Experimental Study on the Performance of ModuleRaft Wave Energy Converter

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Abstract

This article proposes a novel wave energy converter (WEC), referred to as the ModuleRaft WEC. The WEC consists of a floating modular flap and four rafts hinged at the main floating structure. ModuleRaft WEC is unique due to its ability to convert both wave potential energy and wave kinetic energy by utilizing the pitch motion of rafts and floating modular flap. The performance of the ModuleRaft WEC model was evaluated by conducting the wave flume tests. The experimental tests were performed for both unidirectional regular and irregular waves. The experimental results show that the wave height, wave period, significant wave height, average wave period and power take-off (PTO) damping have a significant influence on the capture factor of the ModuleRaft wave energy converter. The capture factor of the ModuleRaft WEC which is a combination of modular flap and rafts is higher than only a modular flap without rafts by 27.7 % in regular wave condition and 6.7 % in irregular wave condition. It indicates that rafts play a positive role by floating and increasing the overall capture factor of the conventional floating modular flap-type wave energy converter.

Keywords: Wave energy converter, Raft, Floating modular flap, Wave flume, Experimental test

1. Introduction

Renewable energy technologies are being developed to meet rising electrical energy demand [1]. Ocean waves are both clean and renewable sources of energy with tremendous global potential for generating electricity. Over the years, different types of wave energy converters have been invented, developed and tested [2]. Among all kinds of devices proposed, raft-type wave energy converters (WECs) consisting of two or more floaters hinged at each floater end use wave curvatures (potential energy) as a source of reaction and power absorption. It has been proven to have the highest wave energy conversion efficiency and good survivability [3]. Andrew [4] presented the McCabe Wave Pump (MWP). The device is constructed with three narrow rectangular steel pontoons (one forward and one aft pontoon hinged to a smaller center pontoon with a damping plate) at an approximate length. The forward and aft pontoons move relative to the center pontoon by pitching around the hinges. Linear hydraulic rams extract the energy from the rotation of the hinges. This energy can be used to generate electricity using a hydraulic motor attached to a generator.

Whereas, pendulum-type wave energy converters, consist of a pendulum which converts wave kinetic energy to useful energy. Some of its advantages include wide frequency response and high energy conversion efficiency under normal sea conditions. T. Mäki presented “WaveRoller”. The WaveRoller WEC is a bottom-mounted, near-shore device which operates at depths of between 8 and 20 meters, approximately 0.3-2 km from the shore. It comprises a single wave-activated body, a flap, attached via a pivot to a basement structure and a foundation template on the seabed. The WEC converts incoming wave power to electrical power by utilizing the pitch motion of the flap.

In this study, we proposed the ModuleRaft wave energy converter, a new concept of wave energy converter inspired by using the benefits of raft type and pendulum type wave energy converters. The wave energy converter is unique due to its ability to convert both wave potential energy and wave kinetic energy by utilizing the pitch motion of the rafts and floating modular flap. The objective of this study is to: 1) Investigate the motion characteristic, performance and optimal condition of the ModuleRaft wave energy converter model based on wave flume testing and 2) Investigate the parameters which affect capture factor of the ModuleRaft wave energy converter.

2. Experimental Test

The experiments were performed in the Flow Informatics Laboratory, Korea Maritime and Ocean University, Republic of Korea as shown in Fig. 1. The wave flume is 7.3 m long (wave direction), 1.0 m wide and has a mean water level of 1 m. The ModuleRaft wave energy converter model was positioned on the central line of the wave flume at a distance of 1.7 m from the wave generator. To calibrate the wave generator and monitor the incident and transmitted waves, two wave gauges (Ultralab ULS sensor, model USS20130) with a resolution of 0.18 mm and a measurement range of 200 to 1300 mm were installed upstream 0.35 m and downstream 0.55 m away from the model.

