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Original Article

Focusing Wave Energy on the Wave Catcher Shore Protection Dual Slope (WCSP-DS) Zigzag Models

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Abstract *- Ocean waves have a large enough energy potential; the model's zigzag placement and the addition of a wave-concentrating collector on the Wave Catcher Shore Protection Dual-Slope (WCSP-DS) is an innovation and engineering technique to capture wave energy. This study aims to produce an increase in the height of the deformation wave and to find the effect of setting the structural model's layout and adding a focusing collector to the increase in overtopping discharge in WCSP-DS. 3D laboratory tests were carried out using a 1:20 model scale for the length, height, and depth scale. Variations in model structure parameters, namely freeboard height (Fb) five variations, focusing collector length (l) three variations; focusing collector width (b) 3 variations; vertical wall height (z) 0.35 m. The results showed that with the longer focusing collector in the three variations of the model's depth-related (d/z) and the three variations of the wave period (T), an increase in the height of the deformation wave (Hdef) in front of the model structure. The freeboard height (Fb) and the structure wavefront height (Hdef) significantly affect the overtopping discharge entering the reservoir. In zigzag model placement the average overtopping discharge entering the reservoir is 5.167 x 10-4 m³/s. The addition of one focusing collector can increase the overtopping discharge (Q) that enters the reservoir by 55.47%, and the addition of two focusing collectors can increase the overtopping discharge (Q) that enters the reservoir by 182.56%*

Keywords *- Freeboard, Overtopping discharge, Renewable energy, Wave energy, Zigzag model.*

1. Introduction

The territorial waters have great potential as a new renewable energy source in Indonesia because most of Indonesia's territory is in the form of water, which is three times larger than the land area. The sea area is 74% of the country's area, with a coastline of 108,000 km. Indonesia's position on the equator, surrounded by two oceans, the Indian Ocean and the Pacific Ocean, has abundant potential for new and renewable energy sources and has not been utilized optimally. Wave energy in Indonesia, if used optimally, can produce more than two Tera Watts of electrical power [1]. Indonesia should be able to meet the current energy demand thanks to taking advantage of seawater's movement in the form of waves when non-renewable oil and fossil fuels are depleted as a substitute energy source. One of the promising forms of renewable energy is ocean wave energy [2,3].

Ocean waves, in addition to having a significant enough energy potential that can be utilized, also have a sizeable destructive power if not controlled; therefore, innovation and engineering are needed to make a dual-function breakwater; besides being used as a beach protector, it can also be used as a wave energy catcher, in converting wave energy to reduce investment costs, which is one of the obstacles that, along with the volatility of the generated electric current, obstacles to the development of wave power plants, it is necessary to think of a dual function so that the selling value of electricity is not expensive and can compete with power plants on land [16]. Incorporating a Wave Energy Converter (WEC) in a coastal structure is the right solution [5,6] for cost efficiency. The WCSP-DS concept in this study is the same as the Wave Energy Converter (WEC), which utilizes wave energy as electrical energy. The ZigZag WCSP-DS model is developing the OWEC breakwater research series researched [7,8]. This WCSP-DS model combines two walls: a vertical side wall of 90° and a sloping side wall with a slope angle of 45°. The zigzag placement of the model and the addition of a wave-focusing collector on the Dual-Slope Wave Catcher Shore Protection (WCSP-DS) is an innovation and engineering technique to capture wave energy. The engineering of concentrating wave energy can potentially increase the wave height in front of the structural model to boost the reservoir's overtopping outflow. The maximum wave height, more significant than the freeboard height, results in overtopping discharge and increases the wave energy captured and utilized to rotate the turbine. This study aims to produce an increase in the height of the deformation wave and to find the effect of setting the location of the structural model and the addition of a concentrating collector to the increase in overtopping discharge on the Dual-Slope Wave Catcher Shore Protection (WCSP-DS).

