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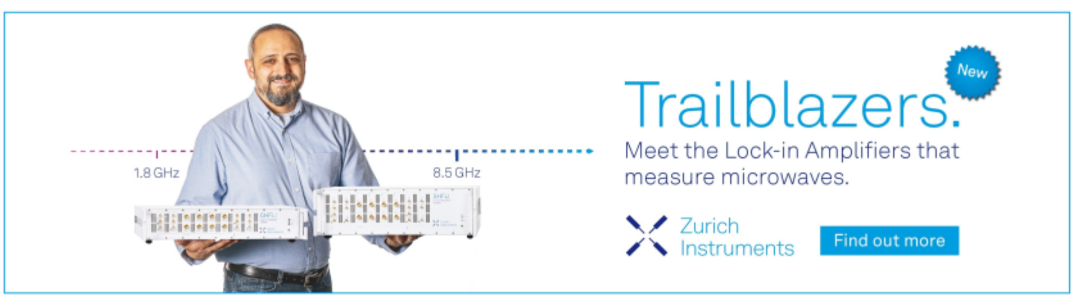

Laboratory Investigation on Wave Run-Up on a Dual-Function Breakwater

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Abstract. A dual-function breakwater model with a function as a coastal protector and as a wave energy converter with an overtopping concept was investigated experimentally in the laboratory. Laboratory investigations were conducted to find out how the wave run-up that occurs in the dual-function breakwater model to support as a wave energy converter with an overtopping concept. Research on wave run-up in dual-function breakwaters is still very rarely carried out, considering that in this study, it is hoped that a large run-up wave can occur so that overtopping can occur, whereas generally, the run-up studies that have been carried out on conventional breakwaters expect the opposite. In this study, a dual-function breakwater model was created which has a combination of slopes and is made smooth and impermeable. The research was conducted on a two-dimensional wave flume, with regular waves and carried out several variations of hydraulic parameters and structural model parameters. The results of this study indicate that the wave run-up that occurs is influenced by the incident wave height and the Irribaren Number. It was found that the greater the height of the incident waves, the greater the wave run-up. It was also found that the large Irribaren Number resulted in a large relative wave run-up as well, wherein this study the relative wave run-up obtained reached a value of about 4.8.

INTRODUCTION

Indonesia is an archipelago country that has a wide coastal area. The length of the coastal area in the Indonesian archipelago is about 81,000km and is the second-longest in the world after Canada. The coastal area is an area that is quite potential. The coastal area can be used for various activities such as trade, industry, tourism, settlement, transportation, and others. Also, many vital objects were built in the area near the coast. Several public facilities are also built on the coast such as ports. Apart from being an area that is quite potential for economic growth, the coast, especially the coastline, also has the potential to experience problems. Problems such as coastal abrasion, deterioration of the coastline, and loss of public facilities and settlements residents who were caused by the quite extreme sea wave attack cause considerable losses. In recent years there many coastal areas in Indonesia were damaged due to high sea waves.

The large potential of the coastal area that can be utilized for various activities, including by fishermen on the coast, of course, requires a supply of electrical energy to support their activities, and also considering the need for coastal protection to protect the coast, it is necessary to think about innovation of a coastal protection model that also functions as a wave energy converter. By innovating coastal protectors that at the same time serve as wave

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energy converters, then the protectors will function double and can provide greater benefits, also, will produce better cost benefits.

Coastal protection, which also functions as a wave energy converter, has been recognized in 2 categories, namely those that utilize the air pressure mechanism in the structure and those that utilize the wave overtopping mechanism on the surface of the structure. In coastal protection that utilizes wave overtopping, a slope structure is designed and studied that can produce large wave overtopping. At the top or rear part of the structure, a reservoir is created to accommodate the overtopping waves, which are then released back to the sea through an energy conversion process.

In this research, a breakwater model is made which also functions as an overtopping wave energy converter. This model makes use of wave overtopping to be collected and converted so that it is included in the category of wave energy converter with the overtopping concept. The breakwater model in this study is made with several characteristics, namely, the slope model is made with a combination of two slopes, the structure is smooth and impermeable, and at the back of the model, there is a reservoir.

