitted in the direction of wave propagation. The wave induced force is provided by the dynamic pressure (total pressure minus hydrostatic pressure) and the flow velocity is the horizontal component of particle velocity. Thus

$$P = \frac{1}{T} \int_0^T \int_{-d}^0 (p + \rho g z) u dz dt \quad (2)$$

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Where the term in parentheses is the dynamic pressure. Inserting the dynamic pressure equation and the horizontal component of velocity and integrating lead to:

$$P = \frac{\rho g H^2 L}{16T} \left[1 + \frac{2kd}{\sinh 2kd} \right] \quad (3)$$

Or

$$P = \frac{nE}{T} \quad (4)$$

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Where, n is the water depth parameter. The value of n increases as a wave propagates toward the shore from 0.5 in deep water to 1.0 in shallow water. Water power (P_r) contained in an elevated reservoir can be calculated with the following equation (Triatmodjo, 2003):

$$P_r = \rho g q h \quad (5)$$

Where, q is the over-topping discharge and h is the pressure head from the differential of surface water level between reservoir and the sea.

Wave Energy Converter

There are several types of marine energy potential that can be exploited, i.e wave energy, tidal energy, energy of currents and ocean thermal energy. The ocean waves are a source of energy that has great potential. Waves that propagate from the deep sea to the shore actually not transported the water but there propagate the energy. Research on power wave technology has done a lot since before. Some of finding system is Oscillating Water Column (OWC), wall and the piston flap system, tapered channel, buoys etc.

Tapered channel technology is one method that has been widely developed because it has several advantages, among which the penstock flow for turbine generation is a steady flow that have changed from the unsteady flow. The main principle of the tapered channel type is capturing the water wave over-topping into a reservoir that has a higher elevation from sea level. The difference in water level between the reservoir and the sea is obtained as pressure head as the important parameter for water power parameter.

Samuel (2010) examined the analysis of wave over-topping for Seawave Slot-cone Generator (SSG) model. The study was conducted by using a test laboratory experiments and numerical simulations. From the results of these studies showed that the effect of wave height is directly proportional to the total volume of over-topping, the greater the wave height, the greater the volume of over-topping. While the influence of the wave period is inversely proportional to the total volume of over-topping, small period has great potential energy that the greater volume of over-topping. The influence of the angle (slope) is small (taper) can provide great value over-topping volumes. The influence of the angle has an important role in wave propagation distance and place (space) to change the wave energy into electrical energy.

(Lee & Lee, 2013) has studied the development of wave power generation device with resonance channel. This study discusses the effect of resonance channel, wave height (H), wave period (T), and the slope of the model to the runoff volume/over-topping discharge into the reservoir and the water level in the reservoir with numerical models. The results of numerical experiments show that the maximum height of the water level in the reservoir is when the slope of the model is 30 degrees with or without a runoff slope above the resonance line. Based on these explanations is known that the flow path of the wave power generation device can consist of two flow paths, ie, the first flow path

through the channel can over-topping (resonance channel), second, over-topping flow paths can be through the peak of the wave power generation device, so can also be said flow path can be through both.

Thaha, M., A., et al (2013) has examined the efficiency of Baron Wave Power Plant through 3D physical model simulation and found several factors that affect the efficiency of wave energy catching on tapered channel models, there are collector geometric wall, the alignment of the channel direction and magnitude of the wave deformation due to the roughness of the slope.

Wave converter devices presented in this paper are the conventional rubble mound breakwater model were modified the slope surface from rough becomes smooth to minimize friction between the surface of a structure and the run-up flow on the slope and therefore it is expected to achieve the maximum over-topping discharge. In the same research object Dwipuspita A., I. (2014) was found that the over-topping discharge is much affected by the relative freeboard, the slope of the structure and wave steepness. The larger the free-board and the wave steepness the smaller over-topping discharge and the smaller the structure slope the smaller the over-topping flow rate.

