Numerical Simulation of Wave Fields around The Submerged Breakwater with SOLA-SURF Method

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Abstract

Bothe two and three dimensional numerical simulation of wave fields around the submerged breakwater is carried out using the SOLA-SURF method. The results of the calculation are compared with the laboratory experiment. It is shown that the side wall boundary condition for the three dimensional calculation of the laboratory tank should be nonviscous(slip-type) to reproduce the experimental data. The calculation method is easily extendible to a field scale case.

Introduction

Numerical simulation of wave fields based on the Navier Stokes(NS) equation has been known to be time-consuming. It has been customarily carried out with some kind of simplifications such as irrotationality for the Boundary Element Method 1, mild slope hypothesis for the long wave approximation, etc. The advancement of the computer technology in recent years, however, has made numerical simulation method based on the NS equation remarkably amenable. It is now possible to integrate the NS equation directly for the simulation of wave fields within a reasonable CPU time.

Also, there is a need for such a study in designing coastal engineering structures of the advanced type. A good example is found in the design of a submerged breakwater around which the flow is quite complicated and the mechanism and extent of scour is not fully understood. In this respect, the need to develop the simulation method of the three dimensional flow structure is quite apparent.

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The objective of this study is to develop a three dimensional simulation method of the wave and flow field around a submerged breakwater. The result will be tested with the experimental study in a laboratory wave tank. The numerical simulation method adopted in this study is the SOLA-SURF method (Hirtet al. 1975, Bulgarelli et al. 1984])

SOLA-SURF Method

Numerical schemes to integrate the NS equations can be characterized in the way to treat time development of the water surface. In the SOLA-SURF method, the kinematic condition of water surface is integrated for prediction of the position of water surface for the successive time step. Then the pressure and velocity are adjusted at the same time to satisfy the set of the governing equations, rendering this method quite effective and versatile. With this method, unfortunately, it is impossible to simulate the breaking wave. Aside for the breaking wave, SOLA-SURF method appears to be quite versatile as it directly deals with the NS equations and can be easily extended to the three dimensional wave field.

The formulation of the SOLA-SURF algorithm is given in the reference and will not be repeated here. The basic equations to be solved are three dimensional equation of continuity and Navier-Stokes equations for the incompressible, viscous fluid and these are not listed herein. In this study, the flow inside the permeable breakwater is also analyzed and the basic equations of motion in this case are linear equations of the Darcy flow given as

$$\frac{\partial \vec{v}}{\partial t} = -\varepsilon \nabla (p + gz) - \frac{\varepsilon \nu}{k} \vec{v} \tag{1}$$

$$\nabla \cdot \vec{v} = 0 \tag{2}$$

where $\vec{v}$ is the three dimensional velocity vector, t is time, ε is the porosity, k is the permeability, p is pressure, g is the gravitational acceleration, z is the elevation, and ν is the kinenamic viscosity. Incorporation of Eqs. (1) and (2) into the SOLA-SURF method is easy since these equations are simplified form of the NS equations. At the boundary of the submerged breakwater with water, continuity conditions of velocity and stress components are applied.

Experimental Condition

Laboratory experiments are carried out with a wave tank, 15m long and 0.6m wide. In this tank a model submerged breakwater is placed piling up model blocks of hexa-pod shape for the case of the permeable breakwater. Fig. 1 shows the wave tank set up of this study. The numerical calculation of this study is carried out under the same conditions as the laboratory experiment.