2. Literature Study

2.1. Wave Energy Converter (WEC)

Wave Energy Converter (WEC) technology utilizes wave energy as a source of electrical energy, this WEC technology that has not been widely developed is the overtopping concept [9]. The first finding with the concept of overtopping is TAPCHAN, a sinking type Overtopping wave energy converter, concentrating ocean waves into the reservoir, the reservoir position is higher than sea level. The variation in the reservoir's water level from sea level through the turbine converts potential energy into kinetic energy. The findings of the floating type of overtopping wave energy converter, namely Wave Dragon, have the same concept as TAPCHAN in raising waves into the reservoir. Wave Dragon uses a reflector to focus the waves. Several studies have been conducted combining WEC and breakwater overtopping; Seawave Slot-Cone Generator (SSG) states the SSG design when measured from the water entering the reservoir, the hydraulic efficiency value is 37%. [9]; Breaking New Ground in Energy Conversion (OBREC) states that the potential of the structure to capture maximum waves is limited because, during high tide conditions, sea level is above the breakwater peak [5]; The Overtopping Wave Energy Converter (OWEC) states that the best model from the variation of the model studied is a combination of the lower and upper walls of the model structure, which are 90° upright walls and 45° sloped side walls [6]

2.2. Wave Fundamental Theory

In comparison between water depth (d) and wavelength (L) or d/L, waves can be classified into three kinds. If the relative depth is below 1/25, these waves are called shallow water waves. Deep water waves are created when the relative depth is more than 1/2. If the relative depth is between 1/25 <d/L <1/2, it is called intermediate depth waves. This study uses the theory of small amplitude waves (Airy) in transitional water conditions that are by the existing research conditions. The theory of small amplitude waves is derived from the Laplace equation. At the boundary conditions, the surface is obtained from the Bernoulli equation with the assumption that the value of y on the surface is equal to the surface of still water so that y = 0 is approximately the same as at y = η, so that he wave propagation speed and length (C and L) in the small amplitude theory are obtained [10] namely:

$$C = \frac{gT}{2\pi} tanh \frac{2\pi d}{L} \quad (1)$$

$$L = \frac{gT^2}{2\pi} tanh \frac{2\pi d}{L} \quad (2)$$

With:

- C = wave propagation speed (m/sec)
- T = wave period (second)
- g = acceleration due to gravity (m/sec²)
- d = water depth (m)
- L= wavelength (m)

2.3. Wave Energy and Wave Power

In the Airy wave theory, the potential and kinetic energy components are equal if the potential energy is set about a stationary water level and all waves propagate in the same direction. So the total energy in one wavelength per unit wavelength is [7]:

$$E_t = E_k + E_p = \frac{\rho g H^2 L}{8} \quad (3)$$

The average energy per unit area is[7]:

$$E = \frac{E_t}{L} = \frac{\rho g H^2}{8} \quad (4)$$

With:

- Ek = kinetic energy per unit of wavelength (joule/m)
- Ep = potential energy per unit of wavelength (joule/m)
- Et = total energy per unit of wavelength (joule/m)
- E = total energy per unit of wavelength (joule/m²)
- H = wave height (m)
- P = water mass density (Kg/m³)
- g = acceleration due to gravity (m/sec²)

In the conservation of energy under constant conditions, where no energy is lost or entered, the equation is developed by relating the wave heights at two points and the energy flux at both points to the same. As the depth charges, the energy per unit area changes between point 1 and point 2. assuming no wave reflection or energy conservation. $F = EnC$ become[11]:

$$(EnC)_1 b_1 = (EnC)_2 b_2 \quad (5)$$

Or, use an equation for energy per unit area, such as equation (4). And for the H2 wave height expressed by [11]:

$$H_2 = H_1 \sqrt{\frac{Cg_1}{Cg_2}} + \sqrt{\frac{b_1}{b_2}} \quad (6)$$

The power available in the reservoir is [12] :

$$D = Q \Delta h \gamma \quad (7)$$

$$Q = {}^{V}/_{t} \quad (8)$$

With:

- Q = overtopping debit (m^3/s)
- Δh = the difference in water level in the reservoir with SWL
- (m)
- γ = specific gravity of water (Kg/m^3)
- V = volume reservoir (m^3)
- t = reservoir full time (second)

2.4. Wave Overtopping.

Wave overtopping is a condition when the incoming wave hits a building; first, it will run up on the surface of the building reaching the maximum limit of the freeboard or the top of the breakwater, and then overtaking past the top of the building [5,9]. While the lesser waves may not cause any runoff, the largest waves may send a significant amount of water to the top of the building.

