捨石防波堤の波浪場及び内部の流れと捨石の安定に関する一計算

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INTRODUCTION

The present study tries to investigate the relation between wave-induced pressures, velocities, and forces work onto the armor particles of rubble mound breakwater slope. Along with this a two-dimensional numerical reshaping-model of uniform sphere particles breakwater was developed to assess the reaction of the surface particles of armor layer against the wave-induced forces.

WAVE SIMULATION

In the present investigation, SOLA-VOF code is utilized to simulate the wave deformation during its interaction with ruble mound structure. SOLA-VOF method has advantage that this can be used simultaneously both for external wave and internal flow without any coupling problem at the interface. Its Navier-Stokes base governing equation is given as follow.

For the external wave motion Navier-Stokes momentum equations read:

$$\frac{\partial w}{\partial t}+\frac{\partial uw}{\partial x}+\frac{\partial w^2}{\partial z}+\frac{1}{\rho_w}\frac{\partial p}{\partial z}-\upsilon_t\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial z^2}\right)+g_z=0 \quad (1)$$

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial uw}{\partial z}+\frac{1}{\rho_w}\frac{\partial p}{\partial x}-\upsilon_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial z^2}\right)+g_x=0 \quad (2)$$

For the flow inside porous structure where Re~150 (steady non-linear laminar flow), e.g. RMB, adapted Navier- Stokes equation were derived (see Van Gent, 1994):

$$\frac{1+c_A}{n}\frac{\partial u}{\partial t}+\frac{1}{n^2}\left(\frac{\partial u^2}{\partial x}+\frac{\partial uw}{\partial z}\right)+\frac{1}{\rho_w}\frac{\partial p}{\partial x}-gau+gbu\sqrt{(u^2+w^2)}+g_x=0 \quad (3)$$

$$\frac{1+c_A}{n}\frac{\partial w}{\partial t}+\frac{1}{n^2}\left(\frac{\partial uw}{\partial x}+\frac{\partial w^2}{\partial z}\right)+\frac{1}{\rho_w}\frac{\partial p}{\partial z}-gaw+gbw\sqrt{(u^2+w^2)}+g_z=0 \quad (4)$$

where, u and w are both filter-velocities. Coefficients *a*, *b*, and c_A are as that used in the Forchheimer equation.

By using this code, the instantaneous distributions of water pressure, velocity, and the surface deformation can be shown.

WAVE-INDUCED FORCES

When a progressive wave pass over the water, the water particles will be displaced by wave-induced pressure from its initial position. These water particles move by certain velocities whose instantaneous distributions are influenced by the instantaneous elevation of water surface above them. If at the same point there is any unit of rubble mound armor particle, this velocity will act as the force, which will accelerates the armor unit into movement if the required conditions are satisfied.

Refer to Brebbia and Walker[1] there are three kinds of force attributable to the wave motion passing over the solid body inside the water, i.e. drag force F_D, inertia force F_I, and lift force F_L. Two other forces working on the immersed body are buoyancy force F_B and weight force W. Adopted the Morison's formulation, the forces are given as follows:

$$F_D=\tfrac{1}{2}\rho_w C_D C_{SD}\tfrac{\pi}{4}D^2u\left|u\right| \quad (5)$$

$$F_I=\rho_w C_I C_{SI}\tfrac{\pi}{6}D^3\tfrac{du}{dt} \quad (6)$$

$$F_L=\tfrac{1}{2}\rho_w C_L C_{SL}\tfrac{\pi}{4}D^2u^2 \quad (7)$$

$$F_B=\rho_w g C_{SI}\tfrac{\pi}{6}D^3 \quad (8)$$

$$W=\rho_s g\tfrac{\pi}{6}D^3 \quad (9)$$

in which ρ_w is unit mass of water, ρ_s is unit mass of sphere, g is acceleration of gravity, D is nominal diameter of the sphere, u is water particle velocity, C_D, C_I, C_L is drag, inertia, and lift coefficient respectively, and C_{SD}, C_{SI}, C_{SL}, is coefficients to take into account the partial submergence. C_{SI} is associated with the reduced volume, while C_{SD} and C_{SL} represent the reduction in projected area parallel to the force direction.

