土木学会論文集 B3（海洋開発）
Vol.67，No.2，2011

EFFECTIVENESS OF A NEWLY DEVELOPED RESONATOR AGAINST TSUNAMIS

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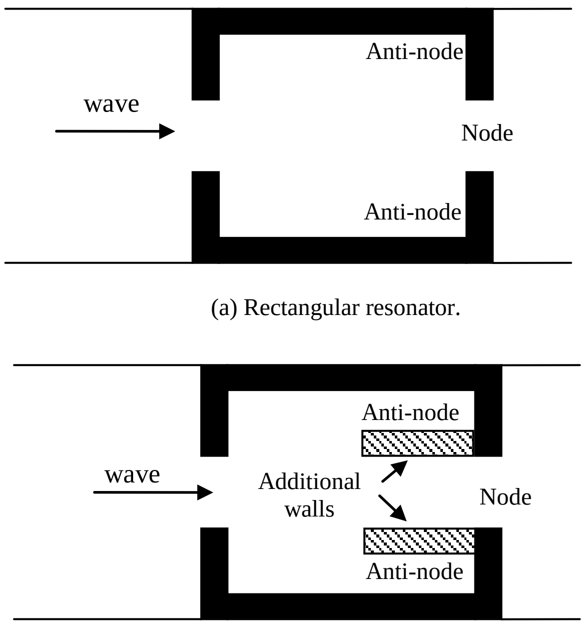
本研究は，従来，制御することが難しいとされてきた超長周期波を対象にして，港口部あるいは湾口部に設けた波浪共振装置による制御効果を主に理論的に検討したものである．この際，超長周期波としては，揺り返し周期が20～30分程度の津波を想定した．算定では，現地のリアス式湾を簡単化したものを対象として，現状でよく利用されている突堤形式の津波防波堤や，これを二重構造にした矩形共振装置型防波堤およびこの装置に付加的な平行堤を設けた新型堤を湾口部に設けることによる湾内津波高の低減効果などを比較検討した．その結果，新型堤は津波の揺り返し周期が比較的長い条件下でも優れた効果が発揮できることなどが判明した．

Key Words **:** *Tsunami breakwater, newly developed resonator*

1. INTRODUCTION

Tsunami is one of the natural disasters which claim the mass of lives and properties with its enormous energy generated by large scale earthquake undersea. Ocean and coastal engineers have been long struggling to develop the effective countermeasure system to protect the coastal lines from tsunami. Although many researchers have been carried out the study of various measures throughout the history of coastal engineering, the effectiveness of the tsunami breakwater systems are still limited to certain level. Due to the nature of the tsunami of which wave period is unknown, it is very difficult to design the harbor protection structure. While a certain breakwater system is effective for a tsunami of certain wave period, the same structure may be almost useless for a tsunami of different wave period.

Among the various types of breakwater systems, wave resonator is one of the effective structures which can attenuate the incoming wave and improve the harbor tranquility. Valemboise[1)] introduced the basic configuration of the rectangular resonator. Mochizuki & Mitsubashi[2)] (1990) developed the Wave Filter Theory of which the basic idea is the analogy between the electronic circuits for low pass filter and water wave resonator. By applying the Wave Filter Theory, a resonator can be designed to protect the harbor from incoming waves of certain wave frequencies ranged between so called pole frequency and cut-off frequency. The basic configuration of a rectangular resonator is shown in **Fig.1(a)** and its effectiveness has been proved experimentally by Nakamura et al[3) 4)].



(a) Rectangular resonator.

(b) Newly developed resonator.

Fig. 1 Wave transformation inside the resonator.

Nakamura et al[5] stretched out the research to investigate experimentally and numerically the effectiveness of the rectangular resonator designed by Wave Filter Theory in the case of very long waves (say wave periods > 1 minutes). It was found that the rectangular resonator is incapable of handling the very long wave effectively.

Nakamura et. al. continued their research on wave resonator and tried to developed a new type of resonator which can handle very long waves effectively. After so many in depth analysis on the resonant behaviors of rectangular resonators and numerical computations which involved a lot of trial and errors, a new-type of resonator was developed by attaching a pair of walls to the rectangular resonator (see **Fig.1**). Its effectiveness for very long waves was verified numerically and experimentally in the previous study[5].

It was realized that the newly developed resonator is a very effective system in dealing with very long waves and it may have a good potential to serve as a tsunami breakwater. In this study, we have numerically examined the effectiveness of the newly developed resonator as a tsunami breakwater.

