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DEVELOPMENT OF A NEW RESONATOR WITH ADDITIONAL WALLS TO ATTENUATE VERY LONG WAVES

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外洋に面する大規模港湾では，数分程度の長周期波の作用による港内係留船の共振動揺による係留索の切断や荷役作業の中断など各種の荷役障害が報告されている．このような長周期船体動揺に対する対策法の一つとして，港口部に波浪共振装置を設け，長周期波の港内への進入を制御する工法が知られている．本研究は，このような共振装置による長周期波の制御をより効果的に行えるようにするため，従来の矩形型共振装置の性能を向上させる工法を提案する．この工法は，矩形型共振装置の港内側の開口部付近に航路に平行に一組の直線堤を付加するもので，特に矩形型共振装置の長周期側における遮蔽効果を改善するためのものである．ここでは，この付加する直線堤による長周期波の制御効果を，鉛直線グリーン関数法に基づく数値解析法を用いて各種の形状寸法に着目した検討を行い，付加する直線堤の効果的な寸法などについて明らかにする．

Key Words: V*ery long waves, a new type of resonator, harbor tranquility*

1. INTRODUCTION

Long period wave agitation is one of the unfavorable events in port and harbor. Long period wave motion in the harbor can make the moored ship move to and fro. It can make the cargo handling difficult and mooring facilities can also be damaged. Structural countermeasure should be provided to protect harbors from such an undesired happening.

Harbor engineers have been investigating the possible countermeasure to attenuate the long period wave in the harbor basin. One of the examples using for this purpose is a wave resonator. The wave resonator is a kind of breakwater system which is usually installed at the harbor entrance (Pier J, Port of Long Beach, USA [1]) as seen in **Fig.1**) or inside the entrance channel to the harbor. It can attenuate the incoming wave and improve the harbor tranquility. Valemboise[2]) introduced the basic configuration of the rectangular resonator. Mochizuki & Mitsubashi[3]) developed the wave filter theory, in which the basic idea is the analogy between the electronic circuits for a low pass filter and a water wave resonator.

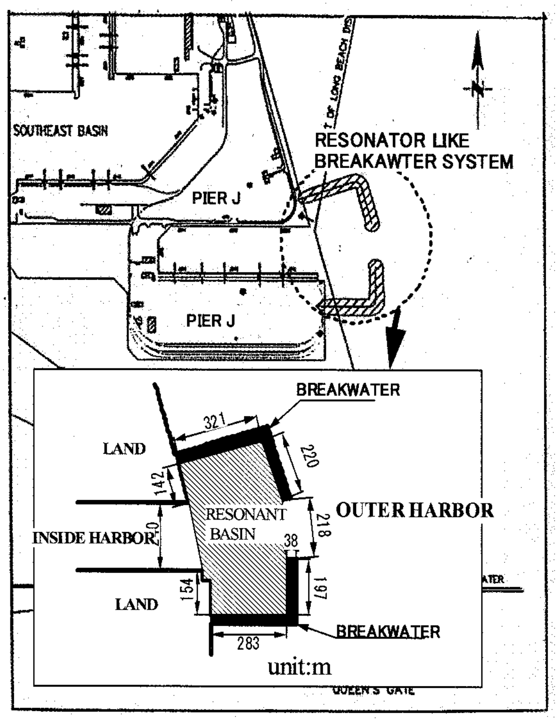


Fig.1 Pier J at the Port of Long Beach[1]), a resonator-like breakwater at the harbor entrance.

2. PREVIOUS STUDY

The typical example of a rectangular resonator designed by WFT is shown in **Fig.2**.

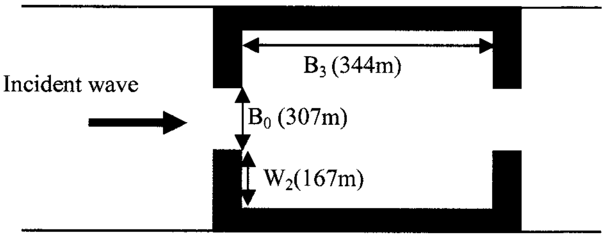


Fig.2 A rectangular wave resonator.