In the overtopping concept for the coastal protection building of wave energy converter, the most important parameter that will affect the effectiveness of the wave energy converter is the overtopping discharge which can be captured. The greater the overtopping discharge captured, the greater the energy conversion that can be generated. Therefore it is very important to know how the influence of the structure/model parameters, hydraulic parameters, and the interaction between the two parameters that occur in the model created in producing overtopping discharge.

This study aims to analyze and get the effect of hydraulic parameters and structural parameters on the amount of wave run-up that can be generated in the breakwater model with the concept of overtopping wave energy converter.

WATER DEPTH AND WAVE CHARACTERISTICS

In terms of the depth of the waters where the waves spread, then the waves are grouped into 3 categories, namely shallow-water waves, transitional water waves, and deep water waves. The limitation of the three categories is based on the ratio between depth and wavelength $\left(\frac{d}{L}\right)$. Deepwater waves if $\frac{d}{L}$ is greater than 0.5, the transition water wave if $0.05 \le \frac{d}{L} \le 0.5$ and shallow water waves for $\frac{d}{L} < 0.05$. Based on the ratio between wave height and wavelength is known as a wave theory called the small-amplitude wave theory or Airy waves, and finite-amplitude wave theory (Stock, Cnoidal, Solitair). Airy's wave theory was passed down based on the assumption that the ratio between wave height and the wavelength or depth is very small, whereas the finite-amplitude wave theory takes into account the magnitude of the ratio between wave height to length and the depth of the water.

Wave characteristics that play an important role related to structure in the coastal and sea area are wave energy. Based on the small-amplitude wave theory, the total energy in one wave is the sum of the kinetic energy and potential energy. Kinetic energy is the energy represented by the effect of water particle velocity, because of wave motion. Potential energy is the energy that occurs due to the displacement of the water level by the presence of waves and formulated as in Eq. 1 [1].

$$E = \frac{\rho g H^2}{8} \tag{1}$$

where E, H and ρ are the energy of the wave, wave height, and density of water respectively. Ocean waves do not transfer mass, but transfer energy.

WAVE RUN-UP

The wave run-up is the height of the water level achieved by the effect of waves that hit the shore or coastal buildings calculated from the still water level (SWL). A wave moving towards buildings will be reflected or broken in the area. Part of the wave momentum gets converted into a water motion sliding up a slope is called a wave run-up [2].

In some coastal protection structures or in conventional one-function breakwaters (breakwaters that only function as coast protection), the height of the run-up is very important to use in determining the top elevation of the structure. The wave run-up is expected to be small so there are no overtopping waves that pass through the top of the structure.

On the dual-function coast protection structure or breakwater that converting wave energy with the concept of overtopping, the wave run-up is expected to be large so that a large number of wave overtopping can occur through the peak. Therefore, it is very important to study the wave run-up in the overtopping wave energy converter breakwater.

When the wave run-up has reached its highest point on the structure, it will run down the slope until the next incoming wave meets this wave run-down and the wave run-up occurs again. The lowest point to which water slams down, measured vertically to the still water level (SWL), is called the height of the run-down wave. The wave run-down is sometimes considered less important than the wave run-up, but they together make up the total wave creep on the slope. Figure 1 shows a sketch of the wave run-up (Ru).

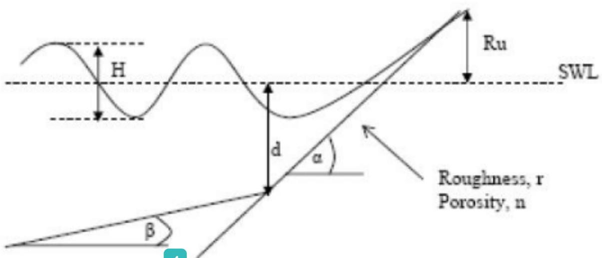

FIGURE 1. Sketch of the wave run-up (Ru) definition

Iribarren in 1938 has simplified the means to determine wave run-up and wave run-down via graphs known as the Iribarren chart. Where is the relative height run-up is a function of Iribarren's number and the type of coastal protection structure layer used. The Iribarren number/formula is shown in Eq. 2.

$$Ir = \frac{\tan a}{\left(\frac{H}{Lo}\right)^{1/2}} \tag{2}$$

where α is the ramps of the structure wall; H is incident wave height and L_0 is the wavelength in the deep ocean.

