DEVELOPMENT OF WAVE ABSORBING SYSTEM USING AN INCLINED POROUS PLATES

I.H. Cho[(1)] and M.H. Kim[(2)]

(1) Dept. of Marine Industrial Engrg., Cheju National University, cho0904@cheju.ac.kr

(2) Dept. of Civil Engrg., Texas A&M University, m-kim3@tamu.edu

INTRODUCTION

Wave absorber, which is the main equipment in wave tank, is installed for the two purposes. First one minimize the wave distortion in the measuring section by reducing the reflected wave generated from the opposite wall of wave tank. Second, it is installed for the promotion of the efficiency of the tank by vanishing the remaining wave disturbance in a short time after stopping the wave generator. Most of passive wave absorber is classified into the vertical and inclined type.

One of the major problems associated with the use of the vertical porous plate is to install many plates to get a desired absorbing efficiency, therefore it demands a large space and incurs the resonance phenomena between plates. In view of this, horizontal porous plate thus may be an alternative candidate as a wave absorber. The formulation of the interaction of a submerged horizontal porous plate with waves is in general more complicated than the vertical porous plate. Wu *et al.* (1998) investigated wave reflection by a vertical wall with a submerged horizontal porous plate. It is found that the plate with proper porosity can significantly reduce not only the wave run-up on a vertical wall but also the reflection coefficient. The efficiency of the horizontal porous plate is strongly dependent to the length of plate and the submergence depth as well as the porous parameter. Yip and Chwang (2000) studied the hydrodynamic performance of a perforated wall breakwater with an internal horizontal plate is studied. It is found that a horizontally submerged porous plate be installed inside the wave chamber can enhance the stability of the structure.

ANALYTIC AND NUMERICAL METHOD

The water wave reflection by a vertical wall with a horizontal submerged porous plate is investigated using the eigenfunction expansion method. The fluid domain was divided into two regions according to the division of porous plate, as shown in Fig. 1. The velocity potential with unknown coefficients are obtained in two regions of the fluid domain by taking into account the boundary conditions on the free surface, the porous plate surface, the wall surface and the sea bottom surface as well as radiation surface. These unknown coefficients in each region are determined by invoking the matching conditions. Newly defined porous parameter $b = 2\pi\sigma / k_1$,at the boundary conditions on the porous plate surface

$\frac{\partial \phi^+}{\partial y} = \frac{\partial \phi^-}{\partial y} = i\sigma(\phi^- - \phi^+) \quad on \;\; y = -d\, ,\, -a < x < 0.$, plays an important role at the performance of wave absorbing and the wave load on the plate. Porous parameter, which is one-to-one correspondence with porosity, will be determined based on a least-square fitting with the measured data obtained from the experiment.

As a numerical tool, a multi-domain boundary element method (BEM) was independently developed to confirm the analytic solutions and involve the inclined/dual porous plates. The computational domain was decomposed into inner and outer domains. Inside the inner region, a simple-source (modified Bessel function of the second kind) distribution were used. For the outer region, an eigenfunction expansion method was used. The inner solution was matched at vertical matching boundaries to the outer solution based on the continuity of pressure and normal velocity.

EXPERIMENTS

In order to validate the theory and numerical procedure developed in the preceding sections, we conducted a series of experiments in the two-dimensional wave tank (20m long, 0.6m wide, and 1.0m deep) located at MOERI(Maritime and Ocean Engineering Research Institutes). Four probes for decomposing incident and reflected wave are installed at the position of 4.0m,4.4m,4.67m,4.864m from the front of porous plate, respectively. The estimation of reflection based on a least-squares technique applied to the measurements from four probes has been described by Mansard and Funke(1980). Regular waves were generated by a user-defined time-voltage input to the wave maker. The wave frequency range used in our experiments was from 0.4 to 1.5Hz. The porous plate model was made of a punched steel plate with 6 different porosities ($P = 0.0567, 0.0740, 0.1008, 0.2267, 0.3, 0.4031$). The length and width of the porous plate were 60cm, respectively. Thickness of porous plate was 1.6mm. The porous plate was attached with desired submerged depth or inclined angle by four vertical steel frames clamped to the tank bottom, as shown in Fig.2.