Nakamura et al[5] carried out the experimental and numerical study on a rectangular resonator designed for the range of wave period 20s to 70s by using the wave filter theory. **Fig.2** shows dimensions of the designed resonator in prototype scale.

According to their experimental and theoretical results, it was pointed out that the effectiveness of the rectangular resonator was decreased for comparatively long waves, typically, wave period T being over 50s (see **Fig.3**). In the figure, the effectiveness of the resonator is estimated by the following wave transmission ratio, Kt_{rms},

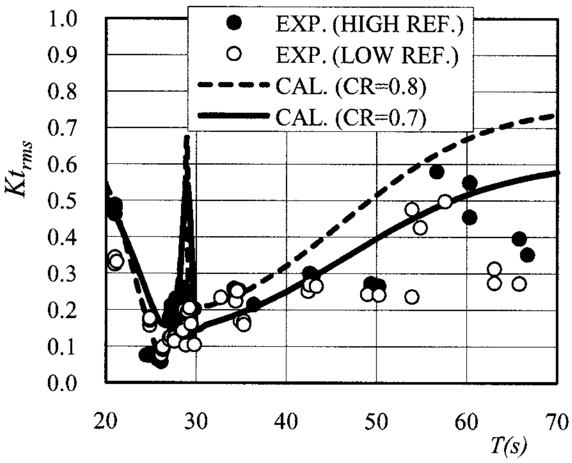


Fig.3 Results of rectangular resonator designed by WFT.

$$Kt_{rms} = \frac{\sqrt{\dfrac{\int_0^{\lambda} H_T^{\,2}\, dy}{\lambda}}}{H_I} \qquad \cdots\cdots\cdots (1)$$

where, H_T: transmitted wave height, λ: transverse width of water channel, y: coordinate of transverse direction of the channel, H_I : incident wave height.

The wave transmission ratio, Kt_{rms}, means the root mean squared value of transmitted wave height along the transverse direction in dimensionless form. In **Fig.3**, results for the two different seawalls, low and high reflective walls, were shown, in which *CR* was a reflection coefficient.

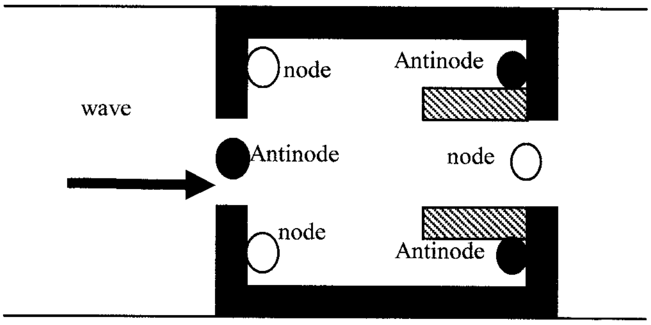


Fig.4 Effective mode of node and anti-node pattern in the resonator. Installation of additional walls.

It will become an important challenge to improve its performance for the long period waves. By carefully checking the wave pattern and wave transformation characteristics about the resonator based on the theoretical results, we have newly proposed a modified resonator. It has a pair of additional walls to the previous rectangular resonator for sheltering from very long waves, as shown in **Fig.4**.

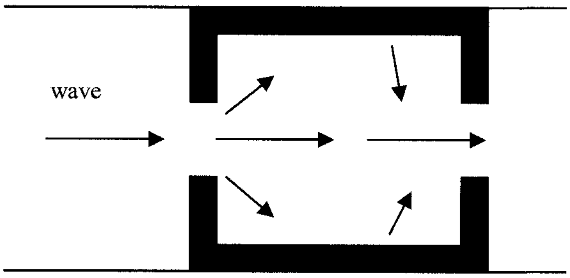
In this paper, performance of the modified resonator has been examined theoretically. Especially, an effective length of the newly installed walls is clarified for various rectangular resonators with different dimensions. In the theoretical analysis, the wave transformation by the periodically arrayed resonators is dealt with for rational estimation of the performance.