2. MECHANISM OF A NEWLY DEVELOPED RESONATOR

One of the known mechanisms of the resonator attenuating the incoming wave is the mode of node and anti-node pattern inside it. **Fig.1** shows the effective mode of node and anti-node pattern inside the new type resonator (anti-node at the corner and node at the harbor-side opening of the resonator) at which the resonator effectively attenuates the incoming wave. Installing a pair of walls to the rectangular resonator can separate the regions of node and anti-node clearly in order to maintain the effective mode of node and anti-node pattern even if the very long waves comparing to the size of resonator enter.

Additional resonant effect is supposed to be generated by the additional walls.

3. CONFIGURATION OF MODEL BAY AND LAYOUTS OF BREAKWATERS

Typical model bay as shown in **Fig.2** was adopted for the study.

From the previous research, we have learned that the newly developed resonator can effectively protect the waves of which five times longer than the longitudinal length of the resonator. In this study, newly developed resonator and the conventional rectangular resonator were designed for the target wave period of 10 minutes or longer. By judging the topographic configuration of the model harbor, we have divided our focus on the study into two parts.

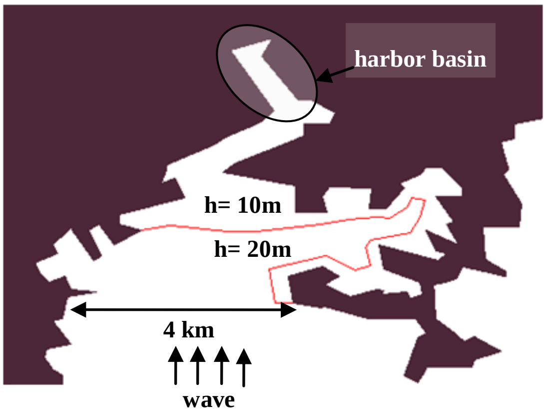


Fig.2 Bay with no breakwater (Layout A).

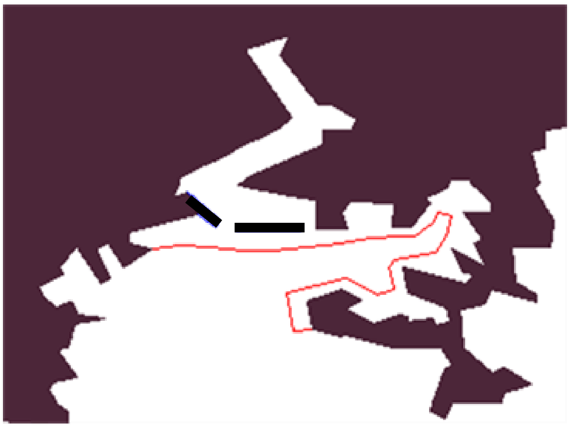


Fig. 3 Bay with conventional breakwater with two opening (Layout B).

Fig. 4 Bay with rectangular resonator near harbor (Layout C).

Fig. 5 Bay with newly developed resonator near harbor (Layout D).

In part one, the full structures of the resonators were placed inside the long and narrow water way which formed an ideal place for the resonators. And comparison on their effectiveness was carried out afterwards. The layouts of the harbor used in part one of our analysis are (A) harbor with no breakwater system (**Fig.2**), (B) harbor with conventional tsunami breakwater system (**Fig.3**), (C) harbor with rectangular resonator (**Fig.4**) and (D) harbor with newly developed resonator (**Fig.5**).

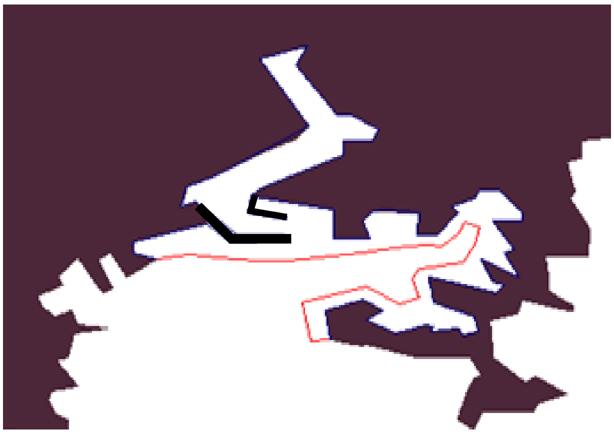


Fig. 6 Half size of newly developed resonator (Layout E).