ARMOR INITIATION

Based on Den Breeker[3] investigation, Norton and Holmes[2] concluded that a rolling motion instead of sliding or lifting characterizes the displacement mechanism for rock armor. For armor initiation determination it is thus appropriate to consider moment balance of all forces about a possible point of rotation. In this case, the contact point between the surface particle and its supporting particle is considered to be the point of rotation. Figure 1 illustrates the application of forces onto single particle.

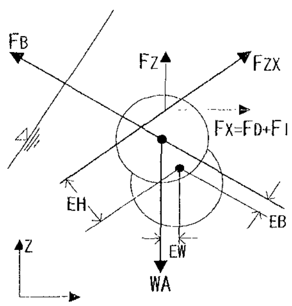

Figure 1 Forces Applied to Single Particle

CALCULATION AND INVESTIGATION RESULTS

The wave model of H=0.18m, T=1.93 sec, SWL=0.6m is applied to rubble mound structure, which constituted from uniform sphere particles of 0.03m in diameter.

Four different cross-sections with approximate slope of 1 : 1.75, 1 : 3, 1 : 5, and 1 : 9 are subjected to the wave attack perpendicularly. In general it gives similar trend of pressures and velocities distribution for all above slopes. The resultant forces are greater at the surface particles located near the water surface. It must have relation with the vertical distribution of velocity.

The first wave reached the slope of the structure after 4 period and started to displace the surface particles. The displacement of particles is not continued after 9 cycles of wave. After the last cycle it was found that most of the particles are moved down while some few were move-up. By investigating the resultant-force diagram, it is understood that the resultant-forces during wave rundown are greater than during wave runup.

Figure 2 shows an example of calculation results consist of relative distribution of pressures, velocities, and resultant force direction worked onto rubble mound structure with slope of 1 : 3.

CONCLUSION

Although further verifications are necessary, this calculation have given idea about the detail processes of interaction between wave and rubble mound structure, especially the reaction of the surface particles against wave-induce resultant forces. Attention must be paid on the determination of effective wave loading and the algorithm of displacement.

The SOLA-VOF code seems appropriate enough for simulating the external wave as well as the flow inside the porous structure.

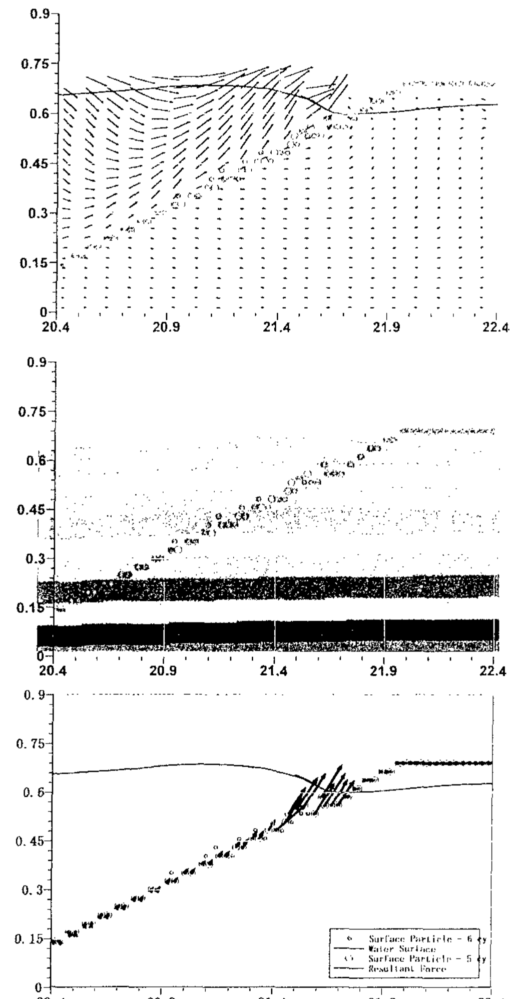

Figure 2 Calculation Results
(top) velocities distribution
(mid) pressure distribution
(btm) resultant-force distribution

REFERENCE

Brebbia, C.A., Walker, S., 1979, *Dynamic Analysis of Offshore Structures*, Newnes-Butterworths, pp. 112-132.

Norton, P.A., Holmes, P., 1992, *Armor Displacement on Reshaping Breakwaters*, ICCE Proceeding 1992, pp. 1448-1460.