Experiment of the Slit Caisson Breakwater with Embedded Resonant Channels

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***Abstract*—In this study, the hydraulic experiment results of the slit caisson breakwater with embedded channels are analyzed comparing with the numerical results. To improve the calmness of a harbor area and wave force acting on the breakwater, the energy dissipation mechanism using the cylinder array was applied to the breakwater. This effect is supported by resonance flow in the embedded channel which can be controlled by the design of the channel. In order to evaluate the wave energy dissipation, the reflection coefficient is used to representing parameter. When the wave period and the natural period of the fluid in the embedded channel were matched with each other, reduction of the reflected waves became maximum. In the hydraulic experiment results, its optimum wave condition and reduction of the reflected waves were more expanded than the numerical.**

Keywords—hydraulic experiment; slit caisson breakwater; embedded channel; wave reflection; energy dissipation; reflection coefficient

I. INTRODUCTION

The permeable structures are used to protect coastal area from wave action. The various type of permeable structures have been proposed and applied to coastal area, such as rubble mound breakwater and slit type breakwater. Until the current slit breakwater, the various researches have been performed. The reflection and transmission waves from the vertical circular cylinder array were approached by numerical analysis [1], [2] and [3]. The energy loss due to flow separation was determined about the circular and rectangular cylinder array [2]. Also the hydraulic experiment results of the vertical cylinder array was compared with the numerical results [4]. These energy loss mechanism of the cylinder array were applied to vertical caisson breakwaters, such as slit-wall type and slit-bulkhead type breakwater [5]. The cylinder array and backside wall combine to a slit caisson unit and the water chambers are constituted by them. Also depending on the slit portion, it is classified as entire-slit and partially-slit breakwater. These various slit-wall breakwater were analyzed by numerical and experimental approaches [6], [7], [8], [9] and [10]. To reduce the wave reflection, the slit breakwater/seawall consisted by bundle of the cylinder array were proposed allowing wave transmission [11].

Nowadays, the slit-wall breakwater having water chamber have been constructed to reduce the wave reflection contributing to the generation of the standing waves at near fluid field. The reflected wave is related with the calmness of harbor area and reducing the wave force on the breakwaters. In these reason, the slit caisson breakwater was constructed in Ulsan New-Port in Korea. However, this slit-wall breakwater has several weaknesses. For the proper energy dissipation of this conventional slit breakwater, the breadth of the water chamber should be matched with a quarter-wavelength. Their relation had been proposed by a numerical method, as $B/L \fallingdotseq 0.22$ [12]. So, for the control the long waves, the water chamber width should be wide in the horizontal direction with respect to incident wave length. Also the slit part of this breakwater is exposed to wave impact load at near free surface, directly.

The objective of this research was to propose the new concept slit caisson breakwater using the embedded channels for reducing the reflected waves. The water column in the embedded channel section has eigenvalue related with mass and restoring forces from shape of water column. The natural period of water column in the channel is critically related with channel length [13]. At the resonant condition, the amplified flow of the water column oscillates between the slit in horizontal direction. Therefore the energy dissipation due to flow separation at the slit plate is maximized in the resonant condition. The resonant mode of fluid in the channel can be

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controlled by design of channels. Also the design of the channel to control the long waves is more reasonable than the conventional slit-wall breakwater. The cross-section view of this breakwater is shown in Fig. 2. In a previous study, the wave reflection characteristics of the slit caisson breakwater with the embedded resonant channel was investigated by numerical analysis [13], [14] and [15]. It analyzed that the effect of the embedded channel design parameters on the reduction of reflected waves. In this study, we attempted to verify this numerical results.

II. Hydraulic Model Test

A. Wave Tank

The hydraulic experiment of a slit caisson breakwater with resonant channels were performed in two dimensional wave tank[53m(L) x 1m(B) x 1.25m (H)] at Korea Institute of Ocean Science and Technology(KIOST). The piston type wave maker is applied at the upstream of wave tank. For evaluates the reflected waves, the three of wave probes were set in front of the model as shown Fig. 1.