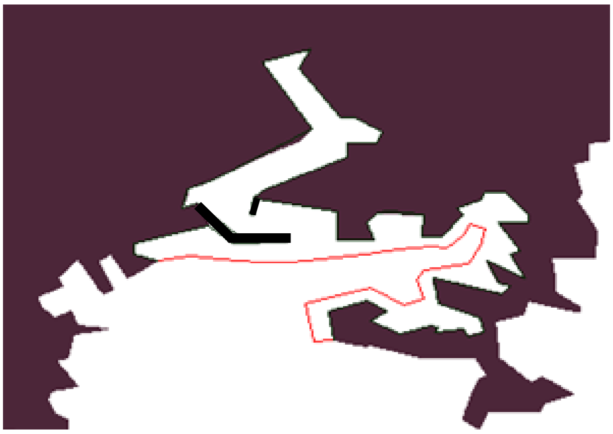


Fig. 7 Half size of rectangular resonator (Layout F).

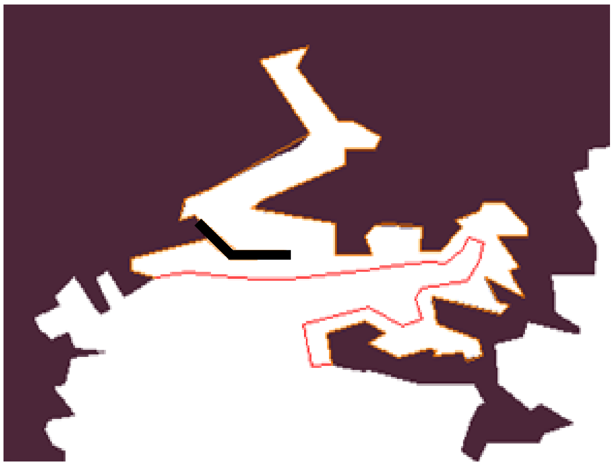


Fig.8 Conventional tsunami breakwater with one wide opening (Layout G).

In part two, supposing the conventional tsunami breakwater system (layout B) to be already constructed in site and utilizing the shape of harbors half size of resonators were installed along with the conventional breakwater. In this case, the existing tsunami breakwater can be considered as a mirror and thereby the resonators perform well as in full size conditions. The layouts of harbor used in part two are (E) half size rectangular resonator with conventional breakwater (**Fig.6**), (F) half size newly developed resonator with conventional tsunami breakwater (**Fig.7**), (G) conventional tsunami breakwater (**Fig.8**). In layouts E, F and G we set the opening of the tsunami breakwater to be wider one which is different from that of layout B. We made this adjustment to ensure the enough space for the cruising of the vessels.

The main objective of all breakwater systems is to protect the harbor basin shown in **Fig.2** from tsunamis.

4. METHOD OF ANALYSIS

The stepwise Vertical Line Source Green Function Method[6] was used to compute the wave field. It is assumed in this study that tsunami is a train of sinusoidal waves with very long wave periods. No wave breaking phenomenon and no overtopping was considered in the computations. The reflection coefficient all over the boundaries was set to 0.9. Taking account the effect of wave refraction into consideration, the water depth inside the harbor basin was set to 10m and offshore 20m.

The calculations were made for the wave periods from 10 minutes to 30 minutes with one minute interval.

5. RESULTS AND DISCUSSIONS

(1) Part One

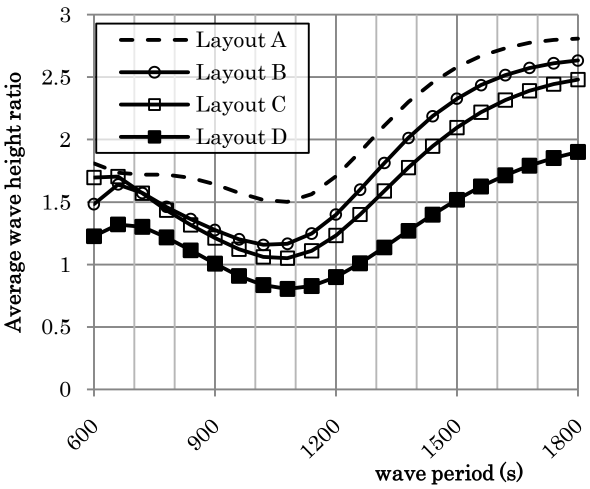


Fig.9 Average wave height ratio of layout A, B, C and D.