Gunbak in 1978 conducted wave run-up and wave run-down tests on the breakwater structure rubble mound with a slope of 1: 2.5 as for the results of this test suggest that the wave run-up for the inclined slopes with the rough surface is shown in Eq. 3 [3].

$$\frac{Ru}{H} = \frac{aIr}{1+bIr} \tag{3}$$

where Ru is run-up; H is incident wave height; Ir is Iribarren number and a, b is the empirical constant.

Other studies related to wave run-up in conventional coastal protection structures have also been carried out such as the performance of perforated screen seawall in dissipating waves minimizing reflected wave and run-up/run-down [4], investigating the effect of wave parameters on wave runup [5], wave run-up and overtopping over smooth and rock slopes of coastal structures without crown walls [6], wave run-up and wave overtopping under very oblique wave attack (cornerdike-project) [7].

Only a few studies on the wave run-up on the dual-function coast protection, especially the coast protection which simultaneously converts wave energy with an overtopping concept have been carried out. One such research is the effect of wave steepness on relative wave run-up on OWEC breakwater [8].

Wave run-up that occurs in the coastal protection structure is strongly influenced by many factors such as structure characteristics, incoming wave characteristics, and water level. In the study of energy-converting coastal protection structure with the concept of overtopping, it is hoped that high wave run-ups can occur to be able to reach the top of the structure and overflow.

RESEARCH METHOD

This research is laboratory-based research which was carried out at the Hydraulics Laboratory, Civil Engineering Department, Faculty of Engineering Universitas Hasanuddin. Research begins by formulating theoretically the concept of wave energy capture through the overtopping mechanism to get the parameters-parameters that have to be varied and which parameters must be measured. After that, the parameters will be varied and will be measured as known.

The pre-research was conducted to determine the capacity of the wave flume and the type of wave generator engine. Determine the characteristics of the waves generated, to obtain the range of wave heights that can be generated by varying the variator (wave period range) and stroke, determine the method of data collection and determine the output data generated from the laboratory. This information is useful in designing the dimensions of the model to be used. After that, designing and modeling the breakwater model including determining the scale model. After the test model is ready, then the tool calibration is carried out.

Tool Calibration and Wave Flume

Tool calibration includes 3 types, first: calibration of wave generators which aims to determine the correlation between the resulting wave height and variations in water depth (*d*). Second: routine calibration for every variation of the period (*T*) running, the calibration is done by resetting the ruler (scale) reading position on the wave flume according to the wavelength that occurs. Third: calibration of the wave probe used to measure the wave height.

Wave probe calibration is used to look for graphs to produce an equation generated by each wave probe which will then be used to find the maximum wave height (*Hmax*) and the minimum wave height (*Hmin*). Tool calibration is carried out before the breakwater model is entered into the flume. In this study, the calibration was carried out at a depth of 15 cm. The probe calibration process in the study is shown in Fig. 2.

FIGURE 2. Probe calibration process in the study

This research was conducted on a wave flume with characteristics having a channel length of 1500 cm, a channel width of 30 cm and an effective depth of the channel is 45 cm, as in Fig. 3. The wave generator is a flap type. The type of wave that is generated is a regular wave. The wave height can be varied by adjusting the stroke or plate in several variations to change the amount of flap deviation.

FIGURE 3. Wave flume and wave generator flap-type used in this study

Breakwater Wave Energy Converter

In this laboratory research, a dual-function breakwater model is made that allows waves to overflow at the top of the structure towards the reservoir to be used for energy conversion. The breakwater is made impermeable and smooth with a slope combination and it has a reservoir at the back to accommodate wave overtopping. This two-function breakwater model is made in two combination slopes (upper and lower slope). A sketch and photo of a two-function breakwater model are shown in Fig. 4.