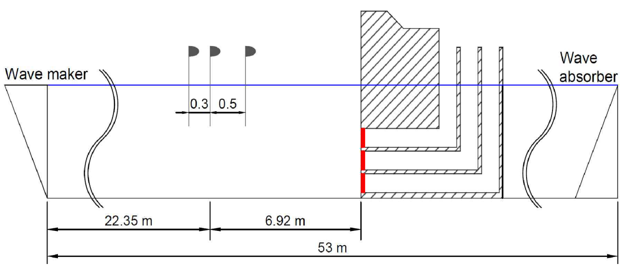

Fig. 1. Two-dimensional wave tank and model set-up [unit: m]

B. Model Set-up

The model of a slit caisson breakwater with resonant channels was made of acrylic material and it was fixed on the wave tank bottom. The functional part of this model was composed of the embedded channels and slit plates, this plates are installed at the channel inlet. The experimental conditions were performed considering various channels and porosity of the slit plates. To account for various channel widths, the removable acrylic plate was used for channel part of this model. To identify these embedded channels, the each of them were named as alphabet A ~ C in Fig. 2.

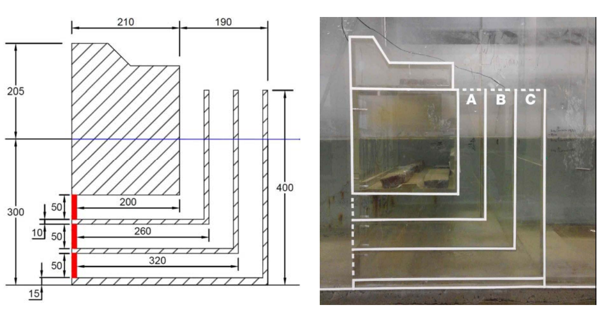

Fig. 2. Sectional view of the model [unit: mm]

The wave energy dissipation at the slit plates is associated with porosity and the resonance of the fluid in the channels. The length of the embedded channel is critically related to the natural period of the fluid in the embedded channel which associated with fluid mass and restoring force at near free surface in the embedded channel. When the incident wave period and natural period of the fluid in the embedded channel are matched, the resonant flow excited by the incident waves is passed through the slit plate and it related with the energy dissipation due to contraction and expansion of the flow cross-section. In order to considering these phenomena, the experimental model was set up as follows:

TABLE I. SUMMARY OF EXPERIMENTAL MODEL

Exp. ID	*No. of Ch.*	*Open Ch.*	*Width of Ch. [mm]*	*Length of Ch. [mm]*	*Period of Ch.*	*Porosity*
A	1	A	50	375	1.23	0.2 0.4 0.6
B	1	B	50	495	1.41	
AB(1)	1	AB	110	430	1.32	
AB(2)	2	A B	50x2	475 495	1.23 1.41	
ABC(1)	1	ABC	170	490	1.40	
ABC(3)	3	A B C	50x3	375 495 615	1.23 1.41 1.57	

The slit plates are located at inlet of the embedded channels and its porosities are considered by 0.2, 0.4 and 0.6. The thickness of the perforated plates are 8 *mm* and the each opening width of this plates are 2 *mm*, 5.3 *mm* and 12 *mm*. The models of the perforated plate are follow as:

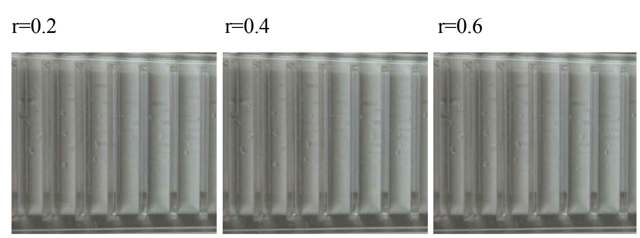

Fig. 3. Model of the perforated plates (porosity, r=0.2, 0.4 and 0.6)

C. Waves

The incident waves of the experiments are considered as regular waves for evaluating the basis characteristics of this slit caisson breakwater. The wave height(H_w) is 0.02m and the wave periods Tw are shown in first column of Table II. A components related to each other, wave period Tw and natural period of the fluid in the embedded channel (T_{ch}) are expressed as non-dimensional parameter(T_w/T_{ch}) in Table II.