3. SHELTERING MECHANISM OF A NEW TYPE OF RESONATOR

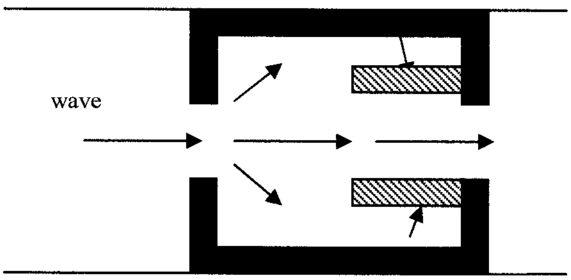
One of the sheltering mechanisms by a wave resonator[4] is to form a node and anti-node wave pattern inside it. **Fig.4** schematically shows the effective mode of node and anti-node pattern inside the resonator, i.e. anti-node at the corners and node at the harbor-side opening of the resonator. However, for the longer waves, positions of the corner and the opening of the rectangular resonator may become too close as compared to the wave length of incoming waves. Therefore, under such a long wave condition, effectiveness of the resonator becomes decreased.

In order to overcome such a difficulty, we have proposed a new measure that is an installation of a pair of straight seawalls with some length to the rectangular resonator as shown in **Fig.4** (hatched portions). These additional seawalls may separate the regions of node and anti-node clearly at the harbor-side opening area even if the very long waves enter the resonator. Therefore, the modified resonator may be possible to maintain the effectiveness even for very long waves.

One more consideration in developing the resonator is related to the wave transformation characteristics inside the resonator. Incoming waves diffract as shown in **Fig.5 (a)** upon entering the resonator. When a pair of additional seawalls is installed as shown in **Fig.5 (b)**, these walls can trap some portion of the wave energy by making a effective standing wave patterns. Consequently it may increase the effectiveness of the resonator action.



(a) Rectangular resonator.



(b) New type of resonator.

Fig.5 Wave transformation inside the resonator.

4. PRELIMINARY EXAMINATIONS

To examine the effectiveness of the new resonator with additional walls, the longitudinal dimension of the rectangular resonator of **Fig.2** is

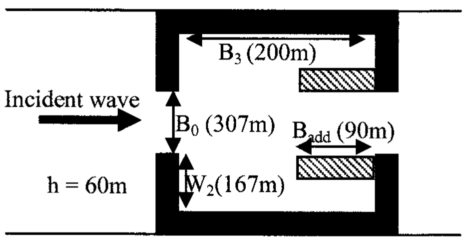


Fig.6 A new type of resonator for comparison.

reduced to 200m and a pair of 90m long additional walls (B_{add}=90m) was installed inside the resonator as shown in **Fig.6**. Other dimensions were kept the same. The Vertical Line Source Green's Function Method (VLG)[5] was used to calculate the wave height distributions around the resonator. In the numerical analysis, the wave field about periodically arrayed resonators was dealt with for similarity to the experimental model test of a single unit of resonators in a long wave flume with a definite width.

Fig.7 shows the calculation results of the new type of resonator of **Fig.6**. It can be seen that the new type of resonator shows the good performance for reducing very long waves instead of keeping the construction cost lower than the previous type resonator. It seems worthwhile to expand the investigation of the new type of resonator by varying major dimensions of the resonator, including a length of additional seawalls, which can affect its performance.

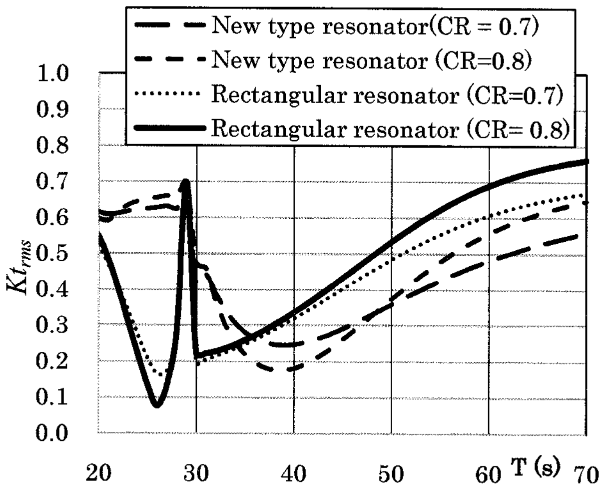


Fig.7 Comparison between the rectangular resonator and new type resonator.