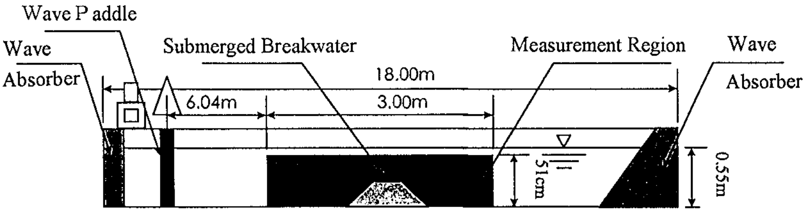


Fig. 1 Wave tank

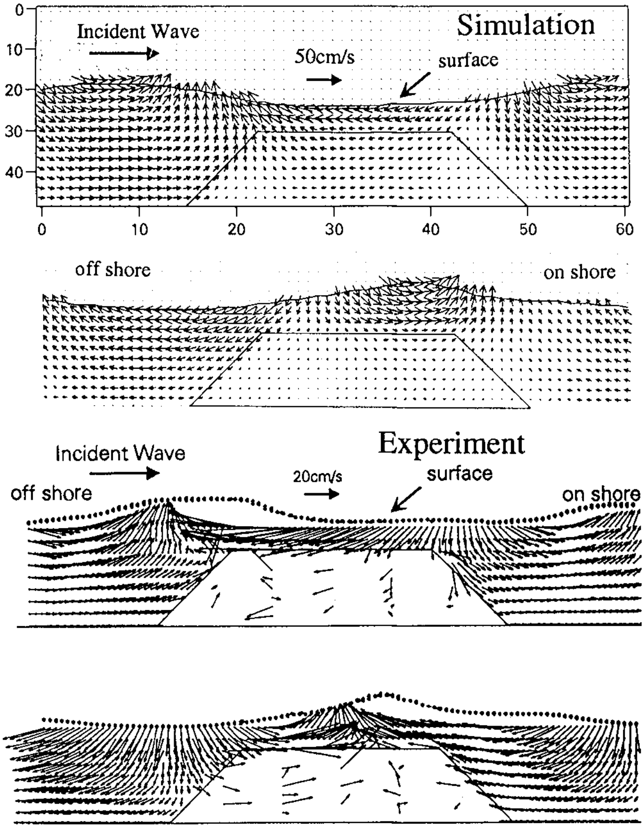


Fig. 2 Comparison of velocity vectors for 2D calculation and lab experiment

The results of the lab study is then compared with the numerical calculation usinf the SO LA-SURF method. For two dimensional study submerged breakwater is placed uniformly over the width, while for three dimensional study the breakwater is placed over the half width of the tank.

The experimental conditions are as follows: incident wave height H of 0.135m, wave period T of 0.15s and water depth h of 0.6m. In the lab experiment, detailed measurement of the velocity vectors is carried out using an electromagnetic current meter to obtain the data that can be compared with the numerical simulation.

Calculation with 2D Breakwater

In this chapter is presented the result with the two dimensional (2D) breakwater, which means that the breakwater is placed to fill the whole width of the wave tank. The objective is to investigate the flow structure around the breakwater in detail and to test the validity of the three dimensional calculation.

Flow structure around 2D breakwater: Figure 2 shows the velocity vector around the submerged breakwater. In this figure, the top two charts indicate the results of simulation with SOLA-SURF method, while the bottom two charts those for the laboratory experiments. The development of wave vector is simulated reasonably well. In the laboratory experiments, the return flow to the offshore direction is observed. This is probably related to the phase difference of wave and horizontal velocity. In the SOLA-SURF method, on the other hand, the return flow is not observed probably because the Sommerfeld's radiation condition for the onshore boundary is effective.

Side wall boundary condition for 3D calculation : Next the three dimensional SOLA-SURF calculation is performed on this 2D breakwater. Fig. 3 gives the resulting water surface elevation. In this calculation, the boundary condition at the side wall of the water tank is set at first as non-slip type, i.e. viscous, condition. It is then observed that there is a considerable gradient in the water surface along the wave ridge, a situation which is not found in the laboratory experiment. This is probably because this calculation is essentially the laminar flow calculation, whereas the flow in the wave tank is at least to some degree turbulent. Therefore, the slip (inviscid) condition for the side wall is adopted for the further calculation. The top and bottom charts of Figure 3 give the calculation result with, respectively, no-slip and slip boundary conditions.