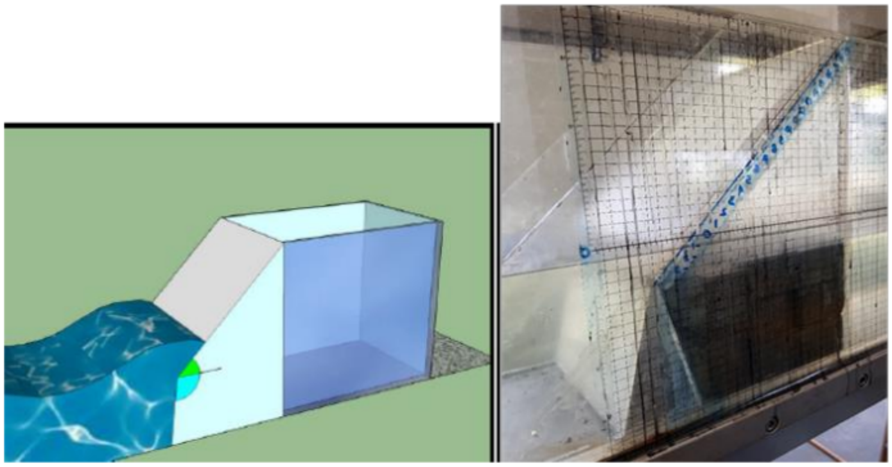

FIGURE 4. Sketch and photo of the two-function breakwater model in this study

RESULTS AND DISCUSSION

One of the main data that is observed and recorded during testing in the laboratory is the wave height in front of the model. From the experimental results and recording wave heights at 2 points in front of the model at the observation location, the maximum value of $Hmax$ and minimum wave height of $Hmin$ were taken. The recording uses the WVFW (Wave View For Windows) application whose program is run on a computer which is then connected to a wave reader, namely wave probe 1 and wave probe 2. Other main data were observed and recorded during laboratory testing is the wave runup and rundown on the model slope.

Relationship of Run-Up (Ru) and Run-Down (Rd) with Incident Wave Height (Hi)

Based on the results of data processing, the relationship between Ru and Rd with Wave Height (Hi), then depicted in graphical form by taking the incident wave height (Hi) as the axis variable x and Ru values with Rd as the Y axis variable for a certain depth then the resulting graph shown in Fig. 5.

From the graph in Fig. 5, it can be seen that the wave period affects the incoming wave height, the 0.9 second period produces a wave height in the range of 1-12 cm, where the height of the wave that occurs is probably caused by the meeting of the incident wave and reflected wave which then causes the incoming wave to the model to become high. The 1.1 second period produces a wave height in the range of 1-9 cm, and a 1.3 second period produces a wave height of 1-5 cm. the run-up heights obtained are 1-10 cm for the three periods. It is also found that at the same wave height of the three periods, for example, wave height of 4 cm, the highest run-up is generated by a period of 1.3 seconds which is almost 7 cm.

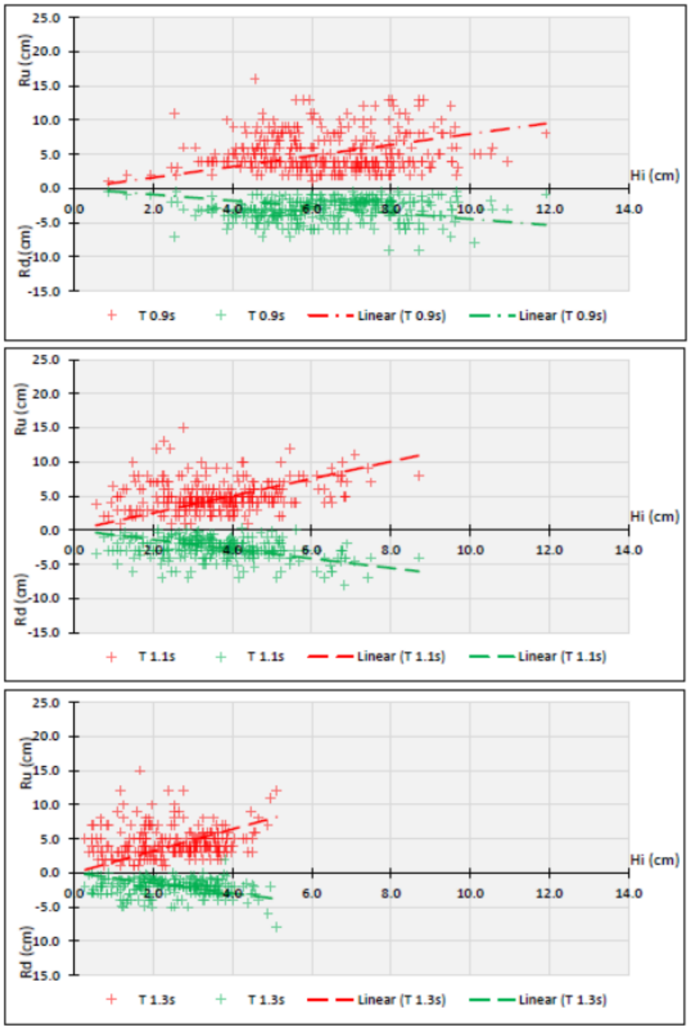

FIGURE 5. Relation of wave height to run-up and run-down

Relationship between Relative Run-Up Value (Ru/Hi) and Relative Run-Down Value (Rd/Hi) with Irribaren Numbers (Ir)