5. PARAMETRIC STUDY ON THE NEW TYPE OF RESONATOR

To perform parametric study on the new type of resonator, the basic dimensions of the resonator without additional wall was firstly designed by the Wave Filter Theory. It is assumed that the water depth is 20m. The water channel width (or the center to center length between the two adjacent resonators) is 668m. The target range of wave period is from 30s to 300s.

Three major parameters of the new resonator were examined in this study. The first parameter is the aspect ratio of a transverse length of resonant basin to a longitudinal length of it ($=W_2/B_3$). It ranges from 1:2 to 1:7.

The second parameter is the ratio of an

additional wall length to a longitudinal length of resonant basin ($=B_{add}/B_3$). For each aspect ratio of the new type of resonator, the effect of an additional wall length ratio has been examined for the range of 0.3 to 0.7.

The third parameter is the ratio of an opening width to a water channel width ($=B_0/\lambda$). The opening width ratio ranges from 0.214 to 0.353. The largest opening width corresponds to 236m in the prototype scale.

For comparison, a jetty type structure having the same opening width ratio as the new resonator case was also examined theoretically. The summary of variations is shown in **Table 1**.

Table.1 Variation of resonator dimensions.
(h= 20m W_2 = 200m)

Aspect ratio ($W_2 : B_3$)	Longitudinal Length (B3)	Additional Wall Length Ratio(B_0/B_{add}	Additional Wall Length (B_{add})	Opening width (B_0)	Channel width(λ)	Opening Ratio (B_0/λ)
1:2	400m	0 ~ 0.7	0m ~ 280m	150m	560m	0.214
1:2.5	500m	0 ~ 0.7	0m ~ 350m	170m	580m	0.241
1:3	600m	0 ~ 0.7	0m ~ 420m	190m	600m	0.267
1:3.5	700m	0 ~ 0.7	0m ~ 490m	210m	620m	0.29
1:4	800m	0 ~ 0.7	0m ~ 560m	230m	640m	0.313
1:4.5	900m	0 ~ 0.7	0m ~ 630m	250m	660m	0.333
1:5	1000m	0 ~ 0.7	0m ~ 700m	270m	680m	0.353
1:5.5	1100m	0 ~ 0.7	0m ~ 770m			
1:6	1200m	0 ~ 0.7	0m ~ 840m			
1:6.5	1300m	0 ~ 0.7	0m ~ 910m			
1:7	1400m	0 ~ 0.7	0m ~ 980m			

In the numerical computation, the VLG method under the assumption of periodically arrayed resonators with the same pitch length was used. Since the wave field about the periodically arrayed resonators can be analyzed by dealing with only one unit of resonators, it is possible to carry out the computation very efficiently. The reflection coefficient of the resonator wall was set to be equal to 0.9 for every part of wall.

6. RESULTS AND DISCUSSIONS

(1)Effect of aspect ratio and additional wall length ratio

Figures 8, 9 and **10** show the calculation results of wave transmission ratio Kt_{rms} for the aspect ratio (W_2/B_3) 1:2, 1:3.5 and 1:7, respectively. From these figures, it can be seen that the larger the aspect ratio, the higher the performance of the resonator dealing with longer period waves. From the aspect of additional wall length ratio, the longer the additional wall, the lower Kt_{rms} value for the long period waves. However it can be also noted that as the wall length ratio is higher, there appear some peaks in the short wave period region. Therefore, the additional wall length ratio of about 0.5 seems to be fair enough to keep the performance of the

