EXPERIMENTAL STUDY ON INTERACTION BETWEEN WAVES AND SUBMERGED FLOATING BREAKWATER SUPPORTED BY PERFORATED PLATES

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Abstract: 有孔式版によって支持された新形式の浮防波堤を提案した．本研究で提案した浮防波堤は係留システムにたるみが生じないことから衝撃力の発生の可能性が低いことが期待されるとともに，運動成分が連成し，波入射時に浮体上部が傾斜面となって砕波を励起しやすいことが特徴である．水理実験を行って緊張係留システムと比較したところ，本研究で提案した浮防波堤はチェーンによる緊張係留に比べて透過率が小さく，エネルギー損失も大きくなることが確認された．

Keywords: *Submerged floating breakwater; perforated plates; wave energy dissipation; transmission coefficient.*

1. INTRODUCTION

The main function of a floating breakwater is to attenuate the wave action. It absorbs the wave energy, reduces the height of incident water waves on the onshore side and protects the facilities behind it. Compared to the gravity breakwaters (solid structures resting on the bottom), floating breakwaters are less expensive; less impact on currents or sediment movements; more esthetic, and transportable. However, such a structure can not block all the wave action. The incident wave is partially transmitted, partially reflected and partially dissipated. Energy is dissipated due to damping and breaking of incident waves and through the generation of eddies at the edges of the breakwater. Due to wave energy the breakwater can be put in motion and a radiated wave is produced which is propagated in both directions i.e. offshore and onshore. The movement of the breakwater is specified in terms of the anchoring which defines the degrees of freedom of the breakwater. However, floating breakwaters are susceptible to damage by waves and require higher maintenance.

Many researches have being carried out to investigate the performance of different types of floating breakwaters. Takaki et al. (2002) studied the performance of floating breakwater with two boxes. They concluded that the performance of the floating breakwater with two boxes is superior to the conventional floating breakwater with a single box. Murali et al. (1997) carried out experimental study to investigate the performance of cage floating breakwater. They suggested to use the mooring lines with adequate stiffness and to select the alignment of the breakwater to make sure its good performance. Bayram (2000) evaluated the performance of sloping float breakwater for protection of small commercial vessels. He found that the main controlling factor for the wave transmission is the inclination of the structure.

Based on the concept of maximum energy dissipation due to reflection and minimum passage of energy beneath the structure, this study proposes the new type of submerged floating breakwater which is supported by perforated plates. Also the chain mooring system is used in this study and this is adopted for comparison. To investigate the performances of the proposed structure, the experiments are conducted in a two-dimensional wave tank. Due to the perforated plates that anchor the floating body with the bottom of the wave tank, there is no slack state in the supporting plates, which forces strong relations among three motions of floating body. Therefore the impulsive tensile force is expected not to act on the mooring system, which is one good advantage compared to traditional mooring chains. Also, when incident waves propagate to structure, top surface of floating body makes slope (roll) and this encourages the wave breaking. This contributes the wave energy loss. The performance of this breakwater to reduce the incident wave energy, in decreasing transmission waves and its dynamic behavior is investigated in this paper.

2. EXPERIMENTAL INVESTIGATION

A set of experiments is done in a two-dimensional wave tank at Nagoya University. The detail experimental setup is shown in Fig.1. The wave tank is 30m long, 0.7m wide and 0.9m deep. The floating breakwater considered in this study is pontoon type and is made of acrylic plate and wooden plate. The floating body is 40 cm long, 68 cm wide and 18 cm deep, as shown in Fig.2. The body is anchored to the bottom of the tank with three types of mooring systems: connection-*Type A* (perforated wooden plate), *Type B* (perforated wooden plate with low permeability) and *Type C* (chain). All the three types of connection are anchored to the bottom plate in the wave tank with three different inclinations (θ= 90°, θ= 60° and θ= 45°). Photo view of the all three types connections are shown in Fig.3. The characteristics of mooring systems are shown in Table 1. For all the inclinations and the connections, floating body is always anchored so that its top surface was at the height of 62 cm from the bottom of the wave tank. Water depth in the wave tank was varied as 62 cm, 65 cm and 68 cm. Regular waves are generated from the wave generator and the wave steepness (H/L) is varied as 0.01, 0.02 and 0.03. The experiments are conducted for the waves of ten different wave periods, i.e., T=0.8s, 0.9s, 1.0s, 1.1 s, 1.2s, 1.3s, 1.4s, 1.6s, 1.8s and 2.0s. Total 810 runs are conducted during the experiment. These conditions are summarized in Table 2.

