Abstract of Dissertation

Study on the Floating Breakwaters Used in Fishery

（水産業に適した浮消波堤に関する研究）

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In fishery, along with the continual expanding of sea cage culturing recently, the floating breakwaters to protect the sea cages from the incoming waves are more and more popularly utilized. As a successful design of breakwaters, it requires small wave loads acting on the breakwaters in addition to the low transmission rate of waves. In particular, as a device used in fishery, it also requires easier construction, lower cost and fewer blockages to the normal seawater exchange. Floating and semi-submerged porous cylindrical structures are proposed as a new promising type of devices used in fisheries for offshore and coastal aquaculture projects. These structures can not only dissipate wave energy but also reflect the energy contained in the incident waves to a satisfied extent. Therefore, it is important to perform a fundamental investigation on the interaction of water waves with floating porous bodies to make a good understanding of its physical mechanism.

For the purpose of designing efficient floating breakwaters, the theoretical and experimental study on the interaction of water waves with a single or an array of truncated porous cylinders is investigated based on the linear potential theory in the present work. The cylinder partly made of porous materials, possesses a porous sidewall, an impermeable bottom. In addition, a porous plate is fixed horizontally inside the cylinder to work as an obstruction to make wave dissipation more effectively and to eliminate the phenomenon of sloshing mode.

Firstly, based on the previous study, the so-called Forchheimer equation is considered. Although after making equivalent linearization to the quadratic term in the equation, the linear form is adopted in according to the linear wave theory, the nonlinearity is mainly remained in the relation with the term of wave slope. Therefore, the Darcy's fine-pore model is applied to the boundary condition on the porous body surface. A non-dimensional parameter b is defined to describe the porosity according to the porous coefficient in Darcy's law. However, it is not directly related to the opening ratio τ of the porous materials. The boundary value problem is then formulated and solved by means of the Eigen-function expansion. The fluid domain is divided into three regions and different Eigen-function series are used. In the case of the porous cylinder with an inner porous plate, the

so-called 'dispersion relation' for the region inside the cylinder is quite different from a conventional one due to the existence of the porous plate. It leads to the Eigen values of complex number. The systematical search for the roots of the so-obtained transcendental equation is described. To the radiation problems, particular solutions are constructed to take account of the normal velocity appearing in the porous boundary condition. A matching is made on the common surface to determine the unknown coefficients in the expansions. Once the velocity potential is determined, the wave loads are evaluated by integrating the pressure difference on two sides of the wetted body surface. To validate the theoretical work and computed results, a series of model tests are carried out in a wave basin, as shown in Fig. 1. The theoretical works are compared with the experimental results and it can be obtained that they are in good consistence with each other. Wave exciting forces decrease as the porosity parameter b (or equivalently τ) increase and significantly reduced compared to the values for impermeable cylinder. In the case of the cylinder without, the phenomenon of sloshing mode can be observed when k_0a=1.84 both in calculation results and in measured data. However, it is no longer observed owing to the existence of the inner porous plate which is fixed at the still water surface. By examining the wave amplitude leeside the cylinder, it is also found that the existence of the inner plate does increase the efficiency of the wave dissipation especially when it is fixed at the still water surface.