Calculation with 3D Breakwater

To test the validity of the three dimensional SOLA-SURF calculation, it is applied to the three dimensional(3D) breakwater. The 3D breakwater occupies half width of the wave tank with the other half free of breakwater. Fig. 4a and 4b give the water surface profile and Fig. 5 and 6 give velocity vectors for both permeable and impermeable submerged breakwaters. In these figures the submerged breakwater is placed to the left half of the wave tank looking in the direction of the wave propagation, occupying from 6.6 to 7.4m in the across-shore distance and 0.0 to 0.3m in the long-shore distance.

Figure 4 shows that the wave profile is deformed over the submerged breakwater section, with somewhat less deformation above the half width over which the breakwater is not present, showing the effect of the 3D calculation. The wave deformation around the impervious breakwater(Fig. 4a) is more remarkable than that for the permeable breakwater(Fig. 4b).

Fig. 5 and 6 give the comparison of velocity vectors at the plane 2.5cm over and 17.5cm under the top surface of the submerged breakwater, respectively. Fig. 5 indicates that the water over the breakwater flows out to the part free of breakwater, which corresponds to the phase of the water surface elevation between these two areas observed in Fig. 4. The impervious breakwater, compared to the permeable breakwater, tends to give more pronounced difference in velocity vectors. Fig. 6 shows that the flow tends to turn around the corner of the breakwater. It is also remarkable that there exists significant amount of flow inside of the permeable breakwater.

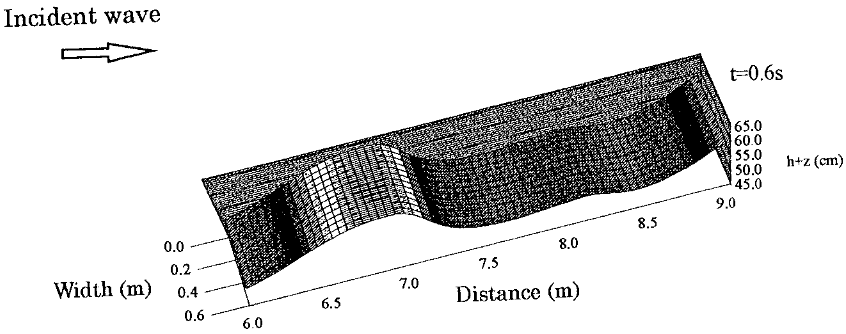
Conclusion

Itt is shown that numerical simulation of three dimensional wave field over a submerged breakwater is possible with the SOLA-SURF method. The breakwater in this case can be impervious or permeable. Simulation results are, on comparison with the laboratory experiments, qualitatively satisfactory.

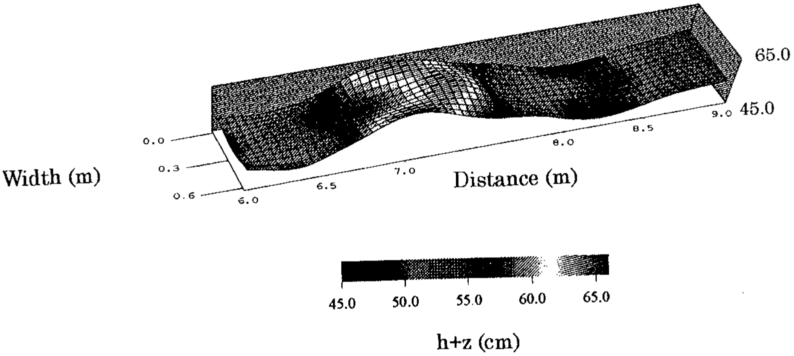
Appendix-Reference

Bulgarelli, U., Casulli, V., and Greenspan, D.(1984): Pressure Methods for the Numerical Solution of Free Surface Fluid Flows, Pinerige Press Swansea U.K., pp.323.