Five wave gauges and two velocity meters are set up in front and behind the floating body to measure the water surface elevation and the water particle velocity during the experiment. Because of the two-dimensional experiment, the sway (Δx), heave (Δz) and the roll (α) of the body occurs due to the wave action and these displacements of the floating body are measured with the laser system composed of four displacement meters. Two vertical laser rays and two horizontal laser rays are focused on a white paper box that is set up at the top surface of the floating body. The mass of the box (see Fig.3) is much less than that of the floating body and it is assumed not to affect the motion of floating body.

Table1: Characteristics of the mooring system

Connection Type	Inclination, θ	Rate of hole area, φ
Type A-45	45°	32.3%
Type A-60	60°	33.6%
Type A-90	90°	39.2%
Type B-45	45°	24.2%
Type B-60	60°	25.2%
Type B-90	90°	29.4%
Type C-45	45°	-
Type C-60	60°	-
Type C-90	90°	-

Table 2: Cases of experiment

Connection Type	Inclination, θ	Water depth, h (cm)	Wave period, T (s)	H/L
Type A	90°,60°,45°	62,65,68	0.8,0.9,1.0, 1.1,1.2,1.3, 1.4,1.6,1.8, 2.0	0.01, 0.02, 0.03
Type B	"	"	"	"
Type C	"	"	"	"
3 cases	3 cases	3 cases	10 cases	3 cases
Total= 3 × 3 × 3 × 10 × 3 = 810 cases				

3. EXPERIMENTAL RESULTS AND DISCUSSION

Experiments are carried out to find the displacements of the floating body, to evaluate the reflection coefficient, the transmission coefficient and the wave energy dissipation by the floating body, to understand the effect of wave steepness (H/L) on the performance of the proposed structure and to evaluate

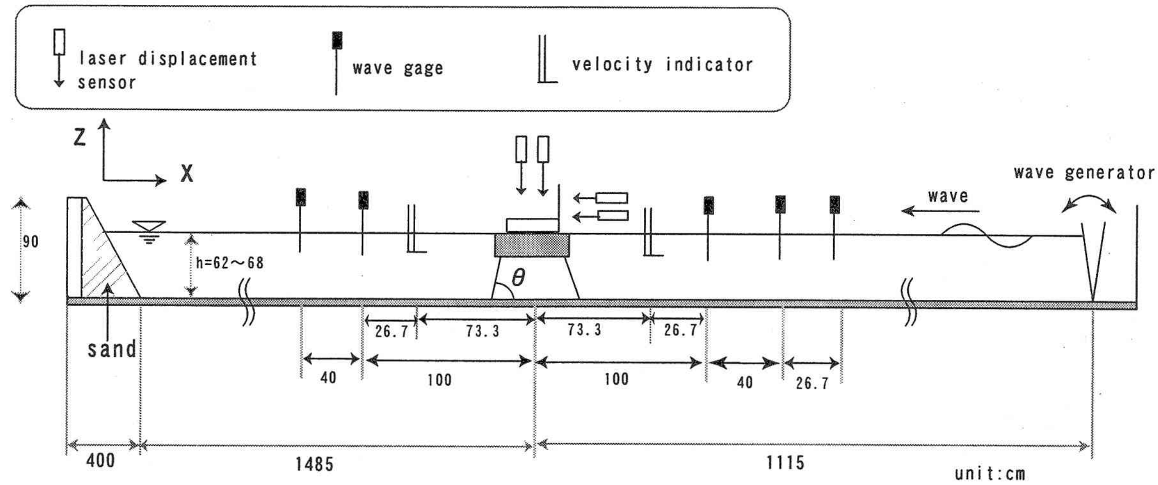


Fig.1 Detail of the Experimental Setup

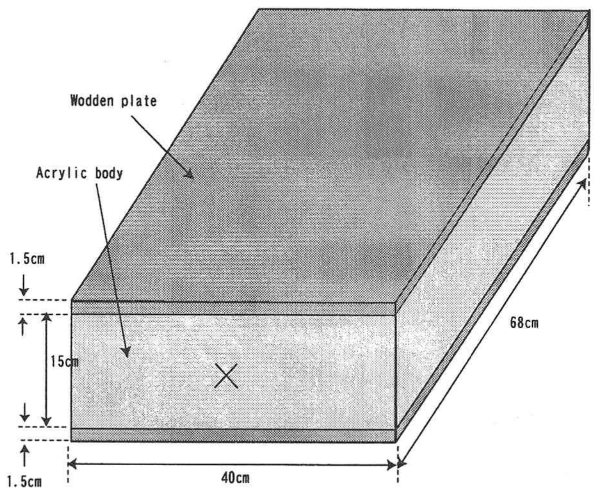


Fig.2 Detail of Floating body (Dimensional view)

