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### STUDY OF MODIFIED PERFORATED BREAKWATER AS RENEWABLE ENERGY DEVICE

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#### ABSTRACT

**Aim:** This study investigates to determine the influence of wave steepness, relative freeboard, and breaker parameters on overtopping discharge at a perforated breakwater. **Methodology and results:** The research method used was using both a numerical model simulations on three-dimensional computational fluid dynamics (CFD) modelling software namely FLOW-3D; and empirical equation computation. The evaluation of both approaches were performed for understanding the characteristics of wave discharge that overtopping the perforated breakwater. The experimental results of modified perforated breakwater revealed that the lowest slope possible with the highest porosity possible can generate the highest value of dimensionless overtopping discharge for wave energy harvesting. **Conclusion, significance and impact study:** The findings of this study formulated the optimum slope and porosity to the highest wave energy harvested. Further studies recommend that data collection from onsite trials of modified perforated breakwater are performed.

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#### **KEYWORDS**

- Dimensionless discharge
- FLOW-3D
- Perforated breakwater
- Wave steepness

#### 1. INTRODUCTION

Renewable energy, as one of the sustainable development goals, renewable energy has become more and more crucial as non-renewable energy reserves are depleting as population and energy consumption are growing exponentially (Asif and Muneer, 2007). As of 2019, the total energy consumption per capita in Indonesia alone has reached 3.53 Barrels of Oil Equivalent (BOE). A significant increase compared to the year 2016 with total energy consumption per capita of 2.85 BOE (Kementrian Energi dan SDM, 2018). The energy used is dominated by nonrenewable energy such as oil and coal emitting gas emissions which promotes global warming (Mohajan, 2011).

Thus, an effective system to harness safe and reliable renewable energy sources such as ocean wave energy will be critical. Oceans cover more than 70% of the planet's surface, and has considered as a reliable source of renewable energy. Based on the cause, ocean energy is categorized into wave, thermal, and tidal energy. Wave energy is caused by wind blowing on top of the sea surface, causing the wave to oscillate and propagates to the shore (Kusuma, 2018). The generated energy from ocean waves does not emit CO<sub>2</sub>. Moreover, based on the research conducted by Yosi (2014), Indonesia's ocean wave has the potential to generate an energy of 2 GW. A wave energy converter (WEC) converts wave energy into power that is used in everyday use.

Ever since it is development in 1980, up to 80 different types of WEC have been utilized (Alamin *et al.*, 2017; Do *et al.*, 2017; Melikoglu, 2018), including the oscillating wave converted (Habaibeh *et al.*, 2010; Farrok *et al.*, 2020). The WEC can be integrated into a breakwater-a coastal structure used for dissipating and reducing incoming wave energy to the shore (Takashi *et al.*, 1992). This modified perforated breakwater has successfully implemented on sloping beaches (Elbisy, 2015). The WEC in the perforated breakwater structure, generates the energy based on the sea discharge, which a function of flow velocity on the structure slope (Setyandito *et al.*, 2022).

This study aims to investigate the performance of a modified perforated breakwater with variations of slopes and porosity on the front wall of a wave energy converter structure. The analyzed performance is in the form of dimensionless discharge captured by the chamber of the perforated breakwater that is influenced by the structure configurations as well as the wave period. The performance analysis includes numerical analysis with Computational Fluid Dynamic

(CFD) software, FLOW-3D, and manual calculation with equations from previous studies (Owen 1980, Franco and Franco, 1999).

#### 2. RESEARCH METHODOLOGY

#### 2.1 Discharge Rate of the Breakwater

To calculate the discharge rate of the breakwater, empirical equations for the overtopping discharge is used. The general equation to calculate the dimensionless overtopping discharge that was developed by Owen (1998) can be used for either sloping or vertical structure. Equation (1) can be used to calculate the theoretical dimensionless overtopping discharge of the sloping structure whereas equation (3) can be used to calculate the dimensionless overtopping discharge of study.