Hirt, C.W. , Nichols, B.D. and Romero,N (1975): SOLA-A Numerical Solution Algorithm for Transient Fluid Flows, Los Alamos Scientific Laboratory LA-5852, pp.1-50.



(1) Slip Condition



(2) Non-Slip Condition

Fig. 3 Side wall Condition of the three dimensional calculation

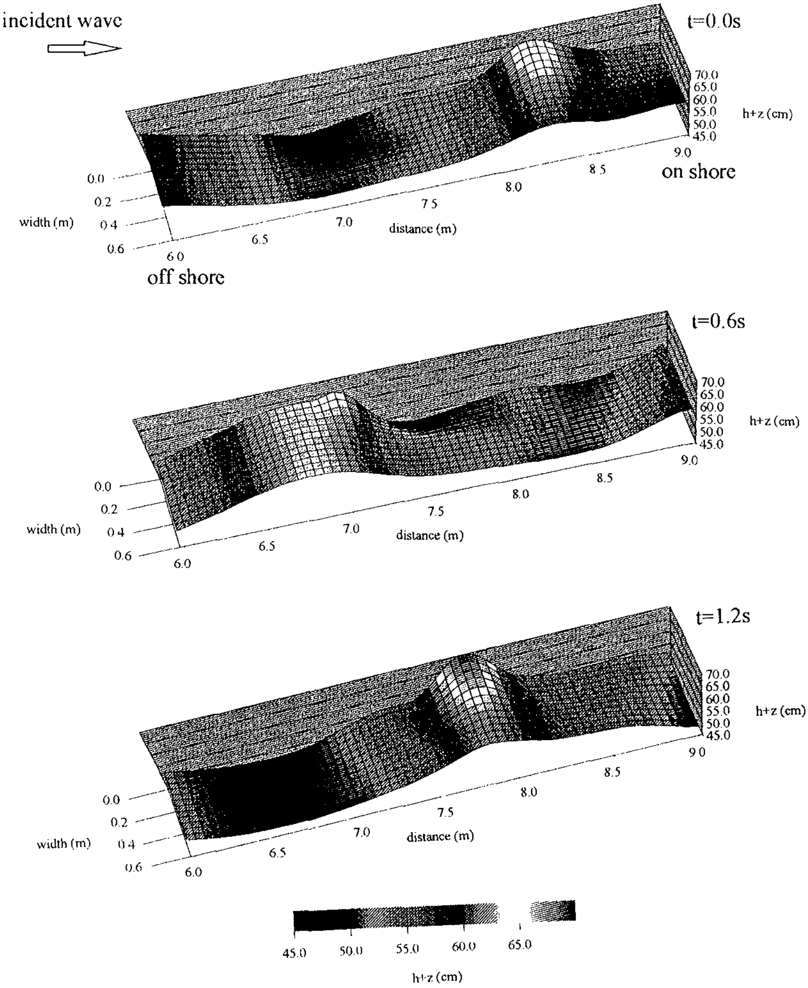


Fig. 4a Water Surface profile for 3D calculation over impervious breakwater

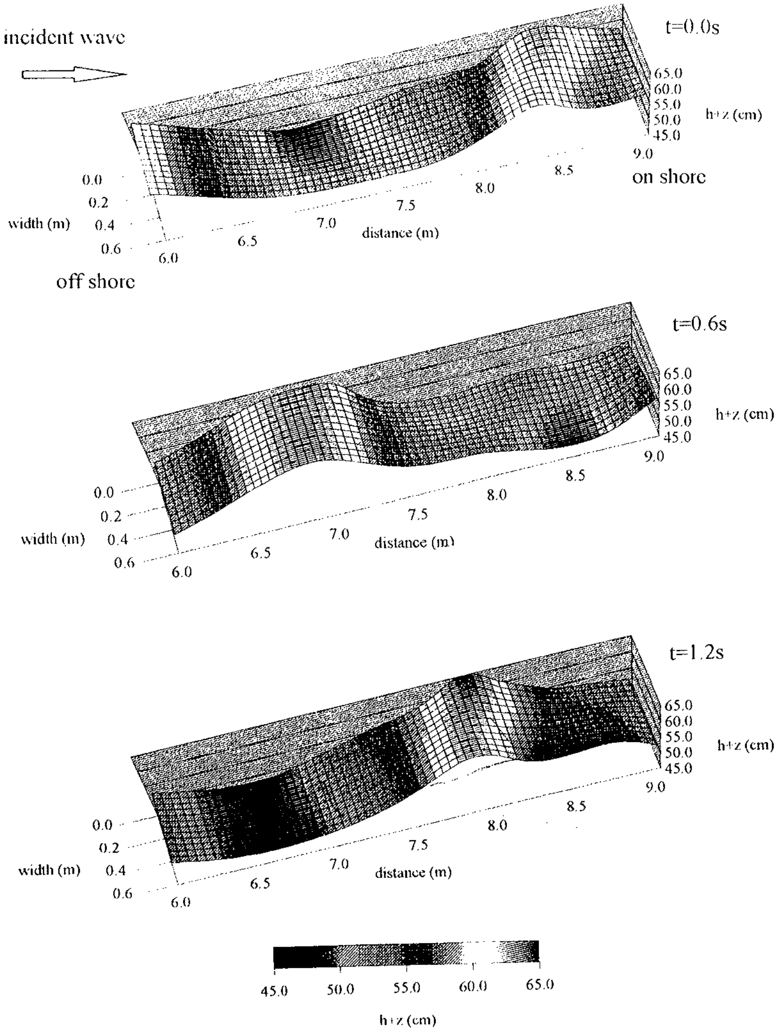


Fig. 4b Water Surface profile for 3D calculation over permeable breakwater

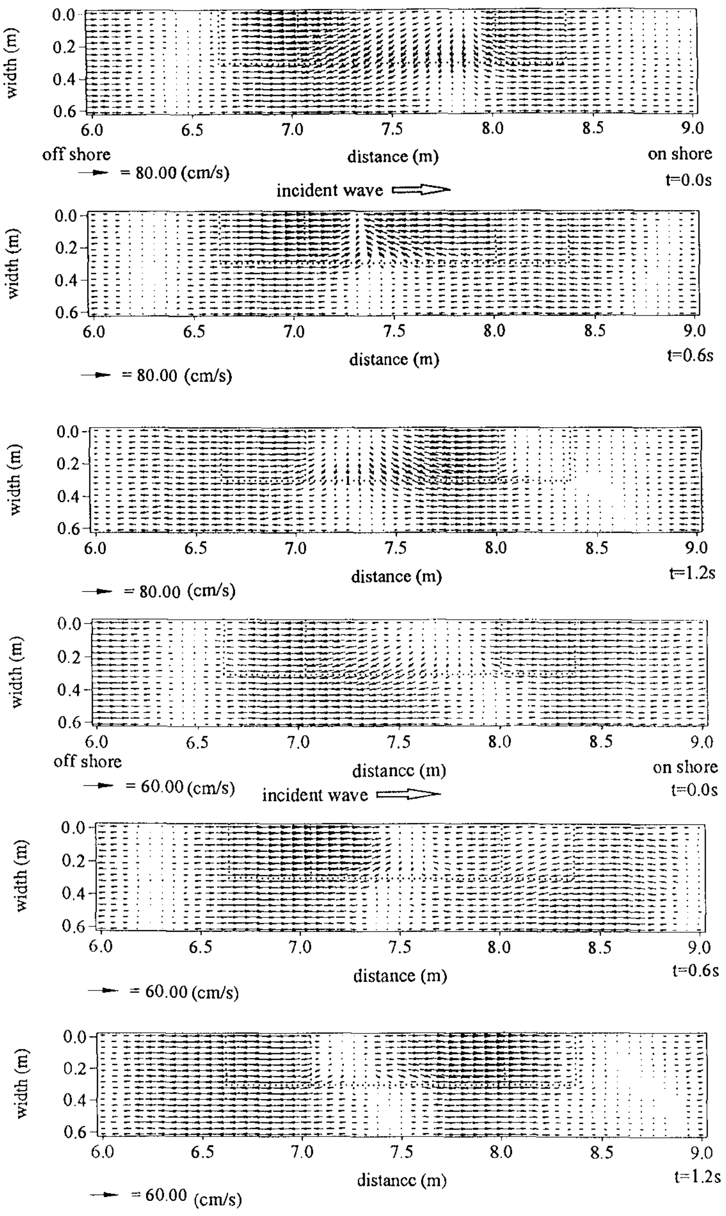


