

Consideration on accuracy and computational efficiency of gas-liquid two-phase fluid simulation against tsunami bore force

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One of the protection facilities against the tsunami is an upright type coastal bank, but there is a high possibility that an impulsive wave force due to the tsunami acts on such an upright levee and knowing its wave strength accurately is important for not only the stability of the structure but also the safety of the back ground. Previous studies showed that it is important to evaluate the angle between wave front and wall surface and the compressibility of air for predicting such impulsive wave force. Therefore, when reproducing such a phenomenon, it is desirable to use a gas-liquid two-phase flow model that can deal with complex interface deformation. However, due to the difference in the density of water and air, disturbance of a slight pressure on the liquid phase side generates excessive pressure on the gas phase side, and numerical instability occurs at the liquid phase interface. Also, for three-dimensional calculation, the calculation cost is high.

In this research, the calculation scheme in the gas-liquid mixed region was modified and the validity of the stability and accuracy of calculation was investigated. In addition, in the matrix calculation when solving the Poisson equation, several different calculation methods were applied, the influence of parallelization efficiency and convergence was examined, and accuracy and calculation efficiency against the tsunami bore force were discussed.

To confirm the accuracy of the bore force, it was compared with the hydraulic model experiment in which the solitary wave acted on the upright wall. In numerical calculations, in order to ensure the stability of the gas phase region and the accuracy of the liquid phase region, the algorithm was improved to be the following scheme; the upwind difference for the air phase region and the difference scheme according to the volume fraction of water in each element in the air-liquid mixed region. Specifically, a hybrid scheme of the first order upwind difference scheme and the second order central difference scheme is used for the discretization of the advection term, and the proportion is represented by the volume ratio of water multiplied by a coefficient. As a result, it was found that if the ratio is determined only by the volume ratio, the waveform becomes smooth and the breaking wave cannot be expressed well, but it was found that experiments can be calculated considerably reproducibly by applying some weight.

Next, the calculation cost was examined. In the calculation of the gas-liquid two-phase flow, the coefficient matrix obtained by the discretization is more complicated than the single-phase flow, and the convergence deteriorates when the calculation is performed by the iterative method. In addition, since the gas-liquid two-phase model calculates not only the liquid phase region but also the gas phase region, the number of non-zero off-diagonal components of the coefficient matrix increases and it takes time to calculate the matrix. Therefore, by considering preprocessing and thread parallelization of matrix solution, the improvement the efficiency of calculation is verified. In the parallelization of matrix solving method, the multicolor method, hyperplane method, JK plane - hyperplane method, normal method was compared. As a result, in the case of HYP-JK, the calculation speed became the fastest, and it was found that the calculation time of about 30% was reduced at the maximum. In addition, compared with the ILU method, the MILU method, and the AMG method for the preconditioned matrix for the 1 billion lattices, it was found that the AMG method converged about 20% as compared with ILU.

In this research, the accuracy and computational efficiency of gas-liquid two-phase fluid simulation were focused. For the estimation of the impulsive force acting on the upright wall, calculation precision was improved by applying a complete windward difference to the gas phase region and a difference scheme corresponding to the volume fraction of the fluid of each element in the gas-liquid mixture region. For computational efficiency, the computation time was reduced by eliminating the dependency between elements during forward substitution and backward substitution processing in the matrix solution and hybrid parallelizing it together with region segmentation method.

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