$$Q^* = ae^{-bR} \tag{1}$$

Where a and b are the empirical coefficient depending on the structure's characteristics, R is the relative freeboard and  $Q^*$  is the dimensionless discharge which can also be defined as:

$$R = \frac{R_c}{H_s} \tag{2}$$

$$Q^* = \frac{q}{\sqrt{gH_s^3}} \tag{3}$$

Where Rc is freeboard, Hs is significant wave height, and q is the average discharge (q per unit length of structure). However, for the vertical perforated breakwater in this study, the equation developed for the perforated front vertical wall by Franco [15] is chosen as the equation fit with the condition of the study.

$$Q^* = 0.082e^{-3R_{\gamma_{\beta}\gamma_{S}}^{1}}$$
(4)

where  $\gamma\beta$  is the factor angle of incidence  $\beta$  of waves which can be seen from Table 1, and  $\gamma$ s is the reduction factor due to structure surface which can be seen from Table 2.

Wave Type	$\gamma_{\beta}$ Value	Condition
Long-crested waves	cosβ	$0^{\circ} \le \theta \le 37^{\circ}$
	0.79	<i>β</i> ≤ 37°
Short-crested waves	0.83	$0^{\circ} \le \beta \le 20^{\circ}$
	0.83 cos (20° - β)	<i>β</i> > 20°

#### Table 1 The factor of wave angle of incidence

#### Table 2 The factor of structure surface

Structure Surface	$\gamma_s$ Value
Plain impermeable wall	1
Plain impermeable wall with recurved nose	0.78
Perforated front (20%-hole area) and deck	0.72-0.79
Perforated front (20%-hole area) and open deck	0.58

#### 2.2 Research Method

The present study is conducted as the flow chart modified from (Setyandito, 2022) shown in Figure 1.



Figure 1 Research method flow diagram

The study is conducted by considering the location of the proposed structure's configurations. The perforated breakwater and wave energy converter integration is planned to be constructed within the ongoing construction of Sanur Beach Harbor in Bali Province, Indonesia. With respect to the location, the terrain that is modelled in the study represents the seabed.

#### 2.3 Numerical Model Setup

It was necessary to create a 3D model of the modified perforated breakwater in Flow-3D Software, and a 3D model of the perforated breakwater with terrain was created using geometrical software such as SketchUp and AutoCAD. In this study, a total of 18 simulations were selected and analysed with six models of the modified perforated breakwater with various geometrical characteristics, including three different angles (30°, 45°, and 90°) and two different porosity (14% and 16%).



Figure 2 Perforated breakwater with 16% porosity and angle of a) 30°, b) 45°, c) 90°

In Figure 2, various geometrical models of the perforated breakwater are shown. A variety of factors determine the dimensions of the modified perforated breakwater. As shown in Figure 2, the modified perforated breakwater dimension is calculated based on the HWL (High Water Level), MSL (Mean Sea Level), and LWL (Low Water Level) condition. The wave was generated with Fenton's Fourier Series theory, with the wave height was set to 2 m, the mean fluid depth to 5.3 m, and the wave period to 8.3 s, 10 s, and 12 s. As illustrated in Figure 3, the computational domain is divided into two subdomains. In a typical test case, the local mesh

(Mesh 1) for computations was chosen to be 0.05 m cell size ( $23 \times 3 \times 17$  m), whereas the general mesh (Mesh 2) was chosen to be 0.3 m cell size ( $80 \times 3 \times 17$  m).



Figure 3 Computational boundary of perforated breakwater

The mesh sizes were chosen as the FAVOR model showed it is sufficient, as shown in Figure 3. The computational burden is naturally relatively high, as the time required to simulate 20 seconds in real-time requires approximately 60 hours on two separate machine-type processor (Intel® CoreTM i7 CPU 2.80 GHz and AMD Ryzen 5 4600H). To fully accommodate the three-dimensional porous model, the virtual geometrical setup is wider than the actual computational domain due to the more complex hydrodynamic interactions within the modified perforated breakwater (mesh 1), which necessitates a higher number computational node. After reconstructing the structure's geometry imported into Flow-3D and configuring the size and scope of the computing grids, the attack wave can be selected.

