Geophysical Research Abstracts
Vol. 21, EGU2019-11871, 2019
EGU General Assembly 2019

Physical modeling of tsunamis generated by submarine volcanic eruptions

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Tsunamis are normally associated with submarine earthquakes along subduction zones, such as the 2011 Japan tsunami. However, there are significant tsunami sources related to submarine volcanic eruptions. Volcanic tsunamis, like tectonic tsunamis, typically occur with little warning and can devastate populated coastal areas at considerable distances from the volcano. There have been more than 90 volcanic tsunamis accounting for about 25% of all fatalities directly attributable to volcanic eruptions during the last 250 years. The two deadliest non-tectonic tsunamis in the past 300 years are due to the 1883 Krakatoa eruption in Indonesia with associated pyroclastic flows and Japan's Mount Unzen lava dome collapse in 1792. At the source, volcanic tsunamis can exceed tectonic tsunamis in wave height. There are at least nine different mechanisms by which volcanoes produce tsunamis. Most volcanic tsunami waves have been produced by extremely energetic explosive volcanic eruptions in submarine or near water surface settings, or by flow of voluminous pyroclastic flows or debris avalanches into the sea. The "orange" alert in July 2015 at the Kick 'em Jenny submarine volcano off Granada in the Caribbean Sea highlighted the challenges in characterizing the tsunami waves for a potential submarine volcanic eruption. The recent activity and collapse of the volcanic cone at Anak Krakatau generated tsunami waves that impacted coasts along the Sunda Strait without any prior warnings and caused more than 400 fatalities on December 22, 2018.

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 simulate submarine volcanic eruptions with varying initial submergence and kinematics. The VTG consists of a telescopic eruptive column with an approximate 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 approximately 0.3 m. More than 300 experimental runs have been performed in summer 2018, which include around 120 combinations of velocities and water depths. The variable eruption velocities of the VTG mimic 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 are recorded by an array of resistance wave gauges. The VTG displacement is measured with an internal linear potentiometer and from above and underwater camera recordings. Water surface reconstruction and kinematics are determined with a stereo particle image velocimetry (PIV) system. Wave runup is recorded with resistance wave gauges along the slope and verified with video image processing. The water surface spike from the concentric collision of wave crest is observed under a limited range of water depths and Froude numbers. The energy conversion rates from the volcanic eruption to the wave train are quantified for various scenarios. The measured volcanic eruption and tsunami data serve to validate and advance three-dimensional numerical volcanic tsunami prediction models.