Efficacy of Water Chamber Type Seawall to Dissipate Incident Wave and Its Performance to Extract Wave Power

Firman Husain¹, M Rusdi Alwi² and Ashury¹

¹ Ocean Engineering Department, Engineering Faculty of Hasanuddin University, Indonesia
² Marine Engineering Department, Engineering Faculty of Hasanuddin University, Indonesia
Email: firman.husain@unhas.ac.id

Abstract. This study examined performance a water chamber type of seawall to dissipate incident wave and also extract wave power. The model of water chamber is consists of two water chamber type. The low reflection wave resulted by flow separation in lower end of vertical wall and it occurs after wave resonant condition. This structure is appropriate for short and long wave condition. A horizontal plate was setup in the end of vertical wall in order to improve performance of water chamber type seawall. This trial test taken to dissipate much longer waves condition and it’s related to utilize the wave energy inside the water chamber. Additional trial of the cross section, such as an adoption of a bevel edge instead of a right angle edge was also examined. It was seen that the seawall of a water chamber type with a horizontal plate is very effective to reduce reflected waves for both short and long waves. Also it was confirmed that large amplifications of pumping mode wave motions in the two water chambers appear for comparatively wide range of wave frequency

1. Introduction
The climate change effect was influence increase frequency of wave attack to the coastal area. This condition is sometimes leads to fatal damage along coastal shore. It condition was also appearing many problem of human life especially that occupied around coastal area. To minimize the risk of wave attack, set up of a wave protection for example seawall to withstand incoming waves is needed to ensure many activities in coastal area keep it running.

In recent time, various type of seawall has been constructed in many places around the world in order to defend coastal area from the wave brunt. While the other seawall models is examine stage in the laboratory scale in order to investigate performance of seawall model to reduce wave reflection and wave overtopping. Application of conventional vertical seawall to protect coastal area resulting the highly reflected wave and it sometimes cause damage in top area of seawall. Tanimoto and Yoshimoto [1] were proposed a type wave barrier called vertically slotted caisson type. This structure has much rectangular hole as serve as the wave dissipater. This type of dissipater seems a good performance to reduce reflected incoming waves and overtopping waves in comparatively deep seas areas. However the structure is suitable for limited conditions only. Typically a water chamber width should be about a quarter length of wave. An improved model of the slotted wall type presented by Cox et al [2]. He has introduced a double wave barriers composed of a perforated wall in the seaward and a solid wall in the shoreward. The effectiveness of this type for reducing wave reflections was
examined extensively and it was reported that the performance was still limited to the comparatively short waves. Furthermore the construction cost may become expensive, especially to build perforated walls and supporting structures.

In the present paper, a type of seawall of highly dissipative has been proposed. This type of water chamber is consists of two chambers and called the double water chamber type of seawall. This model is similar to the double curtain wall proposed by Nakamura et al [3]. To expand the effective range of wave frequency of reflected wave dissipations and also wave amplifications in the chambers, a horizontal plate below the first (front) water chamber was installed. So the first and second chambers separated by a horizontal plate. Comparison test between the double water chamber types of seawall with and without horizontal plate has been carried out. Another type separator called bevel edge shapes was tested to explore the magnification of wave amplification in the second water chamber.

2. Experiment
In order to examine various model seawalls, a series of experiments have been conducted in the wave flume to investigate performance of the model. All experiment activity has been running in the regular wave condition only.

2.1. Experimental apparatus
The model is tested in the flume tank with 30m long, 1m wide and 1.25m high as seen in the figure 1. The wave maker of wave flume using the piston-type put in one side and a wave absorber was installed in the other end side. The experimental model scale is assumed to be about 1/25 of the prototype. Five wave gauges of a capacitance type were used in the experiment and arranged in the wave flume. The first gauge was set in front of the wave maker; the second and third placed in front of the model to measure the incident and reflected wave; the fourth and five gauge put inside the first and second chamber respectively.

