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Submerged Floating Wave Barrier

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ABSTRACT: *The wave interactions with fully submerged and floating dual buoy/vertical porous membrane breakwaters has been investigated in experimentally to validate the developed theory and numerical method in the previous study, in which multi-domain hydro-elastic formulation was carried out in the context of linear wave-body interaction theory and Darcy's law. It is found that the experimental results agrees well with the numerical prediction. Transmission and reflection can be quite reduced simultaneously especially in the region of long waves. The properly tuned system to incoming waves can effectively dissipate wave energy and also offset each other between incident and scattered waves using its hydro-elasticity and geometry.*

1. Introduction

The most floating breakwater proposed so far relatively transparent to the incident waves, especially in the long wave regime. In oder to improve its performance in the long wave region, it is necessary for the structure to occupy the major fraction of water column, or have a large width of approximately one wave length. In view of this, a number of vertical floating membrane breakwater has been investigated by Thomson et al. (1992), Aoki et al. (1994), Williams (1996), Kim and Kee (1996, 1997), Cho et al. (1997, 1998), Kee (2001). Kee et al (2003) summarized several previously study and introduce the fully submerged dual buoy/membrane system with gaps between seafloor and membrane structures. This system can be a possible strong candidate for a new echo-friendly system with outstanding performance as a wave dissipater, which can insure marine scenario, sediment transport, fish passage, surface vessel passing, the water circulation, and the reduced hydrodynamic pressures on the body of structures.

In this paper, the performance of a properly tuned system against the incident waves using the developed theory and numerical method is validated through 2-D wave tank experiments for several limited cases. The optimized test model, which is suitable to limitations of the facilities in the 2-D experimental laboratory, was chosen by a serious of parametric study. The developed numerical solutions in the previous study were found in fairly good agreement with experimental results. The theory and numerical method is not presented in this paper, which can be found in the previous research (Kee 2001).

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2. Experimental Setup

The optimized test model for a given limited condition was a properly devised asymmetric system, which composed of two different mooring types. The front system has dual mooring lines attached at side of buoy and a joint between buoy and membrane, respectively. The rear system one mooring line attached only at the joint. This asymmetric system can further enhance the efficiency of wave barrier, reducing the resonance of system (Kee et al. 2003).

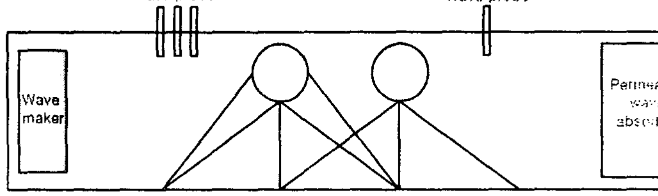

Fig. 1. General view of the wave basin showing the model and test equipments setup.

In oder to verify theoretical computations, a series of experiments were carried out in a wave basin at the Coastal and Harbor Engineering Research Division Laboratory, Korea Ocean Research and Development Institute. The 2-D wave basin was 56m long, 1m wide and 1.25m deep. The down stream wave absorbing beach was located 50m from the wave maker. Details of the basin, the position of the four wave gauges are shown in Fig. 1.

The model breakwater structure is consisted of a flexible membrane, which is suspended from the floating cylindrical buoy and hinged at the steel frame that is fixed into seabed. The flexible membrane was made of a thin stretching-resistible plastic material resembling a plastic tarpaulin. The cylindrical buoy was 35cm diameter, 95cm length, and 0.5cm thickness acryl pipe with two internal acryl plate stiffeners and caps. In addition two still plates are attached acryl caps in order to give enough resistible strength to mooring lines. The total weight is 11.3kg.

Mooring lines are attached to the side of cylindrical buoy and it's joint between membrane and buoy. From the parametric study using numerical code, optimized performance may be obtained for a system with toe mooring angles 33, 29.6 degrees for joint and side of buoy respectively. The mooring line, however for simplicity, has toe angles with 45, 66 degrees for joint and side of buoy respectively, and has been hinged at the pins that were attached to the side of flume as show in Fig 2.