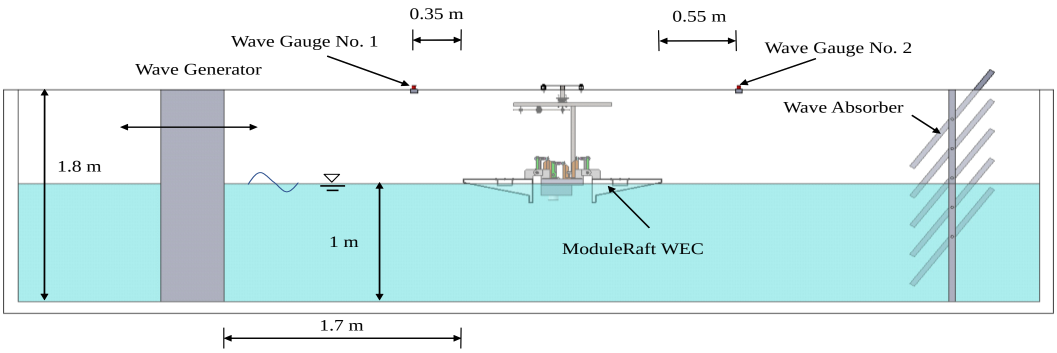


Fig. 1 Schematic sketch of the experimental setup (scaled).

The ModuleRaft wave energy converter model is shown in Fig. 2. The ModuleRaft wave energy converter consists of a floating platform, a modular flap, four hinged rafts and power take-off (PTO) system. The modular flap consists of three modules which are installed at the center of the platform. The raft wave energy converter consists of four rafts, which are connected to the floating platform by hinged joints. The modular flap and rafts each have a PTO system consisting of a compression and tension load cell, electromagnetic brake and angle sensor as shown in Fig. 3. Two quantities were measured i.e. torque and angular velocity on the rotating shaft of the modular flap and raft no.1-4. The electromagnetic brake (model FB19) is used to provide appropriate resisting torque (load) which is representative of a typical external PTO mechanism. Compression and tension load cell (model UMMC-5kgf) is used to measure compression and tension forces. The force multiplies the length of the lever arm (r) then the torque on the shaft is calculated. The angle sensor (model STS60V3-1N) is used to measure the pitch angle of the modular flap, raft no. 1-4 and platform. The derivative of the pitch angle with time, then the pitch angular velocity is calculated. The digital signals from all the sensors are stored at the same time using a data logger (model PT-1624). The experimental rig is shown in Fig. 4.