#### 3. RESULTS AND DISCUSSION

#### 3.1 Dimensionless Overtopping Discharge of Measured and Model Relation

The measured dimensionless overtopping discharge (QMeasured\*) is calculated based on equation (1) and (4) then it is plotted into Figure 4 below to observe its relationship with dimensionless model overtopping discharge (QModel\*). From the graph, the results of the perforated breakwater with the slope of 30° and 45° lie on the x = y line showing both results can be assumed to be the same. As for the slope of 90°, the results are still in the range of the x = y line, thus is still acceptable.



Figure 4 Graph relation of measured and model overtopping discharge

#### 3.2 Wave Steepness (Hs/gT2) and Breaker Parameter (ξ) Relation

Figure 5 shows the relation between wave steepness (x-axis) and breaker parameter (y-axis). From Figure 5 an inverse relationship can be seen between the wave steepness and the breaker parameter, whereas the wave steepness increases, the breaker parameter decreases. It is also worth noting a directly proportional relationship between the structure slope and breaker parameter whereas the slope increases so do the breaker parameter. The structure's porosity does not seem to affect the breaker parameter nor the wave steepness.



Figure 5 Graph relation of wave steepness and breaker parameter



Figure 6 Comparison of wave steepness and breaker parameter of the numerical and physical model

Moreover, the numerical results for the wave steepness and breaker parameter relation were compared with physical model results conducted by Suputra (2021) in Figure 6. The graph shows the physical model value for the breaker parameter is significantly larger than the numerical modelling. On top of that, a similar trend of an inverse relation between wave steepness and breaker parameter is also shown in the physical modelling. It is also seen that for the same slope of 45°, the numerical modelling results are in the range of the physical modelling. These similarities show that the numerical modelling results conform with the physical modelling result.

## 3.1. Relative Freeboard (Rc/H) and Dimensionless Overtopping Discharge (Q\*) Relationship

To represent the general characteristic and performance of a breakwater, the relative freeboard can be utilized. Figure 7 shows the relationship between the relative free board (x-axis) with the dimensionless model overtopping discharge (y-axis).



Figure 7 Graph relation of relative freeboard with dimensionless model overtopping discharge



Figure 8 Graph relation of relative freeboard with dimensionless model overtopping discharge

From the graph in Figure 7, for every increase of slope, the breaker parameter also increases, showing a proportional relationship between the two parameters. Just as before, the porosity does not influence the breaker parameter. Furthermore, the breaker parameter shows an inverse relationship with the dimensionless discharge, with every increase of breaker parameter value, the dimensionless overtopping discharge decreases. A comparison with physical modelling (Suputra, 2021) and past studies (Schuttrumpf, 2001, *Puspita et al.*, 2020) are done. The study conducted by Schüttrumpf (2001), were observing the dimensionless overtopping discharge under the condition of zero freeboard whereas for the study conducted by Puspita *et al.*, (2020), were observing the influence of wave deformation against dimensionless overtopping discharge on OWEC-breakwater integration with low freeboard. The

comparison can be seen on Figure 8. Moreover, under the same value of breaker parameter, the other studies show higher values for dimensionless overtopping discharge. The difference in the yielded dimensionless overtopping discharge despite in the same range of breaker parameter might be due to a different set of conditions were used such as wave period and height. Moreover, a difference in the trend can be observed where the numerical modelling dimensionless overtopping discharge. The result shows a decrease as the breaker parameter increases. This might be due to a small amount of observation data affecting the actual trend. Compared to the result from Schüttrumpf (2001), it can be seen that the numerical modelling result lies under it, validating that the condition for the numerical modelling is with freeboard.

#### 4. CONCLUSION

This study presents numerical analysis approach for assessing wave discharge in the perforated breakwater. The study outcome revealed that an inverse relationship between the slope of the perforated breakwater with the relative freeboard, whereas porosity has a proportional relationship with the relative freeboard. The relative freeboard itself has a proportional relationship with dimensionless overtopping discharge. A proportional relationship between the slope of the perforated breakwater with the wave steepness and breaker parameter. The breaker parameter has an inverse relationship with wave steepness. No significant relationship between breaker parameter and dimensionless overtopping discharge, whereas porosity has proportional relation with dimensionless overtopping discharge. And finally, this study also found that the lowest slope with the highest porosity generates the highest dimensionless overtopping discharge possible from the perforated breakwater.