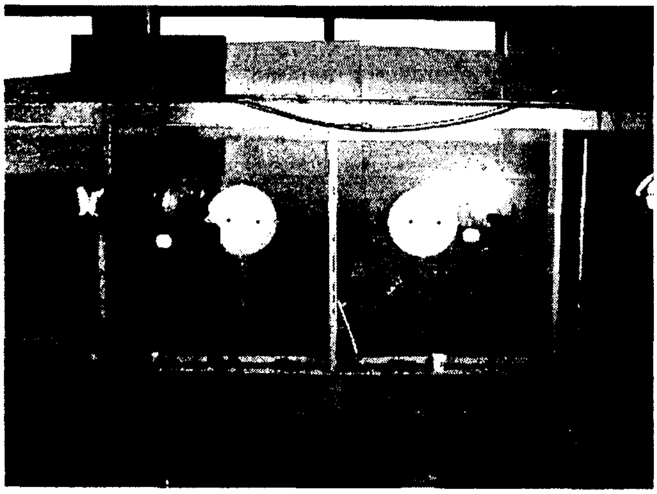

Fig. 2. Two camcoders to capture the motions of buoys.

The mooring line stiffness is 0.74kgf/cm and initial tensions for 2 test cases are given in Table 1. The sys 1 is for a system with single mooring line for front and rear the buoy. Thus sys 1 has exactly same design parameters for both of front and rear buoy/membrane system. The sys 2 is an asymmetric system having two different mooring types, which has dual mooring lines for front system and single mooring line for rear one.

The submergence depth of front and rear buoys was 5cm in 90cm water depth, so the draft of buoys is 40cm from the free surface. The both bottom clearances of front and rear system between seafloor and tip of membrane are 11cm.

The wave height used in our experiments range from 3cm (case1) to 4cm (case2), and 6cm (case3) with sinusoidal attenuated waves in amplitude. The wave periods used in the experiment range from 0.84 sec to 3.02 sec. In our experiment the majority of the measurements were made before the reflections entered the test area in order to get undisturbed data.

In experiment, porosity P=0.1008 has been used on the membranes, such that equivalents to G=5, which is called as Chang's parameter (Chang et al., 1983) for numerical calculation, and the linear relation G=57.63P-0.9717 between porosity and porosity parameter was obtained from experiments for various porous plates (Han et. al 2003).

Location			Symmetric Sys 1	Asymmetric Sys 2
Front Buoy	Right	Side-front		5.9
		rear		4.4
		Jont-front	3.7	4.1
		rear	3.8	2.7
	Left	Jont-front		5.5
		rear		4.7
		Jont-front	3.7	3.2
		rear	3.8	3.5
Rear Buoy	Right	Jont-front	3.7	3.7
		rear	3.8	3.8
	Left	Jont-front	3.7	3.7
		rear	3.8	3.8

Table 1. Initial tensions of each mooring lines with a unit of kgf.

3. Results and Discussions

Fig. 3 shows that the transmission and reflection coefficient for a sys. 1 are plotted as function of relative depth kh with numerical prediction and experimental results for different wave amplitudes. Both comparison of experimental data and present numerical results have generally good agreements, and the overall performance of wave barrier along the wide frequency range is outstanding thanks to the mutual cancelation effects between incident wave and scattered waves by the motion of systems, which offset each other with phase differences. The relatively small and large amplitude waves from 3cm to 6cm were plotted in the Fig. 3. to see the sensitivity to wave heights. As expected, smaller-amplitude waves correlate better with the linear wave-body-interaction theory. Thus, the discrepancy between experimental results and numerical results at vicinity of resonance frequency is mainly attributed to nonlinear effects, and partially some uncertainties. Since this system may have an additional energy losses associated with vortex formation around the bottom edges of the membrane. In addition, one can expect sway/roll critical damping due to viscous and additional membrane damping, which can be material or viscous damping.