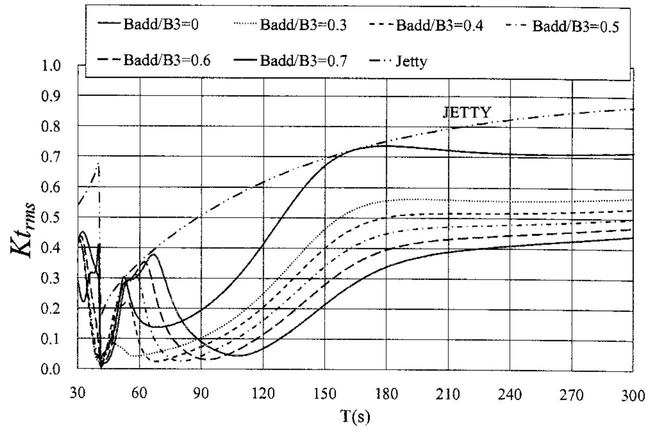


Fig.8 Effect of additional walls; aspect ratio W_2/B_3= 1:2, opening ratio B_0/λ= 0.23)

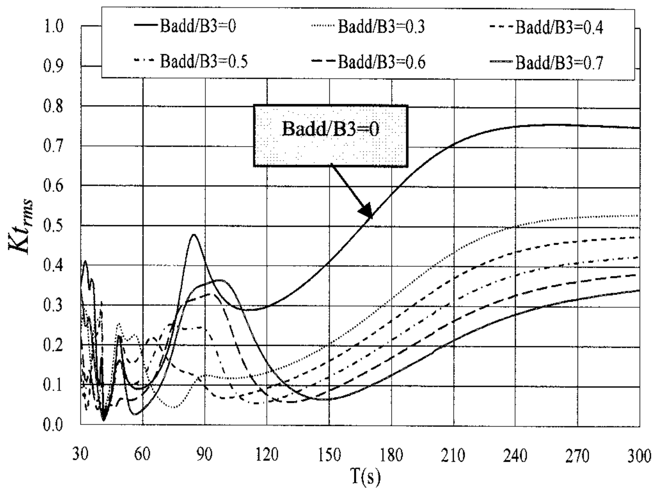


Fig.9 Effect of additional walls; aspect ratio W_2/B_3= 1:3.5, opening ratio B_0/λ= 0.23)

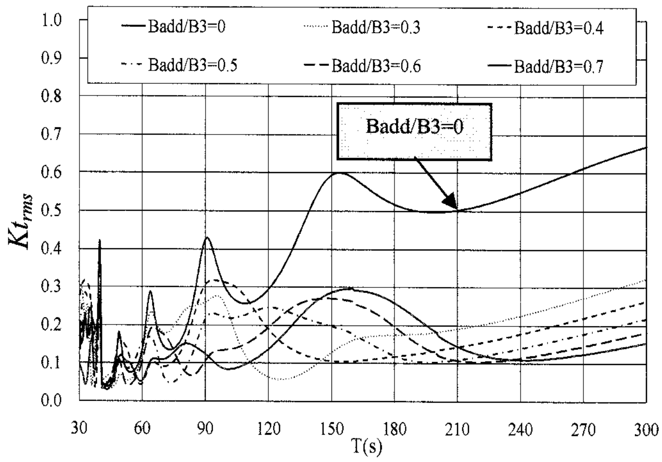


Fig.10 Effect of additional walls; aspect ratio W_2/B_3= 1:7, opening ratio B_0/λ= 0.23.

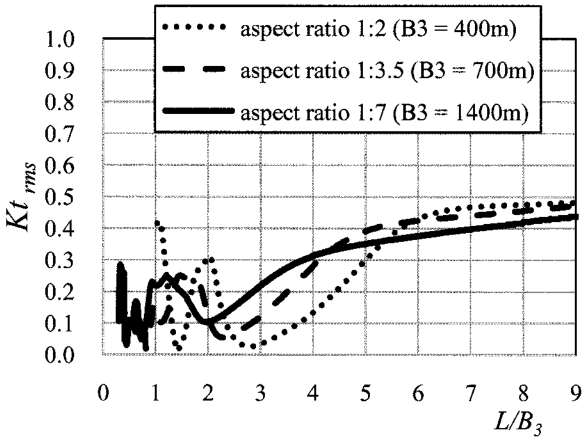


Fig.11 Effect of the ratio of wavelength to longitudinal length of resonators on wave transmission (Additional wall length ratio = 0.5, opening width ratio = 0.23).

resonator effective for short period waves as well as long period waves. One significant fact is that the resonator without additional wall does not show an increase in performance even though the aspect ratio becomes large. It can be seen in **Fig.8** that all resonators are by far effective than the jetty type structure.

