Effect of wave steepness to relative wave run-up on OWEC breakwater

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Abstract. OWEC (Overtopping Wave Energy Converter) breakwater is a coastal structure model concept. The concept is to integrate the breakwater and the overtopping wave energy converter. This coastal protection model concept is equipped with a reservoir at the top of the structure to collect water that overflows from the top of the structure (overtopping). Many factors influence the amount of wave overtopping discharge; one of them is the run-up height. The height of wave run-up that occurs is influenced by many factors, one of which is the steepness of the incoming wave. The effect of the wave steepness to the relative wave run-up on OWEC breakwater is investigated experimentally. The study is carried out in wave flume with regular waves. The OWEC breakwater model is simulated with slope variations and freeboard variations. The results of the study show that small wave steepness value produces a large relative wave run-up value and vice versa. For a review of the structure slope, the results showed that the largest relative run-up value was obtained in the largest slope of the variation of the slope studied, namely 1: 2, at all different freeboard heights.

1. Introduction
One of the most environmentally friendly predicted, renewable and clean energy resources available in this world is wave energy. In the future, this wave of energy resources has the potential to compete with non-renewable energy resources that exist today [1]. This renewable energy source is one alternative to supplement or to replace the current non-renewable energy. Various kinds of research have been carried out these days to develop energy generating devices from waves; however, these devices are still very expensive to develop and have not been able to compete economically with the non-renewable fossil energy. Therefore, researcher consider an idea to reduce the high cost of the wave energy converter (WEC) by thinking that the coastal structure that is built for a purpose, such as breakwater, can be used as wave energy converters, or in other words, we do not make a single stand wave energy converter device, but we integrate them with other coastal structure so that they become one coastal structure with two functions. The integration of WEC devices with other marine facilities has become common especially for near-shore applications. The main reason is triggered by better economic viability through cost-sharing on construction, installation, maintenance and operation as aligned with the main issue faced especially by the current stand-alone WEC device. Looking towards the multi-abilities provided by this integrated device, the application is effective for remote islands [2].

OWEC (Overtopping Wave Energy Converter) breakwater is a coastal structure concept. The concept is to integrate the breakwater and the overtopping wave energy converter. This coastal protection model concept is equipped with a reservoir at the top of the structure to collect water that
overflows from the top of the structure, that what we call as wave overtopping mechanism. Many factors influence the amount of wave overtopping discharge, one of them is the run-up height. Wave run-up is a condition when a wave rises on the surface of a coastal protection structure when a wave hits the structure. If the wave run-up reaches or exceeds the top of the structure, the wave will overflow, which is called overtopping. The higher the wave run-up, the greater the chance that the wave reaches the top of the structure and overflow (overtopping). The height of wave run-up that occurs is influenced by many factors, one of which is the steepness of the incoming wave. The wave steepness is important to wave characteristic that describes the ratio between the height of the incoming wave and the wavelength. This paper aims to determine the effect of wave steepness on relative wave run-up on the OWEC breakwater model.

2. Relative wave run-up
When a wave hits a structure, the wave will rise on the inclined plane of the structure; this is what we referred to as wave run-up. The wave run-up depends on the shape and roughness of the structure, slope of the structure, the water depth at the toe of the structure, the slope of the seafloor, and the characteristics of the wave.

The wave run-up height is defined as the vertical difference between the highest point of wave run-up and the still water level (SWL) as shown in figure 1. Due to the stochastic nature of the incoming waves, each wave will give a different run-up level. In the Netherlands, as well as in Germany, many dike heights have been designed to a wave run-up height $R_u2\%$. This is the wave run-up height which is exceeded by 2% of the number of incoming waves at the toe of the structure.

![Figure 1](image.png)

Figure 1. Definition of wave run-up height $R_u2\%$ on a smooth, impermeable slope.

