Utilization of Double-Water-Chamber Seawall type for Wave Energy Extraction and Wave Dissipation

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Abstract-- **Variation type and model of wave energy converter have been applied in many countries around the world in order to harvest the ocean wave power. A number of other devices were developing and testing by researchers in the experimental scale. In the present paper investigates double-water-chamber seawall performance for wave energy converter. The main body of water chamber seawall is like OWC structure. Savonius water turbine and guide vanes used to extract a wave power instead of air turbine as usually used in the OWC type wave converter. The Savonious water turbine with two blade type was chosen in this study and a guide vanes to guiding the water flow to accelerate the water turbine was applied. Application of double-water-chamber seawall is also intended to reduce the reflection wave. The performance of double-water-chamber seawall was tested in the flume tank in order to obtain the efficiency rate and reflection coefficient.**

Index Term-- **Double-water-chamber type Seawall, Savonius Water Turbine, Guide Vanes, Wave Energy Extraction, Reduce Reflection Wave.**

1. INTRODUCTION

Utilization of wave power to meet the energy demand begins in 1973, the year of the so-called oil crisis. After that many researchers pays attention to develop the wave energy converter to utilize the wave power [1]. Actually, the ocean has been providing the energy from the sea wave power and it's enough to supply the electricity demand to support human activities. The limited negative environmental impact of its exploitation is a motivation for the use of wave power and development of wave power devices [2]. Compare to the wind and solar power device that can generate power to 20-30 percent only, the wave power devices can generate power up to 90 percent of the time [3]. Moreover, the density of water is 850 times as dense of air, it allows more energy can be generated from the waves and the space of wave energy installation need 1/200 the land area only of wind and requires no access road. Based on the global status report, renewable energy accounted for only ~22.1% of global electricity production at the end of 2013 [4], and there is thus a great possibility to increase the supply of wave power, especially ocean wave power.

Many countries have used ocean wave power to meet electrical demands. Various wave power converters have been used to increase the wave power supply, and many other different technologies are under investigation and development [5]. One of the most popular systems used to extract wave energy is the oscillating water column (OWC). The OWC comprises a partially submerged chamber and an air turbine as an energy extraction device. As the oldest water converter device type, so many researchers have investigated the ability of an OWC model to extract energy from ocean waves [6-15]. However, from the point of view of the efficiency of wave energy conversion, an OWC plant does not perform as well as other renewable-energy plants, such as wind power plants and tidal power plants. Despite the low efficiency of the OWC, the OWC plays other important roles in addition to extracting energy, such as the role of a breakwater that protects an area behind. It is thus necessary to consider the multiple roles of the OWC in developing a more effective wave power plant in the future.

The present paper introduces and examines the development of a new wave power converter called the double-water-chamber seawall. It has developed from the previous work by Husain et al [16]. Although there is a lack of references for this type of wave converter, it has a shape similar to that of the OWC structure. Water turbine was used to extract the wave power instead of air turbine as usually uses in the OWC type. An axisymmetrical guide vanes were installed to guide water flow to accelerate rotation of water turbines. By using the double-water-chamber seawall conversion efficiency rate is expected can be improved and the reflection coefficient can be reduced.

2. THE DOUBLE-WATER-CHAMBER SEAWALL MODEL

New model of double-water-chamber seawall is developed from the previous experiment model, namely single-water-chamber seawall. Original model has one chamber only comprised by the breadth (B2) and wall draft (d2) as seen in the Figure 1. Additional breadth (B1) and wall draft (d1) makes the present model becomes two chambers. It is intended to make the effective wavelength characteristic wider than the previous model to improve the efficiency rate and reduce the reflection wave.

