STABILITY RELATIONS OF ARMOR RUBBLE STONE ON A SUBMERGED WIDE-CROWN BREAKWATER

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1. INTRODUCTION: An accurate estimation of the stable weight of an armor unit is requisite for efficient design of submerged breakwater. Recently, a stability model for spherical armor unit is proposed [1,2] by considering the acting wave forces. This paper presents a stability model of rubble stones on a submerged wide-crown breakwater in relation to the acting wave forces.

2. EXPERIMENTAL PROCEDURE: Stability tests on different types of rubble stones on a submerged wide-crown breakwater were carried out using an indoor wave tank, as shown in Fig. 1. Regular waves were generated using three different periods (T = 1.0s, 1.4s, 1.8s). For each wave period and for every designated locations on the slope and on the crown of the structure, the critical wave height of each sample were determined. Then, the corresponding wave forces, water particle velocities and water surface elevations were measured by cantilever-type wave force meters, electromagnetic-type velocimeter and electric capacitance-type wave gauges, respectively. Critical wave height is defined as the minimum wave height required to move a given sample of armor stone. Three classes of rubble stones with varying weights of 6.2g, 9.5g, and 19.6g were chosen in this experiment. The sample stones were classified according to the size, D_e/d, and flatness ratio, L_2/L_1, where D_e is the equivalent sphere diameter of the rubble stone of equal weight and density, d(= 7cm) is the crown water depth, L_2 is the height of the sample stone and L_1 is the stone dimension parallel to the direction of flow. The stone sample classification is given in Table 1, where L is the wavelength and x is the horizontal distance referred from the leading crown-edge, positive in onshore direction.

3. THEORETICAL STABILITY ANALYSIS: A stability model developed for spherical armor unit [1,2] considers the contact angles between armor units, method of placement and manner of movement. The stability motion of a given armor unit can be initiated by rolling, sliding, or up-lifting movement. The model for spherical armor unit was derived based on rolling motion, since this is the most critical condition among the stability motions. This manner of movement indicates that the overturning moment acting on the armor unit overcomes the restoring moment; thus, the model were obtained from the equilibrium state of moments. Moreover, by following the video analysis of the moving stones, sample stones with $L_2/L_1 > 0.6$ in non-embedded condition generally moves in rolling motion. Thus, the stability relation of armor rubble stone was derived based on this stability motion. By modifying the spherical armor unit model, the new stability relation is generalized in the following equation.

$$S(L_2/L_1)[(W_c \sin\theta + Fp_m) + nFp_m] = (W_c \cos\theta - Fn_m) \tag{1}$$

where W_c is the critical stable weight of the armor unit in water, θ is the slope angle of the submerged breakwater ($\theta = 0$ on crown), Fn_m is the maximum normal force, Fp_m is the maximum parallel force, $S = (L'_2/L_2)(L_1/L'_1)$, L'_2 and L'_1 are the vertical and horizontal moment arms, respectively, $n = \varepsilon/L'_2$, $K = L'_2/\sqrt{(L'_1)^2+(L'_2)^2}$, and ε is the eccentricity given by the following equation,

$$\varepsilon = (\frac{8D_e}{3})\frac{(K-K^2)^{3/2}}{[\cos^{-1}(1-2K)-(1-2K)(\sin(\cos^{-1}(2K-1)))]}. \tag{2}$$

For easier evaluation of the stable weight, Eqn. 1 is expressed in terms of one wave force component. The relationship is given in the following equation [2].

$$Fp_m = \phi Fn_m \qquad Fz_m = \phi Fx_m \tag{3}$$

where ϕ is the coefficient determined by least square method. On the slope and crown of the submerged breakwater for non-embedded condition $\phi = 1.0$ [2].

4. STABILITY OF ARMOR RUBBLE STONES: The relationship between the dimensionless critical stable weight, $W_c/\rho_w g h D_e^2$, and the maximum dimensionless wave force, $Fp_m/\rho_w g h D_e^2$, are given in Figs. 2 and 3, where g is the gravitational acceleration, h is the still water depth at the measuring point and ρ_w is the

density of water. It is revealed that the critical wave force increases with D_e/d. The comparison between the experimental results and the proposed models are plotted in the figure. Regardless of the size and flatness ratio, on the slope, the model is in good agreement with the experimental values. On the crown, the model are well correlated with the experimental values except at some locations in the non-breaking zone where the stability model underestimates the measured values. In this range,the relation given by Eqn. 3 may not be applicable; thus, an exact relationship between the acting wave forces is deemed necessary.

5. CONCLUSIONS:

The results obtained from this study can be summarized as follows:

(1) A model for armor rubble stone relating the stable weight with the wave forces acting is derived.