![Plan view](image1)
![Side view](image2)

**Figure 1.** Wave flume and experimental installation

All typical model bodies of the double water chamber type seawall made from the transparent acrylic plates with 10 mm thickness. It aimed to observe the effect of an opening height of the bottom channel. The seawall model was installed at about 19.2m apart from the wave maker. Breadths of the two chambers are fixed. Hence the first chamber width located offshore side is 25 cm (B1) and the second one nearshore side is 23cm (B2). In the experiment, comparison tests between double water chamber type seawall with and without a horizontal plate (see figure 2 and figure 3) have been carried out. The two different heights, say e2=5cm and 10cm, were adopted in the experiment. The dimension of e2 is varied by moved vertically of horizontal plate include the second vertical wall for giving the necessary opening height e2. In an additional trial, the bevel edge model (see figure 4) as separated in second chamber instead of right angle shaped model has been examined.
The dimensions of these three types of a double water chamber seawall models are summarized in Table 1. The type 2 consist of two kinds namely type 2a and type 2b and difference lies in height of second water channel (e2).

Table 1. Principal dimensions of the model bodies

| Model bodies                  | Type 1 | Type 2 (a) | Type 2 (b) | Type 3 |
|-------------------------------|--------|------------|------------|--------|
| Total breadth (B)             | 50cm   | 50cm       | 50cm       | 50cm   |
| Breadth of first chamber (B1) | 25cm   | 25cm       | 25cm       | 25cm   |
| Breadth of second chamber (B2)| 23cm   | 23cm       | 23cm       | 23cm   |
| Draft depth of first chamber (d1) | 18.5cm | 18.5cm   | 13.5cm     | 18.5cm |
| Draft depth of second chamber (d2) | 29.5cm | 29.5cm   | 24.5cm     | 29.5cm |
| Height of first water channel (e1) | 15cm   | 10cm       | 10cm       | 10cm   |
| Height of second water channel (e2) | 5cm    | 5cm        | 10cm       | 5cm    |
| Mound water height (hm)       | 34cm   | 34cm       | 34cm       | 34cm   |
| Water depth (h)               | 50cm   | 50cm       | 50cm       | 50cm   |

2.2. Experimental condition
In the experiment, the range of wave period was from 0.7 to 3.5 s. For each wave period condition, the two different wave height conditions, H= 8 cm and 16 cm, were used. For comparatively short wave period conditions, only the wave condition of H=8cm was adopted because of wave breaking. Height of water depths from the bottom flat is 50 cm (hm) and from the mound is 34.5 cm (d1). The heights of both are kept constant through the experiment.

3. Numerical analysis
The numerical analysis used in this study is based on the wave source distribution method with a linear damping proportional to a fluid velocity, developed by Nakamura and Ide [4]. In the numerical analysis, at first, the fluid domain around the seawall is divided into two regions, hence non-damping and damping wave region. Some distance from the front of body to the seaward of semi-infinite region is assumed to be non-damping wave region, where the potential flow theory without non-damping can...
be applied. The surrounding wave region about the seawall structure is assumed to be a damping wave region, where wave energy dissipation takes place that is proportional to a fluid velocity. According to the previous study [3], the damping wave region was set to be equal to the region from 1/60 of wavelength in front of the seawall face to the shore side of it. The same criterion was adopted in this study. In the damping wave region, it was assumed that the vortices are uniformly distributed in the fluid domain. The resultant equation of motion is similar to the one derived by Sollitt and Cross [5] for the homogeneous porous media except for an inertial term of porous materials,

$$\frac{\partial \bar{q}}{\partial t} = -\frac{1}{\rho} \nabla (p + \gamma z) - f_c \bar{q}$$  \hspace{1cm} (1)

Where, $\bar{q}$ is the fluid velocity vector around the body, $\rho$ is fluid mass density, $\nabla$ is the gradient operator, $p$ is the fluid pressure, $\gamma$ is the fluid weigh density, $z$ is the vertical coordinate, $\omega$ is the angular frequency of wave, $f_c$ is the equivalent linear damping coefficient. The fluid motion described by equation (1) is irrotational, therefore the velocity potential can be defined in the idealized damping wave region. To represent the velocity potential in each region, the wave source distribution method was firstly applied. Hereinafter is considering the matching boundary conditions between two wave regions, i.e. the non-damping and damping regions. The following equation of the Green’s functions was used in the analysis for non-damping region.

$$G (x, z; X, Z) = -\frac{i}{k} \frac{(k^2 - k_n^2)}{k^2 - k_n^2} \cosh(k h + z) \times \cosh(k h + Z) \exp(ik_c|x - X|)$$

$$\sum_{n} \frac{1}{k_n} \frac{(k_n^2 + k_c^2)}{k_n^2 + k_c^2} \cos k_n(h + z) \times \cos k_n(h + Z) \exp(-k_n|x - X|)$$  \hspace{1cm} (2)