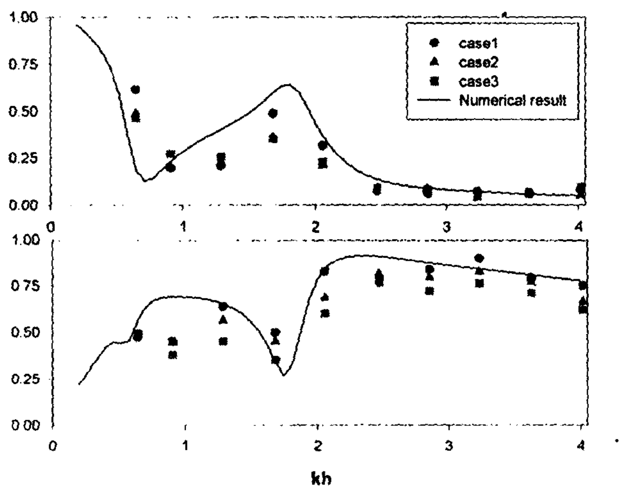

Fig. 3. Transmission and reflection coefficient for sys. 1.

The measured sway and roll motion amplitudes by the motion capture using two camcoders were analyzed. The roll amplitude comparison is not presented here, due to the some difficulties for analysis of the experimental data. Fig. 4 shows that the sway amplitudes of the rear and front buoys for a relative depth. The experimental sway amplitudes generally agree well with the numerical prediction. The sway amplitude η_{rs}/A of rear buoy generally is lowers then the sway amplitude η_{fs}/A of front buoy, except even if the numerically predicted sway amplitude of rear buoy at resonance frequency $kh = 0.6$ is greater then the sway amplitude of front buoy. It is interesting to note that the general trend of sway motion of rear buoy is well correlated to the trend of transmission coefficient. It is also quite interesting to note that the experimental motion of front buoy, in the long wave region, is slightly larger than that of rear buoy, even if one can expect, intuitively, large pivotal motion of buoys since it is restrained by single mooring attached to the joint. In this long wave region, the reflected and transmitted waves seem to be pretty much reduced simultaneously. It is mainly due to the wave energy dissipation through fine pores on the membrane with a fluid viscosity. It is also partially due to the uncertainty such as sway/roll critical viscous damping by the viscous fiction around the surface of buoy.

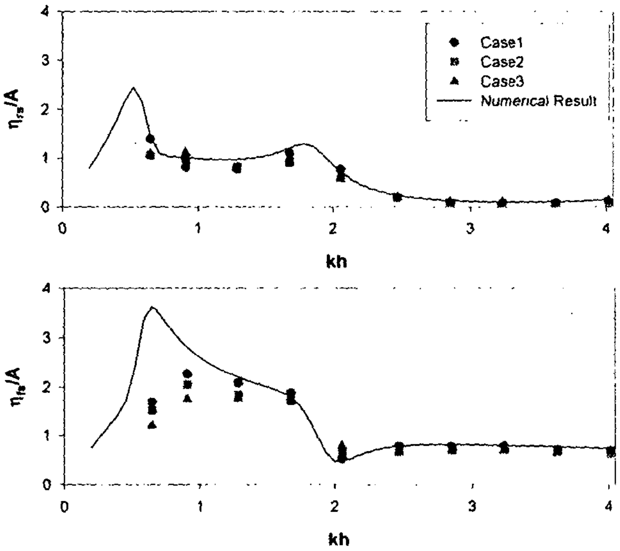

Fig.4. Sway motions for front and rear buoys for sys. 1.

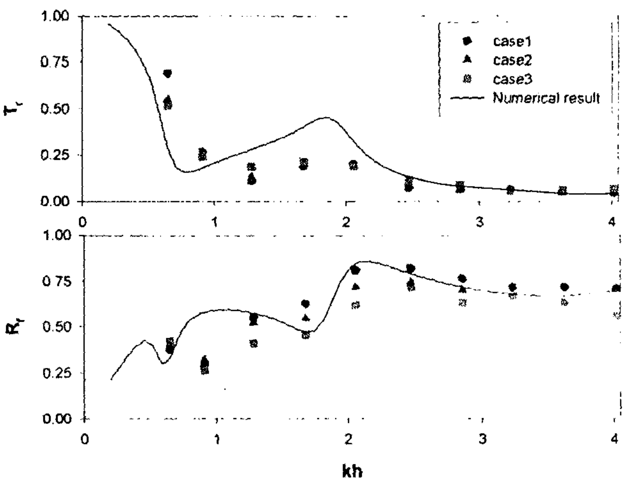

Fig. 5. Transmission and reflection coefficient for sys. 2.