TABLE II. EXPERIMENTAL WAVE CONDITIONS AND RELATION WITH THE CHANNELS

T_w [sec]	T_w / T_{ch}			
	A T_{ch}=1.23sec	*B* T_{ch}=1.41sec	*AB(1), AB(2)* T_{ch}=1.32sec	*ABC(1), ABC(3)* T_{ch}=1.40sec
1.18	0.96	0.84	0.89	0.84
1.23	1.00	0.87	0.93	0.88
1.27	1.05	0.91	0.98	0.92
1.35	1.10	0.96	1.02	0.86
1.42	1.15	1.01	1.08	1.01
1.49	1.21	1.06	1.13	1.06
1.57	1.28	1.11	1.19	1.12
1.67	1.36	1.18	1.27	1.19
1.77	1.44	1.26	1.34	1.26
1.89	1.54	1.34	1.43	1.35
2.20	1.64	1.43	1.53	1.44

D. Separation of Incident and Reflected Waves

To identify the components of the waves, the measured wave elevation data were separated into incident and reflected wave components. For separating these waves, the three of the wave probes were set in front of the caisson breakwater model in Fig. 1, and these measured data were applied to least squares method for separation of the incident and reflected waves [16]. The example of the time series data is follow as :

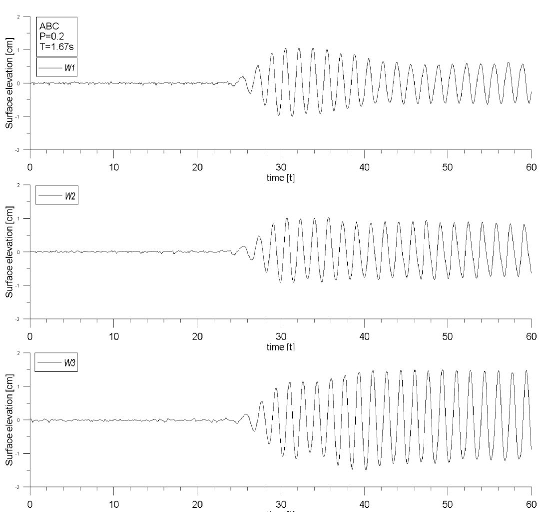

Fig. 4. Time series data of free surface elevation at wave probes [Exp. ID: ABC(1), porosity: 0.2, T_w=1.67sec]

III. EXPERIMENTAL RESULTS AND DISCUSSION

In order to evaluate the energy dissipation performance of the slit caisson breakwater with embedded channels, the reflected wave components were expressed as the reflection coefficient K_R and these were compared with numerical reflection coefficient results which was proposed in [13]. After that, the hydraulic experimental results were compared with each other and these were discussed.

The snapshots of the hydraulic experiment are shown in Fig. 5 and Fig. 6. At the single embedded channel cases, the oscillating flow is amplified from the incident waves and this flow is shown as piston motion of the water column in the embedded channel.

The motion of the water column in the embedded channel shows the non-phase difference about the incident waves. The surface elevation of the wave column is more amplified than the incident waves. In the double channel cases, the surface elevation amplitude of each embedded channel are different, but its phase change in the surface of each channel was same.

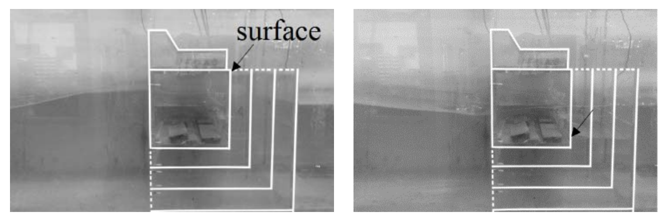

Fig. 5. Wave motion and surface elevation in the embedded single channel [Exp. ID: ABC(1), T_w=1.67sec]

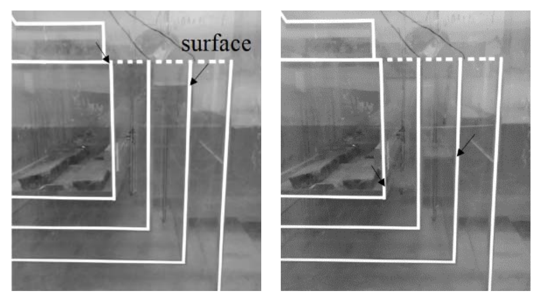

Fig. 6. Surface elevation in the embedded double channel [Exp. ID: AB(2), T_w=1.67sec]

The variable embedded channel shape, porosities of the slit plate and wave periods were considered as experimental parameters in Table I and II. The length of the embedded channel is associated with the wave length, which is directly affected by the energy dissipation effect. To analyze this phenomenon, the relation between the wave length and the length of the embedded channel was shown by non-dimensional parameter(T_w/T_{ch}). When the wave period and natural period of the embedded channel are matched ($T_w/T_{ch} \fallingdotseq 1$), the wave energy dissipation effect is maximized.