Fig.11 shows the relations between the ratio of wavelength to longitudinal length of new type of resonator and Kt_{rms} for the aspect ratio (W_2/B_3) of 1:2, 1:3.5 and 1:7. It can be seen that resonators of all three aspect ratios can control long waves of which length is shorter than about five times as long as the longitudinal length of the resonator. In this case, the value of Kt_{rms} is less than 0.4. In other words, it can be said that the longitudinal length of the new type of resonator should be designed to be longer than 1/5 times wave length of the expected waves.

(2) Effect of opening width ratio

Figures 12, 13 and **14** show the calculation results of wave transmission characteristics for various opening width ratios under three different aspect ratios of 1:2, 1:3.5 and 1:7, respectively. In these figures, the additional wall length ratio is fixed to 0.5.

From these figures, it can be seen that the narrower the opening width of the resonator, the higher the performance of it. However, the difference in the magnitude of Kt_{rms} for various opening width ratios is not so much. So, the opening width ratio could be determined from the size of vessels allowed to enter the harbor.

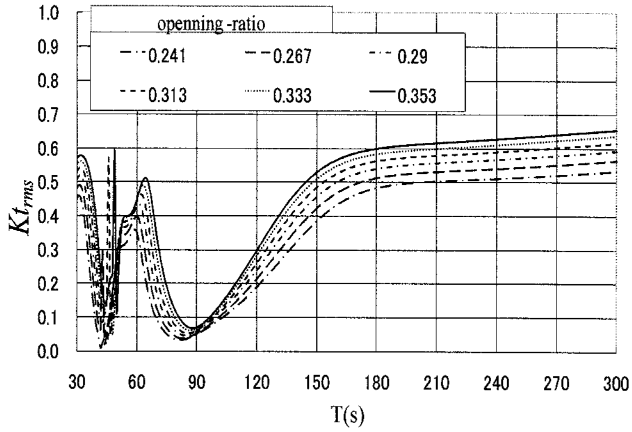


Fig.12 Effect of the opening width ratios (aspect ratio=1:2, additional wall length ratio =0.5).

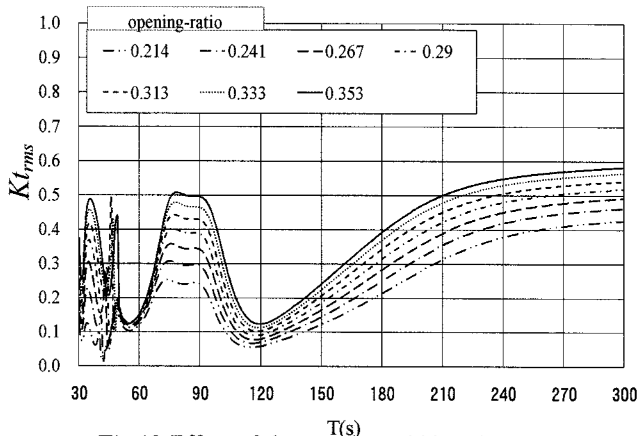


Fig.13 Effect of the opening width ratios (aspect ratio=1:3.5, additional wall length ratio =0.5).