After attaching one more mooring line at the side of front buoy, the whole system can be asymmetric since the both system design parameters are not same. As expected intuitively, the resonance can be reduced, compared to the symmetric system. Fig. 5 shows that the transmission and reflection coefficient for a asymmetric system are plotted as function of relative depth *kh*. The numerical predictions have excellent agreements with experimental results for different wave amplitudes. The performance of asymmetric system, in the long wave region and resonance frequency region $kh = 1.8$, is a litter bit better than that of symmetric one.

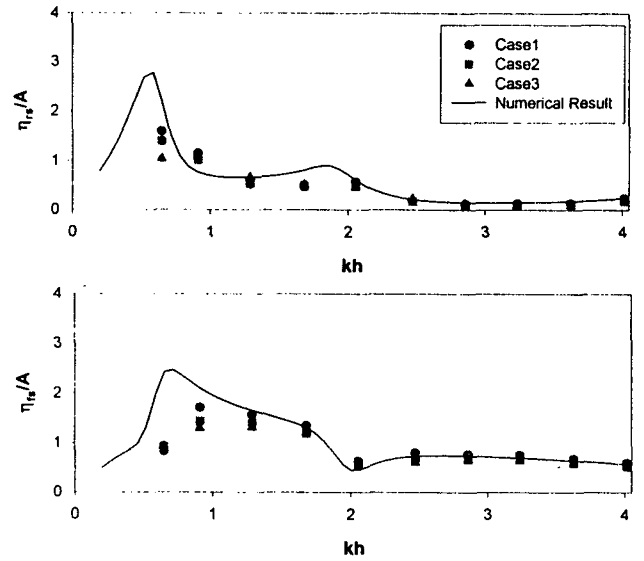

Fig.6. Sway motions for front and rear buoys for sys. 2.

The corresponding results comparisons between front and rear buoy displacements are shown in Fig. 6 with good agreements. An additionally attached to the side of front buoy does slightly reduce the amplitudes of sway motion normalized by wave amplitude A, when it is compared to the amplitudes for sys. 1. The discrepancy between experimental and numerical results in very long wave region, can be attributed to the effects of the nonlinear viscous drag force around fully submerged cylindrical buoys, which does not account in the numerical method.

Thus, from those comparison, we can expect some potent capacity as an ideal breakwater which can reduce both reflection and transmission in the frequency range of $0.6 < kh < 1.8$, to insure much safer sea state for a vessel passing through the fully submerged breakwater. Thus, this breakwater can avoid the seabed erosions, in front of structure, which occurs subsequently against a high wave reflection. The both of symmetric and asymmetric model can have excellent performance as a wave dissipater, showing 50% reduction of transmitted wave up to $kh = 0.6$, which corresponds to the wave period of 15sec in the water depth of 15m.

Thus, it can be concluded that the fully submerged dual buoy/porous-membrane breakwater system has excellent wave blocking and wave energy dissipating efficiently for relatively longer wave frequency regions. In addition, the breakwater can insure marine scenario, water circulation, sediment transport, fish passage, surface vessel passing, and the reduced hydrodynamic pressures on the body of structures. From these comparison and analysis, it is shown that a properly devised asymmetric system, which complements each other, can enhance its efficiency based on the mutual cancellation effect between incident waves and scattered waves. In addition, the porosity imposed on membrane can further dissipate wave energy and also eliminates possible resonance of system.

5. Conclusions

Experiment had been conducted in 2-D wave basin, using the two optimized models which was chosen through a series of parametric study under the limited condition of experimental lab. The comparison between numerical and experimental results show good agreements, and also show the generally outstanding performance as wave barrier along the overall frequency range. Both model can reduce simultaneously the reflected and transmitted waves expecially in the frequency range of $0.6 < kh < 1.8$.

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