Effect of Wave Power Device Arrangement in Double-Water-Chamber Type Seawall towards Wave Power Extraction Rate and Wave Dissipation

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Abstract. Utilization of the ocean energy to meet the electricity need is important to realization. The increasing need for electricity and environmental issues are the reasons. In last several decades a number of studies on wave energy device have been carried to find the effective one. In this paper, the double-water-chamber type seawall is basically adopted that has a similar structure to the OWC was examine to extract wave power. In the experiment various arrangement of wave power device inside the double water-chamber was tested to obtain optimum of wave extraction rate. Another function of the double water-chamber as wave dissipation is also clarified in the experiment. Based on experimental result the maximum wave energy conversion efficiency is about 30\% and the reflection coefficient of the double-water-chamber seawall is about 0.3 on average.

1. Introduction
Development of wave energy converter device has been started in last several decades in Europe. By 1980 there are more than one thousand patents had been registered [1] and its increase until now. The global awareness about the importance of clean energy source contributes to developed wave energy converter. Nowadays many countries have utilized energy from the ocean wave to meet their energy demand. Various wave power converters have been used to increase the wave power supply, and many other different technologies are under investigation and development [2]. Energy from ocean wave is most attractive to be exploited. It can be harnessed 90 percent of time compare to the solar and wind power device only 20-30 percent.

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 [3]. Although there is a lack of references for this type of wave converter, it has a shape similar to that of the OWC structure. It is well known that the oscillating water column is the most developed type of wave energy converter [4]. In double-water-chamber seawall, the water turbine was used to extract the wave power instead of air turbine as usually uses in the OWC type. An asymmetrical guide vane was 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. Nakamura et al. were confirmed that applied asymmetrical guide vanes to extract tidal current power and experimentally found out that such guide vanes are able to improve the efficiency of a water turbine, typically about 50\% of the efficiency [5]. Therefore, the present experimental study examines applicability of a similar method of power extraction device and the resultant possible efficiency as a wave power extraction device for double water chamber. By employing the wave
damping theory developed by Nakamura and Ide, the effectiveness of the double water chamber seawall as a dissipater of reflection waves is also examined and clarified [6].

2. Wave Power Device Component
The main wave power device component that use to extract wave power comprises of wave-guide vanes, water turbine and water chamber as substructure.

2.1. Wave Guide Vanes and a Water Turbine
When an incident wave reaches the structure, the water turbine will rotate due to of water flow that hit the blade. However the rotating of water turbine by water flow is deficient, therefore a wave-guide vane is needed. The wave guide vanes used in the experiment composed of four thin plates in an asymmetrical arrangement as seen in Figure 1. In the right and left ends two square plate are joined respectively. At the center of the guide vanes, a Savonius water turbine was installed to extract the wave power as much as possible. In this experiment the Savonious turbine type using two blades was applied in the study [7].

![Figure 1. The wave-guide vanes and a water turbine](image)

The dimensions of guide vanes and water turbines are summarized in Table 1.

| Table 1. Principal dimensions of the wave guide vane |
|-----------------------------------------------------|
| Outer width of the guide vane $La$                    | 240 mm |
| Outer height of the guide vane $Lb$                   | 240 mm |
| Inner width of the guide vane $Lc$                    | 140 mm |
| Inner height of the guide vane $Ld$                   | 140 mm |
| Width between outer and inner side $Le$               | 50 mm  |
| Length of guide vane $Lf$                            | 360 mm |
| Width of guide vane $Lg$                             | 130 mm |
| Diameter of turbine $Lh$                             | 120 mm |
| Length of turbine $Li$                               | 350 mm |

2.2. Double-Water-Chamber Seawall
The double-water-chamber seawall is consisting of two water chambers. It was designed to expand the effective wavelength characteristic. It was also intended to improve the efficiency rate and reduce the
reflection wave. In this experiment, there are three types arrangement of wave-guide vanes mounted inside the double-water-chamber. Here, the wave-guide vanes were installed in the first chamber for all type arrangement as shown in Figure 2. In the type 02, there is no gap spacing just below the first curtain wall and two others types that are type 01 and type 03 gap spacing are exist. The specific of type 03 besides have a gap spacing, it also has overlap arrangement. The description of three types are summarized in Table 2.

![Figure 2. The double-water-chamber seawall models with different type arrangement](image)

| Description                        | Type 01  | Type 02  | Type 03  |
|------------------------------------|----------|----------|----------|
| Breadth of first chamber (B1)      | 220mm    | 220mm    | 180mm    |
| Breadth of second chamber (B2)     | 260mm    | 260mm    | 260mm    |
| Total breadth of chamber (B)       | 500mm    | 500mm    | 460mm    |
| Draft depth of first wall (d1)     | 83mm     | 113mm    | 92mm     |
| Draft depth of second wall (d2)    | 113mm    | 113mm    | 113mm    |
| Gaps (g1)                          | 17mm     | 17mm     | 17mm     |
| (g2)                               | 30mm     | no gap   | 22mm     |
| Overlapping                        | -        | -        | 30mm     |
| Wall thickness (tw)                | 10mm     | 10mm     | 10mm     |

3. Experiment Activity
3.1. Experimental Condition
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 gauges was set in front of the wave maker, while 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.