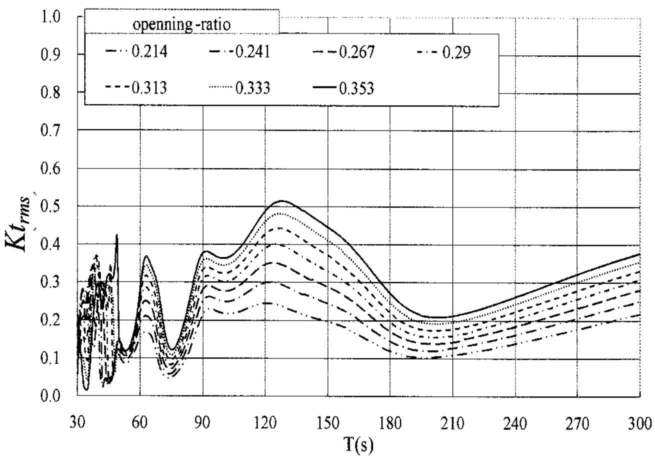
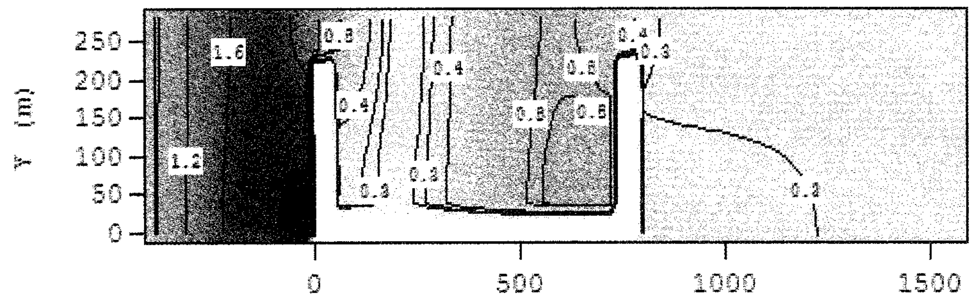
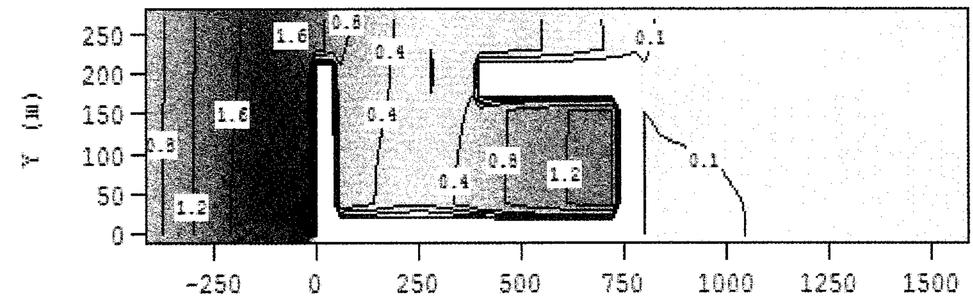


Fig.14 Effect of the opening width ratios (aspect ratio=1:7, additional wall length ratio =0.5).



(a) Without additional walls



(b) With additional walls

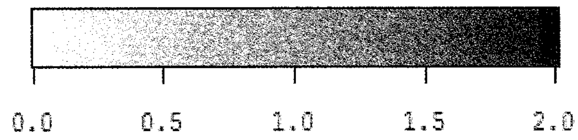


Fig.15 Wave height distribution around the resonator (Aspect ratio = 1:3.5, wave period T=120s).

(3)Wave height distributions

Fig.15 shows the wave height distributions around the resonator for the aspect ratio of 1: 3.5, (a) without additional wall and (b) with additional wall of wall length ratio of 0.5 and opening ratio of 0.214. Because of the symmetry in vertical direction, only the half parts of the resonators are shown in figures.

The effective node and anti-node pattern can be seen in this figure. Anti-node can be seen behind the additional wall and node at the opening at the harbor side. Special care might be taken for the region behind the additional wall since it is likely to be the region of high wave resonance. However, the ships could drive more safely through the new type of resonator since the middle region of the resonator seems to be calmer in new type of resonator than old one.

7. CONCLUSION

For the same range of wave periods, the new type of resonator shows the significant improvement especially in dealing with the long period waves. The construction cost can be cut by using the new type of resonator keeping the efficiency for sheltering the harbor. The new type of resonator has the very good tendency to solve the problem of long period wave motion in harbor for its high performance in dealing with very long waves. Experiments to check its applicability is underway.

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