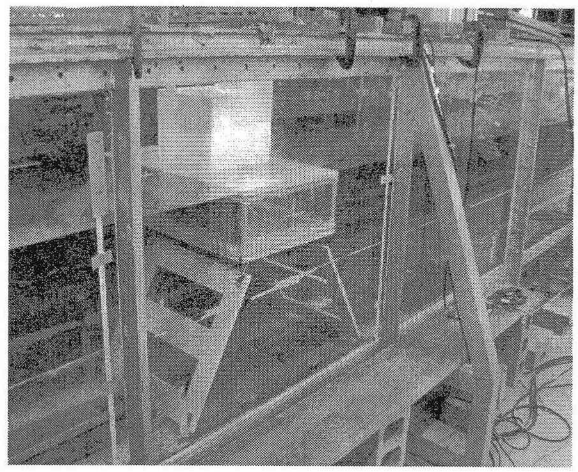


Fig. 3(a) Photo view of the Floating body anchored with Type A connection (θ=60°)

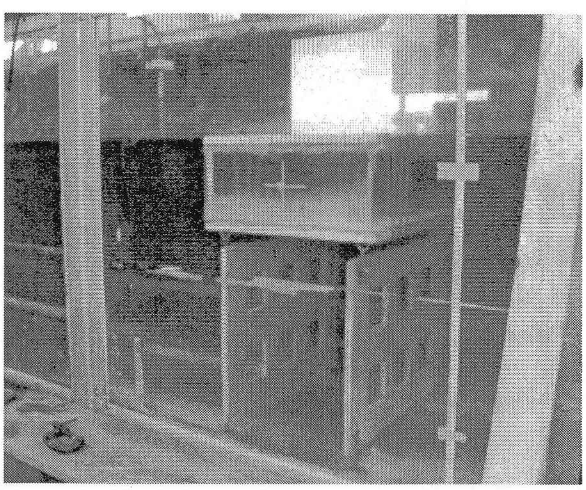


Fig. 3(b) Photo view of the Floating body anchored with Type B connection (θ=90°)

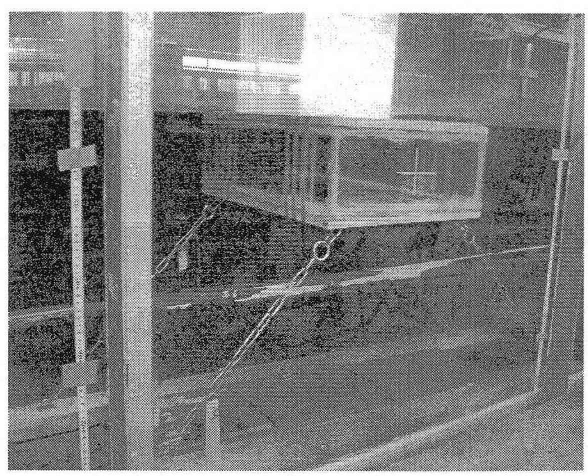


Fig. 3(c) Photo view of the Floating body anchored with Type C connection (θ=45°)

the performance of perforated plates as a mooring system compared to that of the mooring chains. These results are discussed in the following sections:

a) Evaluation of displacements of floating body

The displacements in heave (Δz), sway (Δx) and roll (α) are shown in Fig. 4(a) for the condition of connection Type A (perforated wooden plates) with 60° inclination and 3 cm submergence depth (h=65 cm). The half-filled symbols in the figure represent the wave breaking over or behind the floating body. The effects of wave steepness (H/L) on these displacements are also shown in the figure. It is seen that wave breaking occurs up to the value of

