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The Effect of Wave Deformation on Overtopping Discharge in Wave Energy Converter (OWEC)-breakwater

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Abstract: Overtopping is one of the most dynamic phenomena that occur in coastal structures. The amount of overtopping is influenced by many factors and is an interesting research study to this day. Overtopping discharge formula obtained from empirical studies. However, research on the effect of waved eformation on overtopping discharge, especially on coastal structures with the concept of Wave Energy Converter (WEC)-breakwater integration is still limited. An experimental study was conducted to analyze and obtain the effect of waved eformation on overtopping discharges that occur at OWEC-breakwater with multi slope. OWEC-breakwater models are tested on 2D wave channels with several variations in wave height, wave period and water level. From the results of the study, it was found that the greater the value of the reflection coefficient, resulting in a greater number of overtopping. It was also found that the greater the value of the breaker parameter causes the overtopping discharge to increase. This study also obtained a range of breaker parameter values outside the range of breaker parameter values which has been obtained widely.

INTRODUCTION

One renewable energy source that is always available on Earth is ocean wave energy. About >70% of the earth's surface is an ocean. With the increasing demand for energy, it is time to use sea waves as an alternative energy source while the supply off ossil fuel sandnon-renewable oils is running low.

Various kinds of research in the field of renewable energy have been aggressively developed to open up new dimensions of environmentally friendly renewable energy technologies that can reduce the dependence on the use of fossil fuels. However, in its application, renewable energy source technology, especially, ocean wave energy, still faces a major problem which is the large cost when compared to the conventional non-renewable energy technology.

Wave Energy Converter (WEC) technology can be categorized based on several aspects including the location of operation, wave conditions and its working principle. Based on these aspects, WEC technology is divided into 4 concepts which are wave activated body, point absorber, oscillating water column and overtopping. Lopez by Mustapa *et al*.[1] shows a break-down of the categories of WEC technologies that have been developed around the world. The most popular and most developed WEC technology is based on the point absorber concept while the overtopping concept has not been developed much.

In order to reduce the high cost of Wave Energy Converter (WEC) devices that operate alone is to integrate it with or in other maritime structures such as breakwaters or coastal protectors so that sharing costs are obtained.

The current break water only functions as a wave energy destroyer, even though the wave is one of the most potential renewable energy sources. Therefore, conventional breakwater with one function, namely wave's energy destroyer is changed to dual-function breakwater that is wave energy catcher and shore protector. The breakwater structure is equipped with a reservoir at the top, to catch and collect wave overtopping that passes through the top of the structure so that the conventional break water is transformed into an Overtopping Wave Energy Converter-breakwater (OWEC-Breakwater).

The concept used in overtopping wave energy converters is to bring the rising waves into the reservoir through the wave overtopping mechanism. The water that is stored in the reservoir which is located higher than the sea level has a potential energy content to be utilized. The amount of water that is contained in the reservoir and the amount of head height that can be obtained is very dependent on the amount of wave overtopping discharge that overflow through the top of the structure. Therefore, the amount of overtopping discharge that can begen erated by OWEC break water due to the in fluence of waved eformation in front of the structure is very important to be studied in this study.

Literature review

Wave reflection: Wave reflection is a form of wave deformation due to incoming waves that hit a coastal structure and cause reflection waves. The magnitude of the wave reflection is called the wave reflection Height (Hr).

The basic parameter for measuring the reflective characteristics of a coastal structure is called the Reflection Coefficient (Kr), defined as the ratio of the height of the reflected wave, Hr to the height of the incident wave, Hi. The formula of the wave Reflection Coefficient (Kr) shown in Eq. 1:

$$Kr = \frac{Hr}{Hi} = \sqrt{\frac{Er}{Ei}} \quad (1)$$

There are a number of parameters that affect Kr values of a coastal structure under different wave conditions. Therefore, taking various parameters into account, many different equations are proposed to assist in the design of individual breakwaters under specific environmental conditions. Wave reflection is greatly influenced by the slope of a surface in comparison with the wavelength. For example, as a waveapproaches a vertical seawall, most of the energy will be reflected. However, when a wave approaches a mildly sloping beach, most of the energy dissipates through breaking and only a small amount of the energy is reflected[2].