Average wave height ratio inside the harbor was used to compare the effectiveness of different types of structures. Average wave height ratio is the ratio of average wave height inside the harbor basin (shown in **Fig.2**) to the incident wave height.

The results are shown in **Fig.9.** It can be seen that the effectiveness of the resonators are better than conventional tsunami breakwater system. Layout D which is a harbor with newly developed resonator shows the best performance. The superiority of the newly developed resonator seems more apparent for the longer wave periods.

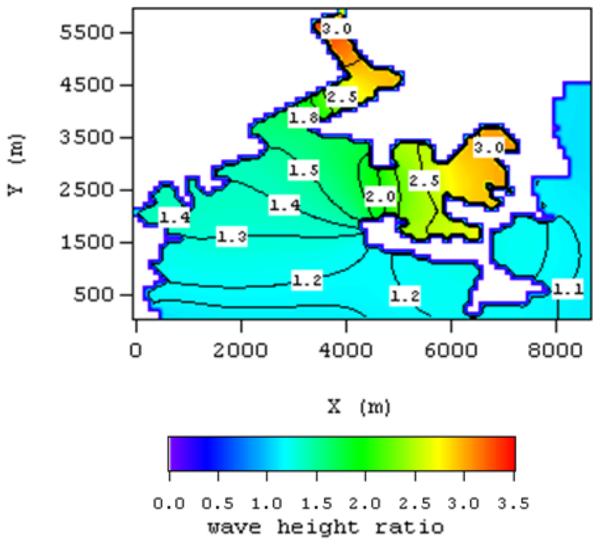


Fig.10 Wave height distribution of layout A. (T= 25 minutes)

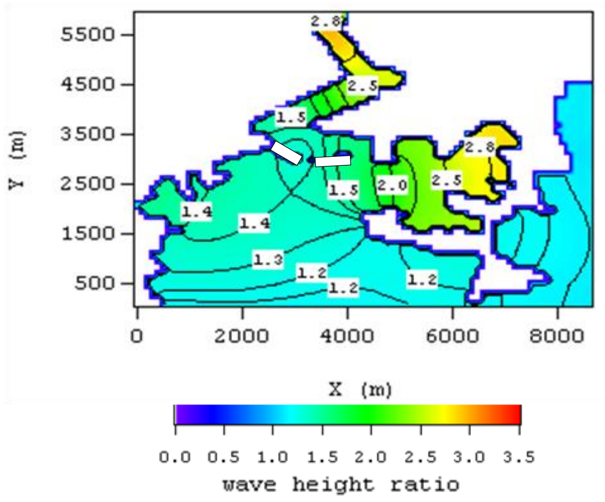


Fig.11 Wave height distribution of layout B. (T= 25 minutes)

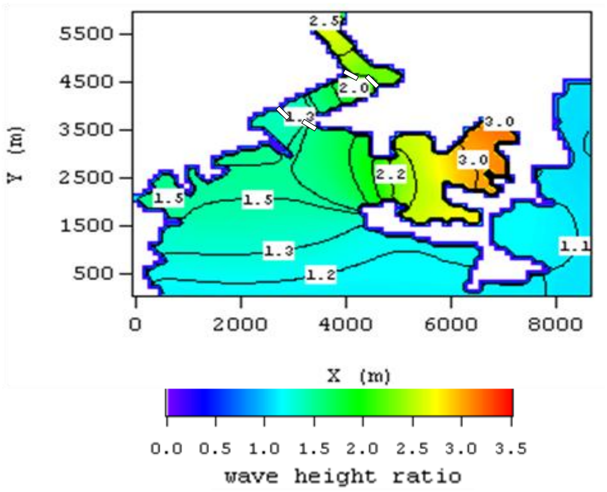


Fig.12 Wave height distribution of layout C. (T= 25 minutes)