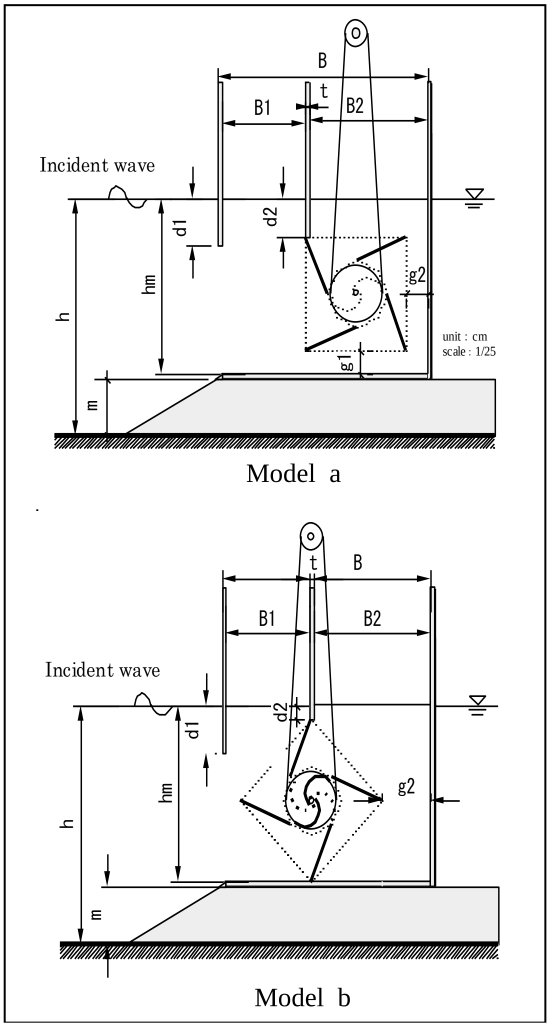

Fig. 1. Two types case examination of guide vanes arrangement inside the chamber.

There are two models of double-water-chamber seawall was examined and dimension of two arrangements are summarized in Table I.

TABLE I

Dimensions of the double-chamber-type seawall model

Description		Model a	Model b
Breadth of first chamber	*B1*	200mm	200mm
Breadth of second chamber	*B2*	280mm	280mm
Total breadth of chamber	*B*	500mm	500mm
Draft of first wall	*d1*	100 mm	100mm
Draft of second wall	*d2*	80 mm	30mm
Gaps	*g1*	50mm	-
	g2	50mm	117mm
Wall thickness	*t*	10mm	10mm

3. EXPERIMENT

3.1. The wave extraction devices (Guide Vanes and Water Turbine). The guide vanes used in the experiment comprised four thin plates in an asymmetrical arrangement and were connected with square plates at the left and right ends as seen in Figure 2. This arrangement is intended to guide the water flow so that rotates the turbine. At the center of the guide vanes, a Savonius water turbine was installed to extract the wave power as much as possible. The Savonious turbine type using two blades was applied in the study [17-18].

Dimensions of the guide vanes and water turbine are summarized in Table II.

TABLE II

Principal dimensions of the guide vane.

Description		Dimensions
Outer width of the guide vane	*La*	240 mm
Outer height of the guide vane	*Lb*	240 mm
Inner height of the guide vane	*Lc*	140 mm
Inner width of the guide vane	*Ld*	140 mm
Width between outer and inner side	*Le*	50 mm
Length of oblique plate	*Lf*	130 mm
Length of guide vane	*Lg*	360 mm
Diameter of turbine	*Lh*	120 mm
Transverse length of turbine	*Li*	350 mm

3.2. Experimental setup. The experiment was conducted at various wave periods of $T = 1.2$ to 3 s. For each wave period, the experiment was conducted at two wave heights, $H = 8$ and 16 cm. The water depth (h) from the bottom flat was 50 cm and that from the mound was 37 cm. These water depths were kept constant throughout the experiment. The mound height was 12 cm. To examine the effectiveness of the proposed double-water-chamber seawall in extracting wave power and dissipating wave energy, a series of experiments was carried out in a long wave flume at Ehime University. The model scale assumed here is 1/25. The model was made of transparent acrylic plates with thickness of 10 mm, which allowed the observation of the interior of the chamber during the tests. The flume tank was 30 m long, 1 m wide and 1.25 m high as shown in Figure 3. A piston-type wave maker was installed at one end of the tank and a wave absorber at the other end. The seawall model structure was installed 18.4 m from the wave maker. Four wave gauges of capacitance type were arranged in the wave flume. The first gauge was set in front of the wave maker, the second and third were placed in front of the model to estimate coefficients of reflection from the model, and the fourth was placed in the chamber of the model.