As results from separation of the incident and reflected waves, the reflection coefficients(K_R) of the hydraulic experiments and numerical analysis are compared with each other in the Fig. 7, 8 and 9. The reflection coefficient of the each cases are compared by porosities between 0.2 and 0.6 and presented as normalized wave period. In these figures, the solid line is the result of numerical analysis and circle symbols are results of the experiment.

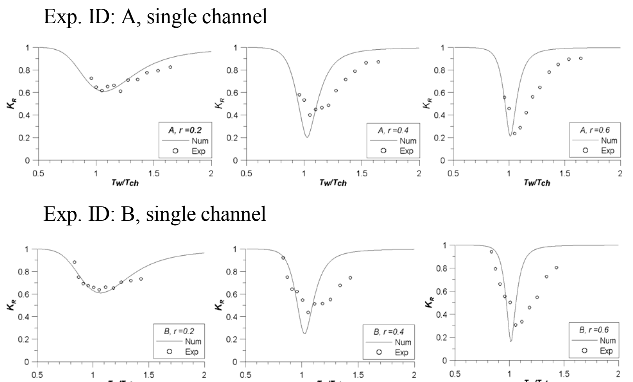

Fig. 7. Reflection coefficient K_R comparing with numerical analysis and hydraulic analysis (Exp. ID: A and B, porosity: 0.2, 0.4, 0.6)

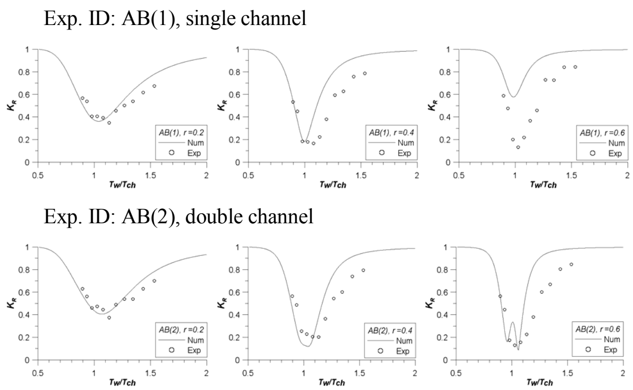

Fig. 8. Reflection coefficient K_R comparing with numerical analysis and hydraulic analysis (Exp. ID: AB(1) and AB(2), porosity: 0.2, 0.4, 0.6)

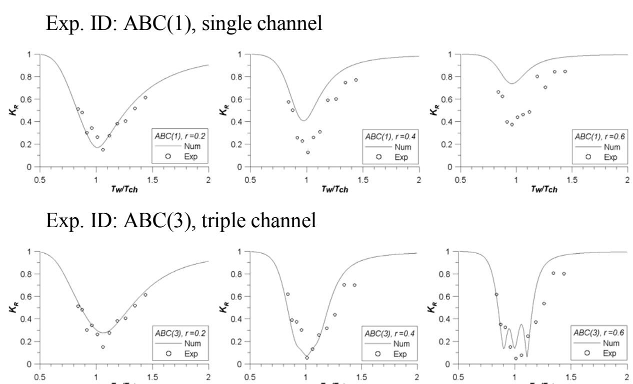

Fig. 9. Reflection coefficient K_R comparing with numerical analysis and hydraulic analysis (Exp. ID: ABC(1) and ABC(3), porosity: 0.2, 0.4, 0.6)

In the entire cases, reflection coefficients of the numerical results and experimental results are properly matched. Exceptionally hydraulic experiment cases of AB(1) and ABC(1) about porosity 0.6, the experiment reflection coefficients are more reduced than the numerical results. It means that the optimal porosity conditions and the band of reflection coefficient were more expanded than the numerical results, especially wide channel cases. From the hydraulic experiment results, not only the energy dissipation in the slits but also the energy dissipation mechanism due to the cross-section contraction from the front side of the breakwater to the embedded channel that were applied.

