Development of A coupled Stabilized Mixed MPM and DDA for Fluid-Structure Interaction Problems

Shinnosuke Matsumi[1], Ryota Hashimoto[2], Bodhinanda Chandra[3], and Toshiro Hata[1]

[1] Graduate School of Advanced Science and Engineering, Hiroshima University, Higashi-Hiroshima, Japan; E-mail: d245650@hiroshima-u.ac.jp, thata@hiroshima-u.ac.jp
[2] Department of Civil and Earth Resources Engineering, Kyoto University, Kyoto, Japan; E-mail: hashimoto.ryota.6e@kyoto-u.ac.jp
[3] Department of Civil and Environmental Engineering, University of California, Berkeley, CA, 94720, United States; E-mail: bchandra@berkeley.edu

Abstract

In recent years, river embankment failures have become a common issue worldwide, with many of these failures caused by overtopping. In Japan, these incidents have increased, prompting the application of the armor levees that cover the slopes of river embankments with concrete blocks as a countermeasure. To evaluate the resistance of these reinforced river levees against overtopping flow, a numerical method that integrates the interactions between soil, fluid, and structure is necessary. While our goal is to develop a fully coupled three-phase (soil-fluid-structure) analysis method, our current focus is on developing a coupled MPM (Material Point Method) and DDA (Discontinuous Deformation Analysis) for fluid-structure interaction problems.

The developed method utilizes the stabilized mixed MPM [1] for incompressible fluid, and DDA [2], a discontinuum-based method with an implicit scheme, for modeling discrete structures such as the concrete blocks of armor levees. Fluid-structure interactions are treated as contact between fluid particles of MPM and the polygonal blocks of DDA, formulated using the penalty method. Since both the stabilized mixed MPM and DDA employ implicit time integration, the discrete equations of MPM and DDA are fully coupled, solving the displacement and pressure fields in MPM and the displacement field in DDA monolithically. This monolithic approach allows for the use of larger time increments than the existing continuum-discontinuum methods adopting an explicit scheme, enhancing applicability for a long-term phenomenon such as the entire process from the rise of the river water levels to overflow.

To verify the developed method, we conducted several benchmark tests, including dambreak flow and wedge entry into water. Initial results demonstrated the method's efficacy in capturing the complex interactions between fluid and structure, accurately predicting the physical behavior. These findings suggest that the method is promising for evaluating reinforced embankments.

Keywords

Stabilized mixed MPM, Discontinuous Deformation Analysis, fluid-structure interaction

References

[1] Chandra, B., Hashimoto, R., Kamrin, K., & Soga, K. (2024). Mixed material point method formulation, stabilization, and validation for a unified analysis of free-surface and seepage flow. *arXiv preprint arXiv:2402.11719*.

[2] Shi, G.H. & Goodman, R.E. (1989). Generalization of two-dimensional discontinuous deformation analysis for forward modelling. *Int. J. Numer. Anal. Geomech.*, 13, 359-380.