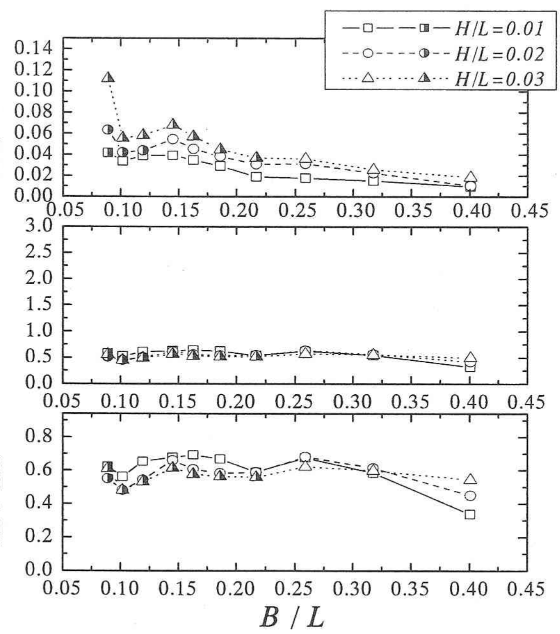


Fig. 4(a) Relative displacements of the floating body (TypeA-60, h=65)

B/L=0.22 for wave steepness H/L=0.03 and up to the less value of B/L for wave steepness 0.01 and 0.02. This happens because the wave with more steepness can easily break compared to the less steep wave. Incase of the chain mooring system (Type C), wave breaking occurs up to the value of B/L=0.18 for wave steepness H/L=0.03. So it prevails that the perforated plates mooring system encourages the wave breaking more compared to that of the chain mooring system. Also, due to the inclined (45° and 60°) perforated plates that anchor the floating body, there are less sway and heave motions, but more roll motion of the body compared to that of vertical perforated plates. This roll motion of the body makes it tilted and causes its top surface inclined that result it acts as a wave absorbing slope of the incoming waves. This causes the breaking of waves over or behind the structure and dissipates the incident wave energy. This phenomenon is clearly seen in the Fig. 4(b). Here it is seen that the wave is breaking over the top surface of the inclined floating body during its rotational motion. So the mechanism results the shortening of the reflected and transmitted wave heights and dissipating of the waves energy, which is shown in following section.

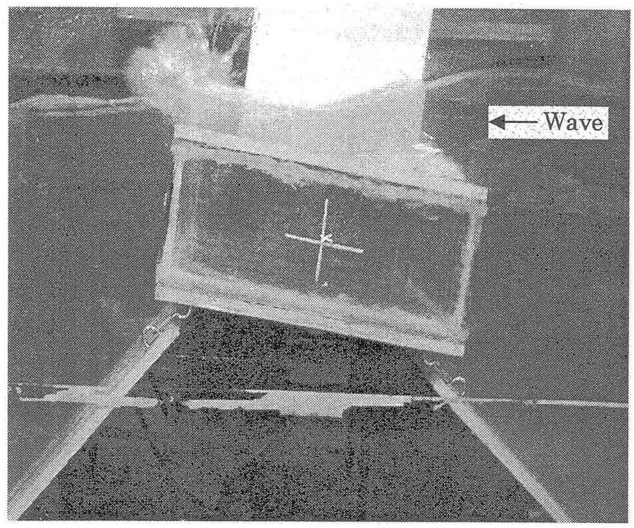
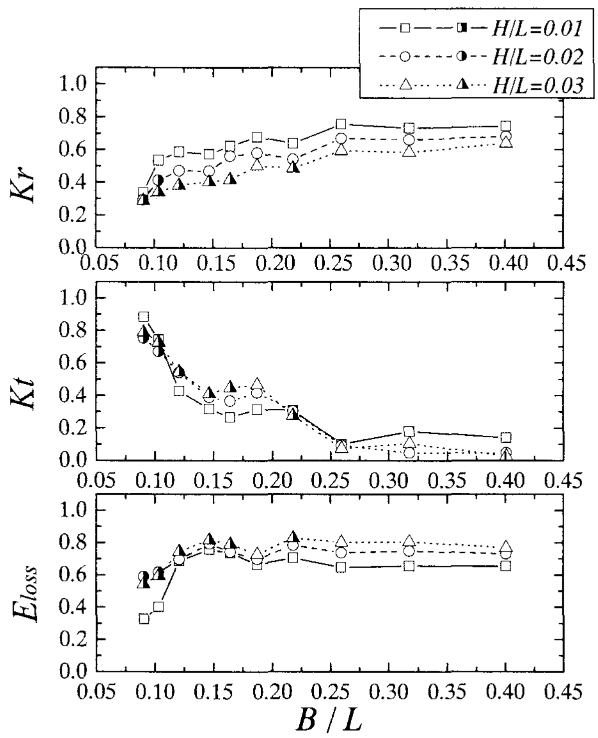


