

RECENT ADVANCES OF LBM FOR TSUNAMI MODELLINGS: AN ENHANCEMENT OF IMPACT PRESSURE CALCULATION BY FOURTH-ORDER CUMULANT MODEL

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INTRODUCTION

Tsunamis, though infrequent, wield devastating power upon coastal regions, necessitating accurate simulation techniques to comprehend their impact and enhance disaster preparedness. Despite the significant advancements in modern computational fluid dynamics, these simulations continue to pose considerable challenges, encompassing numerical intricacies and substantial computational expenses. In the context of this issue, the lattice Boltzmann method (LBM) has garnered attention for its ability to perform high-performance simulations of large-scale tsunamis due to its remarkable computational efficiency. In recent years, there have been reported instances of utilising the LBM for tsunami simulations, and its application is poised to increase further in the forthcoming research. In this study, we present the recent advances of the LBM for tsunami modelling, especially in the non-hydrostatic three-dimensional free surface flow model and discuss future development. We will demonstrate an enhancement of tsunami impact pressure simulations using the fourth-order cumulant model (Geier et al. 2017).

THE LATTICE BOLTZMANN METHOD

The LBM is a relatively new computational fluid dynamics (CFD) approach for simulating incompressible fluid flows. It represents the fluid flows as a set of virtual particles moving on a grid, where each particle carries information about the distribution of fluid variables. Through a series of collision and streaming steps, the particles collectively simulate the behaviour of the fluid. Because the LBM does not have to solve the pressure Poisson equation, it is known for its parallelizability, such as using GPU and versatility in handling complex geometries and physical phenomena.

In the conventional collision models of the LBM, there was an issue of computational instability, particularly in high Reynolds number flows. Recently, with the introduction of the 4th-order cumulant collision model, this problem has been progressively addressed. This opens up new possibilities for applying the LBM to violent flow fields such as those found in tsunami flows. In particular, accurately simulating the impact pressure is a crucial requirement for understanding tsunamis.

The cumulant collision model imposes constraints on even higher-order cumulants beyond moments like momentum. One of the distinctive features of the collision model is its satisfaction of Galilean invariance for the system and its high level of statistical independence between cumulants, leading to enhanced numerical stability in high Reynolds numbers.

In this study, we applied the fourth-order accuracy cumulant model to the single-phase free surface flow model to validate its reproducibility of tsunami impact pressures in violent flow fields.

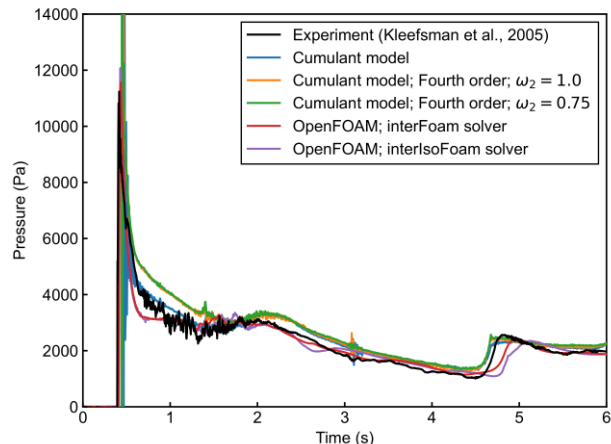


Figure 1 - Comparison of the fluid pressure acting on a structure between experimental and numerical results.

RESULTS

Figure 1 compares the impact pressure results on a structure calculated by the cumulant model and experimental results. While numerical oscillations are observed in the peak pressure with the conventional (i.e., not fourth-order accuracy) cumulant model, the fourth-order cumulant model significantly improves the problem. Additionally, compared to the commonly used two-phase flow solver in OpenFOAM, the results of this study are comparable to previous models.

Although the conventional cumulant model exhibits no numerical instability in violent flow fields, making it suitable for simulating tsunamis, the fourth-order cumulant model is optimal for more advanced pressure calculations. Furthermore, the cumulant model allows for adjustments to bulk viscosity. Upon adjusting this value, the issue of pressure oscillations is further mitigated. This is attributed to reduced acoustic errors caused by excessive numerical fluctuations due to sound waves. However, excessively high bulk viscosity may decrease computational accuracy, so this value must be determined through trial and error by verifying the numerical results.

Through the current study, we have demonstrated that the fourth-order cumulant model for free surface flow is suitable for calculating tsunami pressures with high accuracy. We have also found that adjusting the bulk viscosity is beneficial to suppress acoustic errors. As a future outlook, research on applying this method to wave modelling can be considered.

REFERENCES

Geier M., Pasquali A. and Schönherr M (2017): Parametrization of the cumulant lattice Boltzmann method for fourth order accurate diffusion part I: Derivation and validation, Journal of Computational Physics, ELSEVIER, Vol. 348, pp. 862-888.