Fig. 5 Horizontal velocity vectors of 3D calculation
(Top three figures for impervious breakwater and bottom three for permeable one.)

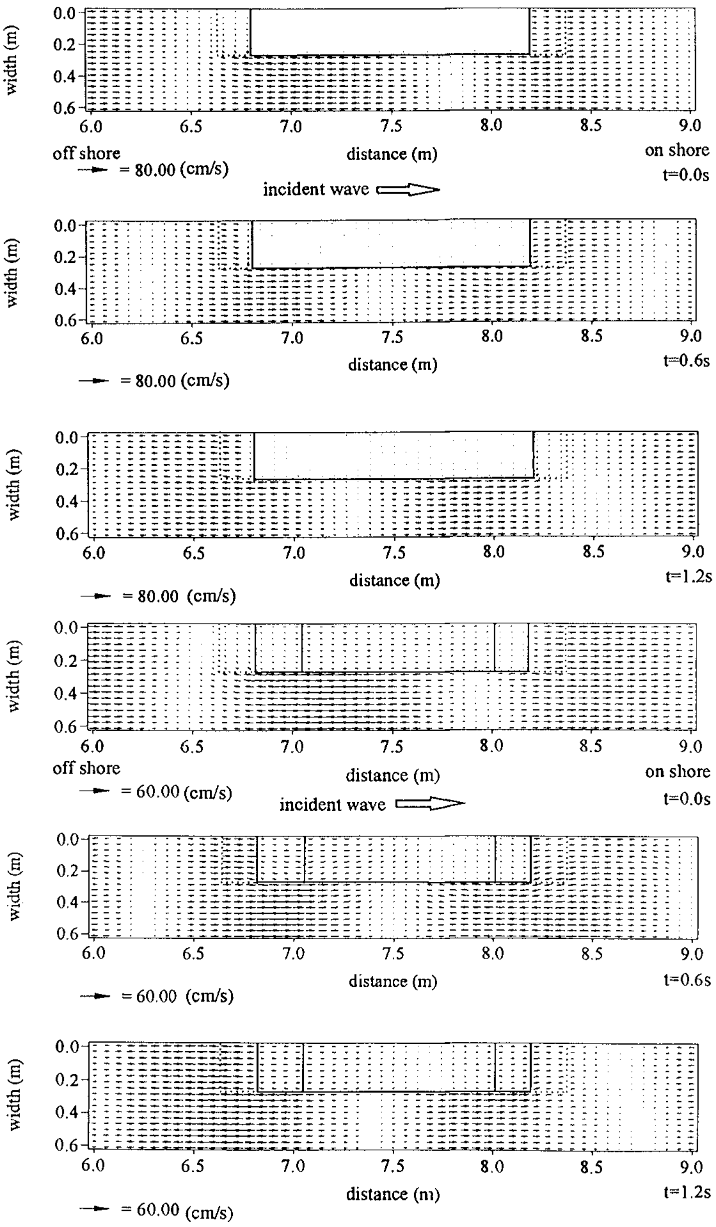


Fig. 6 Horizontal velocity vectors of 3D calculation
(Top three figures for impervious breakwater and bottom three for permeable one.)