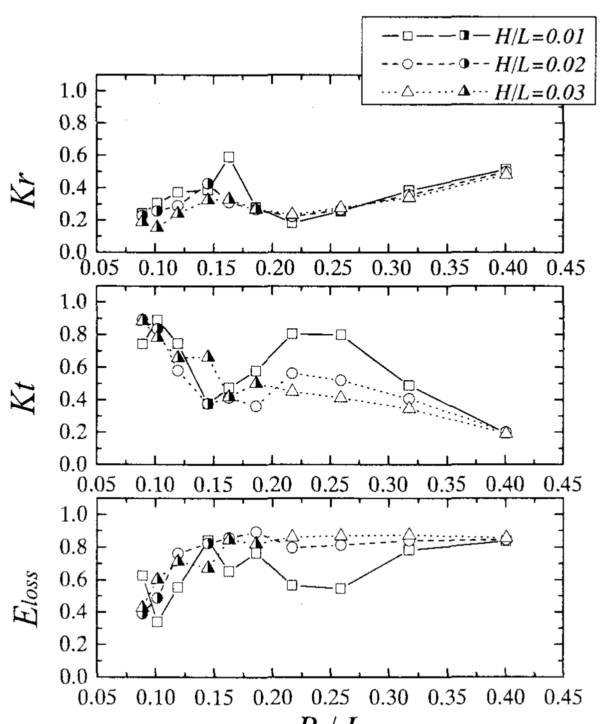
Fig. 4(b) Wave breaking occurred during the experiment due to the rolling motion of the body

b) Evaluation of reflection coefficient, transmission coefficient and wave energy dissipation by the floating body

The main objective of this research is to dissipate the incident wave energy and to reduce the reflected and transmitted wave heights with the help of the proposed structure. From the wave gauges data recorded during the experiment on both the onshore and offshore sides of the floating breakwater, the coefficient of reflection (*Kr*), the coefficient of transmission (*Kt*) and the dissipation of incident wave energy by the structure (*Eloss*) are calculated. *Kr* and *Kt* are calculated by decomposition of the waves into reflected and incident waves using three gauges method. The value of *Eloss* is calculated as $Eloss = \sqrt{1 - Kr^2 - Kt^2}$. It means that the higher value of *Eloss* (near to 1) represents the more energy loss. Fig. 5 shows the variation of *Kr*, *Kt* and *Eloss* with B/L ratio for the cases of connection Type B with 45° inclination and the submergence depth (d) are 0 cm and 3 cm respectively. The coefficient of reflection (*Kr*) does not vary much with the B/L ratio. But the value of *Kr* is seen smaller in the case of 3 cm submergence compared to that of no submergence of the floating body. In both of the cases the coefficient of transmission (*Kt*) is seen decreasing with increasing the B/L value. The average value of *Kt* is seen below 0.5 in both the cases which is one of the main objectives of this research. From the figure it is seen that the most of the incoming wave energy is being dissipated by the floating body. The average value of *Eloss* is seen greater than about 0.7 in both of the cases. The

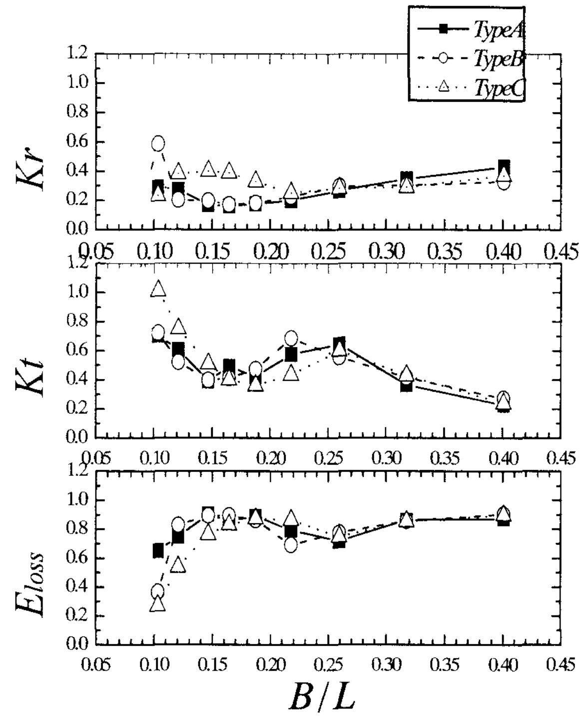


(a) h = 62 cm (d = 0 cm)