3. Literature Review

Earliest information on calculating over-topping rates was found since the 1950s (Reeve, D. et al, 2004), the results of which are presented in the Shore Protection Manual SPM (1984). This was developed by a number of researchers and mostly by Owen (1980) who established the formulation that continues to be used today. In the next steps, comprehensive works of over-topping which addresses for different structural forms has been carried out and published by HR Wallingford. The mean over-topping discharge for a plain rough-armored slope may be calculated by the following equations:

$$R^* = \frac{R_c}{(T_m(gH_s)^{0.5})} \quad (6)$$

$$q^* = a \exp\left[-\frac{bR_s}{r}\right] \quad (7)$$

Where, a and b are empirical coefficients depends on the slope of the structure and r is the roughness coefficient. R_c is the free-board defined as the height of the crest above the still water level, H_s is the significant wave height, g is acceleration due to gravity and T_m the mean period of the wave at the toe of the structure. Equation (above) is valid between the limit $0.05 < R^* < 0.30$. The mean over-topping discharge rate per meter length of the structure in $m^3/s/m$ is $q = q^* T_m$.

Recent work by Van Der Meer and Janssen (1995) in Pilczyk, K., W., (1998) on the flatter and composite structures produced a former formula on wave over-topping, made a distinction between breaking (plunging) and non-breaking (surging) waves on the slope. The new set of formulae relates to breaking waves and is valid up to a maximum which is in fact the non-breaking region. This procedure is in accordance with wave run-up on a slope. The new (rewritten) formula (Van Der Meer, 2002) for wave over-topping on dikes is as follows :

$$\frac{q}{\sqrt{gH_s^3}} = \frac{0.06}{\sqrt{\tan\alpha}} \gamma_b z_p \exp\left[-4.7 \frac{R_c}{H_s} \frac{1}{z_p \gamma_b \gamma_f \gamma_\beta \gamma_\theta}\right] \quad (8)$$

Equation (8) will be valid for the range of $z_p \leq 2$, while the maximum value such presented in Equation (9) will be valid in the range of $z_p \geq 2$.

$$\frac{q}{\sqrt{gH_s^3}} = 0.2 \exp\left[-2.3 \frac{R_c}{H_s} \frac{1}{\gamma_f \gamma_\beta}\right] \quad (9)$$

Where, $\tan \alpha$ is the slope of the structure; $z_p = \tan \alpha / (s_p)^{0.5}$ is breaker parameter; s_p is wave steepness; $\#_b$, $\#_i$, $\#_v$ and $\#_3$ are a reduction factor for a berm, slope roughness, oblique wave attack and vertical wall on slope respectively.

The concept of energy conservation in these works is $E_i = E_t + E_r + E_d + E_c$, where E_c is the caught wave energy into the reservoir. Transmitted wave energy (E_t) assumes will be zero due to no waves passing the reservoir. Dissipated energy (E_d) will depend on the value of the wave conditions, especially the type of the wave breaking over sloping walls. According to Van Der Meer and Janssen (1995) in KW Pilarczyk (1998), the wave will break on the value $z_p < 2$ or slope $\leq 1 : 3$. In this condition, the value of E_d would be great, otherwise E_c and E_r will be small. The expected conditions in the experiment is the value of each becomes larger, while E_r and E_d became a smaller. This condition will be obtained through great value of over-topping discharge, while the large volume of over-topping rate will be obtained on the value $z_p > 2$ or slope $\geq 1 : 3$ to a certain limitation.

Over-topping discharge (q) is much influenced by wave and structure characteristics. The EuroTop Team (2007) obtains that the wave steepness is much affected exponential to the overtopping rate. Bao C., H., et al. (2014) found that the wave over-topping flux is influenced by wave period. Besides, it is also strongly influenced by the waves breaking types on the slope of the structure. Wave breaking type is divided into 3 types, namely spilling, plunging and surging breaker. Among the three types of wave breaking are predicted to provide larger over-topping flow rate than the other two types are the type of surging. This is because the type of surging where waves are considered late rupture, although there will still be broken. Classification of breaker type related to the over-topping discharge summarized by Schuttrumpf, et. al. (2007) in Dwipusita (2014) where the Equation (8) applies to $z_p < 2$ with spilling and plunging wave conditions, while the maximum value of Equation (9) applies to $z_p > 2$ the type of breaker is surging wave conditions.

4. Methodology

The study was conducted with physical model simulation in The Coastal Engineering Laboratory, Department of Civil Engineering, Hasanuddin University, Indonesia with 1:20 geometric scale. The simulations were performed in the 1500 cm x 30 cm x 45 cm wave flume. The breakwater model made from acrylic material in the various slopes and free-board to study the influence of those variables to the over-topping rate. In order to catch the over-topping rate, the model equipped with reservoir behind the structure crest. Sectional illustration of the experiment is presented in Figure 1.

