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Large-scale laboratory experiments on tsunamis generated by submarine volcanic eruptions in a wave basin

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Among the wide spectrum of volcanic tsunamis, the most devastating events have been caused by extremely explosive eruptions, pyroclastic flows and debris avalanches of underwater or near surface volcanos. The 2015 “orange” alert at the Kick ‘em Jenny submarine volcano in the Caribbean Sea highlighted the challenges in characterizing the tsunami waves for a potential submarine volcanic eruption. The 2018 Anak Krakatau eruption and flank collapse generated tsunami resulted in a near water surface setting of the volcanic vents similar to these laboratory experiments and relevant for the remaining and future tsunami hazards.

Source and runup scenarios are physically modeled using generalized Froude similarity in the three dimensional NHERI tsunami wave basin at Oregon State University. A novel volcanic tsunami generator (VTG) was deployed to study submarine volcanic eruptions with varying initial submergence and kinematics. The VTG consists of a telescopic eruptive column with an outer diameter of 1.2 m. The top cap of the pressurized eruptive column is accelerated vertically by eight synchronized 80 mm diameter pneumatic pistons with a stroke of 0.3 m. More than 300 experimental runs have been performed which include around 120 combinations of velocities and water depths. The variable eruption velocities of the VTG can mimic a wide range of processes ranging from relatively slow mud volcanoes and rapid explosive eruptions. The gravitational collapse of the eruptive column represents the potential engulfment and caldera formation. Water surface elevations and onshore runup are recorded by an array of resistance wave gauges and runup gauges. The VTG displacement is measured with an internal linear potentiometer and above and underwater camera recordings. Water surface reconstruction and kinematics are determined with a stereo particle image velocimetry (PIV) system. The water surface spike from the concentric collision of wave crest is observed under a limited range of Froude numbers. The energy conversion rates from the volcanic eruption to the wave train are quantified for various scenarios. Predictive equations of wave and spike characteristics are obtained and compared with existing linear and non-linear theories. The measured volcanic eruption and tsunami data serve to validate and advance three-dimensional numerical volcanic tsunami prediction models.