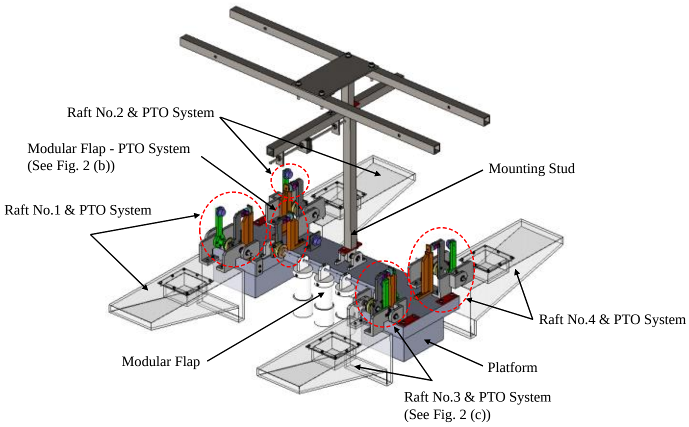


Fig. 2 The ModuleRaft WEC model

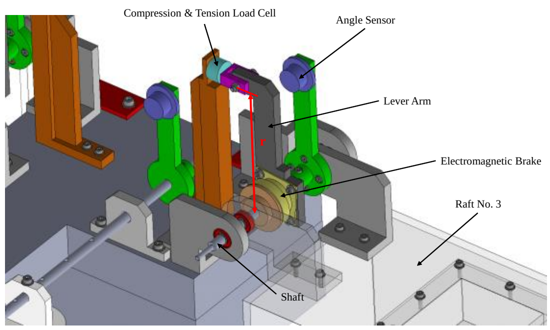
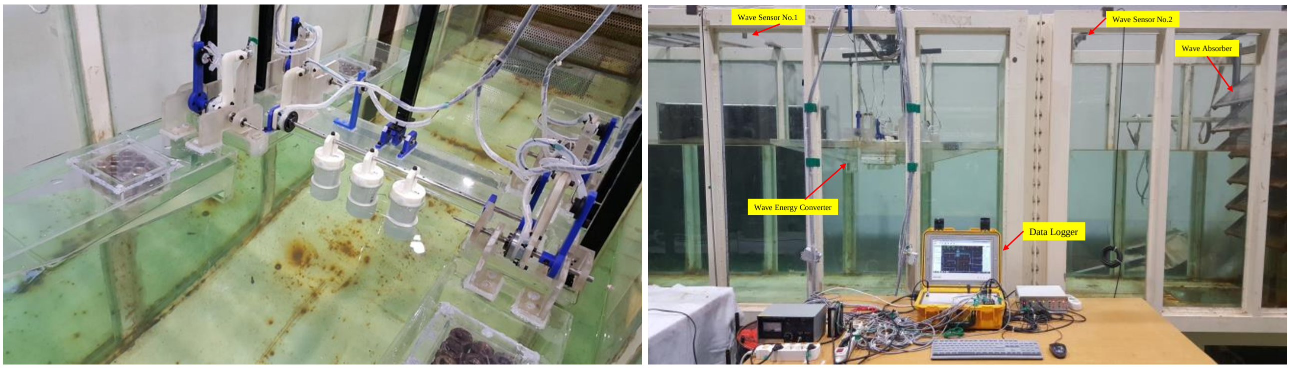


Fig. 3 The PTO system



(a) (b)

Fig. 4 Experimental rig: (a) The 1:32-scale ModuleRaft WEC model in the wave flume, (b) Data recording tools

3. Test Conditions

In this study, experimental tests were performed in regular and irregular waves to understand the hydrodynamic behavior of the ModuleRaft WEC. The first set of experimental tests were carried out for regular waves with water depth = 1 m. The main objective is to the effect of wave height, wave period and PTO damping on capture factor of the ModuleRaft WEC. The second set of experimental tests were carried out for irregular waves with water depth = 1 m. The regular and irregular wave conditions (REG) are summarized in Table 1.

Table 1 Regular (REG) and irregular (IRR) tested wave state

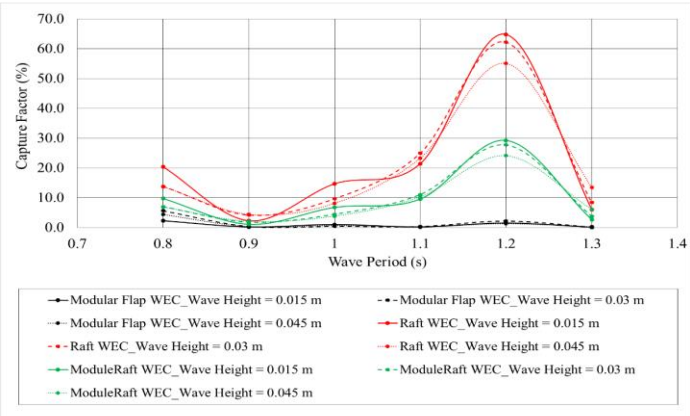
REG	T (s)	H (m)	REG	T (s)	H (m)	REG	T (s)	H (m)
1	0.8	0.015	7	0.8	0.030	13	0.8	0.045
2	0.9	0.015	8	0.9	0.030	14	0.9	0.045
3	1.0	0.015	9	1.0	0.030	15	1.0	0.045
4	1.1	0.015	10	1.1	0.030	16	1.1	0.045
5	1.2	0.015	11	1.2	0.030	17	1.2	0.045
6	1.3	0.015	12	1.3	0.030	18	1.3	0.045