Wave overtopping, apart from depending on wave height, wave period, wavelength, and water surface, an example of wave parameters, also depends on the structure's geometric layout and material properties [13]. The average discharge per linear meter of wave overtopping (q) is expressed in units of m3/s or l/s per m. The average overtopping discharge is often used to assess the permissible overtopping waves because the average overtopping discharge is considered stable at around 1000 waves [14]. The two formulas below generally express the average overtopping discharge, where a and b are variable coefficients based on the structure's geometry. The overtopping discharge and freeboard height are dimensionless parameters with the initials Q and R [15].

$$Q = a \exp(-bR) \tag{9}$$

$$Q = aR^{-b} \tag{10}$$

3. Research Methods

3.1. Place of Implementation, Research Tools and Materials

The research was done at the Gowa Faculty of Engineering's Laboratory of Coastal and Marine Engineering Environment, Hasanuddin University Makassar, Indonesia, in a wave pool measuring 15 m long and 10 m wide. The adequate depth of the channel is 0.87 m. At the end of the channel, a wave absorber functions to absorb and reduce wave reflections. The wave generator and wave maker are connected to a computer to produce the desired wave height using two computer controllers. One is used to record data generated from the wave probe, and the other is used for the input frequency, amplitude, and time length data. Running will be generated by the wave generator—using eleven 304 stainless steel wave probes and PTFE String AWG 30 to measure the height of water level fluctuations. The construction of the model is made of a 2 mm iron plate, and the focusing collector is made of 2 cm plywood with an L elbow as support. Bolts are used to attach the freeboard to the model, and silicone glue prevents leakage at the freeboard joints when varying the freeboard height.

3.2. Simulation Model and Design

The variation of the WCSP-DS model studied consisted of 3 variations of the model. MTD is a model with zigzag placement (forming an angle of 90°), both MD1 models are models with the zigzag arrangement, and the addition of a focusing collector is one time the length of model one. A third is MD2, which is the addition of a focusing collector twice the size of model one. The research model is shown in Figure 1, the model's variation is shown in Figure 2, and the model's dimensions can be seen in Table 1.

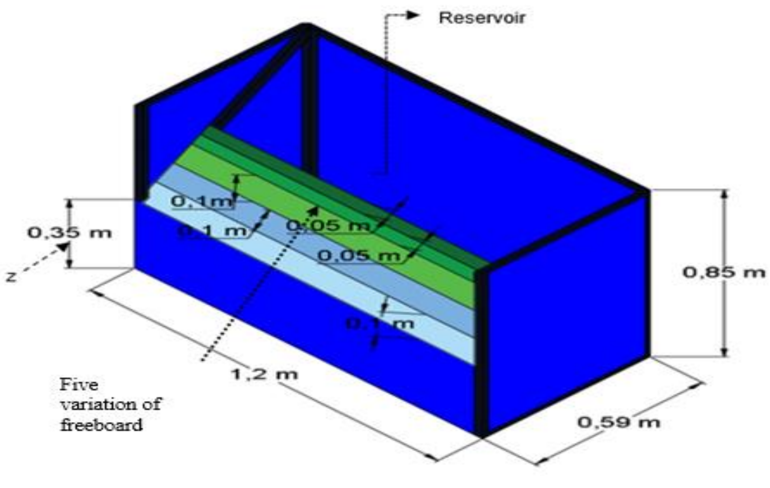

Fig. 1 Research Model

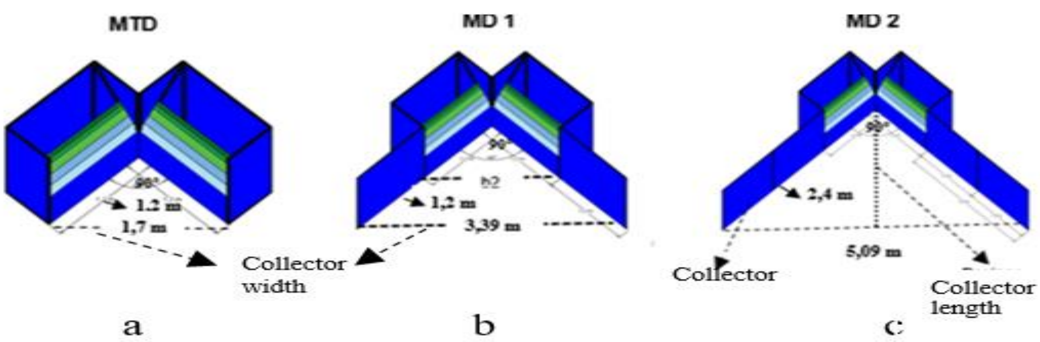

Fig. 2 a. MTD is a model with zigzag placement (forming an angle of 90°), b. the MD1 model is a model with a zigzag arrangement, and the addition of the collector focus is one time the length of model one. c. MD2, which is the addition of a focal collector twice the size of the model one.