Wave breaking and breaker type: Of all the various processes to which water wave s are subject, wave breaking is one of the most important to coastal engineers since it greatly influences the magnitudes of the forces experienced by coastal structures. Unfortunately, breaking is possibly the most difficult wave phenomenon to describe mathematically. At present, very few properties of breaking waves can be predicted with reasonable accuracy.

Waves may break in a number of different ways. Steep waves on mild slopes tend to break by spilling water gently from their crests and there is a little reflection of the incident wave energy. In contrast, long low waves on steep slopes tend not to break at all. Instead, they surge up and down the slope with most of the wave energy is reflected[3].

The different visual characteristics of breaking waves provides a classification of breaker types which is spilling breakers, plunging breakers and surging breakers. These are the three main breaker types but since, there are smooth transitions between them, various sub-classifications have been proposed. The term "collapsing breaker" is sometimes used for breakers between plunging and surging but further subclassifications are not standardly used[4].

Breaker type can be identified using the breaker parameter or also known as surf similarity parameter or Irribaren number defined in terms of beach or structure slope (tan θ) and wave steepness (Hi/L0). The formula of breaker parameter can be seen in Eq. 2:

$$\xi = \frac{\tan\theta}{\sqrt{\frac{Hi}{L0}}} \quad (2)$$

The combination of structure slope and wave steepness gives a certain type of wave breaking as shown in Fig. 1. For ξ m-1,0>2 waves are considered not to be breaking (surging waves), although there may still be some breaking and for ξ m-1,0<~2 waves are breaking. For wave run-up on slopes, the transition from plunging to surging is given in this manual at ξm-1,0 = 1.8 which is very close to a value of 2. Waves on a gentle foreshorebreak as spilling waves and more than one breaker line can be found on such a foreshore. Plunging

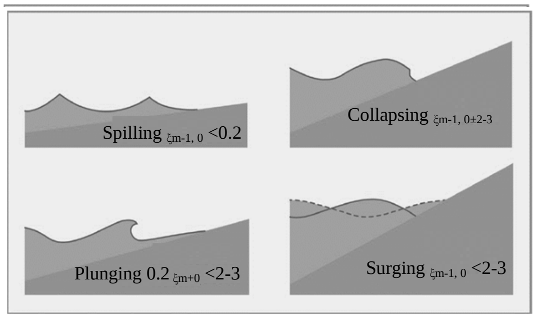

Fig. 1: Breaker type on a slope[5]

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 larger 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[5].

Wave overtopping: Wave overtopping occurs if the crestlevel of the coastal structures is lower than the highest wave run-up level. In that case, the freeboard defined as Rc the vertical difference between the SWL and the crest height becomes important. Wave overtopping depends on the freeboard and increases for Rc decreasing freeboard height Rc. Usually, wave overtopping for rubble slopes and mounds is described by an average wave overtopping discharge q which is given in m^3 sec^{-1} per m width or in l sec^{-1} per m width.

Physical modeling is generally used to study wave overtopping and develop empirical formulas to predict it. The many relevant parameters that influence this phenomenon make it difficult to develop theoretical or numerical approaches that represent the nature of overtopping well. In contrast, experimental tests are a well-established and reliable method for determining average overtopping waves for coastal structures[5]. However, the actual empirical formula does not predict individual overtopping of waves very accurately because the scale and effects of the model always exist at some level in the physical model.

The dimensionless overtopping discharge $Q^* = q/gH^3m0$ is a function of the wave height, originally derived from the weir formula[6].

Wave overtopping is a function of hydraulic parameters such as wave height, wave period, wavelength and water level as well as functions of structural parameters such as geometric, layout and material structure properties.

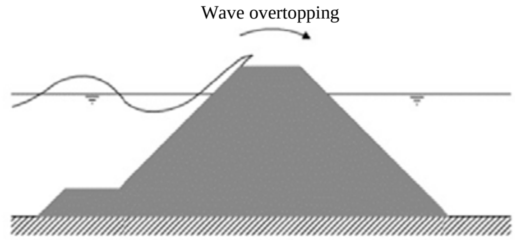

Fig. 2: Wave overtopping defination sketch

Some overtopping predictions are very difficult to predict precisely given the fact that subtle changes in wave conditions, water level, characteristics and structure geometry can have a very large effect on the level of overtopping. Wave overtopping definition sketch can be in Fig. 2.