The general formula that can be applied for the 2% wave run-up height for relatively gentle slopes (1:2 and gentler) is given by equation 1. The relative wave run-up height $R_u2\%/H_m0$

$$\frac{R_u2\%}{H_m0} = 1.65. y_b. y_f. y_\beta. \xi m - 1,0$$

(1)

Where $R_u2\%$ is the wave run-up height exceeded by 2% of the incoming waves (m), $y_b$ is the influence factor for a berm, $y_f$ is the influence factor for roughness elements on a slope, $y_\beta$ is the influence factor for oblique wave attack, and $\xi m - 1,0$ is the breaker parameter/surf similarity/Iribaren number. When the influence is not present, the influence factor becomes 1.0. If a certain influence is present, the value of the influence factor becomes smaller than 1.0, and the wave run-up and wave overtopping discharge will decrease [3].
Various studies on wave run-up have been carried out in the laboratory. The most frequently used experimental results in determining the wave run-up height in the coastal structure are the results of the Irribaren experiment. The results of the Irribaren experiment, which is a graph in figure 2 that shows the relationship between the Irribaren number values (Ir) and the relative wave run-up height (Ru/H) on some types of coastal structures, showing that the highest relative waves run-up are obtained from the smooth slope and impermeable structures.

![Figure 2. Relationship between Irribaren number (Ir) and relative wave run-up (Ru/H) on some types of coastal structure [4].](image)

The Irribaren number shown in equation 2.

$$Ir = \frac{\tan \theta}{\left(\frac{H}{L0}\right)^{0.5}}$$  \hspace{1cm} (2)

Where Ir is Irribaren number, $\theta$ is structure slope (°), H is wave height and L is wavelength.

3. Wave steepness

Wave steepness is defined as the ratio of wave height to wavelength ($s_0 = \frac{H_{mo}}{L_0}$). This will tell us something about the wave’s history and characteristics. Generally, a steepness of $s_0 = 0.01$ indicates a typical swell sea and steepness of $s_0 = 0.04$ to 0.06 a typical wind sea. Swell seas will often be associated with long-period waves, where it is the period that becomes the main parameter that affects overtopping. Definition of wave steepness shown in figure 3.

![Figure 3. Definition of wave steepness [5]](image)
The combination of structure slope and wave steepness gives a certain type of wave breaking, which is spilling, plunging, and surging, as shown in figure 1. For $\xi > 2 - 3$ waves are considered not to be breaking (surging waves), although there may still be some breaking, and for $\xi < 2 - 3$ waves are breaking. Waves on a gentle foreshore break as spilling waves and more than one breaker line can be found on such a foreshore. Plunging waves break with steep and overhanging fronts, and the wave tongue will hit the structure or backwashing water. The transition between plunging waves and surging waves is known as collapsing. The wavefront becomes almost vertical, and the water excursion on the slope (wave run-up + run down) is often the largest for this kind of breaking. Values are given for the majority of the larger waves in a sea state. Individual waves may still surge for generally plunging conditions or plunge for generally surging conditions.

4. Experimental study

4.1. Experimental facility and equipment

Research in the form of physical model tests of OWEC breakwater was conducted at Hydraulic Laboratory Faculty of Engineering Universitas Hasanuddin where the scale is given is a scale of 1:20. The wave channel used in this study has a length of 15 m and a width of 30 cm; the effective depth of the wave channel is 45 cm. The wave generator of this wave channel is a flap type. This wave-making flap-type created wave motion, the top of the flap is connected to the drive plate using a stroke, and the bottom of the flap is a hinge. The flap movement is controlled through a rotary motion of the drive plate; the flap movement is rotational motion. The wave raises from this flap movement/flutter. The experimental setup illustrated in figure 4.

Figure 4. The illustration of the physical model test in a wave flume.

Wave characteristics that are incoming wave height that can be generated by wave generators on wave channel are in the range of 2-12 cm and the period's height that can be generated by wave generators are in the range of 0.6 to 6 seconds. While the type of wave that is generated in this wave channel is a regular wave, the incoming wave height can be varied by adjusting the stroke in several variations to change the magnitude of the flap deviation. The wave period ($T$) can be varied by adjusting the rotational speed of the drive plate on the wave generators.

The OWEC breakwater, which is a smooth slope impermeable dike model form is simulated with slope ($\tan \theta$) variations and freeboard ($R_c$) variations. The model is also simulated with the variations of wave parameters, which is the incoming wave height ($H_i$) and the wave period ($T$).