(2) The flatness ratio, L_2/L_1, is an important parameter in stability description of armor rubble stone.

REFERENCES

[1] Mizutani, N., Iwata, K., Rufin, Jr. T. M., and Kurata, K.(1992): Laboratory Investigation on the Stability of a Spherical Armor Unit of a Submerged Breakwater, *Proc., 23rd International Conference on Coastal Engineering*, Vol. 2, pp. 1400-1413.

[2] Rufin, T.M. Jr., Iwata, K. and Mizutani, N. (1993): Stability Model of a Spherical Armor Unit of a Submerged Breakwater, *Proc., 25th International Association for Hydraulic Research*, Vol. 4, pp. 190-197.

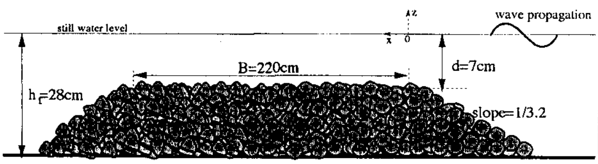
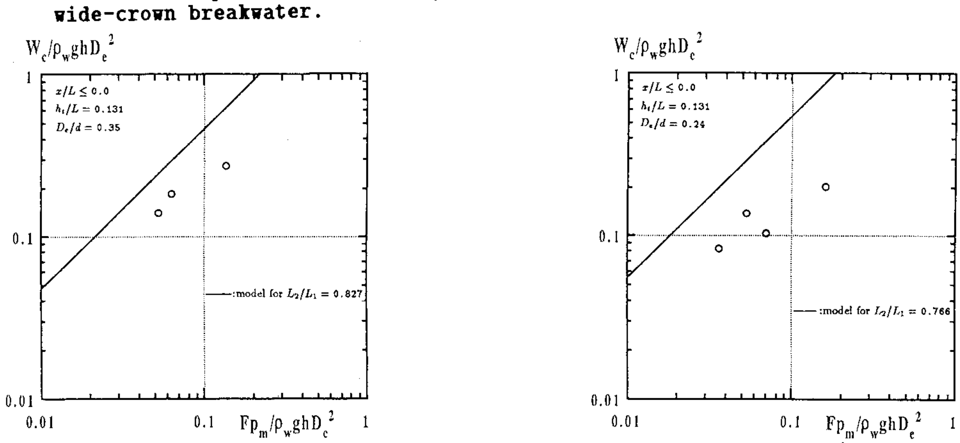


Fig. 1 Schematic diagram of the submerged wide-crown breakwater.

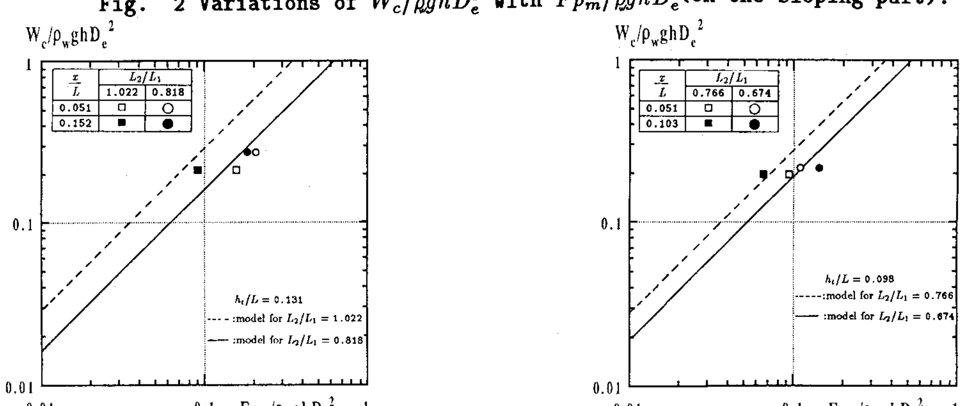
	SHAPE CONFIGURATION	D_e/d 0.35	0.28	0.24
$\frac{L_2}{L_1}$	ROUND-TYPE	0.827	0.674	0.766
	FLAT-TYPE	0.565	0.697	0.421
	EDGED-TYPE	0.818	1.021	1.10

Table 1 Classifications of stone sample.



(a) Round-type($L_2/L_1 = 0.827$) **(b) Round-type($L_2/L_1 = 0.766$)**

Fig. 2 Variations of $W_c/\rho g h D_e^2$ with $Fp_m/\rho g h D_e^2$(on the sloping part).



(a) Edged-type **(b) Round-type**

Fig. 3 Variations of $W_c/\rho g h D_e^2$ with $Fp_m/\rho g h D_e^2$ (on the crown part).