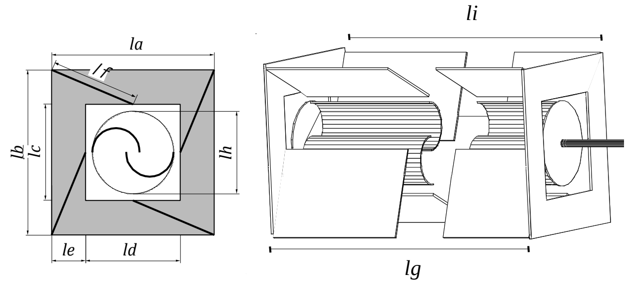

Fig. 2. Guide vanes and water turbines

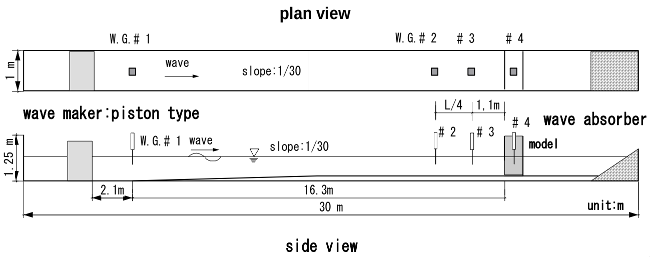

Fig. 3. Wave flume and experimental installation.

3.3. Procedures of experiment. Initially, the water turbine and guide vanes were installed horizontally inside the chamber as shown in Figure 1. In this case, the turbine is driven by water flowing from the lower opening of the front curtain wall. The propagation of water flow is directed by the axisymmetric guide vanes to increase the rotation of the water turbine. The pumping wave mode, which occurs inside the chamber, is also expected to increase the rotation of water turbines.

The rotating motion of a water turbine by wave action is transferred to a torque meter mounted above the seawall model through a pulley and belt system. The torque meter is connected to an electromagnetic brake that simulates the resistance load of an electric generator. The torque meter also captures the angular velocity of the rotational shaft. The torque meter used in the experiment has capacity of 1 N.m and a maximum speed of rotation of 6000 r/min.

To check the rate of extraction of wave energy by the Savonius turbine mounted within axisymmetric guide vanes, the work done by the water turbine against the resistance torque given by the magnetic brake was observed for various resistance levels under each set of wave conditions of the definite wave height and period. In this observation, the measurement system comprised a torque converter and a revolution counter. Wave reflection coefficients under the condition of wave energy extraction were also obtained.

4. POWER COEFFICIENT ANALYSIS

The power coefficient C_P is known as the energy conversion or extraction rate and is defined as

$$C_P = \frac{P_T}{P_W} \tag{1}$$

where P_T is the work done by the water turbine against the rotational resistance applied. P_W is the wave power of incident to a seawall and can be obtained as

$$P_T = \frac{1}{t}\int_0^t M_T \cdot \omega \quad dt \tag{2}$$

where M_T is the torque moment of the resistance measured by the torque meter, ω is the angular velocity of the pulley, and t is the duration of the observation, which is usually five or six times the wave period.

P_W is equal to the well-known property of the wave energy flux and can be expressed as

$$P_W = \frac{1}{8}\rho \cdot g \cdot H^2 \cdot C_g \cdot b \tag{3}$$

where ρ is the fluid density, g is the gravitational acceleration, H is the wave height at the position of the seawall measured as an incident wave, and b is the transverse length of the water turbine. C_g is the group velocity at which energy is transported in the waves and is given by

$$C_g = n \cdot C \tag{4}$$

In which n is defined by

$$n = \frac{1}{2}\left[1 + \frac{2kh}{\sinh 2kh}\right] \tag{5}$$

where h is the water depth and k is the wave number. And C is the corresponding wave celerity to the given wave period T and water depth h at the site

5. EXPERIMENT RESULTS

Figure 4 shows variations in the power coefficient for various amounts of resistance torque under the two conditions of the wave height. The typical result shows that the resistance torque gradually increased for fixed wave conditions; e.g., the wave height is 8 and 16 cm and the wave period T is 2.2 s in this example. The figure reveals that the power is not a maximum for the largest value of resistance torque. Because the rotational motion of the turbine becomes a minimum or stop under the largest resistance torque.