Overtopping waves is a very dynamic and irregular process. This process can be characterized by overtopping wave discharge. In reality, there is no constant overflow at the top of the structure during overtopping. The wave overtopping process is very random in time, space and volume. The highest waves will push large volumes of water upwards in peaks in a short period of time whereas lower waves may not produce any overtopping.

Most of the methods and predictions for the formula for the average amount of overtopping originating from physical modeling in laboratory facilities, lead to the development of an empirical relationship between the amount of overtopping discharge with wave parameters and structure parameters. Many researchers have tried to develop methods and formulas to predict the overtopping of coastal structures under certain conditions. The prediction formula is very diverse and in a wide variety of results.

Jimenez[7] examined the effect of wave interactions on the structure expressed in the dimensionless parameter that is the breaker parameter based on the spectral average wave steepness to overtopping discharge. The results noticed that larger breaker parameters induce higher overtopping discharges. Furthermore, similar trend lines are observed for the different performed tests: as wave height (and wave period) increases within the same series, although the breaker parameter remains constant, the overtopping discharge increases due to a decrease in the relative crest freeboard.

MATERIALS AND METHODS

Experimental set-up: Physical model tests are performed on 2D wave channels. The length of the wave channel is 15 m, width is 0.3 m and height is 0.45 m. The water depth can be varied from 0.0-0.40 m.

The wave channel is equipped with a flap-type wave generator. The waves generated are regular waves. There is a wave absorber located at the end of the wave channel. The sketch of the experimental set-up shown in Fig. 3.

In this study, an innovative breakwater model was made based on the concept of breakwater-WEC integration by utilizing an overtopping mechanism. Breakwater which was used to destroy waves was changed into wave catchers breakwater by completing the structure with a reservoir at the top of the structure. This breakwater model is then called OWEC breakwater (overtopping wave energy converter breakwater). The function of the reservoir is to catch and collect wave overtopping that passes through the top of the structure. The water that is captured into the reservoir in the form of overtopping discharge will produce a difference in waterlevel between the reservoir and sea level which can then be used to produce power. Sketch of the OWEC-breakwater innovation and the parameters that affect this research shown in Fig. 4. In this physical model test, a number of parameter variations are performed. The summary of the research variations can be seen in Table 1.

Table 1: Summary of the research variations

Variation of parameters	No. of variations
Wave height (H)	3 variations 0,04, 0,05, 0,06 m
Wave period (T)	3 variations: 0,9, 1,1, 1,3 s 3 variations
Water deep (d)	0,15, 0,17, 0,19 m
Freeboard (Rc)	2 variations: 0,06, 0,08 m

Fig. 3: Description of the experimental set-up

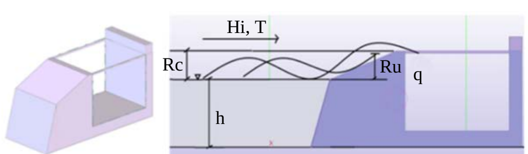

Fig. 4: OWEC-breakwater innovation model and the parameters that affect in this research

this physical model test, a number of parameter variations are performed. The summary of the research variations can be seen in Table 1.

RESULTS AND DISCUSSION

This study aims to analyze and obtain the effect of wave deformation in this case, the effect of wave reflection and wave breaking on overtopping discharge (q) at OWEC-breakwater.

Effect of breaker parameter (ξ) on dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) in OWEC-breakwater: To determine the effect of wave deformation that occurs in front of the structure stated in the breaker parameter (ξ) on the amount of wave overtopping discharge that can be generated, a relationship is made between the breaker parameter (ξ) to the dimensionless overtopping discharge ($q/(gH^3)^{0.5}$).

If the parameter breaker (ξ) and dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) are plotted by taking the value of the breaker parameter (ξ) as the x-axis variable and dimensionless overtopping discharge ($q/(gH^3)^{0.5}$)as the y-axis variable for variations in water depth and freeboard height, the results are as shown in the Fig. 5-7.

From the graph in Fig. 5-8, the following results are obtained: The value of ($q/(gH^3)^{0.5}$) increases with the value of ξ increase. This is similar to the results of Jimenez's in 2017. The value of the breaker parameter is large (ξ>2), meaning that the dominant breaker type that occurs is the surging type. It was also found that the largest overtopping discharge was obtained at a depth of 0.19 m with a low freeboard of 0.06 m.

