II－562 LABORATORY INVESTIGATION ON THE ESTIMATION OF WAVE FORCES ACTING ON A SPHERICAL ARMOR UNIT OF A SUBMERGED BREAKWATER

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1. INTRODUCTION: In the design of submerged breakwater, the complete understanding of the mechanisms and accurate estimation of the wave forces acting on an armor unit are very important in the solution of practical problems concerning the design and construction of coastal structures. Hence, this paper aims to present the experimental investigation on the estimation of wave forces acting on a spherical armor unit of a submerged breakwater.

2. EXPERIMENTAL PROCEDURE: Laboratory observations of wave forces acting on a spherical armor unit of a submerged breakwater were carried out using an indoor wave tank. The submerged breakwater, as shown in Fig. 1, was installed using spheres of diameter, $D = 3$ cm. Regular waves were generated using three different periods, and for each period four different values of wave height were assigned. The incident wave height was adjusted so that both breaking and non-breaking waves attacked the submerged breakwater. For each trial, water surface profile, horizontal and vertical water particle velocities (u and w) and horizontal and vertical wave forces (F_x and F_z), for both non-embedded and embedded conditions were measured. The methods of wave force and velocity measurements are shown in Fig. 2.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS: The Morison's equation is employed in estimating the wave force and is given by,

$$Fx = \frac{1}{8}C_{Dx}\rho\pi D^2 u\sqrt{u^2+w^2} + \frac{1}{6}C_{Mx}\rho\pi D^3\dot{u}; \qquad Fz = \frac{1}{8}C_{Dz}\rho\pi D^2 w\sqrt{u^2+w^2} + \frac{1}{6}C_{Mz}\rho\pi D^3\dot{w} \quad (1)$$

where, $\dot{u}$ and $\dot{w}$ represent the horizontal and vertical accelerations, respectively. The correlation coefficient, r is used to determine the applicability of the Morison's equation and is given by,

$$r = \sqrt{1 - \overline{\{Fc(t) - F(t)\}^2}/\overline{F(t)^2}} \quad (2)$$

where, $Fc(t)$ and $F(t)$ are the calculated and measured wave forces respectively, and the overline suggests time average. The Morison's equation is not applicable when r is less than 0.9 [2], since the difference between $Fc(t)$ and $F(t)$ is not negligible. The applicability of the Morison's equation is given in Fig. 3, wherein H_I is the incident wave height and L is the wavelength. As shown in the figure, Morison's equation is generally applicable for non-embedded condition when $x/L \leq 0.20$ and almost not applicable for embedded condition. However, by comparing the present and the previous experiment with deeper water depth, it was confirmed that the range of applicability for both non-embedded and embedded conditions increases as d, depth of water, increases.

The values of the drag coefficients (C_{Dx}, C_{Dz}) and the inertia coefficients (C_{Mx}, C_{Mz}) were determined by least square method; and, the characteristics of the drag and inertia coefficients for non-embedded condition are determined by plotting the values of C_{Dx} and C_{Mx} versus the horizontal Keulegan and Carpenter number (KC_x), as shown in Fig. 4 and 5. The relation shows that C_{Dx} approach a constant value around 0.70 to 0.80 as KC_x increases; and, C_{Mx} is almost constant around 1.30 to 1.40 as KC_x increases. It can be observed in the figure that the present values have almost the same tendency as compared to the formulated value for a single sphere [2]. Therefore, for insignificant effect of lift force, the horizontal wave force for non-embedded condition can be evaluated with Morison's equation using the drag and inertia coefficients formulated for a single sphere. However, the correlation coefficients of the vertical measured wave force and the calculated one using Morison's equation were generally smaller than 0.90; thus, in this experiment, Morison's equation is not suitable in the evaluation of the vertical force [1]. And this may be largely attributed to the lift force caused by the bottom proximity effect. It should be noted that the maximum wave force becomes large when Morison's equation is not applicable; thus, the establishment of estimation method for this case is a very important future research problem.

4. CONCLUSIONS: Based on the experimental results, the main results obtained from this experimental study are summarized as follows:

(1) Morison's equation was found to be applicable in the estimation of the horizontal wave force in a given range of the non-embedded condition. Moreover, the drag and inertia coefficients formulated for a single sphere can be applied in the case of the non-embedded condition.