The experiment was repeated for another wave conditions. The optimum condition of the resistance torque corresponds to the maximum wave power extracted for given wave conditions.

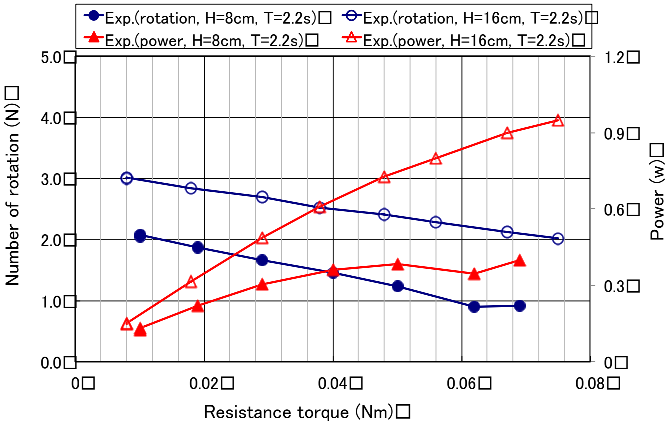

Fig. 4. Relation between the turbine rotation and wave power for various resistance torques.

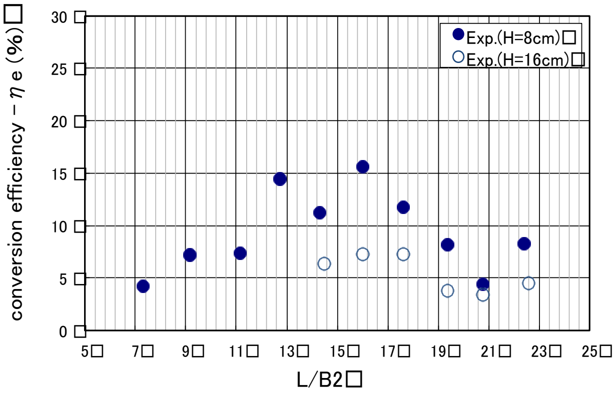

Fig 5. Efficiency rate for each wave condition as a function of *L/B2* (model a)

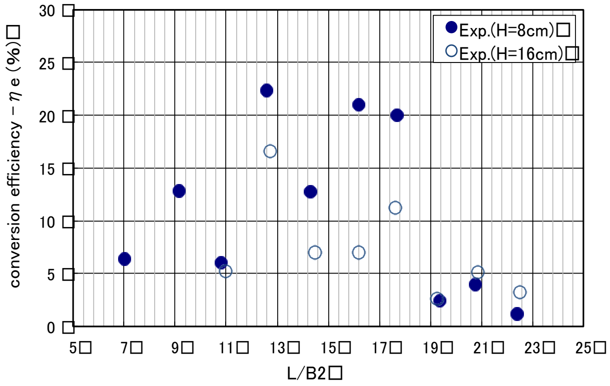

Fig. 6. Efficiency rate for each wave condition as a function of *L/B2* (model b)

5.1. Wave energy extraction rate. Figure 5 and 6 show the results for the rate of wave power extraction under the optimum conditions of the resistance torque (peak efficiency rate for each wave condition). Solid circles represent the results for a wave height of 8 cm while open circles represent the results for a wave height of 16 cm. The vertical axis of the graph define conversion efficiency ηe and horizontal axis define *L/B2*, where *L* is wave length and *B2* is breadth of the second chamber. In the From the figure 5, it can be seen that the maximum efficiency of the wave energy conversion is about 15% and occurs in the conditions *L/B2* = 16.

In order to increase the efficiency, the guide vanes were mounted in the chamber different with the first trial. In the second trial, the guide vanes setup by rotated 45 degrees from the initial position as seen in Figure 1 model b. The result reveals that the maximum efficiency of the wave energy conversion is increasing and reach to 23% and occurs in the conditions about *L/B2* = 13 as shown in the Figure 6. This optimal condition may be closely related to the optimal amplification condition of the wave motion in the water chamber. In the single-water-chamber seawall the maximum of efficiency is about 18% only. This means that the new model is better than the previous model. It is well known that the efficiency of the wave energy converter has been a main issue until now, because there is no one type of them to be dominant [19]. Compare to the LIMPET developed by WaveGen (8.7%), Mighty Whale developed by Jamstec (13.2%) [20], the efficiency of the present model is higher than both of them (23%).