Table 1. Dimensions of the Research Model

Dimensions	Symbol	Prototype (m)	Model (Cm)
Structure			
Model's front height	z	7,0	35
Model's back height		17,0	85
Model length		24	120
Model width		11,8	59
Collector width	b	34;79,8;118	170,399,509
Collector length	l	17;34;51	85,170,255
Reservoir			
Length		24	120
Width		11.8	59
Freeboard height	F_b1	2	10
	F_b2	4	20
	F_b3	6	30
	F_b4	7	35
	F_b5	8	40

3.3. Data collection procedure

The data collection procedure is calibrating the wave height recording instrument before conducting the research. Furthermore, the model is placed in a wave basin and then filled with water until it reaches the specified elevation. Then, after the components are ready, the wave simulation begins by inputting frequency, amplitude data, and time running time on a PC connected to the wave maker. The wave maker creates waves according to the input amplitude data. The water level fluctuations in the wave probe at the front eleven points of the model are stored automatically on the computer. The time of catching waves that enter the reservoir is recorded with the help of a stopwatch. The water level in the reservoir is recorded after the running time is finished—the probe changes according to variations in depth and period. Finally, running research was carried out according to the simulation design in Table 2.

The design of the simulation model can be seen in Table 2.

Table 2. Simulation Design

Model	F_b	T	d/z
MTD	F_b1	3 variation	3 variation
	F_b2	3 variation	3 variation
	F_b3	3 variation	3 variation
	F_b4	3 variation	3 variation
	F_b5	3 variation	3 variation
MD1	F_b1	3 variation	3 variation
	F_b2	3 variation	3 variation
	F_b3	3 variation	3 variation
	F_b4	3 variation	3 variation
	F_b5	3 variation	3 variation
MD2	F_b1	3 variation	3 variation
	F_b2	3 variation	3 variation
	F_b3	3 variation	3 variation
	F_b4	3 variation	3 variation
	F_b5	3 variation	3 variation

4. Results and Discussion

The water level fluctuation data is obtained by measuring in front of the model using 11 wave probes. The water level fluctuation data is then processed using the Fortran (Zero Up-Crossing) to get a wave height profile for each running model on 11 probes. Data on the height of water level fluctuations in the three research models (MTD, M1, and M2) can be seen in Table 3.

Table 3. Data on water level fluctuations in the variation of the research model on variations of Fb, T, and d/z at amplitude a= 0.04 m

Model	d (m)	Fb (m)	T (s)	d/z	Wave Height on Wave probe (m)										
					1	2	3	4	5	6	7	8	9	10	11
MTD	0.30	0.40	2.0	0.857	0.105	0.116	0.097	0.078	0.041	0.092	0.126	0.108	0.046	0.143	0.253
	0.30	0.35	2.3	0.857	0.096	0.093	0.145	0.096	0.066	0.124	0.124	0.076	0.097	0.173	0.287
	0.35	0.30	2.3	1.000	0.114	0.090	0.132	0.076	0.054	0.128	0.105	0.066	0.109	0.214	0.276
	0.40	0.15	2.6	1.143	0.045	0.117	0.106	0.051	0.121	0.117	0.081	0.043	0.122	0.226	0.287
	0.40	0.50	2.6	1.143	0.049	0.097	0.073	0.053	0.116	0.099	0.070	0.046	0.104	0.198	0.240
MD1	0.30	0.40	2.0	0.857	0.099	0.052	0.111	0.130	0.072	0.037	0.097	0.110	0.044	0.143	0.282
	0.30	0.35	2.3	0.857	0.077	0.088	0.148	0.114	0.042	0.116	0.125	0.120	0.090	0.245	0.360
	0.35	0.30	2.3	1.000	0.093	0.097	0.133	0.081	0.057	0.124	0.115	0.075	0.084	0.202	0.288
	0.40	0.15	2.6	1.143	0.044	0.132	0.102	0.044	0.129	0.140	0.113	0.071	0.138	0.259	0.327
	0.40	0.05	2.6	1.143	0.046	0.114	0.081	0.046	0.122	0.125	0.088	0.071	0.123	0.233	0.289
MD2	0.30	0.40	2.0	0.857	0.109	0.071	0.137	0.167	0.119	0.040	0.093	0.109	0.086	0.173	0.278
	0.30	0.35	2.3	0.857	0.089	0.096	0.142	0.119	0.046	0.125	0.138	0.110	0.106	0.263	0.379
	0.35	0.30	2.3	1.000	0.106	0.089	0.148	0.095	0.052	0.126	0.118	0.067	0.110	0.219	0.303
	0.40	0.15	2.6	1.143	0.075	0.155	0.121	0.051	0.144	0.150	0.139	0.091	0.187	0.315	0.386
	0.40	0,05	2.6	1.143	0.071	0.121	0.084	0.054	0.126	0.126	0.113	0.099	0.124	0.235	0.313