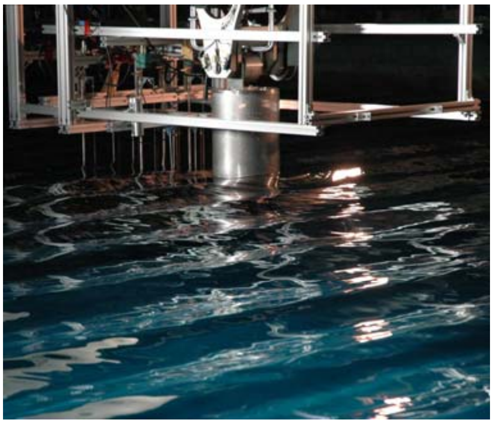

Fig. 1 A Sketch view of the experiment of a single porous cylinder

Secondly, effort is made to establish an empirical relationship between porosity parameter b used in computation and the opening ratio τ of model materials. The effect of wave slope ε will be included in this relationship by taking into account of the quadratic term in pressure drop through porous materials. The relationship between these two parameters is important in the comparison of computational results to the measured data, which has not been reported in the previous works up to the authors' knowledge. This task is tackled by systematical comparison between the calculation results and experimental data and the application of Least-Squares Method. Then, it can be written as $b = \frac{(17.80/\varepsilon + 143.2)\tau^2}{1 + 1.06\tau}$. It should be reminded that this empirical formula is based on the tests with perforated metal materials. The application of it should be made by caution. It is questionable when applied to the radiation problem. It works quite well for the wave exciting forces, although effort should be made to confirm the coefficients are valid for either radiation problem or freely floating problem. Further should be made to find out the best empirical relation between the non-dimensional porosity parameter b and opening ratio τ of model materials.

Thirdly, the validation of Haskind relations is examined for the porous body both in theoretical deduction and in numerical calculation. Some of Haskind relations are still valid without any change, such as the symmetry of added mass and damping coefficients, and the haskind-hanaoka theorem, etc. On the other hand, such as, the damping coefficient, the relations between two diffraction problems, and the Bessho-Newman Relations etc., in addition to the conventional components, they obey the Haskind relation with a correction of the energy dissipation, which caused by the porosity. For example, the total damping consists of two components, i.e. the conventional wave-radiating damping and the porous damping caused by the porosity.

Fourthly, the drift forces acting on the porous bodies, which are of second-order in the wave amplitude, are computed from quadratic products of the first-order quantities. The second-order wave drift force is computed by the near-field method based on the pressure integration, and validity is confirmed by comparing with the corresponding value computed by the 'far-field method' based on the momentum conservation theorem. The drift force is composed into two components. As well as the conventional part evaluated by the integral of scattering wave amplitudes at far field, there exist the second part caused by the energy and momentum dissipation through the porous body surface, which makes more significant contribution than first component. On the other hand, the energy cannot be reflected (for short waves) or transmitted (for long waves) totally because of the existence of the energy dissipation caused by the porosity. Therefore, for long waves, the drift force on the porous body is bigger than those on an impermeable one, while for short waves the opposite is true.

Finally, the diffraction of waves by an array of floating porous circular cylinders with or without an inner porous plate is considered in detail based on the linear wave theory. For the sake of designing more effective floating breakwaters, the transmission of waves propagating through the array is also calculated. To deal with hydrodynamic interactions among a great number of bodies, a hierarchical interaction theory is adopted, which saves computation time efficiently. Consequently, as shown in Fig. 2, a series of model test of an array of porous cylinders are carried out in the basin to validate the theoretic work and the calculation results. The draft of the cylinders, the depth of the inner porous plate and the spacing between adjacent cylinders are adjusted to investigate their effect on the transmission of waves propagating through the arrays. The inner plate plays a role to eliminate the sloshing mode in the case of wave exciting surge force and pitch moment. It works well to increase the efficiency of wave dissipation. Furthermore, it can be obtained from the numerical results that, the total loads, the mean transmission rate and the drift force on arrays of porous cylinders with an inner porous plate decrease significantly compared to other cases. The porosity eliminates the peak of transmission rate appeared in the case of impermeable cylinders. In particular, the transmission rate can be reduced to 0.4 or even less if the cylinders are arranged in two or three parallel lines. These advantages open a broad prospect for the porous cylinders to be utilized as breakwaters.

Fig. 2 A Sketch view of the experiment of an array of porous cylinder

In summary, based on the present study, with proper adjustment of the size of the cylinder, the number of the cylinder, spacing between adjacent cylinders, draft, and location of the inner porous plate and so on, the effective of wave dissipation caused by the cylinder array and the total loads acting on the cylinders might be optimized. An effective breakwaters can be made by porous cylinder array with relative smaller number than the active ones used in fishery.

Furthermore, for purpose of the practical application of porous breakwater, further researches should be done on the effect of quadratic law, the motion response to the incident wave, and nonlinear wave theory.