Effect of wave reflection coefficient (Kr) on dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) in OWEC-breakwater: To determine the effect of wave reflection on the amount of overtopping discharge that can be generated, a relationship is made between wave reflection coefficient (Kr) to dimensionless overtopping discharge ($q/(gH^3)^{0.5}$).

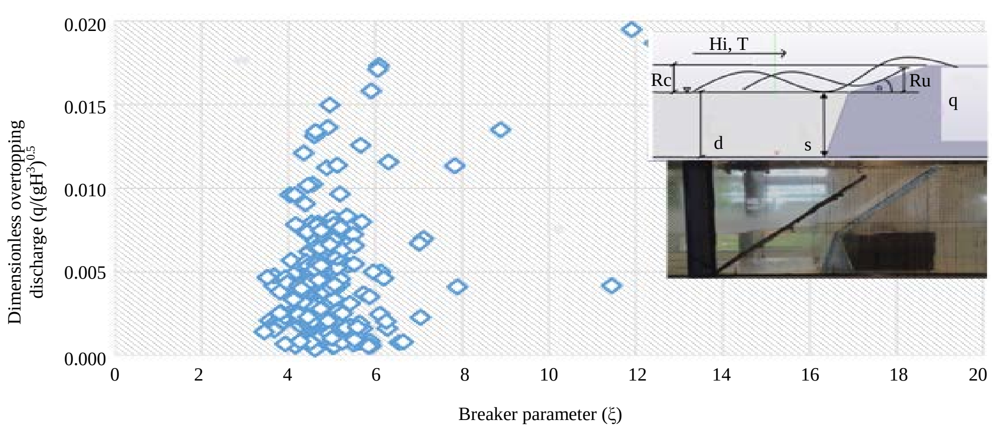

Fig. 5: The relation of breaker parameter (ξ) with dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) on OWEC-breakwaterat a depth of 0.15 m with a height freeboard of 0.08 m; d = 0.15m, Rc = 0.08 m

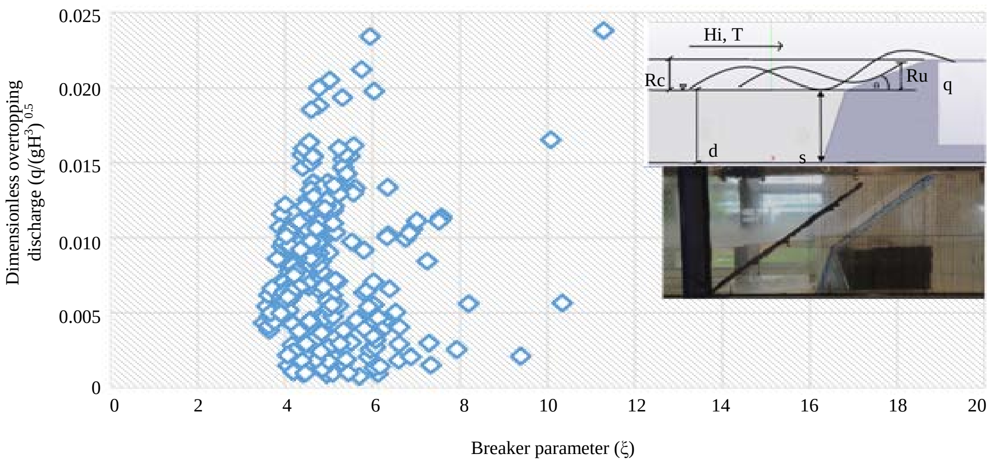

Fig. 6: The relation of breaker parameter (ξ) with dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) on OWEC-breakwater at a depth of 0.17 m with a low freeboard of 0.06 m; d = 0.15 m, Rc = 0.08 m