Table 3 shows that from the overall running research model (MDT, MD1, and MD2), the most significant wave height is on wave probe 11 (WP.11), which is positioned at the length of the collector on the MTD, and its position is fixed. The effect of variations in the MTD model (the model without the inclusion of a collector), MD1 (the model with in addition of 1 collector length), and the MD2 model (the model with the addition of 2 collector lengths) shows that the addition of a collector to the WCSP-DS zigzag model has a significant effect on increasing the front wave height structure models.

4.1. Effect of Period (T) on the value of Wave Height in Front of the Model Structure on MTD, MD1, and MD2

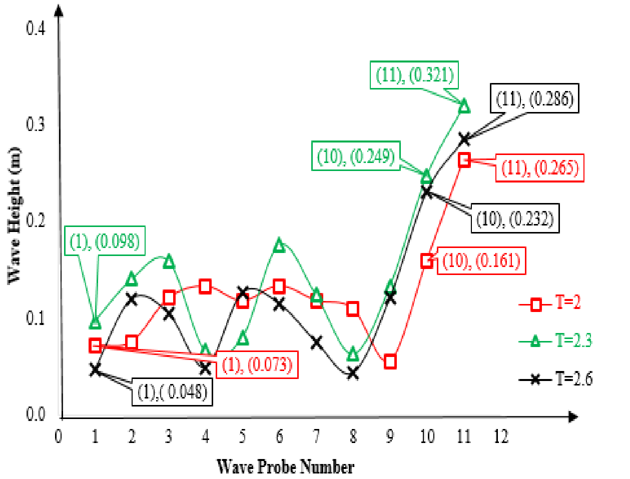

Fig. 3 Effect Period (T) on the value of Wave Height in Front of the Model Structure on MTD at the condition

Fig. 3 shows that in the model without the addition of a concentrating collector (MTD), the wave period (T) has no discernible impact on the wave height in front of the structural model. Wave height values are ordered from the largest to the most minor 0.321 m (T=2.3 s), 0.286 m (T=2.6 s), and 0.265 m (T=2 s). This condition is at a freeboard height of 0.3m, so the wave height does not contribute to the discharge because it cannot run off into the reservoir.

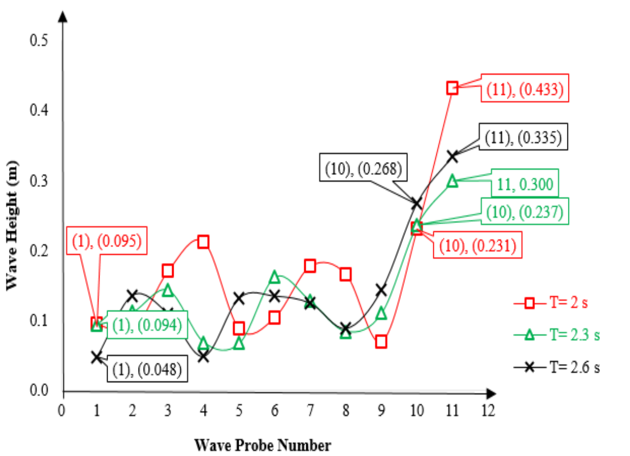

Fig. 4 Effect of Period (T) on the value of Wave Height in Front of the Model Structure at MD1

In Fig. 4, the wave height values are sorted from large to small 0.433 m (T=2 s), 0.335 m (T=2.6 s), and 0.3 m (T=2.3 s). This condition is at a freeboard height of 0.3 m, so the wave height at T= 2 s at T=2.6 s can contribute to the discharge because it can run off into the reservoir.

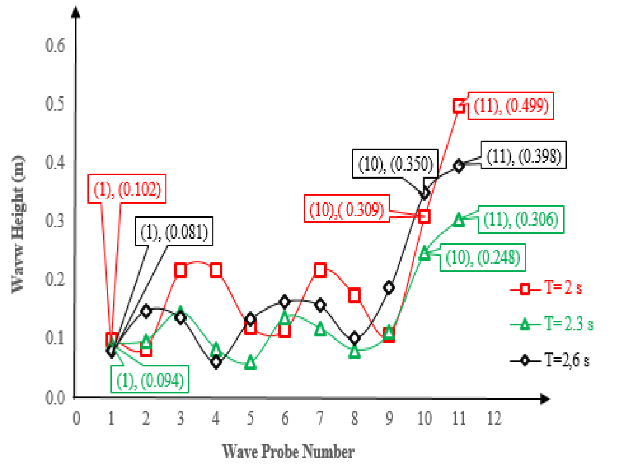

Fig. 5 Effect of Period (T) on the value of Wave Height in Front of the Model Structure at MD2