The hydraulic experiment results were shown together below in Fig. 10. The optimal porosity of the slit plate appear according to the configuration and the width of each channel. At the single wide width channel case ABC(1), the condition of the small porosity 0.2 and 0.4 shows better energy dissipation which is influence by the inertia of the fluid mass in the embedded channel. In the wide width channel cases, the condition of reduced reflection coefficient is wider than the small width channel cases.

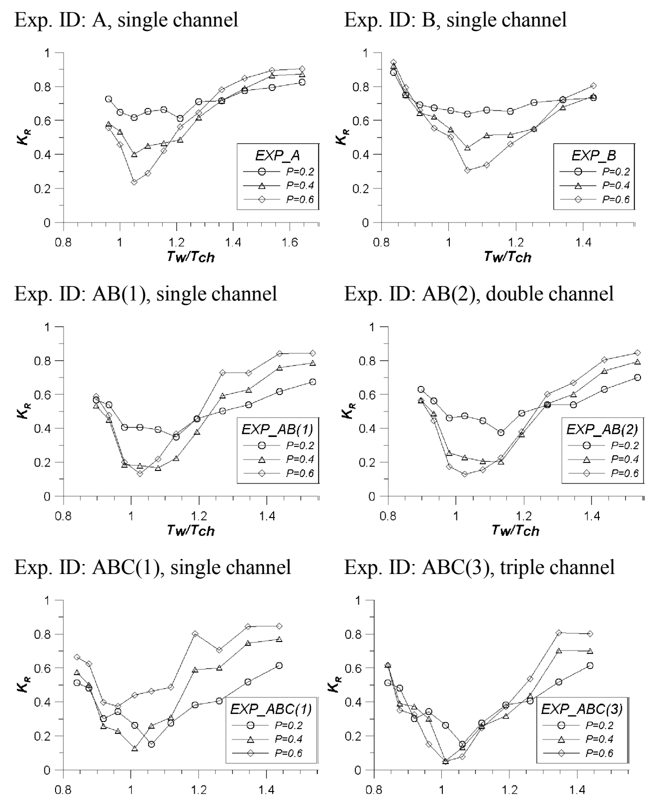

Fig. 10. Reflection coefficient K_R of the hydraulic experiment results

IV. Conclusion

The objective of this research was to propose the new concept slit caisson breakwater using the embedded channels for reducing the reflected waves. The water column in the embedded channel section has eigenvalue related with mass and restoring forces from shape of water column. The natural period of water column in the embedded channel is critically related with channel length. At the resonant condition, the amplified flow of the water column oscillates between the slit plate in horizontal direction. Therefore the energy dissipation due to flow separation at the slit is maximized in the resonant condition. This resonant mode of fluid in the channel can be controlled by design of the embedded channels. Also the this system is more reasonable to control the long waves than the conventional slit-wall breakwater.

The wave reflection characteristics of the slit caisson breakwater with the embedded resonant channel was investigated by hydraulic experiment and it compared with numerical results [13]. The reflection coefficients were influenced by several parameters related with the embedded channel and slit plate. These parameters are incident wave period(T_w), width of the channel(B), porosity of slit and the number of the embedded channels. Each of parameters were influenced on reflection coefficient which represent the wave energy dissipation.

When the resonant mode of water column in the embedded channel is properly formed, the incident wave energy dissipation is maximized. The resonant period was shown at near matching condition of incident wave period and natural period of the fluid in the embedded channel($T_w/T_{ch}≒1$). The reflection coefficient of the hydraulic experiment are more decreased than the numerical results due to the influence of water column inertia and cross-section contraction between front side of the breakwater to the embedded channel. Comparing the results of the same width of single and multi-channel cases, both of the numerical and experimental results shows that the range of the wave period and porosities about the low reflection is expanded in the multi-channel cases. Identifying the basic characteristics of coastal structures through these researches, it can help improve the performance of coastal defense structures.

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