Anak Krakatau Landslide Tsunami Relapse Potential Hazard

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Abstract. Mount Anak Krakatau has a potential hazard that will emerge within 50 years from present time when the peak cone reaches a height that critical to landslides. The Tsunami wave runup as high as 80 meters sweep the steep coast Sebesi and Rakata islands is measured inside the Krakatau volcano complex, during the eruption event and followed by flank collapse on December 22, 2018. The finite volume numerical method of the 3-D Hydrodynamic Model is used to evaluate the potential hazards of Anak Krakatau. Landslide materials with different densities and volumes will be simulated and evaluate which density produce the best estimate of the potential for Tsunami Run-Up waves within the Krakatau complex and Tsunami waves that will sweep and damage the coastal areas of the Sunda Strait. More importantly, the simulation results will provide the tsunami-induced surface current signature information that can be observed by broad range measurement devices, together with an efficient early warning system on the coast, will save life.

1. Introduction
The tsunami caused by material landslide from the eruption of Mount Anak Krakatau on 22 December 2018 is a recurrence of the Tsunami which was caused by the Magma Chamber Collapse during the eruption of Mount Krakatau on August 28, 1883. This tsunami caused more than 400 lives along the coast of the Sunda Strait. The first wave reached the cities of Anyer and Merak in Java after 35 - 40 minutes, and 10 minutes later reached Tanjung Lesung, Banten and the coast of Kalianda Lampung. [1] The potential hazard of a recurrence of Tsunamis due to material landslide from the eruption of Mount Anak Krakatau needs to be detected quickly using wave height signature detection technology and Tsunami induced current velocity to avoid casualties. The rate of growth of Anak Krakatau first emerged from the sea in 1928, located near the northeast wall of the steep basin formed by the collapse of the 1883 eruptive caldera of Krakatau. The volcano grew around the main vent of the 1883 eruption, about halfway between the former Danan crater and Perbuwatan. [2] Surtseyan and Vulcanian eruption types during the period 1928 - 1981 resulted in cones as high as 200 m asl in 1981. [3] Taking into account the collapse of the main vent structure material in the 2018 eruption, the predicted growth of the volcano's western slopes will accumulate from material deposits, filling the natural lake formed from the December 2018 eruption at the same rate as the growth from 1928-1981. Although the results of the bathymetric survey of landslide material deposits on the southwest side show significant silting [4], the material landslides on this slope towards the southwest still have the potential to trigger tsunami waves in the future.

2. Methodology
Digital elevation models and scenarios considered
The collapse of the Anak Krakatau Volcano was simulated on a digital elevation model (DEMNAS) obtained from the Geospatial Information Agency (BIG) (c. 7.5 m resolution), bathymetric map (BATNAS) from the Geospatial Information Agency (150 m resolution) for the entire area of the Krakatau Compound Islands (Fig. 1). The resulting final DEMNAS, which is the calculated grid used for numerical simulations, is a 1000 x 1000 grid with a spatial resolution of 10 m (Fig. 1).

Several DEMNAS elevation lines are modified to reconstruct the sliding surface of landslides which are useful for determining the plane boundary of the landslide. The landslide field is oriented toward the southwest, with a collapse volume of 0.220 km$^3$. In the simulation, the landslide material is released in one event.

2.1 Numerical model

VolcFlow 2D and 3D numerical codes [6] were used to simulate the Anak Krakatau landslide and tsunami propagation. This code is based on a two-dimensional (2D) depth average approach, modified to incorporate 3D interactions with higher accuracy; Landslides and seawater are simulated using the general shallow water equations of conservation of mass and momentum. In the model, water interacts with bathymetry/topography and run-up on the beach, other complex 2nd order 3D effects are not taken into account, and sediment erosion and transport are also neglected.

We simulate the propagation of water using a density of 1000 kg/m$^3$. Since the erupted material from Mount Anak Krakatau consist largely of coarse pyroclastic material with a chemical composition from basaltic (general) to dacite (rarer) [3], we used a density of 1600 kg/m$^3$ to simulate landslides.[5] show that the fluidity density variation is used to simulate the propagation of landslides. Topography after a simulated landslide, with a horseshoe shaped slope plane and the amplitude of the triggered waves clearly visible. However, since in this paper the discussion is focused on evaluating the wave height and flow velocity signatures at the water surface due to tsunami, we chose a constant density calculation grid to simulate the overall landslide propagation.

3. Result
When interacting with water, the landslide material triggers waves with a maximum initial wave height of approximately 50 m, measured approximately 35 seconds after collapse at 1 km west of the landslide plane. The resulting wave then propagates radially away from the landslide area, reaching the islands of Sertung, Panjang and Rakata (Figure 2) in less than 1 minute, with an amplitude of 30 to 40 m. Due to the propagation of the landslide to the southwest, the highest waves are generated in this direction. The wave profile obtained within the Kratatau Islands shows the 3 series of waves with an amplitude of 12 m and a period of about 150 s (wavelength of 3.3 km). This was followed by another 5 m wave, with a smaller period of about 60 s (wavelength of about 1.5 km). [5].

4. Discussion

Effect of initial parameters on wave characteristics

The volume of landslide material and the sequence in which they occur (i.e in one time collapsed due to slope failure) are the parameters that most influence the characteristics of the triggered tsunami [5] (Giachetti et al. 2012). In this Mount Anak Krakatau model involves landslide volume of 0.220 km$^3$ material. The evaluation of a steeper landslide plane would lead to landslides more rapidly into the water, and thus possibly cause higher waves. However, steeper landslide plane will produce smaller volume and generate smaller waves. Because in this study our aim was to calculate the realistic tsunami wave signature triggered by the eruption of Mount Anak Krakatau landslide material, we chose to
compare the results of the 2D Depth Averaged Model and the 3D Model by minimizing the volume of the landslide material.

Effect of bathymetry / topography on tsunami characteristics.

To determine the initial landslide material volume, we used the available topographic data (DEMNAS data, 7.5 m spatial resolution) and bathymetry (BATNAS data, 150 m resolution) for the geometry model of the Krakatau Islands. New topographic and bathymetric data after the December 2018 eruption were not used in this study.

Tsunami hazard

Our simulations show that the resulting first wave has a maximum amplitude of about 50 m. This altitude is reached about 1 km West from the landslide area (i.e. Sertung Island), inside the Krakatau Complex Islands.

5. Conclusion

Both 2D and 3D hydrodynamics simulations show that the resulting first wave has a maximum amplitude of about 50 m with run-up height of 75 m. This altitude is reached about 1 km West from the landslide area (i.e. Sertung Island), inside the Krakatau Complex Islands.

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