#### 5. ACKNOWLEDGEMENT

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#### REFERENCES

- Alamian, R., R. Shafaghat, R. Bayani, and A. H. Amouei. 2017. An Experimental Evaluation of the Effects of Sea Depth, Wave Energy Converter's Draft and Position of Centre of Gravity on the Performance of a Point Absorber Wave Energy Converter. *J. Mar. Eng. Technol.* 16(2): 70-83.
- Al-Habaibeh, A., D. Su, J. McCague, and A. Knight. 2010. An Innovative Approach for Energy Generation from Waves. *Energy Convers. Manag.* 51(8): 1664-1668.
- Asif, M and T. Muneer. 2007. Energy Supply, Its Demand and Security Issues for Developed and Emerging Economies. *Renew. Sustain. Energy Rev.* 11: 1388-1413. Doi: 10.1016/j.rser.2005.12.004.
- Do, H.T. *et al.*, 2017. Proposition and Experiment of a Sliding Angle Self-Tuning Wave Energy Converter. *Ocean Eng.* 132: 1-10.
- Elbisy M. S., 2015. Estimation of Regular Wave run-up on Slopes of Perforated Coastal Structures Constructed on Sloping Beaches. Ocean Eng. Vol 109, pp. 60-71.
- Farrok, O., K. Ahmed, A. D. Tahlil, M. M. Farah, M. R. Kiran, and M. Islam. 2020. Electrical Power Generation From the Oceanic Wave for Sustainable Advancement in Renewable Energy Technologies. *Sustainability*. 12(6): 2178.
- Franco, C and L. Franco. 1999. Overtopping Formulas for Caisson Breakwaters with Nonbreaking 3D Waves. *J. Waterw. port, coastal, Ocean Eng.* 125(2): 98-108.
- Kementerian Energi dan Sumber Daya Mineral, Handbook of Energy and Economic Statistics of Indonesia. 2018.
- Kusuma, A. 2018. Ocean Energy Overview: Feasibility Study of Ocean Energy Implementation in Indonesia.
- Melikoglu, M. 2018. Current Status and Future of Ocean Energy Sources: A Global Review. *Ocean Eng.* 148: 563-573.
- Mohajan. H. 2011. Greenhouse Gas Emissions Increase Global Warming. Int. J. Econ. Polit. Integr. 1: 21-34.
- Owen. M. W. 1980. Design of Seawalls Allowing for Wave Overtopping. *Rep. Ex.* 924: 39.
- Puspita, A. D., M. S. Pallu, M. A. Thaha, and F. Maricar. 2020. The Effect of Wave Deformation on Overtopping Discharge in Wave Energy Converter (OWEC)-breakwater. J. Eng. Appl. Sci. 15(9): 2058-2064.
- Schüttrumpf, H. 2001. Wellenüberlaufströmung bei Seedeichen Experimentelle und theoretische Untersuchungen (H. Schüttrumpf).

- Setyandito, O., Nizam, A. J. Pierre, G. D. Saputra, Y. Wijayanti, M. Anda. 2022. Numerical Analysis of Velocity Magnitude on Wave Energy Converter System in Perforated Breakwater. *Intl. Journal of Renewable Energy Development*. 11(1): 27-33. Doi: https://doi.org/10.14710/ijred.2022.38535.
- Suputra, G. D. 2021. Penelitian Awal Model Konversi Energi Gelombang dengan Dinding Porforasi Berkatup, Universitas Gadjah Mada.
- Takahashi, H. Nakada, H. Ohneda, and M. Shikamori. 1993. Wave Power Conversion by a Prototype Wave Power Extracting Caisson in Sakata Port, in *Coastal Engineering 1992*, pp. 3440-3453.

Yosi, M. 2014. Potensi Energi Laut Indonesia. J. M&E. 12(1): 54-66.