Enhanced field observation-based physical and numerical modelling of tsunami-induced boulder transport – Phase 1: Physical experiments

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Introduction

Coasts around the world are affected by high-energy wave events like storm surges or tsunamis depending on their regional climatological and geological setting. By focusing on tsunami impacts, our interdisciplinary research group combines the abilities and experiences of different sciences in order to improve the knowledge about near- and onshore tsunami hydrodynamics. We investigate the transport of coarse clasts – so called boulder – caused by tsunami impact by a combination of field observations, laboratory experiments and advanced numerical modelling. In phase 1 of the project we conduct physical laboratory experiments based on real-world data in terms of bathymetric/topographic setting and boulder shapes. The experiments lead to new insights in tsunami-boulder interactions as compared to existing oversimplified experiments. Following the experimental phase we will develop an enhanced numerical boulder transport model (BTM) based on an existing two-phase model (PUDASAINI, 2012). The BTM will consider processes which are neglected in existing BTMs (e.g. non-idealized boulder shapes and sediment load).

Field observations

On the island of Bonaire (Lesser Antilles) several supralittoral boulder deposits indicate high-energy wave impacts on the island. Although Bonaire was in the focus of several previous studies it has not yet been clarified whether these were deposited due to tsunamis or storm-surges. In our project the nearshore bathymetry as well as several boulder deposits of Bonaire, are used as realistic reference. The utilization of real-world templates for laboratory boulder transport experiments and comparing processes with idealized setups is an innovative approach for the study of nearshore tsunami hydrodynamics and interactions with bathymetry and boulders.

Experimental setup

Experiments are conducted in the 33.5 m long tilting flume at the Institute of Hydraulic Engineering University and Water Resources Management (IWW) at RWTH Aachen University for several divergent boundary conditions. Utilizing idealized (cubes, cuboids) and realistic shaped boulders allow comparing their behaviour during tsunami impact. Some boulders are equipped with in-built inertial measurement units (IMU) which allows for registering essential data, such as boulder acceleration, inclination and velocity directly out of the boulder. Tsunami bores in the tilting flume are generated by a combination of pumping time and valve position. Valve positions as well as pumping times are adjustable by computer which ensures reproducible experiments. The flume consists of two centrifugal pumps of 30 kW with 400 l/s conveying capacity each followed by one valve. By a flume width of 1 m creation of bores up to 0.19 m (representing an app. 10 m wave prototype) is possible. Therefore, experiments are conducted in a scale of 1:50.

We use three different bathymetric setups (Fig. 1). The inclined ramp setup (Var. 1) is commonly used in similar studies and enables result comparisons. Furthermore, as an innovative approach, we create two stepped bathymetries resembling the low-plunging cliffs of Bonaire. During a survey on Bonaire, boulder deposits were captured by the structure-from-motion technique and digitally processed (Fig. 2a & 2b). Boulder replicas are created by three-dimensional prints of the digital boulder data. Finally we investigate influences of sedimentary load on boulder transport mechanism. For this purpose we install a sediment bed in the flume which is set in motion by the bore.

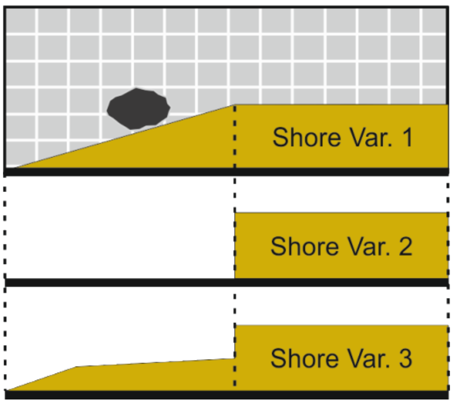

Figure 1: Bathymetric setups.

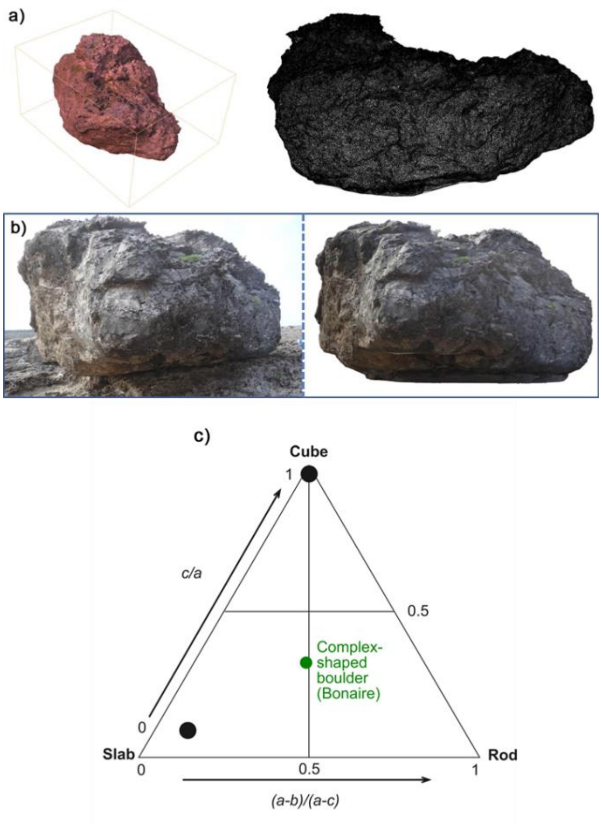

Figure 2: a) Perspective view and mesh model of a boulder deposited on Bonaire. b) Comparison between the original photograph and the numerical model). c) Contrasting shapes of idealized (black dot) and complex-shaped (green dot) boulder (a, b, c = main axes of boulder).

Measurements

The IMUs enable us to exactly identify the actual forces acting on a boulder. This allows new insights into the interactions between the tsunami bore and boulder. The bore impact on boulders as well as boulder transportations are also captured by high-speed video enabling qualitative analysis and comparisons of transport paths under divergent boundary conditions.

Since we equip both idealized as well as realistic boulder replicas with IMUs, we are able to obtain the degree of influence of boulder shapes (from cubic to flat and realistic; Fig. 2c) and bathymetry (uniform, step, stepped) on transportation path, mode and distance. Therefore we determine this influence not only qualitatively but also quantitatively. Partly coloured sediments ensure recognizable video results and their interpretation by the use of photographical software. Furthermore, bore velocity as well as height are measured. All quantitative and digitally collected experimental data enable the exact and well controlled validation of the later numerical model in the channel.

Outlook / Numerical model

The BTM development begins after completion of the experimental phase. The model will be able to simulate interactions between bathymetry/ topography, tsunami bore, boulder and sedimentary load for local scales. The opportunity to simulate sediment-boulder interactions within a tsunami bore and implementation of non-idealized boulders will be a next major step forward in the field of numerical boulder transport modelling. The broad database, achieved from the experimental phase, will be an excellent basis for calibration and validation purposes for enhanced BTM with real two-phase mass flow model.

References

PUDASAINI, S.P. (2012): *A general two-phase debris flow model*. Journal of Geophysical Research – Earth Surface 117, F03010.