In Fig. 5, the wave height values are sorted from the largest to the most minor 0.499 m (T=2 s), 0.398 m (T=2.6 s), and 0.306 m (T=2.3 s). This condition is at a freeboard height of 0.3 m, so the wave height at T= 2 s at T=2.6 s can contribute to the discharge because it can run off into the reservoir. Figures 2, 3, and 4 show that the concentrating collector significantly increases the wave height in front of the model structure.

4.2. Effect of Wave Steepness (H_1/L) on Overtopping Discharge of Three Research Models (MTD, MD1, and MD2)

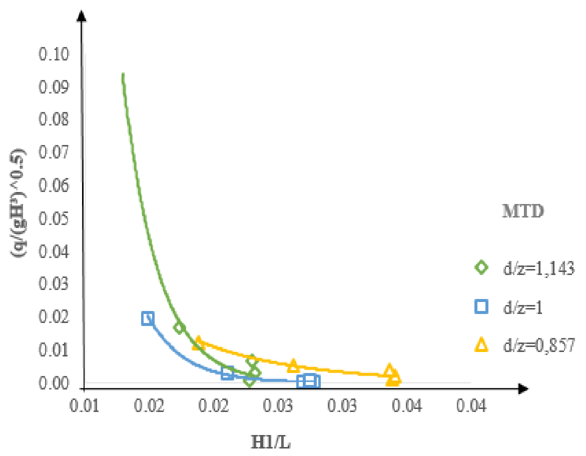

Fig. 6 Effect of Wave Steepness (H1/L) on Relative Overtopping Discharge ($q/(gH^3)^{0.5}$) on MTD

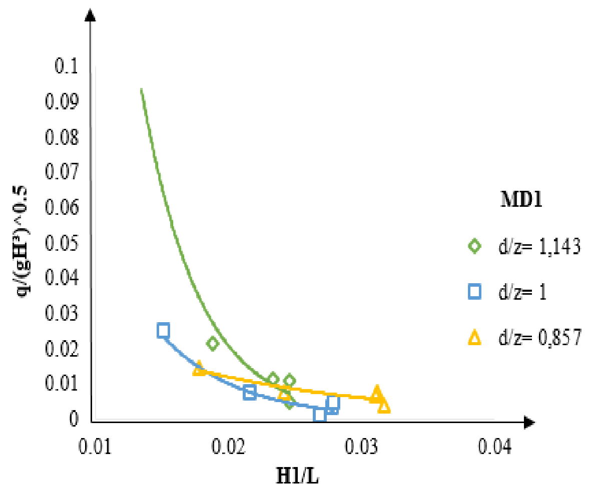

Fig. 7 Effect of Wave Steepness (H1/L) on Relative Overtopping Discharge ($q/(gH^3)$^0.5) on MD1

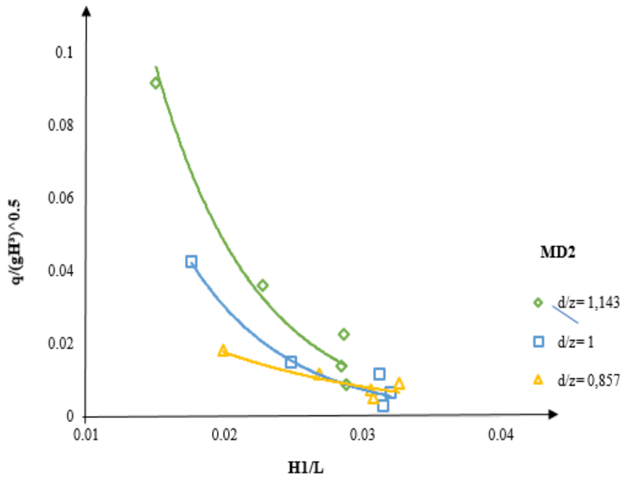

Fig. 8 Effect of Wave Steepness (H_1/L) on Relative Overtopping Discharge ($(q/(gH^3))^{0.5}$) on MD2