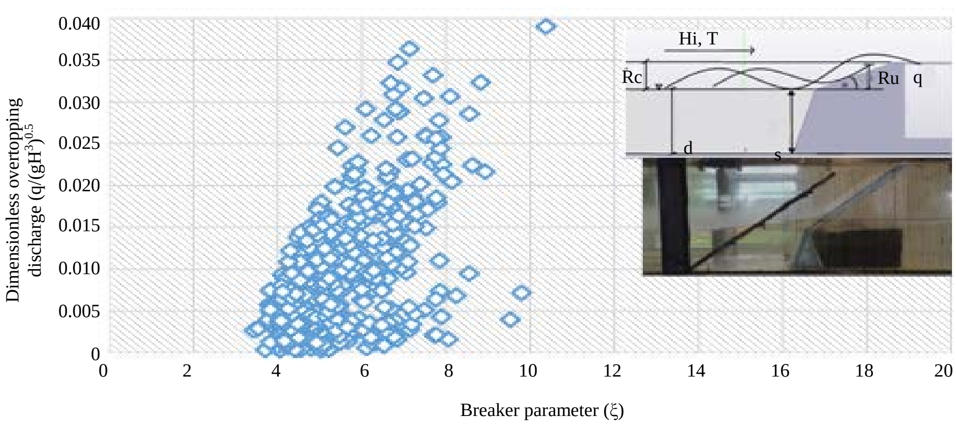

Fig. 7: The relation of breaker parameter (ξ) with dimensionless overtopping discharge ($q/(gH^3)^{0.5}$) on OWEC-breakwater at a depth f 0.19 m with a low freeboard of 0.06 m d = 0.19 m, Rc = 0.06 m

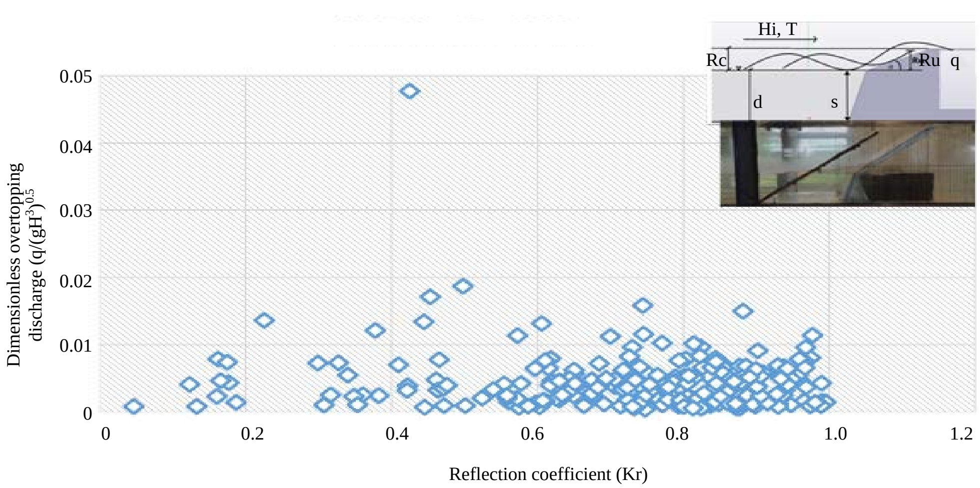

Fig. 8: The relation of reflection coefficient (Kr) with dimensionless overtopping ($q/(gH^3)^{0.5}$) on OWEC-breakwater at a depth of 0.15 m ; d = 0.19 m, Rc = 0.06 m