For a higher wave height (16 cm), the efficiency of wave energy conversion reduces for two models. This may be due to the high resistance of water flow around the turbine.

Figures 7 and 8 show the possible extraction of wave power on the prototype scale converted from the above experimental results. The figures confirm that the possible output of wave power on a prototype scale for a wave height *H* = 2 m is about 25 kW and 30 kW in average, for model a and b, respectively. For a wave height *H* = 4 m, the possible output of the power of the prototype is 65 kW and 100 kW in average for model a and b, respectively. The wave power output from the double-water-chamber seawall is seemed to be adequate for the electricity consumption of appliances used in everyday life. By water-chamber seawall can be estimated typically total breadth (B=B1+B2) is 12.5m, water height in the mound (hm) is 9.25m and transverse length of the turbine is 8.75m.

Figure 9 shows the time history of the rotational speed of the turbine for different wave conditions; *T* = 2.2s in model (a) and *T* = 1.8s in model (b) with the same wave height (*H* = 8 cm). In the figure, the vertical axis shows the number of revolutions per second (rps) of the turbine. It is seen that the rotational speed of the turbine changes with time. This means that the power output during one wave cycle is not constant.

To smooth the rotational motion, an improvement of the mechanical transmission, such as the application of flywheels, may be necessary

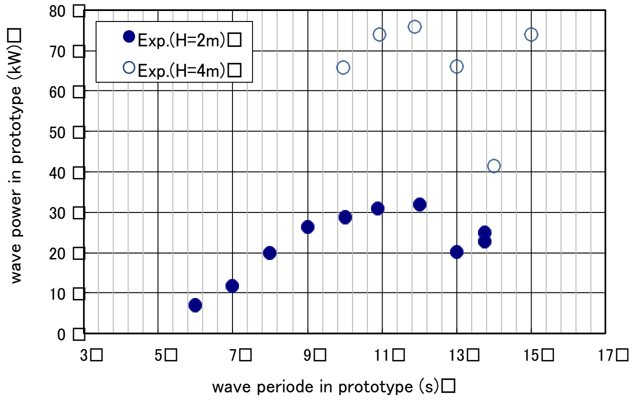

Fig. 7. Possible extracted wave power on a protype scale (model a).

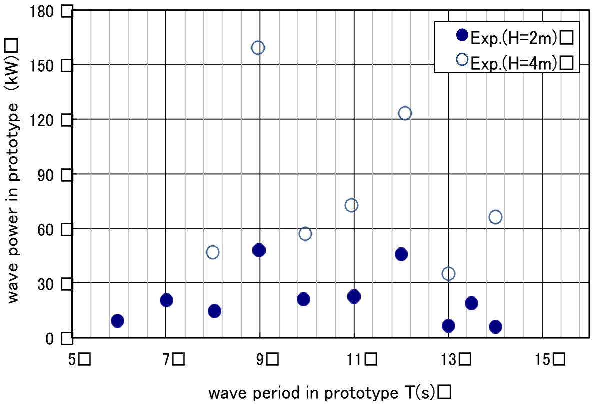

Fig. 8. Possible extracted wave power on a protype scale (model b).