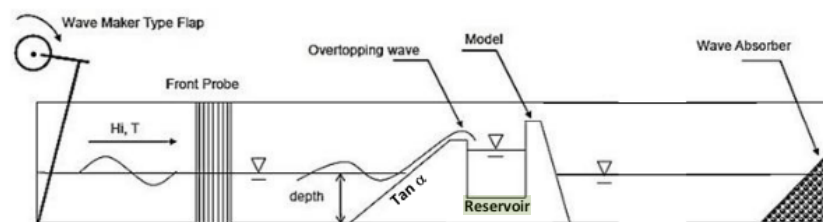


Fig.1. Setup model in the wave flume.

Six types of model are distinguished on the slope and free-board height was simulated with the various regular wave heights (4 cm to 10 cm) and period (0.95 s to 2 s) as well as water depth (17.5 m to 22.5 cm). The variables studied were over-topping discharge in the unit length of structure crest (q) through the measurement of water level in the reservoir, the height and period of incident waves as well as reflected waves. Non-dimensional parameters

derived by the Stepwise method involves influencing parameters of which are free-board height (R_c), the slope of the structure ($\tan \alpha$) and wave steepness (H_i/L_o). The results were compared to the Van Der Meer equations. From waves energy conservation can be determined amount of energy waves that can be captured and mobilized into electrical power.

5. Results and Discussion

The results of this study are presented chronologically from obtaining curve and equation for over-topping discharge based on the research boundaries that has been set out previously, then presented the distribution of wave energy, wave power and scale mapping efficiency obtained. Restrictions research may include the type of wave that is used and over-topping discharge analysis is divided into two categories, namely breaker parameters (z_p) < 2 and z_p > 2. The wave type used in the previous studies generally irregular waves that represented by the significant wave height (H_s), while in this study, the wave that is used is a regular wave in which all of the incoming wave height (H_i) are taking into account. Figure 2a presents the non dimensional relationship between over-topping discharge (q) and the relative free-board (R_c) in the range of z_p < 2. The result was compared to the Equation (8). Over-topping discharge maximum value is given by Equation (11) and is presented in comparison with the maximum value given by Equation (9). Figure 2b shows a scatter of experimental data on the value of z_p > 2 compared with the results of Equation (9).

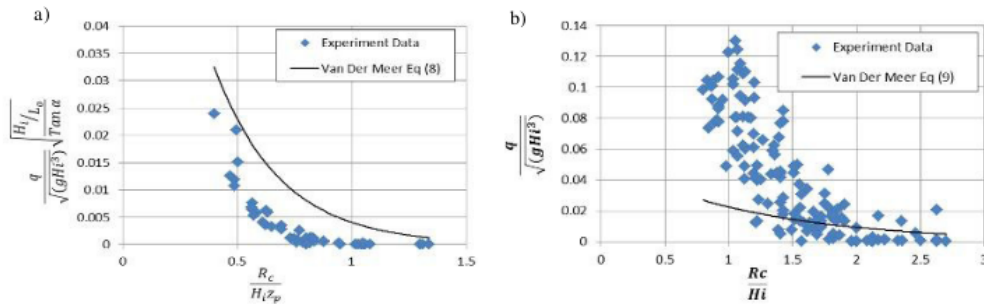


Fig. 2. Relationship over-topping discharge (q) with relative free-board (R_c), a) for z_p < 2 and b) for z_p > 2.

Although the trend of the Van Der Meer curve and experimental data is similar in exponential form such shown in Figure 2a, there are differences significantly in the values of q , where the experimental data is below than Van Der Meer curve that calculate using the Equation (8). The difference is caused by the differing of utilized wave height. The experiment data analysis is using the whole of the incoming wave height (H_i), producing the higher wave frequency compared to the utilizing of H_s in the Equation (8). Visually indicated in the experiment that the higher frequency of the wave the increasing the number of breaking waves under the value of z_p less than 2. Figure 2b shows the significant differences in the discharge rate (q) between the experimental data and the Equation (9). In the range of values R_c/H_i > 1.5, both value is close enough, while on the value of R_c/H_i < 1.5, the experimental data quite larger than Equation (9) on the value of R_c/H_i = 1. This difference is due to the number of over-topping waves in the experiment much more than the Equation (9). If the equation derived from these data, it obtains the following equation of q :

$$\frac{q}{\sqrt{(gHi^3)} \sqrt{\tan \alpha}} = 0.34 \exp\left(-7.41 \frac{R_c}{Hi z_p}\right)$$

(10)

With the maximum value of:

$$\frac{q}{\sqrt{gH^3}} = 2 \exp\left(-3.145 \frac{R_c}{H}\right) \tag{11}$$

When the incoming wave reaching the slope of the structure, the energy will break-down into the energy captured in the reservoir, reflected energy and dissipated energy. Figure 3 presents each part of the energy in the function of free-board height and breaker parameters. Wave energy captured is calculated by the amount of power that is caught in the reservoir (P_r) that can be calculated using Equation (5).