3.2. Experimental Procedure

In this experiment, the model of double-water-chamber seawall was setup inside wave flume. The water turbine and guide vanes were installed horizontally inside the chamber. The water turbine is driven by water flow from the lower opening in front part of curtain wall. Application of axisymmetric guide vanes is intended to direct the water flow to increase rotation of the water turbine. The pumping wave mode, which occurs inside the chamber, is also expected to increase the rotation of water turbines. There are three arrangement types of installation guide vanes and water turbine will examine. Based on result of examination, the highest wave amplification from three type arrangements was selected to continue wave energy extraction test. 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 rotational resistance applied 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. Analysis of the Power Coefficient (Rate of Wave Power Extraction)

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

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

where $P_T$ is the work done by the water turbine against the rotational resistance applied and can be obtained as

$$P_T = \frac{1}{\omega} \int_0^t M_T \cdot \omega \, dt$$

where $M_T$ is the torque moment of the resistance measured by the torque meter, $\omega$ 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 the wave power of incident to a seawall equal to the well-known property of the wave energy flux and can be expressed as

\[
P_w = \frac{1}{8} \rho \cdot g \cdot H^2 \cdot C_g \cdot b
\]  

where \( \rho \) 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.

### 5. Experiment Results

#### 5.1. Wave Amplification

Figure 4 shows typical results of the wave amplifications in the new arrangement of guide vanes of type 01. The wave amplification is defined as the ratio of a wave height in each water chamber (\( H_c \)) to an incident wave height (\( H \)). In the figure, experimental results corresponding to the two different wave heights \( H = 8 \)cm and \( 16 \)cm are plotted to make clear the influence of wave height on the wave amplification. In the figure, a theoretical result based on the damping wave model is also specified. From this figure, it can be seen that the wave amplifications in the two water chambers increases with \( L/B \). For the second water chamber, the wave amplification for \( H=8 \)cm is higher than the one for \( H = 16 \)cm. For the condition \( L/B > 6 \), the wave amplifications in the two chambers are in the range between 1.0 and 1.5. This tendency may contribute higher wave energy extraction rate. We can see the reasonable agreement between the theoretical and experimental results on wave amplifications for the first water chamber. However, for the second chamber, the theoretical computation result overestimates the wave amplification, especially for longer wave conditions and higher wave height condition, \( H=16 \)cm. These quantitative differences may be caused by the higher hydrodynamic resistance in the guide vane in the experiment.

![Figure 4. Wave amplification results of type 01](image)

Figure 5 shows wave amplification result of the arrangement of guide vanes of type 02 mounted in the chamber. The second type of arrangement is similar to the previous type, but without a gap spacing between the first vertical wall and the guide vanes. It may allow the water particles of incident wave to come into the water chamber only through the slot of guide vanes and a gap under guide vanes. The figure reveals that the wave amplification results of both the water chambers are comparatively lower than the result of type 01. It can be seen that the gap spacing just below the first curtain wall is important to amplify the piston mode wave motions in both the water chambers. Computational results of the two wave amplifications show poor quantitative agreement with the experimental result, especially in the long wave condition. However, it can be confirmed that there are qualitative agreements between the two results, typically variations of the wave amplifications with \( L/B \).
Figure 5. Wave amplification result of type 02

Figure 6 shows the result of wave amplifications in the two chambers of type 03. It can be seen that the wave amplifications in both the chambers are comparatively high as compared to the previous three types. Specifically, the wave amplification in the second chamber is greater than 1.5 for longer waves and medium wave heights. Further the wave amplification in the first chamber is also about 1.5 in average for longer waves. We can see the reasonable agreement between the experimental and theoretical results, especially regarding the second water chamber. From these comparisons, it is confirmed that the gap spacing below the first curtain wall and the overlapping structure of the first wall on the guide vane are effective to increase the wave amplifications in the first and second water chambers.

Figure 6. Wave amplification result of type 03

5.2. Wave Amplification

Figure 7 shows wave power extraction rates of this model as a function of $L/B$. The figure reveals that the maximum efficiency of the wave energy conversion is about 30% and it occurs under the condition $L/B = 7$ ($T = 1.8$ s). This optimal condition may be closely related to the optimal amplification condition of the wave motion in the water chamber. For a higher wave height ($H = 16$ cm), the efficiency of wave energy conversion is a little bit decreased and maximum wave power extraction rates about 23%. This result is higher than the previous work by Firman et al. [8]. The important aspect of the result here is comparatively high efficiency under the condition of shorter waves that correspond to the nominal wave conditions.
Figure 7. Efficiency rate

Figure 8. Possibility extraction power

Figure 8 shows the possible extraction of wave power on the prototype scale, which is converted from the experimental result of type 04 model based on the Froude’s low of dynamic similarity. The figure reveals that possible extraction of wave power is about 50 kW for a wave height $H = 2$ m and 120 kW for $H = 4$ m on average.

5.3. Wave Amplification

Figures 9 and 10 show the results of reflection coefficients $Cr$ for the model of type 01 and type 03, which corresponds to the cases of comparatively higher wave amplifications in the chambers. In both cases, the minimum reflection appears about $L/B=8$ which corresponds to comparatively high wave amplification conditions as seen in Figures 4 and 6, respectively.

5.4. Possibility of wave extraction on the prototype scale

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Figure 9. Wave reflection of type 01

Figure 10. Wave reflection of type 03

There are some qualitative differences between the experimental and theoretical results. The difference may be resulted from the three-dimensional structural effects of the model, in which the rotating disc is stored in the transverse end part of the guide vane with 30 cm breadth. It can be seen that the reflection coefficient $Cr$ is less than 0.5 for comparatively wide range of $L/B$, e.g. $L/B$, =6 to 12.

6. Conclusion

The maximum conversion efficiency founded about 30% and 23% in wave condition of $H = 8$ cm and $H = 16$ cm respectively. 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. The wave power that can be extracted on a prototype scale is estimated at about 50 kW for a wave height $H = 2$ m and 120 kW for $H = 4$ m on average. It is enough for electricity use
in everyday life. The detailed information of the wave height and period conditions at the site is required, in order to realize optimum efficiency of the structure.

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