II −19 SIMULATION OF NONLINEAR BEHAVIOR OF FLOW AROUND OBSTACLES

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1. Introduction

Numerical models have been developed for analyzing the resistance force interacted between wave and structures, and applied with sufficient accuracy to practical problems. However, it is normally assumed either that there are no solid structures capability of withstanding the tsunami, or that the effect of a solid structure can be expressed in terms of a roughness coefficient, such as Manning's *n*, which is selected without/with due consideration of the hydraulic characteristics. Since the effect of obstacles is important for disaster prevention of tsunami in shallow water and on land, it is necessary to analyze the resistance force interacted between wave and structures. Two-dimensional numerical model with Manning's *n* which is selected without/with consideration of the hydraulic characteristics might not represent the interaction between wave and structures because that model could not analyze exactly the effect of structure for tsunami (Aburaya & Imamura, 2002; Hong & Imamura, 2003). In this study, therefore, three-dimensional numerical tsunami model try to be developed to analyze the nonlinear behavior of flow around obstacles, based on the Navier-Stokes equations.

2. Verifications of Numerical Model

2.1 *Solitary wave as initial condition*

This problem deals with the motion of a solitary wave (Fig. 1). A solitary wave is a wave consisting of a single elevation of fluid, of height H_0 not necessarily small compared with the total depth, *d*, of the fluid. The run up, R, of a solitary wave on a vertical wall has been calculated for of H_0/d. Laitone's formulas (the 1-order solitary wave) for the free-surface profile and velocity fields were used to compute the initial conditions of the incident wave. Table 1 shows the numerical conditions of all cases. The solution of the first approximation to the solitary wave is shown as

$$\eta = H_0 \left[\sec h \sqrt{\frac{3H_0}{4d^3}} (x - ct) \right]^2 \quad (1)$$

$$c = \sqrt{g(d + H_0)} \quad (2)$$

The wave run up ratio, *R/d*, as computed by the three-dimensional numerical model, is compared with experimental data (Camfield and Street,1968) in Fig 2. Clearly, the results from the model show good agreement with experimental results.

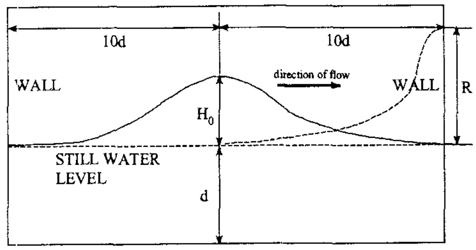


Fig. 1. Definition sketch showing a solitary wave in a channel

Table 1. Numerical Conditions for solitary wave

	Ho/d	DX	DY	DZ	DT
Case 1	0.40	0.5	0.5	0.1	0.0025
Case 2	0.30	0.5	0.5	0.1	0.0025
Case 3	0.25	0.5	0.5	0.1	0.0025
Case 4	0.20	0.5	0.5	0.05	0.0010

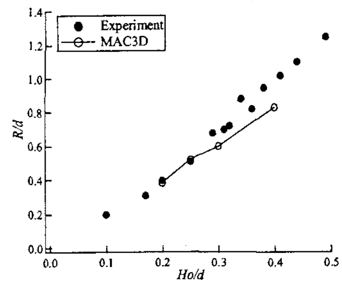


Fig. 2. Wave run up on a vertical wall (R/d)

2.2 *Open-channel flow*

The length of open-channel is 1200 cm and the width is 30cm. The wave heights are measured at four locations; x=50cm, 120cm and 200cm in the channel to be compared with the result of calculation with the two- and three-dimensional model. A mesh system with 400 cells in the x-direction and 60cells in y-direction, 50 cells in the z-direction was used to represent the computation region. Table 2 shows the numerical conditions of all cases. For comparing with three-dimensional models, the case of two-dimensional model is carried out. The reason for using much smaller vertical size than horizontal spacing is that we know *a priori* that the field variables change more rapidly in the vertical direction than in the horizontal direction.

