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A STUDY ON WAVE FORCES ACTING ON A RUBBLE STONE OF A SUBMERGED WIDE-CROWN BREAKWATER

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1. INTRODUCTION: A thorough knowledge of the mechanism and fundamental characteristics of the wave forces acting on a given armor unit is deemed necessary in the design of submerged breakwater. Moreover, the establishment of an accurate estimation method of the wave forces acting on an armor unit is very essential in the design and construction of coastal structures. The present paper deals with the pertinent characteristics of wave forces acting on different shapes of rubble stone on a submerged wide-crown breakwater and investigates the applicability of the Morison's equation in the estimation of the acting wave forces.

2. EXPERIMENTAL PROCEDURE: Laboratory experiments of wave forces acting on a rubble stone were performed in an indoor wave tank. Three classes of rubble stones with varying weights of 6.2g, 9.5g and 19.6g were chosen in this experiment. For each class, round-type($S_1/S_2 = 1.6$), edged-type($S_1/S_2 = 2$) and flat-type($S_1/S_2 = 3$) stones were used in the investigation. The stones are characterized by the shape ratio S_1/S_2, where S_1 and S_2 are the mean maximum and minimum dimensions of the stones, respectively. For spherical and cubic type of stones the shape ratio is taken to be equal to unity. Regular waves were generated with three different wave periods($T =$ 1.0s, 1.4s, 1.8s) and for each wave period four different values of incident wave height were assigned($H_I =$ 3cm, 5cm, 7cm, 10cm). For each sample of rubble stones, the vertical and horizontal wave forces(Fz, Fx), vertical and horizontal water particle velocities(u, w) and water surface profile were measured in designated locations on the submerged breakwater, for both non-embedded and embedded conditions. Three types of submerged breakwater were used and installed using spherical armor units of parameters $D_e/d =$ 0.35, 0.28, 0.24,, where D_e is the equivalent sphere diameter of the rubble stone sample and d(=7cm) is the crown water depth. The breakwater was constructed with a crown width $B=$ 220cm, water depth from the toe of the structure $h_t=$ 28cm and a slope of 1/3.2.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS:

3.1 **Time History of Wave Forces:** Based on the experimental results, profiles of time histories of the wave forces acting on rubble stones are almost similar to the results obtained by Mizutani *et al.* [1] for the spherical armor units. The type of profiles observed are generally classified into five types: Single-peak(S-type), Pulse(P-type), Zigzag-type(W-shape and V-shape), and Double-peak(DP-type). For non-embedded condition, S-type is very common for Fx in the range of $x/L < 0$ for non-breaking wave conditions, where x is the horizontal distance from the leading crown-edge of the submerged breakwater and L is the wavelength. Profiles of W-shape and V-shape are noticeable for Fz for both breaking and non-breaking wave conditions when $x/L > 0$. On the other hand, P-type is a usual profile for Fx for breaking wave conditions around the vicinity of the crown- edge of the submerged breakwater. And DP-type profiles are generally observed for breaking wave conditions for Fz in the range of $x/L < 0$ and for Fx in the range of $x/L > 0$.

3.2 **Maximum Wave Forces:** Variations of $Fx_m/\rho_w g H_I D_e^2$ and $Fz_m/\rho_w g H_I D_e^2$ with x/L, where ρ_w is the density of water, are shown in Fig. 1. Regardless of the shape of the rubble stone, the maximum dimensionless wave force is located at $x/L = 0$; thus, the vicinity around the crown-edge of the submerged breakwater is confirmed to be the most critical location of the submerged breakwater. In general, the magnitude of $Fx_m/\rho_w g H_I D_e^2$ for edged-type of bigger horizontal projected area is larger than the other types of stone; whereas, flat-type of stone obtains the biggest magnitude for $Fz_m/\rho_w g H_I D_e^2$.

3.3 **Drag and Inertia Coefficients:** The values of the drag and inertia coefficients were determined by the least square method; and the relation of the horizontal component drag and inertia coefficients(C_{Dx}, C_{Mx}) with horizontal component Keulegan-Carpenter number(KC_x) for non-embedded condition are shown in Fig. 2 and 3. The relation shows that C_{Mx} for each type of stone approaches a constant value as KC_x increases, the range of values are given as follows: round-type(1.0-1.4), flat-type(0.6-1.0) and edged-type(1.0-2.0). For C_{Dx}, the following are the convergence value as KC_x increases: 0.8 for round-type, 0.6 for flat-type and 1.2 for edged-type. Also, the mean value for an equivalent spherical armor unit were presented in the figures. The mean value is in good correlation with the round-type stone($S_1/S_2 = 1.6$). This implies that the drag and inertia coefficients of a stone of shape ratio approaching unity has a similar characteristic with that of its equivalent spherical armor unit. The relationship of $CD_z - KC_z$ and $CM_z - KC_z$ for all stone shapes are quite scattered and this may be largely attributed to the lift force caused by the bottom proximity effect.

3.4 **Applicability of Morison's Equation:** In the estimation of wave force, Morison's equation is commonly employed and the correlation coefficient, r, is used to determine the range of applicability. The Morison's equation is not applicable when r is less than 0.9 [2]. The result shows that regardless of stone type, the Morison's equation is applicable in the estimation of horizontal wave force, as given in Fig. 4, for non-embedded condition when $x/L < 0.2$ and almost not applicable for embedded condition.

