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Hybrid 3D-2D modelling of landslide-generated tsunamis

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The tragic tsunami events of Indonesia, the 28th September 2018 Palu Bay landslide and the partial collapse of the Anak Krakatau volcano on the 22nd December 2018, and Greenland, the Karrat Fjord landslide on the 17th June 2017, have brought new attention to slope-failure tsunami genesis. Earlier modelling attempts, based on the Lituya bay tsunami were mostly based on mesh-based solvers of the Navier-Stokes (NS) and incompressible continuity equations. This entailed tracking the interfaces between solid and liquid phases as the granular landslide enters the water.

In this work, we attempt to overcome the limitations of mesh-based models while maintaining affordable the total computational time. For this purpose, we present a methodology to couple the 2D shallow-water solver HiSTAV with the 3D Smooth Particle Hydrodynamics based NS solver DualSPHysics. Recently, DualSPHysics has been coupled with the Chrono-Engine library, developed as general-purpose simulator for three-dimensional multi-body problems with support for very large systems, which benefits from advances the in parallel and distributed computing solutions for fluids and multibody systems. Furthermore, Lagrangian, meshless SPH solvers present many advantages when computing interactions between objects or structures and the flow, naturally dealing with unsteady and nonlinear flows, extreme deformations and complex topological evolutions.

The shallow-water model HiSTAV, developed at CEris, Instituto Superior Técnico, benefits from a computational implementation, featuring a distributed and heterogeneous computing framework for hyperbolic solvers, that makes it particularly suitable to integration with 3D solvers. The mathematical core of HiSTAV is governed by the hyperbolic shallow-water equations, with depth-averaged transport of granular-fluid mixtures, solved by a 1st order explicit and fully conservative method. Specific changes to the numerical scheme, namely 2nd order discretization and non-hydrostatic pressure terms, are proposed and evaluated regarding the obtained solution quality improvements. The most notable influence of these terms is on breaking wave cases, where 1st order schemes are unable to capture the waveform with an acceptable error.

The proposed modifications, coupled with the computational gains in HiSTAV, aim at providing a fast and robust platform for tsunami modelling at all relevant scales, from source to run-up, in

both natural and built environments.

The strategy to couple DualSPHysics and HiSTAV is based on the bi-directional link at the 3D-2D interfaces modified to take into account that the 3D information is not organized in cells or nodes. The solution of the NS equations is integrated in an overlapping region of the domain and provides data that is passed to the 2D domain by the boundary eigenvalues. This strategy is mathematically exact in the absence of complex topography or bottom friction. Boundary conditions for pressure and velocity are then updated at the boundary of the 3D model for the next relevant SPH time step. Computational gains are attained by the fact that the 2D simulations are run in accordance with the 2D CFL condition and thus not at all 3D time steps.

The method is applied to the problem of forecasting the impacts of a landslide induced tsunami in the Tagus estuary.