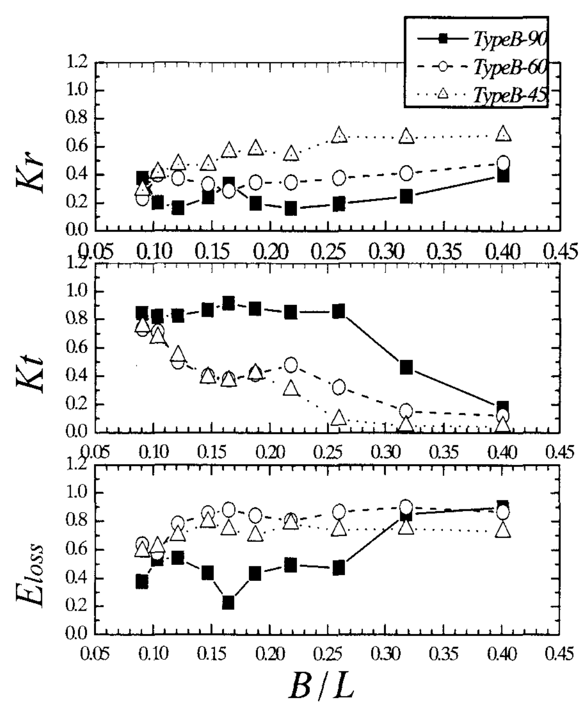


(b) h = 65 cm (d = 3 cm)

Fig.5 Wave control function of TypeB-45 Connection



(a) effect of mooring system



(b) effect of inclination angle

Fig.6 (a) Comparison between TypeA-60,B-60,C-60 (h=65cm,H/L=0.02) (b) Comparison between TypeB-90,B-60,B-45 (h=62cm ,H/L=0.02) dissipation of the wave energy can be caused by the generation of eddies by the perforated plates and breaking of the waves by the floating body.

c) Evaluation of the performance of perforated plates as a mooring system compared to that of the mooring chains

Fig. 6(a) shows the comparison among the performances of the three different mooring systems with respect to wave reflection, wave transmission and wave energy loss. It is seen that the perforated plates (Type A and Type B) show less reflection and less transmission of waves and also higher energy loss compared to those of the mooring chains connection (Type C). The performances of perforated plates (Type B), in controlling the wave reflection, transmission and energy losses by the floating body, with three different inclinations to the bottom of the wave tank are compared in Fig. 6(b). It shows that the vertical connections (90° inclination) are good in controlling the wave reflection, but its performance is poor in controlling the wave transmission and energy dissipation. On the other hand, inclined connections (45° and 60° inclinations) are good in controlling the wave functions. It is also seen that 60° inclination shows better performance compared to that in the case of 45° inclination [see Fig. 6 (b)]. It shows that the floating body supported with 60° inclined plates causes less reflection coefficient and higher energy loss than that of the supported with 45° inclined plates. The movement (sway and heave) of the floating body is restricted by the inclined connections compared to that of the vertical connection. That is why the body supported by inclined connections can dissipate more energy and lessen the transmitted wave heights comparing with supported by vertical connections. Also, it is understood that the body supported with 60° inclined plates causes more stable position than that is supported with 45° inclined plates. That's why 60° inclined supports gives better result than that of 45° inclined supports.

4. CONCLUSION

Two-dimensional experimental study is carried out to evaluate the performances of the submerged floating breakwater in controlling the wave reflection, wave transmission and wave energy dissipation. From this study, following conclusions can be made:

1) Submerged floating breakwater supported by perforated plates with 25% to 40% hole area can play a great role in attenuating the wave heights transmitted to the shore. It also dissipates a very good amount of incoming wave energy.

2) The performances of perforated plates as a mooring system are better in controlling the wave energy and wave transmission by the floating body than that of the mooring chains.

3) The perforated plates that anchor the submerged floating breakwater to the bottom of the wave tank show better performance of wave controlling by the floating body, when they are connected to the bottom with 60° inclination than that of 45° and 90° inclination.

4) Zero submergence of the floating body (d=0 cm) gives better result compared to that of the 3 cm and 6 cm submergences.

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