4.2. Physical model

The Overtopping Wave Energy Converter breakwater (OWEC breakwater) is a coastal protection model concept. This model concept is the result of integration between breakwater and wave energy converter (WEC). On the back of this coastal protection model, there is a reservoir to catch and to collect the overflowing waves from the top of the structure (overtopping). This model is in 1:20 scale length. The freeboard of this OWEC breakwater model is varied with 3 variations 12.5 cm, 10 cm, 7.5 cm, and the
slope of this OWEC breakwater model is varied with 3 variations \( \tan \theta = 0.5 \) (slope 1:2), \( \tan \theta = 0.4 \) (slope 1:2.5), and \( \tan \theta = 0.3 \) (slope 1:3) as shown in figure 5 and figure 6.

![Figure 5](image1.png)

**Figure 5.** Freeboard variations of the OWEC breakwater model.

![Figure 6](image2.png)

**Figure 6.** Slope variations of the OWEC breakwater model.

The wave characteristics which is the incoming wave height \( H_i \) varied with 3 variations 6 cm, 7 cm, and 8 cm and the wave period \( T \) which is directly related to wavelength \( L \) also varied with 7 variations 0.6 s, 0.7 s, 0.8 s, 0.9 s, 1.1 s, 1.2 s, and 1.3 s, as presented in table 1.

| Wave Parameters | Variation |
|-----------------|-----------|
| Wave Height (cm)| 6         |
|                 | 7         |
|                 | 8         |
| Wave Period (s) | 0.6, 0.7, 0.8, 0.9, 1.1, 1.2, 1.3 |

The test conducted is summarized in table 2. The test conducted with a smooth, impermeable slope formed the reference case.

| Model | Tan \( \theta \) | Rc  | Hi     | T          |
|-------|------------------|-----|--------|------------|
| 1     | 0.5 (slope 1:2)  | 12.5 cm | 3 variation | 7 variation |
|       |                   | 10 cm  | 3 variation | 7 variation |
|       |                   | 7.5 cm | 3 variation | 7 variation |
| 2     | 0.4 (slope 1:2.5)| 12.5 cm | 3 variation | 7 variation |
|       |                   | 10 cm  | 3 variation | 7 variation |
|       |                   | 7.5 cm | 3 variation | 7 variation |
| 3     | 0.3 (slope 1:3)  | 12.5 cm | 3 variation | 7 variation |
|       |                   | 10 cm  | 3 variation | 7 variation |
|       |                   | 7.5 cm | 3 variation | 7 variation |
5. Result
This study was conducted to provide results on how the effect of wave steepness on the relative wave run-up. The relative wave run-up parameter is one of the most important parameters in the study of Overtopping Wave Energy Converter (OWEC) breakwater. Figure 7 (a) (b) (c) shown the resulting chart of the relationship between wave steepness and the relative wave run-up, with slope variations and freeboard variations on the OWEC breakwater model.

**Figure 7** (a) Relationship between wave steepness and relative wave run-up for slope 1:2, slope 1:2.5 and slope 1:3 for freeboard heights of 12.5 cm; (b) Relationship between wave steepness and relative wave run-up for slope 1:2, slope 1:2.5 and slope 1:3 for freeboard heights of 10 cm; (c) Relationship between wave steepness and relative wave run-up for slope 1:2, slope 1:2.5 and slope 1:3 for freeboard heights of 7.5 cm.
A few explanations can be drawn from figure 7 (a, b, c). First, it appears that the blue trendline on the chart that represents slope 1: 2 always looks at the very top of the other trendline, which represents slope 1: 2.5 and 1: 3, so from the chart it appears that slope 1: 2 produces the highest relative wave run-up (Ru/Hi), second, it appears that the trendline on the whole chart (the relationship between wave steepness (Hi/L) and the relative wave run-up (Ru/Hi) is decreasing exponentially; thirdly, the largest relative wave run-up Ru/Hi value is seen on freeboard (Rc) 10 cm.

6. Conclusions
From this study, it can be concluded that, in all freeboard heights condition shown that large wave steepness value, results in a small relative wave run-up value, or it can be said that, the smaller the wave steepness, the higher the run-up produced will be. So, if we expect a high run-up wave, the wave steepness value must be small. This result is also following the empirical formula of Iribarren. Finally, it can be concluded from the results of this study that, the highest run-up performance can be obtained from the steepest slope, namely slope 1: 2, and the wave steepness with small values.

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