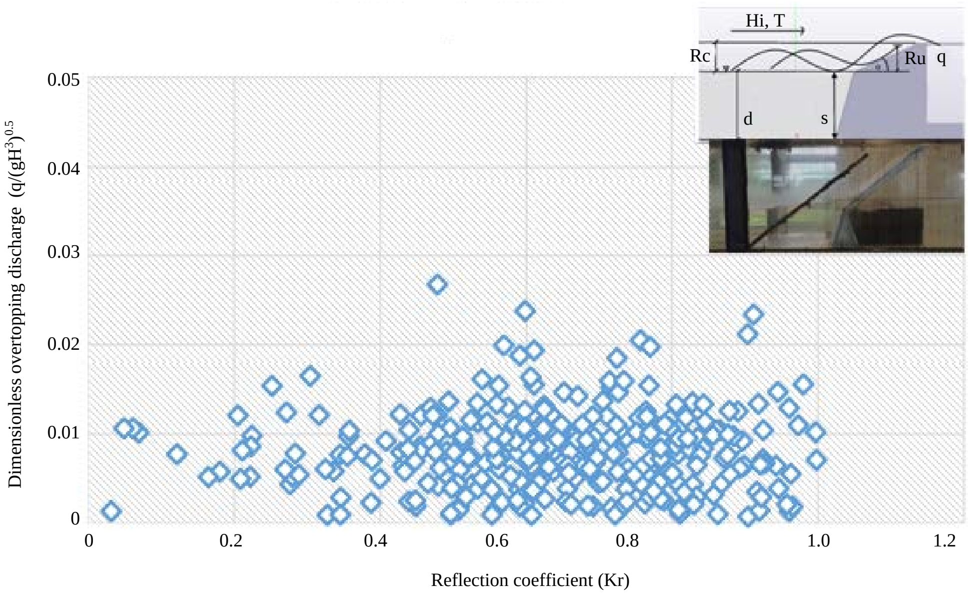

Fig. 9: The relation of wave reflection coefficient (Kr) with dimensionless overtopping discharge $(q/(gH^3)^{0.5})$ on OWEC-breakwater at a depth of 0.17 m with a low freeboard of 0.06 m; d = 0.17 m, Rc = 0.06 m

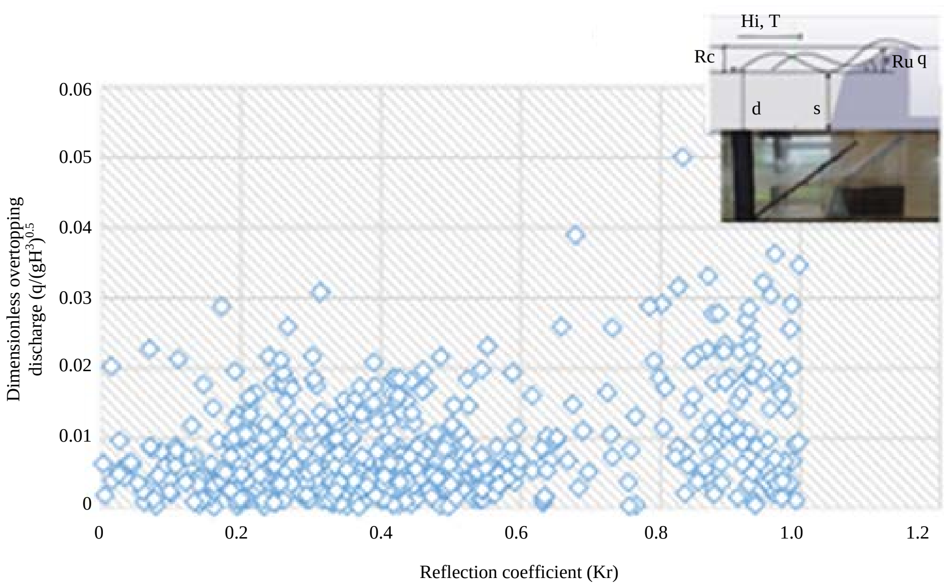

Fig. 10: The relation of wave reflection coefficient (Kr) with dimensionless overtopping discharge $(q/(gH^3)^{0.5})$ on OWEC-breakwater at a depth of 0.19 m with a low freeboard of 0.06 m; d = 0.19 m, Rc = 0.06 m

If the reflection coefficient (Kr) and dimensionless overtopping discharge $(q/(gH^3)^{0.5})$ are plotted by taking the value of reflection coefficient (Kr) as the x-axis variable and dimensionless overtopping discharge $(q/(gH^3)^{0.5})$ as the y-axis variable for variations in water depth and freeboard height, the results are as shown in Fig. 8-10.

From the graph in Fig. 6, the following results are obtained: this study generally obtained a large reflection coefficient value (there are quite a lot wave reflection coefficient values close to 1). It was also found that generally, a large reflection coefficient value produces a large dimensionless overtopping discharge value, especially, in the OWEC breakwater model with a water depth of 0.19 m and low freeboard of 0.06 m.

CONCLUSION

Some conclusions can be obtained from this study, first, overtopping discharge increases with the increasing values of breaker parameter. Second, the range of breaker parameter values obtained from this research is large which is 4-6. Third, the dominant breaker type obtained from this study is the surging type. Fourth, from the OWEC-breakwater model innovation with multi-slope, the wave reflection coefficient value obtained is large (close to 1) wherein general, it is also found that a large reflection coefficient value results in more overtopping discharge.

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