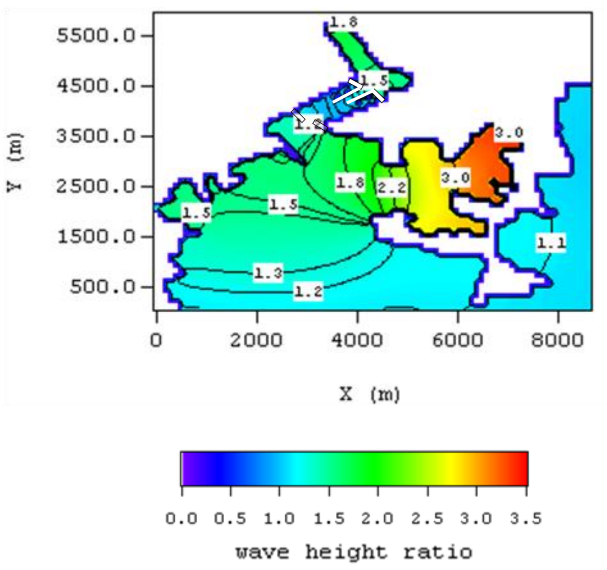


Fig.13 Wave height distribution of layout D. (T= 25 minutes)

Figs. 10, 11, 12 and 13 show the wave height distribution for the wave period of 25 minutes at which the differences in wave height ratio can be seen quite clearly. Here also, layout D shows the best performance by forming the clear node and anti-node pattern. It should be noted that the wave height behind the additional wall was relatively high so that it should not be located near the human residence or the wall should be high and strong enough to resist the high wave. In fact, it is advisable to utilize the natural coastal line where people does not live as the inner wall of the resonator to reduce the risk as well as the construction cost.

(2) Part Two

Figs. 14 show the average wave height ratio in the case of layouts E, F and G. Again, the newly developed resonator (layout E) shows its better performance than other type of structures.

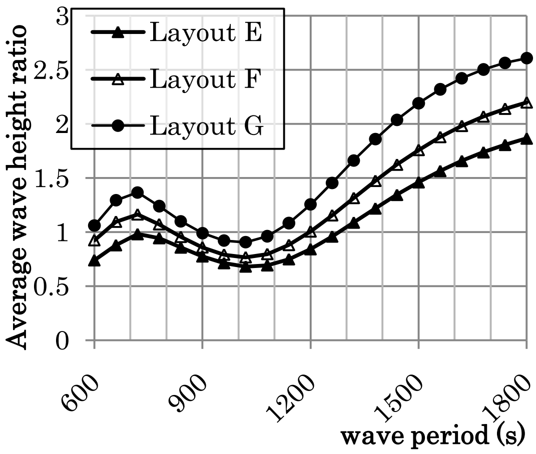


Fig.14 Average wave height ratio in harbor basin of Layout E, F and G.

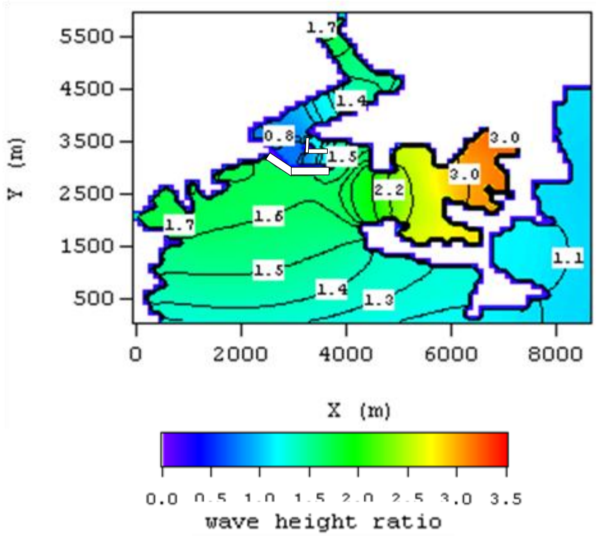


Fig.15 Wave height distribution of layout E. (T= 25 minutes)

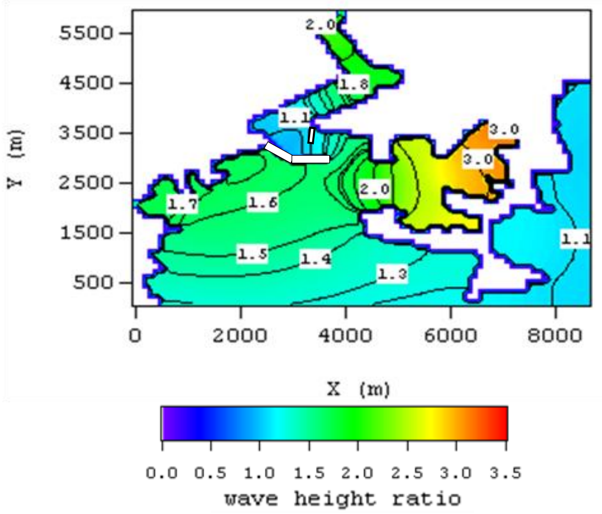


Fig.16 Wave height distribution of layout F. (T= 25 minutes)