Based on Fig. 6, 7, and 8 show that the effect of wave steepness (H_1/L) on relative overtopping discharge ($q/(gH^3)$^0.5) in the three research models has the same graphic trend, namely, the greater the wave steepness value (H_1/L) will decrease gradually. Exponential value of the relative overtopping discharge ($q/(gH^3)$^0.5) at a fixed wavelength condition, the greater the value of H. The most considerable overtopping discharge value in the three models is in the same condition, namely when the water level is relatively on the sloping side of the model (d/z = 1.143). Figure 6 (MTD.) relative overtopping discharge value $(q/(gH^3))^{0.5}$). Are in the range of values of 0.00654 – 0.1027, and (H_1/L) is in the range of values of 0.0129 – 0.0232, but when the position (H_1/L) is in the range of values of 0.0261 – 0.0341 the value ($q/(gH^3)$^0.5) was in the condition (d/z) = 0.857, namely the condition position of the water level on the model's vertical wall that contains a value $(q/(gH^3))^{0.5}$) in the range of values of 0.0011 - 0.0054. The relative overtopping discharge value $(q/(gH^3))^{0.5}$) is shown in Figure 7 (MD1); they are between 0.0048 to 0.1035 in value, and (H_1/L) is in the range of values of 0.0135 – 0.0246, but when the position (H_1/L) is in the range of values of 0.0242 – 0.0311 values (The largest $q/(gH^3))^{0.5}$) is in the position (d/z) = 0.857, i.e., the water level is on the vertical wall of the model with a value of $(q/(gH^3))^{0.5}$) = 0.0076. Based on Figure 8 (MD2), the relative overtopping discharge value $(q/(gH^3))^{0.5}$). It is in the range of 0.0088 – 0.0914, and (H_1/L) is in the range of 0.0150 – 0.0288.

4.3. Relationship between the Percentage of Wave Height and Discharge (Q) entering the reservoir at the Relative Depth of the Model (d/z)

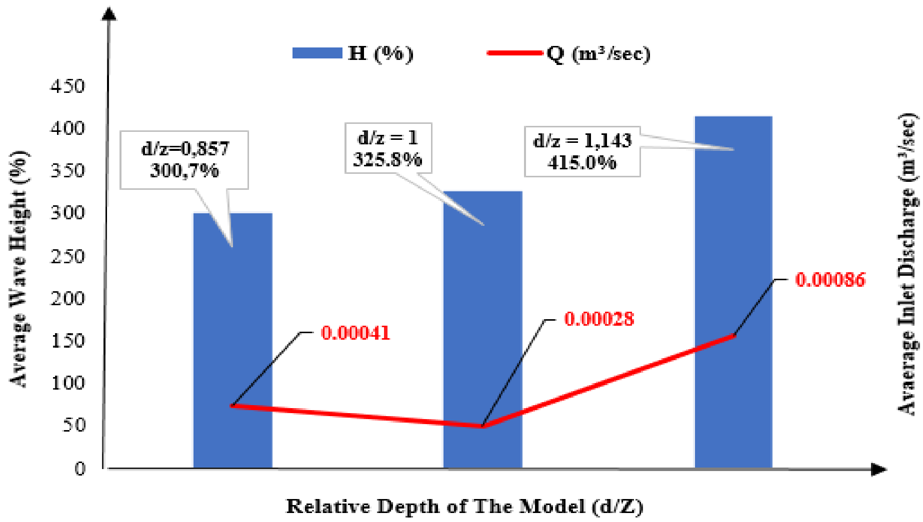

Fig. 9 Relationship of Wave Height Percentage and Overtopping Discharge Entering the Reservoir on MTD