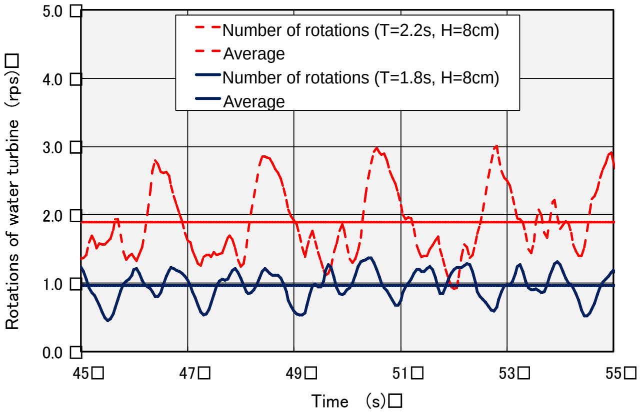

Fig. 9. Variation of the rotational speed of two cases

5.2. Wave reflection. In this study, the double-water-chamber structure is subjected to not only for extraction of wave power but also dissipation of reflected waves. Figures 10 and 11 show the coefficient of wave reflection *Cr* as a function of *L/B2*, where *L* is the wavelength and *B2* is the breadth of the second chamber. Solid circles represent experimental results for a wave height of 8 cm while open circles represent experimental results for a wave height of 16 cm. The solid line is a theoretical estimation of *Cr* calculated by the damping wave model developed by Nakamura and Ide [21]. However, application of the theoretical model is limited to a double-water-chamber seawall with guide vanes and turbine is not included in the theoretical calculation. In model (a), *Cr* remains low for *L/B2* ratios of 9, and then increases gradually for higher ratios as shown in Figure 10. In model (b) is a minimum at *L/B2* = 7 and after that, the *Cr* is tending to increase. The minimum of *Cr* in the two cases is about 0.3 and it is related to the pumping mode resonance in the water chamber. The previous model the minimum of Cr is about 0.4, little be higher than the present model. This result reveals that the structure works well as a wave dissipater especially for short waves.

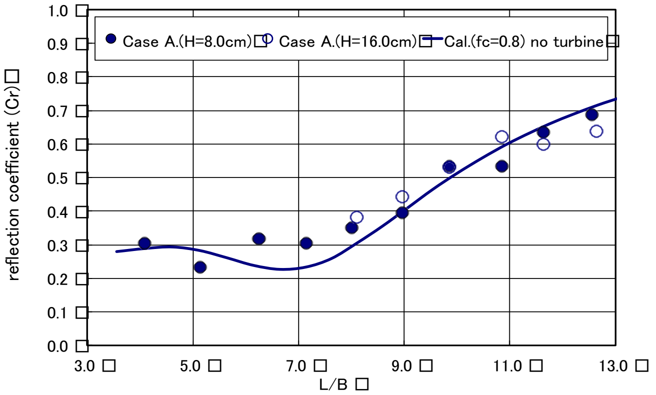

Fig. 10. Coefficient of wave reflection versus L/B2 (Model a)

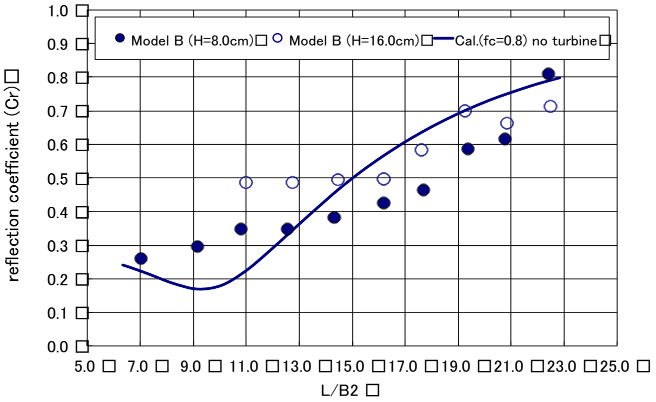

Fig. 11. Coefficient of wave reflection versus L/B2 (Model b)

6. CONCLUSION

1) In the previous work, the maximum conversion efficiency is about 18%, and the recent result of experiments using double-water-chamber seawall, the maximum conversion efficiency is about 23%. Despite increasing the efficiency

value is not so high, the double-water-chamber seawall shows the good performance to use as wave energy converter. 23% shows the fairly efficiency value, compare than other wave energy converter WEC types.

2) Another role of the structure, such as the breakwater function to reduce the reflection wave shows good result. In the recent experiment *Cr* being about 0.3 on average for a wide range of wave period and in the previous work is about 0.4 on average.
3) The wave power that can be extracted on a prototype scale is estimated as about 25 kW for a wave height $H = 2$ m and 65 kW for $H = 4$ m of the model (a). For the model (b) the output power is estimated about 30 kW for a wave height $H = 2$ m and 100 kW for $H = 4$ m. Such power levels are significant in terms of providing electricity for use in everyday life.
4) In order to realize optimum efficiency of the structure. It requires the detailed information of the wave height and period conditions at the site where is the structure will be installed.

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