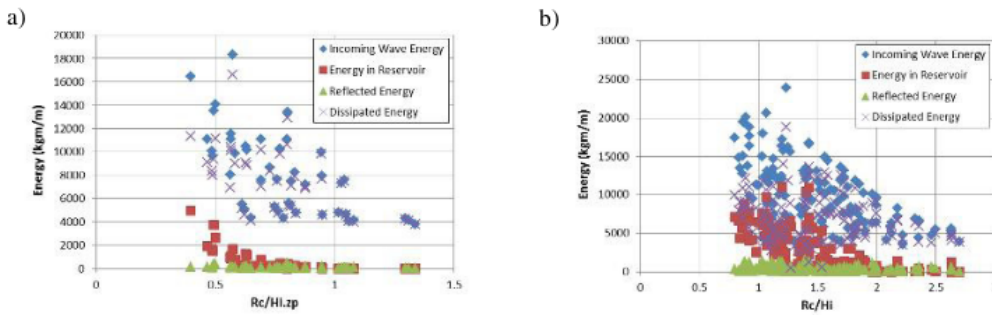


Fig. 3. Wave energy distribution, a) distribution for $z_p < 2$ and b) distribution for $z_p > 2$.

Figure 3 shows the distribution of the incident wave energy, namely captured energy in the reservoir, reflected energy and dissipated energy. In Figure 3a, a part of energy that can be captured is quite small compared to the broken energy before reaching the crest of the structure. Although the same thing is shown in Figure 3b, but the maximum value of energy that can be captured is large enough compared with the results of calculations using Equation (7). Therefore, the good design of wave catcher device is in the value of z_p more than 2, where z_p is the function of the slope of the structure ($\tan \alpha$) and wave steepness (H/L_0). The conditions described above, can also be presented on the scale of wave power (P). Figure 4 presents a comparison map of available incoming wave power, captured power in the reservoir both for experimental result and calculation by Equation (8) and (9).

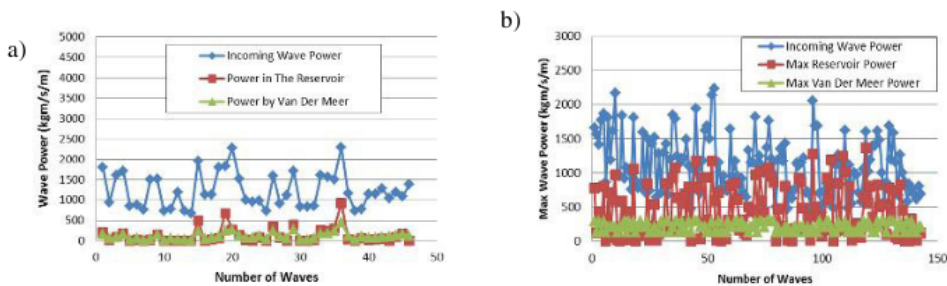


Fig. 4. The wave power availability and potentially mobilized, a) for $z_p < 2$ and b) for $z_p > 2$.

Figure 4a shows the power rate that can be caught in the reservoir is quite small, either by the experimental data or by the calculation using Equation (8). The results showed that only around 7.37% in average of power that can be captured in a reservoir on the condition of $z_p < 2$, smaller than 8.73% in average calculated by Equation (8). Figure 4b shows the maximum rate is about 34% of the wave power that can be captured on the condition $z_p > 2$.

Conclusions and Recommendation

From the above description, it can be concluded and recommended the following:

1. Experiments using all incoming wave height (H_i) producing over-topping discharge (q) is smaller than the Van Der Meer discharge for the breaker parameter (z_p) smaller than 2, while the maximum rate of q is greater than the Van Der Meer result for the z_p higher than 2.
2. The wave power efficiency achievement for the value of $z_p < 2$ is about 7.37% in average, while the wave power efficiency for $z_p > 2$ is 34% in average.
3. Further research for improving the efficiency achievement of the wave energy utilization is much required as one of the potential sources of renewable energy.

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