IRR	T_e (s)	H_s (m)	IRR	T_e (s)	H_s (m)	IRR	T_e (s)	H_s (m)
1	0.8	0.015	6	0.8	0.030	11	0.8	0.045
2	0.9	0.015	7	0.9	0.030	12	0.9	0.045
3	1	0.015	8	1	0.030	13	1	0.045
4	1.1	0.015	9	1.1	0.030	14	1.1	0.045
5	1.2	0.015	10	1.2	0.030	15	1.2	0.045

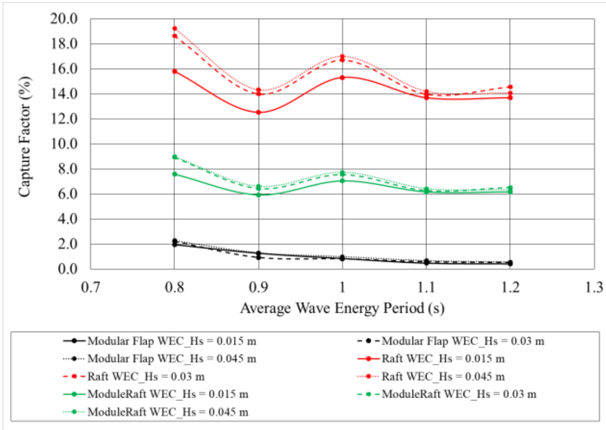
4. Results and Discussion

Fig. 5a shows the variation in capture factor of the ModuleRaft wave energy converter with wave period and wave height under regular wave conditions. It can be seen that the capture factor for the raft wave energy converter is larger than the modular flap wave energy converter for all wave period and height. Furthermore, the capture factors of the ModuleRaft wave energy converter which is a combination of modular flap and rafts are larger than that of modular flap wave energy converter without raft. The maximum capture factor of the ModuleRaft wave energy converter = 29.2 % at wave period = 1.2 s and wave height = 0.015 m. It implies that rafts play a positive role as a multifunctional device by floating and increasing the overall capture factor of the conventional floating modular flap-type wave energy converter.

Fig. 5b shows variations in capture factor with a range of average wave energy periods = 0.8 to 1.2 s and significant wave heights = 0.015, 0.03 and 0.045 m of modular flap, rafts and the combination of modular flap and rafts WEC under irregular wave conditions. It can be seen that the capture factor for the raft WEC and ModuleRaft WEC is higher than the modular flap WEC for all average wave energy periods and significant wave heights. In case of modular flap WEC, the maximum capture factor = 2.3 % obtained at average wave energy period = 0.8 s and significant wave height = 0.045 m. For raft WEC and the combination of modular flap and rafts WEC, the maximum capture factor = 19.2 % and 9 % respectively, obtained at average wave energy period = 0.8 s and significant wave height = 0.045 m. Irregular waves consist of a mixture of waves with different length, period and height. Therefore, it is quite difficult to operate the WEC and meet the resonance condition under irregular wave condition. Thus, the capture factor of the modular flap, rafts and the ModuleRaft WEC tends to be lower than the WEC which is tested under regular wave conditions.



(a)



(b)

Fig. 5 (a) Variations in capture factor of modular flap, rafts and the combination of modular flap and rafts with wave period and wave height under regular wave conditions. (b) Variations in capture factor of modular flap, rafts and the combination of modular flap and rafts with average wave energy period and significant wave height under irregular wave conditions

5. Conclusions

In this paper, a hybrid concept of raft and modular flap-type WEC, named ModuleRaft WEC is presented. The results from regular and irregular waves test indicated that the wave height, wave period, significant wave height, average wave energy period and PTO damping have a significant influence on capture factor of the ModuleRaft WEC. In case of regular wave conditions, the capture factor of the ModuleRaft WEC was larger by 27.7 % when a combination of modular flap and rafts was used rather than only a modular flap without rafts at wave period = 1.2 s and wave height = 0.015 m. In case of irregular wave conditions, the capture factor of the ModuleRaft WEC was larger by 6.7 % than only a modular flap without rafts at average wave energy period = 0.8 s and significant wave height = 0.045 m. It indicates that rafts play a positive role by floating and increasing the overall capture factor of the conventional floating modular flap-type wave energy converter.

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