Prior to the design and fabrication of MOERI's wave absorber, the prototype(length=3m, width 8m) of the horizontal/inclined porous plates in front of rigid wall is tested in a square basin. In similar way of two-dimensional experiment, four probes for decomposing incident and reflected waves are installed at the position of 3m,3.65m,4.24m,4.92m from the front of porous plate. Regular waves were generated by the wave maker with the frequency range from 0.5 to 2.0 Hz. The test is conducted for the horizontal(d=15cm) and inclined ($\beta = 5^o, 10^o$) porous plates with the fixed porosity ($P = 0.1$) at the water depth 1.5 m.

NUMERICAL RESULTS AND DISCUSSIONS

The analytic solutions are compared in Fig. 3 with the BEM-based numerical solutions. For the BEM result, 350 total elements with 100 elements on the free surface were used in order to give correct results. The two solutions are in good agreement.

In the following, the comparison of reflection coefficient between the analytic solution and experimental results conducted in the two-dimensional wave tank located at the MOERI is shown in Fig. 4. For the comparison, the porous parameter corresponding to the porous plate used at the experiment should be determined. Porous parameter is closely related to the porosity and local shape of the porous plate. If the hole of punched plate is sufficiently small and is arrayed uniformly, porosity becomes dominant to the characteristics of porous plate rather than local shape. To obtain the relationship between porous parameter and porosity, we use the least-square fitting technique. The porosity parameter corresponding to given porosity is updated by minimizing the squared error throughout repeating calculation and the final value is determined. To investigate the correspondence relation between them, we plot the data set in Fig. 5 together with a regression line. The fitted curve is the linear function which is expressed by b=57.63P-0.9717.

The characteristics of reflection coefficients by a vertical wall with the inclined porous plate is shown in Fig. 6 using the boundary element method. Porosity is fixed at 0.1008 and non-dimensional length of plate is $a/h = 1.0$. The rear of plate is set to still water and the fronts of plate is submerged at 5, 17cm. As inclined angle increases, the reflection coefficients is reduced in high frequencies range, but the reflection coefficients increases in the range of $0.2 < a/\lambda < 0.4$. The measured values generally follow the trend of the computed curve. This results support the validation of the linear functional formula b=57.63P-0.9717.

Based on the series of computations, we found that the optimal range of porosity is $0.07 < P < 0.12$ and the inclined porous plate having an optimal range $10^o < \beta < 20^o$ shows better efficiency than the horizontal one. To design the prototype wave absorber for installation at MOERI's square basin, the model test for inclined porous plate is conducted in a square basin with the length(3m) and the width(8m). Water depth is fixed at 1.5m and porosity is 0.1. Fig. 7 shows the reflection coefficients by a vertical wall with a horizontal(d=15cm)/inclined($\beta = 5^o, 10^o$) porous plate. As it is expected, inclined porous plate shows better efficiency than horizontal one.

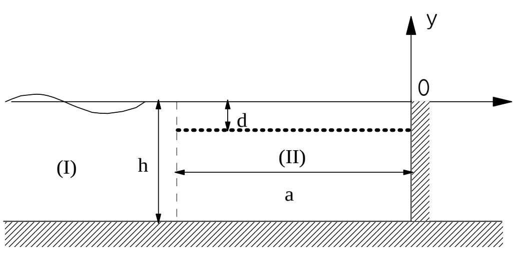

Fig.1 Definition sketch of a submerged horizontal porous plate with a vertical wall

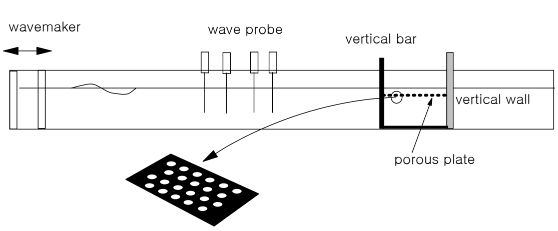

Fig. 2 Experimental set-up for measuring the reflection coefficients by a vertical wall with a submerged porous plate

