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Advanced physical and numerical modelling of tsunami induced boulder transport

Jan Oetjen (1), Max Engel (2,3), Holger Schüttrumpf (1), and Shiva P. Pudasaini (4)

(1) RWTH Aachen University, Institute of Hydraulic Engineering and Water Resources Management (IWW), Aachen, Germany, (2) Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Belgium, (3) Institute of Geography, University of Cologne, Germany, (4) Institute of Geosciences and Meteorology, Geophysics Section, University of Bonn, Germany

Numerical models for simulating tsunami-induced transport of coarse clasts (boulders) are of great importance in tsunami research since deposited boulders can provide detailed information regarding the transport-causing event. Due to the highly complex and sensitive transport mechanics, well-validated boulder-transport models are required for appropriately reconstructing past tsunami events and to simulate possible future events with high accuracy.

Current numerical models are solely able to simulate the behavior of idealized shapes like cuboids, spheres or prisms and do not account for sedimentary load in the tsunami wave, which might substantially influence the boulder transport dynamics, and thus the total transport distance due to the drag and other interacting forces. Therefore, we propose a novel approach, based on the immersed boundary technique combined with the general two-phase mass flow model of Pudasaini (2012), for simulating an arbitrary shaped boulder interacting with a sediment-laden flow.

In physical boulder-transport experiments, we observed a strong influence of the boulder shape not only on the transport distance but also on a standardized and repeatable boulder behavior. Experiments were conducted for subaerial, partially submerged and submerged conditions utilizing idealized boulder shapes (cuboids) as well as a complex shaped boulder model resembling a boulder from the island of Bonaire (Engel and May, 2012). The motions (transport distances and directions) of the boulder were analyzed for each run by video processing. Tests were repeated until the results showed a normal distribution for boulder-transport distance. For partially submerged conditions, a minimum of 37 experiments were necessary for the cubic boulder, while for the complex boulder 16 and for the flat boulder nine were required to obtain normally distributed results, for example.

Recognizing the experimental results, the need for numerical boulder-transport models accounting for non-idealized boulder shapes is obvious. We apply an immersed boundary approach in which we implement the arbitrary shaped boulder as a highly resolved point cloud in Lagrangian coordinates. The developed algorithm detects the boulder shape, a convex hull with allowance of concave segments, and its orientation to the Cartesian grid of the main program within the beginning of every computational time step. Subsequently, the velocities from the fluid and solid phase acting on every boundary node are interpolated and recalculated from influencing grid cells outside the boulder while the velocity inside the boulder is kept to zero. In our approach, boulder movement is not determined by submergence-depending threshold functions but by a dynamical formulation that is generally valid.

We will present detailed results of the physical experiments focusing on the model sensitivity and the behavior of different boulder shapes. Furthermore, we will show the functionality of the numerical model and its performance by comparing the numerical results with those of the experiments.

References

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