Based on the results of data processing, the relationship between Ru/Hi and Rd/Hi with Irribaren Number (Ir), then depicted in graphical form by taking the Irribaren Number (Ir) as the axis variable X and Ru/Hi values with Rd/Hi as the Y axis variable for a certain depth then the resulting graph shown in Fig. 6.

From the graph in the figure it can be seen that the wave period affects the value of Irribaren Number. A wave period of 0.9 seconds produces an Irribaren Number value in a range of 3-7, a wave period of 1.1 seconds produces an Irribaren Number value in a range of 4-11 and a wave period of 1.3 seconds results in Irribaren Number value ranging from 5-20. The effect of the period on the relative run-up value shows that the 1.3 second wave period produces the highest relative run-up value compared to the other two wave periods, with the relative run-up value reaching about 4.8. It can also be seen that a large Irribaren Number value results in a large run-up relative.

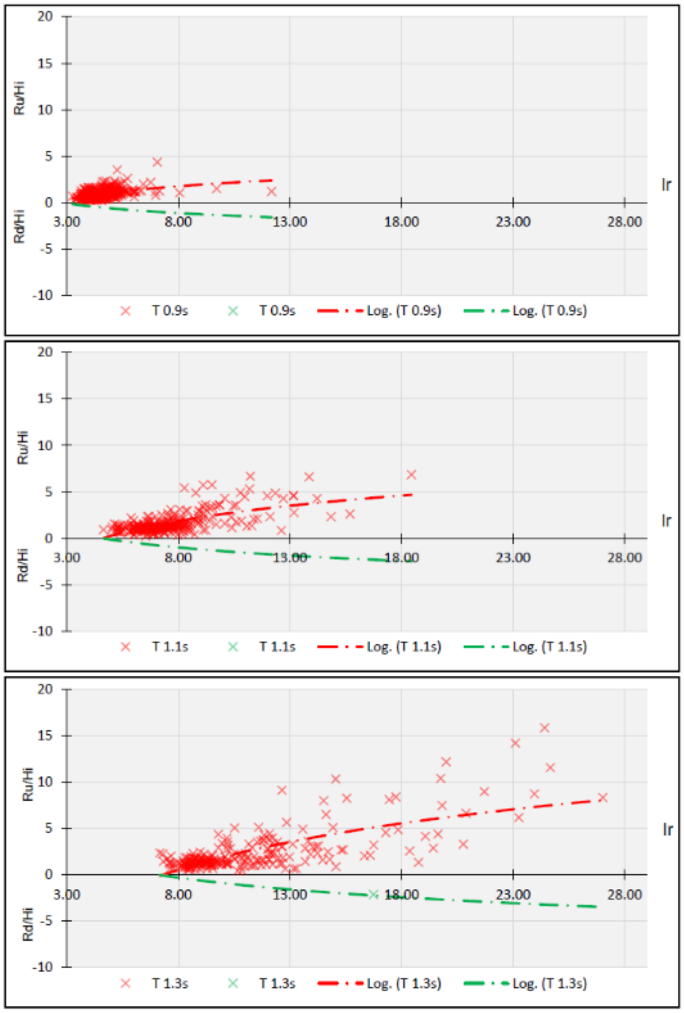

FIGURE 6. Relation of Irribaren Number to run-up and run-down

CONCLUSIONS

From this research, the following conclusions are obtained: first. in general, from the range of values in this study, it is found that the value of run-up relative increases with the increase in the value of Irribaren Number, second, the relative run-up values obtained from this study are generated from the relationship between the Irribaren Number and the relative run-up, resulting in a high relative run-up value. Third, the bigger the incident wave the bigger the wave run-up that is produced.

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