Where, $(x,z)$ is a field point in the wave filed, $(X,Z)$ is a source point, $h$ is a water depth, $k$ is a progressive mode wave number, $k_n$ is an evanescent mode wave number and $k_o$ is a wave number corresponding to deep water wave condition. $k$ and $k_n$ are obtained by solving the following dispersion relation equations,

$$\omega^2 = gk \tanh(k h), \omega^2 = -gk_n \tan(k_n h) \hspace{1cm} (n = 1, 2, 3, \cdots)$$  \hspace{1cm} (3)

For a damping wave field, the corresponding Green’s function $G_D$ derived by Nakamura and Ide [4]. It is shown as,

$$G_D(x, z; X, Z) = -\sum_{n} \frac{i}{\mu_n} \frac{(\mu_n^2 - \lambda^2)}{\mu_n^2 - \lambda^2} \cos \mu_n(h + z) \times \cos \mu_n(h + Z) \exp(i\mu_n|x - X|)$$  \hspace{1cm} (4)

Where, $\lambda$ is defined by eq. (5), in which $\mu_n$ is a complex wave number, which is given by solving the following dispersion relation in a damping wave field,

$$\lambda = \frac{\omega^2}{g} (1 + if_c) = \mu_n \tanh(\mu_n h)$$  \hspace{1cm} (5)
4. Result of Experiment

4.1. Wave reflection

Figure 5 shows the result of wave reflection coefficient Cr as a function of L/B. Here, L is a length of wave corresponding to the water depth at the toe of a sloped mound, and B is a total breadth of the double water chamber type seawall. In the figure, the reflection coefficients of the two different cases are shown, typically with and without a horizontal plate below the first water chamber. Also, numerical computation results are shown. The equivalent linear damping coefficient fc=0.3 was used after some trial and error approach.

![Figure 5](image.png)

**Figure 5.** Comparison Cr of the water chamber with and without horizontal plate.

It can be seen that there are two minimum reflection points for different values of L/B regardless of with or without a horizontal plate. The tendency is very clear for the computation results. It is caused by the excitations of pumping mode wave resonance in the first and second water chambers. Under the resonant condition, flow separations and resultant vortex formations around the lower edge of the curtain walls become evident and predominant. Therefore, the wave energy dissipation increases under these resonant conditions.

By addition of the horizontal plate, the minimum reflection point corresponding to larger value of L/B shifts to much longer wave condition, i.e. from L/B=8 to 11. It may be resulted from increased amount of an oscillating water mass for the second water chamber by the horizontal plate. Therefore, the new type of double water chamber seawall is effective to dissipate reflected waves for much wider range of wave frequency.

Figure 6 shows the result of reflection coefficient for the case with a horizontal plate, but for different bottom channel height e2, say 5cm and 10cm. It can be seen that the effective range of wave frequency becomes narrow with increasing the bottom channel height e2. However, the absolute value of Cr for the case of e2=10cm becomes smaller than the case of e2=5cm for intermediate range of wave frequency.
Figure 7 shows the computation result of reflection coefficient for various values of \( e_2 \), i.e., \( e_2 = 3 \text{cm} \) to \( 15 \text{cm} \) in the model body. From this figure, we can see the similar tendency to figure 6. It becomes clear that the minimum reflection point corresponding to the longer wave condition shifts gradually with increasing the channel height \( e_2 \). However the reflection coefficient between the two minimum reflection points becomes larger with decreasing \( e_2 \). It is a kind of secondary effect for expanding the effective range of wave frequency.

From the practical point of view, it may be important to estimate the reasonable value of \( e_2 \) by considering both the effective range of wave frequency and also the absolute value of \( C_r \) between the two minimum reflection points. Under the limited condition such as given in figure 7, the channel height of \( e_2 = 5 \text{cm} \) is a kind of optimum condition.

Figure 6. \( C_r \) of different channel heights below a horizontal plate (\( e_2 = 5 \text{cm} \) and \( 10 \text{cm} \). \( H = 8 \text{cm} \))
4.2. Wave amplification

For effective wave energy extractions, much larger wave amplifications in the water chamber are usually required for wider range of wave frequency. A wave power extraction device based on the well-known oscillating water column type is typical. Figure 8 shows typical results of the wave amplifications in the two water chambers. The wave amplification is defined as the ratio of a wave height in each water chamber (Hc) to an incident wave height (H). In the experiment, we have confirmed that almost the same wave height appears in the water chamber because of the excitation of pumping mode wave motions in the chambers. In figure 8, the results corresponding to the case of e2=5cm are shown. However, it includes the two different results corresponding to the case of a right angle shaped plate and that of a bevel edged shaped plate. The latter cross section was adopted to magnify the wave amplification in the second wave chamber.