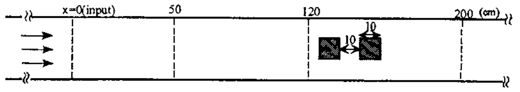
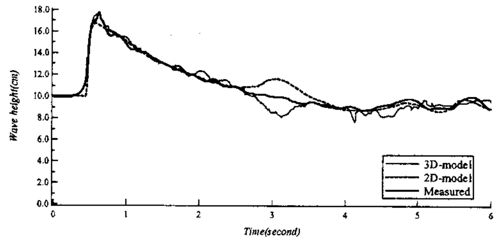


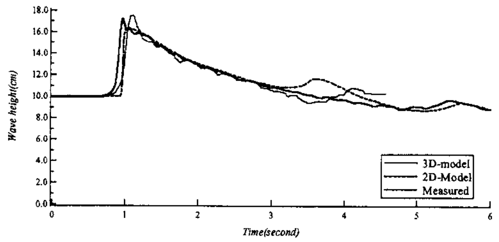
Fig. 3. The sketch of open-channel

Table 2. Numerical Conditions for wave in open-channel

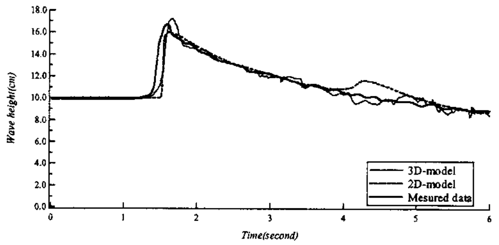
	DX	DY	DZ	DT
Case 1 (3Dmodel)	2cm	2cm	0.5cm	0.002s
Case 2 (2Dmodel)	2cm	2cm	-	0.002s



(a) at x=50cm



(b) at x=120cm



(c) at x=200cm

Fig. 4. Comparison of wave profiles at x=50cm, 120cm and 200cm

The comparison of wave profiles is shown as Fig. 4. As shown here, the results of three-dimensional model are similar to results of two-dimensional model as compared with measured data in the height and time. Consequently, It is confirmed that the calculation results using three-dimensional model show good accuracy with measured data. Also, the comparison between measured and calculated maximum wave height at each point is shown as Fig. 5. In the shallow water and on the land with obstacles, the nonlinear effect and the change of pressure according to velocity change in vertical direction become significant. But two-dimensional model cannot represent because the reasons as follows. Two-dimensional model is based on the shallow water theory with assumption that velocity of horizontal direction (x-direction) is uniform in vertical direction. And, the pressure that is ignored a velocity change in vertical direction (z-direction) consists of hydrostatic pressure. Furthermore, the first-order upwind scheme that is applied to the two-dimensional model for convection term causes truncation error so that dissipation error might be large.

On the other hand, three-dimensional model represent real phenomenon more than two-dimensional model because there is no assumptions like as the case of two-dimensional model. Also, in numerical approximation, three-dimensional model apply second-order upwind scheme to convection term that generates smaller numerical error than first-order upwind scheme. According to the reasons, the results of three-dimensional model show more good accuracy than the results of two-dimensional model as shown Fig. 5.

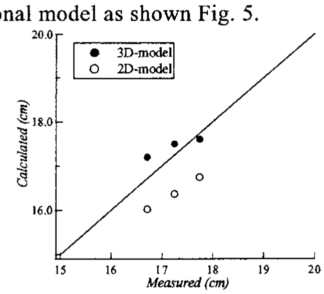


Fig. 5. Comparison between measured and calculated maximum wave heights at each point

In this study, the verifications of three-dimensional numerical tsunami model are carried out. According to the results, it is clarified as follows. The calculated results for solitary wave problem show good accuracy with measured data. Also, it is confirmed that three-dimensional model represent the wave flow more than two-dimensional model. In spite of the good accuracy of verifications in three-dimensional model, the model is not applied to the flow of open-channel including obstacles because a problem is occurred. The problem is that velocity of water particle has more rapid change than expected water velocity around obstacles. It is necessary for analysis of flow around obstacle to solve the problem.

References

Camfield, F.E. and Street, R.L. (1968), J. of Waterways and Harbors Division, ASCE95, WW1, pp.6380.

Laitone, E.V. (1960), The second approximation to cnoidal and solitary waves, J. Fluid Mech., Vol. 9, pp.430-444.