(2) Large value of the non-dimensional force is concentrated around the crown-edge of the submerged breakwater; thus, the vicinity around the crown-edge is revealed to be the most critical location.

5. REFERENCES

[1] Mizutani, N., Iwata, K., Rufin, T. M. Jr., and Kurata, K., Experimental Study on Wave Forces Acting on an Armor Unit of a Submerged Breakwater, *Proc. Intl. Symp. on Natural Disaster Reduction and Civil Eng'g.,* 1991, pp. 107-115.
[2] Iwata, K. and Mizutani, N., Experimental Study on Wave Force Acting on Submerged Sphere, *Proc. 8th OMAE,* Vol.2, 1989, pp.145-152.

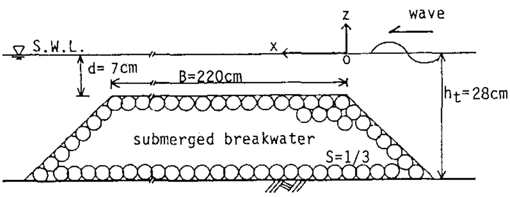
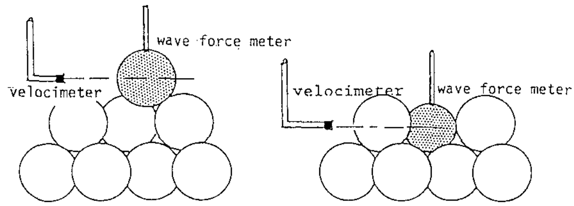
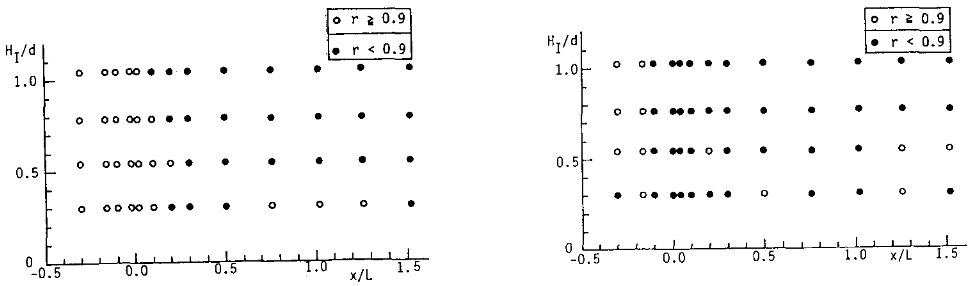


Fig. 1 Schematic diagram of submerged breakwater.



(a) non-embedded (b) embedded

Fig. 2 Methods of wave force and velocity measurement.



(a) non-embedded (b) embedded

Fig. 3 Relationship of H_I/d with x/L.

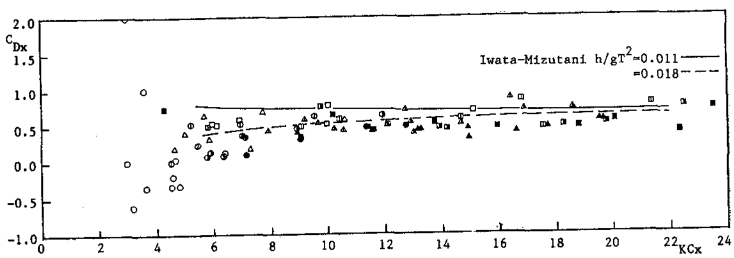


Fig. 4 Relationship of C_{Dx} with KC_x.

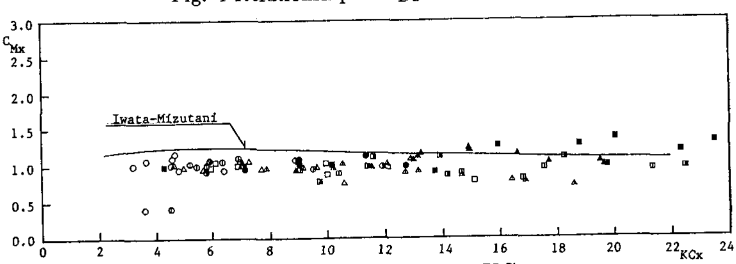


Fig. 5 Relationship of C_{Mx} with KC_x.