From this figure, it can be seen that there is no or very little difference on the wave amplifications between the two different cross sections. For both the models, the wave amplification reaches peak at first in the first water chamber for shorter wave conditions. Then, it does in the second water chamber for longer wave conditions. The consistency between experimental and computational results on the wave amplification becomes worse near the peaks of wave amplification on the two water chambers. It may be considered that the wave amplification near the peak conditions is strongly dissipated by the existence of sharp edges.

Figure 8. Wave amplification of right angle and bevel edge shaped in first and second water chamber

Figure 9 shows the results of the wave amplifications in the two water chambers without the horizontal plate. The agreement between the experimental and computational results is not good, especially for the second water chamber. It may be caused by the strong wave energy dissipation around the lower edge of the second vertical wall. Comparing the result with horizontal plate case (see figure 8), the peak values of the wave amplification for without horizontal plate in the two water chambers become lower significantly.

Figure 10 shows the influence of an incident wave height on the wave amplification in the two water chambers of the double water chamber type seawall with the horizontal plate. As seen in the figure, the wave amplification in the second water chamber varies significantly with the incident wave height, especially under the resonant condition of the second water chamber.
Figure 9. Wave amplification result in first and second chamber without horizontal plate

Figure 10. Wave amplification result in first and second chamber with a horizontal plate (water channel height $e_2=5\text{cm}$, $H=8$ and 16cm)

Figure 11 shows the result of wave amplifications in the first and second water chambers in case of $e_2=10\text{cm}$ (the channel height under the horizontal $e_2=10\text{cm}$). As compared with figure 8 which corresponds to the result of $e_2=5\text{cm}$, the wave amplification in the second water chamber increases for a larger channel height $e_2$ especially under the resonant wave period condition.

In order to magnify the wave amplification especially in the second water chamber of the double water chamber type, the installation of the horizontal plate under the first water chamber is very effective. Further, if the channel height $e_2$ is comparatively large, we can expect much larger wave amplifications in the second water chamber.
Figure 11. Effect increase of water channel height on wave amplification in the first and second chamber with horizontal plate (e1=10cm and e2=10cm)

5. Conclusion

- By installed a horizontal plate in the lower end of second vertical wall, performance of seawall water chamber is more effective to reduce wave reflections and also wave amplifications in the two chambers as compared to the original model without a horizontal plate.
- Increasing the bottom channel height under the horizontal plate, effective range of wave frequency for the dissipation of reflected waves becomes narrow. However, wave height amplifications in the water chambers, especially in the second water chamber, magnifies significantly.

Based on the experimental result of a double water chamber type with a horizontal plate, the wave amplification value shows good result. Therefore, it possible to continue to extract wave power using a double water chamber type with a horizontal plate as a substructure by installed an air turbine or water turbine in the future work.

Reference

[1] Tanimoto, K. and Yoshimoto, Y. 1982. Theoretical and experimental study of reflection coefficient for wave dissipating caisson with a permeable front wall, Report of Port and Harbor Research Institute, Vol.21, No.3, pp. 43-78
[2] Cox, R. J., Horton, P. R., and Bettington, S. H. 1998. Double walled low reflection wave barrier, Proc., 26th, Coastal Eng. Conf., ASCE, pp. 2221-2234
[3] Nakamura, T., Kohno, T., Makimoto, K. And Kamikawa, H. 2000. Enhancement of wave energy dissipation by a double curtain-walled breakwater with different drafts, Proc., of Int., Conf. Coastal Structures 99, Vol. 1, pp. 533-540.
[4] Nakamura, T. and Ide, Y. 1997. Analysis on wave transformations and wave forces about an angular body considering wave energy dissipations, Proc., of Civil Eng. in the Ocean, Vol.13, pp. 177-182 (in Japanese)
[5] Sollit, C. K. & Cross, R. H. (1972): Wave transmission through permeable breakwater, Proc., 13th, Coastal Engineering Conf., ASCE, pp. 1827-1846