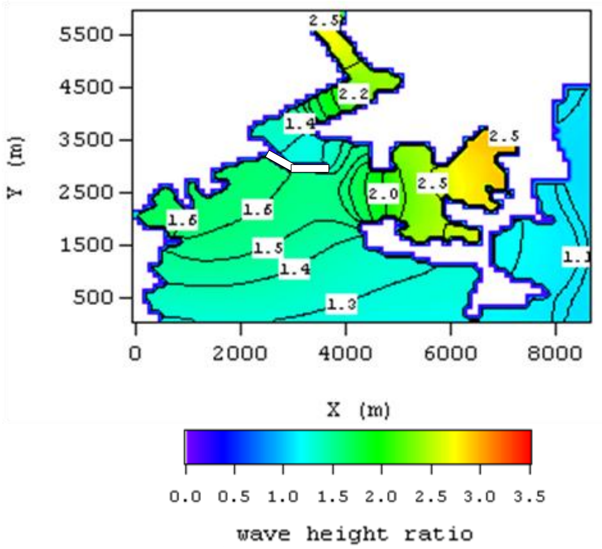


Fig.17 Wave height distribution of layout G. (T= 25 minutes)

Figs 15, 16 and 17 show the wave height distribution at the wave period of 25 minutes for the layouts E, F and G, respectively. It can also be seen that the rectangular resonator and newly developed one act their function properly even in a half size dimension.

(3) Comparison on the Effectiveness

In order to determine the degree of effectiveness of each breakwater system, we have defined the following ratio as:

$$\text{Effectiveness of Layout N} = \frac{H_{avg}(\text{Layout A})}{H_{avg}(\text{Layout N})}$$

where H_{avg} is the average wave height ratio in the harbor basin.

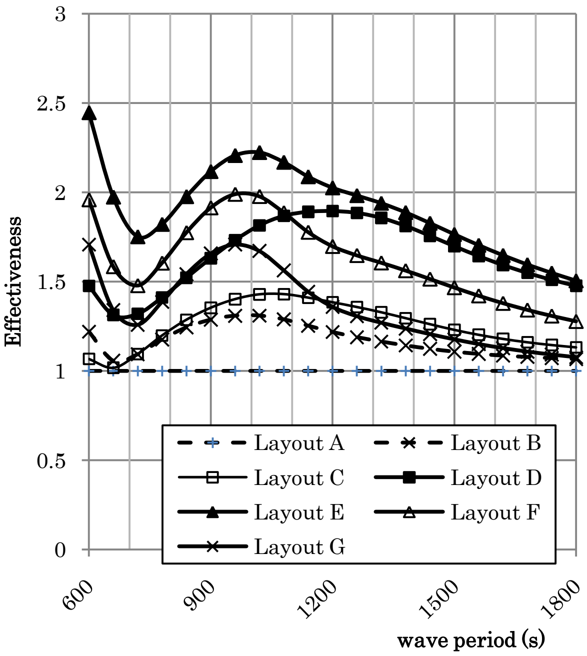


Fig.18 Comparision of the effectiveness of the breakwater systems.

Fig.18 shows the comparisons of the effectiveness of each breakwater system. It can be seen that the effectiveness of newly developed resonators are higher than other structures in both a full size (Layout D) and a half size (Layout E) conditions.

6. CONCLUSIONS

Although it still needs to be confirmed experimentally, the newly developed resonator showed the attractive performance against the tsunamis. Because of its flexibility to combine with the existing conventional breakwater system if the condition is favorable as in the part two of our study, the performance of the tsunami breakwater systems can be enhanced dramatically. Although it may be seen that construction of the newly developed resonator as a tsunami breakwater system is quite costly because of very large in scale, the cost can be greatly reduced if the natural beach or banks are in a condition to utilize as an inner wall of the resonators. In this case, only the transverse walls and additional walls will be needed to construct. As a conclusion, the newly developed resonator can be effectively used as a tsunami breakwater according to the numerical computations although more numerical and experimental investigations are needed to be carried out.

ACKNOWLEDGEMENT: This research is partly supported by the Grants-in-Aid for Scientific Research (C) of the Japan Society for the Promotion of Science (Principal Investigator: Takayuki Nakamura, Grant Number 22560514).

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