

NATURAL HAZARD SIMULATION: MULTIPHYSICS PARTICLE-BASED TECHNIQUES FOR STRUCTURAL IMPACT ASSESSMENT

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Abstract

Climate change is dramatically increasing the frequency and severity of natural hazards such as debris flows, landslides, and mud flows, posing critical threats to structures, ecosystems, and human life. Addressing these challenges requires rigorous mathematical foundations capable of capturing the complexity of multiphysics phenomena involving large deformations and complex material interactions. While the Finite Element Method (FEM) is well-established in many engineering fields, it shows inherent limitations when dealing with large strain regimes. To overcome this drawback, particle-based methods have emerged as powerful alternatives. Among these, the Material Point Method (MPM) stands out as a hybrid technique blending the advantages of both mesh-based and mesh-free methods, naturally handling large deformations while retaining a continuum description of the material. This contribution presents recent advances in MPM formulations, including irreducible and mixed formulations stabilized using variational multiscale (VMS) techniques [1], as well as partitioned coupling strategies combining MPM with FEM and DEM [2,3]. Furthermore, we are actively developing multiscale approaches that couple depth-averaged shallow water models with full 3D formulations, enabling efficient yet accurate simulations across vastly different spatial scales. These mathematical tools enable high-fidelity simulation of multiphysics interactions between water, air, granular materials, and complex boundaries in mountainous environments, ultimately supporting improved risk assessment and mitigation strategies for climate-driven hazards. All algorithms are implemented within the open-source *Kratos Multiphysics* framework.

Keywords: MPM, FSI, VMS, mixed stabilized formulations

References

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