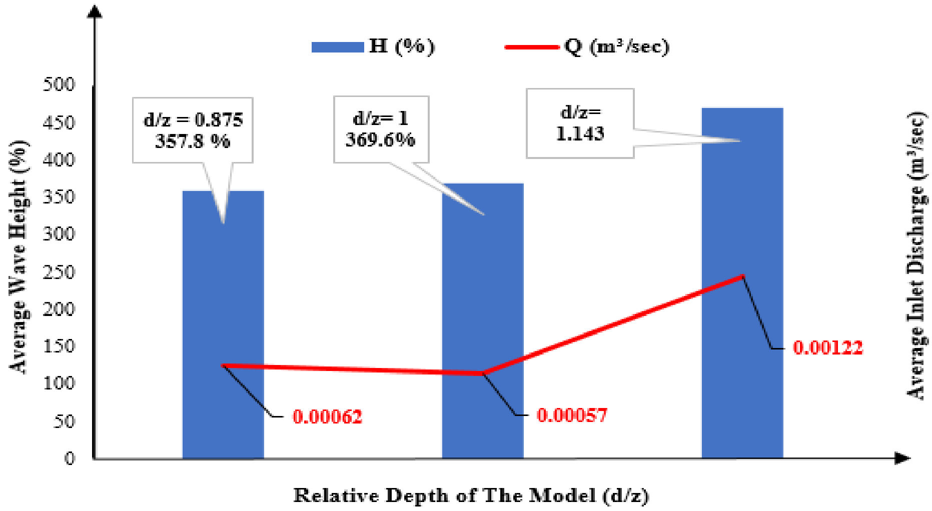

Fig. 10 Relationship of Wave Height Percentage and Overtopping Discharge Entering the Reservoir on MD1

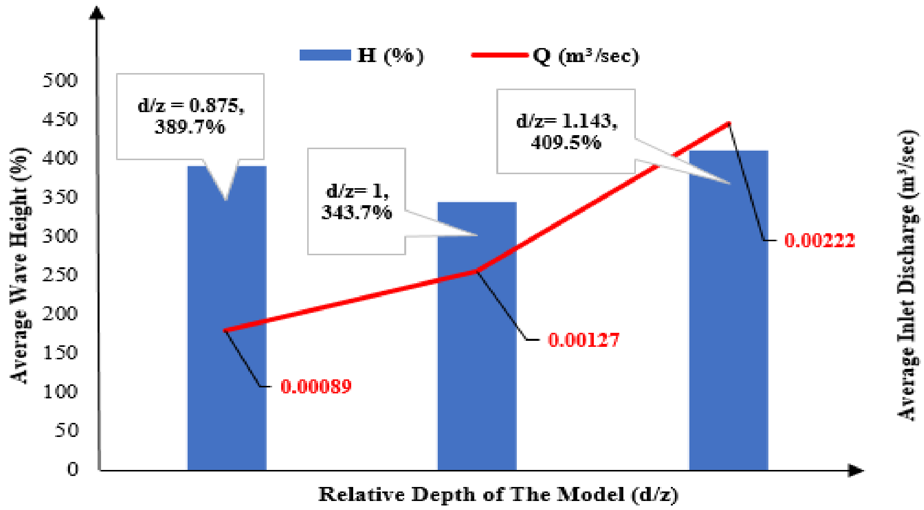

Fig. 11 Relationship of Wave Height Percentage and Overtopping Discharge Entering the Reservoir on MD2

Fig. 9 and 10 have the same trend graph, indicating that the greater the value (d/z), the more significant the percentage increase in the average wave height (bar graph) in both models. The increase in wave height on MTD and MD1 in conditions (d/z) = 1, the average Q value entering the reservoir (line graph) is oppositely related to the rise in wave height because the overtopping occurs only at the freeboard height of 0.1 m and 0.2 m. Therefore, the highest wave height is on MTD and MD1 in conditions (d/z) = 1 of 0.281 m for MTD and 0.288 for MD1 because the waves that enter the narrowing area at the freeboard height of 0.3 m to 0.4 m cannot run over into the reservoir and become a reflected wave, causing the wave height to increase due to the meeting between the reflected wave and the incident wave. On the other hand, figure 11 does not show the same graph trend as in MTD and MD1; on MD2, there is a decrease in the graph of the percentage increase in wave height (bar graph) at condition (d/z) = 1. Still, the average Q value entered into the reservoir increases (line graph) compared to MTD and MD1 because the incoming wave height in the narrowing area can run over into the reservoir up to a freeboard height of 0.3 m. After all, the height of the structure crest is lower than the run-up wave level, so the reflected wave at MD2 causes the percentage increase in wave height to decrease.

5. Conclusion

It can be concluded that the increase in wave height in front of the WCSP-DS structural model is influenced by wave parameters (H and T) as well as structural parameters, namely the relative depth of the model (d/z), collector focussing of the wave and freeboard height (Fb). Adding a wave-focused collector on the WCSP-DS can increase the runoff discharge (Q) that enters the reservoir. The freeboard height (Fb) and wave height in front of the structure (Hdef) significantly affect the reservoir's runoff discharge. In the zigzag model (MTD) placement, the average runoff that enters the reservoir is 5.167 x m^3/s. The addition of one concentrated collector (MD1) can increase the average runoff discharge (Q) entering the reservoir by 55.47%, and the addition of two concentrated collectors (MD2) can increase the average runoff discharge (Q) entering the reservoir by 182,56%

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