4. CONCLUSIONS: Results obtained are summarized as follows: (1) Regardless of the shape of the armor unit, the vicinity around the crown-edge of the submerged breakwater is confirmed to be the most critical location. (2) Time histories of the wave forces acting on rubble stones are classified into five types(P-type, S-type,W-shape,V-shape,and DP-type). (3) The drag and inertia coefficients of the non-embedded stone with a shape ratio approaching unity can be characterized by its equivalent spherical armor unit. (4) The Morison's equation is generally applicable in the estimation of the horizontal wave force for non-embedded condition when $x/L < 0.2$.

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[2] Iwata, K. and Mizutani, N.(1989): Experimental Study on Wave Force Acting on Submerged Sphere, *Proc., 8th OMAE*, Vol.2, pp.145-152.

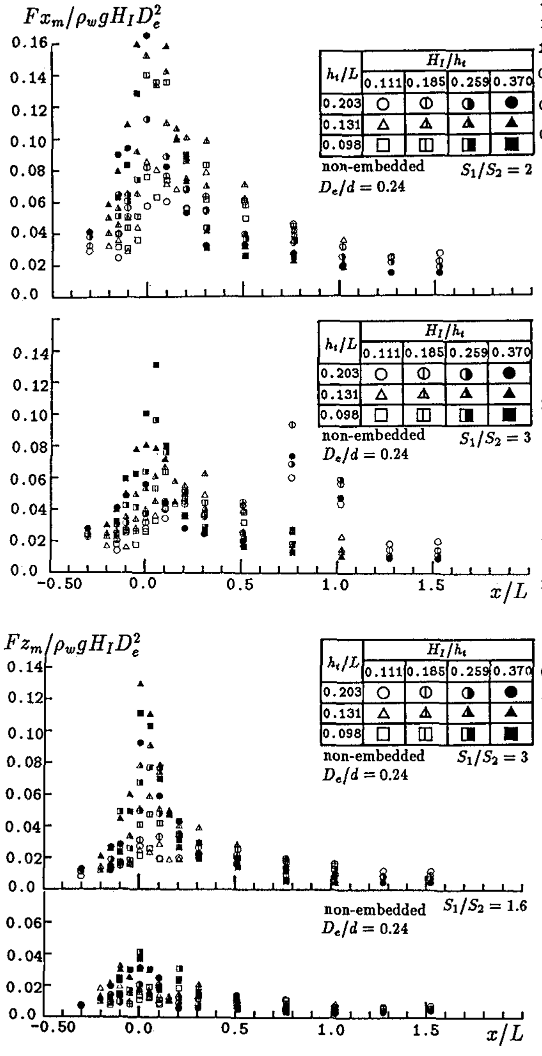

Fig.1 Variations of $Fx_m/\rho_w g H_I D_e^2$ and $Fz_m/\rho_w g H_I D_e^2$ with x/L.

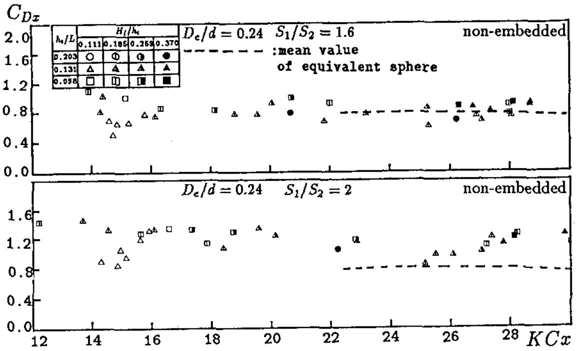

Fig.2 Relationship of C_{Dx} with KCx.

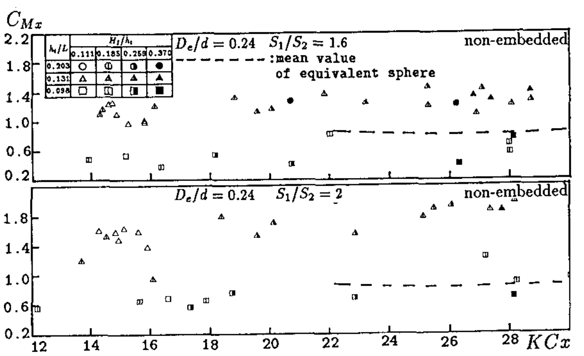

Fig.3 Relationship of C_{Mx} with KCx.

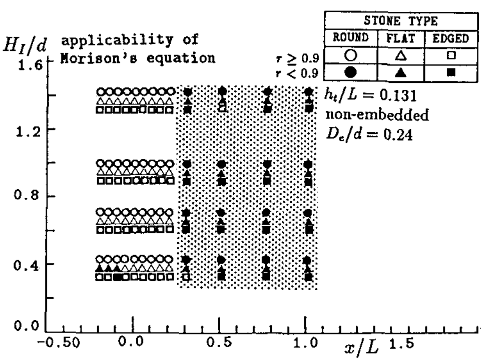

Fig.4 Variation of H_I/d with x/L.