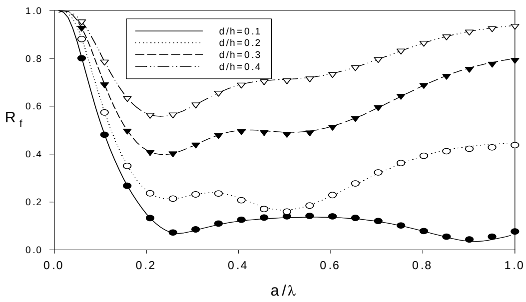

Fig. 3 Reflection coefficient of an horizontal porous plate as function of non-dimensional wavelength a/λ and submergence depth for $a/h=1.0, b=5.0$ (Lines are for analytic solutions and symbol are for BEM solutions)

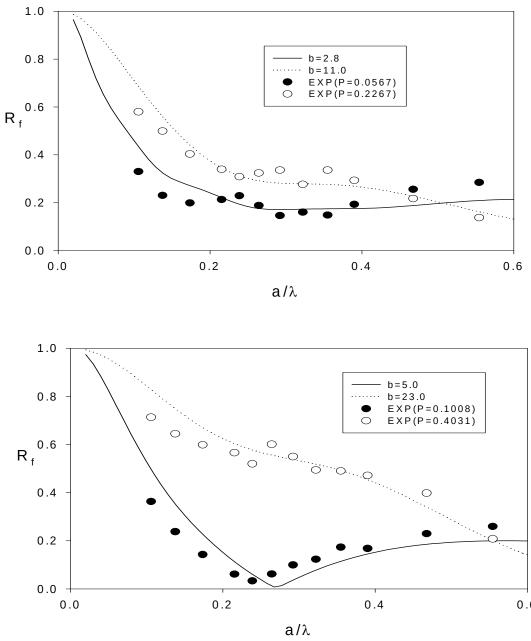

Fig.4 Comparison of theoretical reflection coefficients with experimental results as a function of a/λ for $d/h=0.025, a/h=1.0$

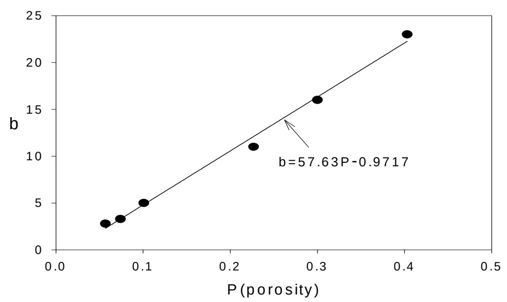

Fig.5 Regression line between the porous parameter and the porosity

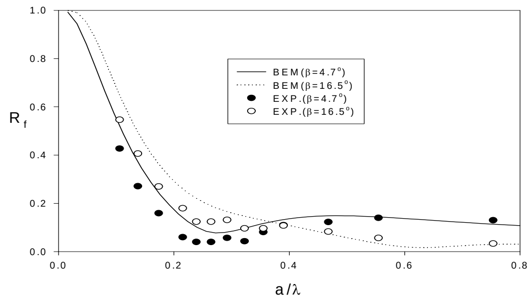

Fig.6 Comparison of numerical (BEM) and experimental results for an inclined porous plate with a vertical wall as function of a/λ and inclined angles for $P=0.1008, a/h=1.0$

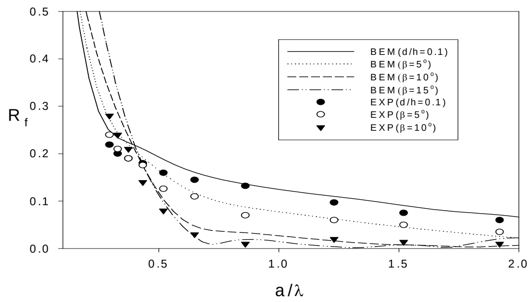

Fig.7 Comparison of numerical (BEM) and experimental results in a square basin for submerged porous plate as function of a/λ and inclined angle for $P=0.1, a/h=2.0$

REFERENCES

Wu, J.H., Wan, Z. and Fang, Y. (1998) "Wave reflection by a vertical wall with a horizontal submerged porous plate", *Journal of Ocean Engineering*, Vol.25, No.9, 767-779.

Yip, T.L. and Chwang, A.T. (2000) "Perforated wall breakwater with internal horizontal plate", *Journal of Engineering Mechanics* ASCE, Vol. 126, No.5, 533-538.