Tsunami generation processes by pyroclastic flows during 1883 Krakatau eruption, Indonesia

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The 1883 Krakatau eruption is the best example for understanding the impacts of volcanogenic tsunamis on oceanic environments. Although a lot of studies have challenged to reveal the tsunami generation mechanisms, there have been problems with three major hypotheses yet. The hypotheses and their problems are as the followings. (1) Caldera collapse hypothesis: the computed waveform with negative first arrival does not match observed tsunami with positive first arrival as recorded at the tide-gauge station. (2) Phreatomagmatic explosion hypothesis: the submarine deposits in the vicinity of Krakatau were mainly composed of pumice and ash with little or no evidences of lithic fragments from old Krakatau that a submarine explosion would produce. (3) pyroclastic flow hypothesis: the volume of pyroclastic flow previously used is too little, and simple decrease in bathymetry due to the emplacement of pyroclastic flow can not describe the effects of interactive forces of pyroclastic flows on seawater. Although some previous studies pointed out based on geological records that the largest tsunami was generated by a pryoclastic flow, the detail processes have not been investigated yet. In this study, we focused especially on (3) pyroclastic flow hypotheses, and analyzed tsunami behavior using two-layer shallow water models, which can consider the effects of interaction between pyroclastic flow and seawater.

Two types of two-layer shallow water model were used in this study. One is for denser pyroclastic flow than seawater, and another is for lighter one. We adopted 20 km^3 as the volume of submarine pyroclastic flow (Mandeville et al., 1996). The pyroclastic flows with 1100 kg/m^3 (for dense-type model) and 900 kg/m^3 (for light-type model) were erupted with sine function from the circular source with 1.5-2 km radius, north of old Rakata Island. Mass flux necessary to temporally sweep the sea off 10 km from Krakatau as historically recorded should be more than 10^{10} kg/s, based on experimental and theoretical studies of Legros and Druitt (2000). Therefore, we adapted 10^7-10^8 m^3/s as a mass flux. Parameter studies were conducted with two models and above initial conditions. In numerical simulation, the procedure for the continuation of regions was used for 83.33 m grid in proximal area and 250 m grid in distal one. Computed wave characteristics were compared with observed ones at some locations where wave data have been measured just after the eruption.

In all numerical computations using two models, just after pyroclastic flow began to enter sea, the sea-level rapidly rose because the flow pushed seawater toward the far area. After that sea level gradually recovered, resulting in tsunami generation with positive peak. A light-type model simulated the shoreline displacement by pyroclastic flows. Results from both dense-type and light-type models are almost same because the momentum transferred from pyroclastic flows into seawater are almost same. The distribution patterns of submarine pyroclastic flows can be also compared with the submarine deposits. Computed wave heights of tsunami at locations in the coastal areas well matched with data inferred from historical and geological records. Only at the southernmost of Sumatra, wave height became less than inferred value. In the western and southwestern area, wave characteristics are strongly affected by bathymetry with steep slope between Krakatau and Sumatra. At Batavia in the north of Java, the first positive peak reached within 2.7 hours with the long wave period. These wave characteristics match with records at the tide-gauge station. Our results suggest that the pyroclastic flow entering sea would be more probable mechanism of large tsunami during the 1883 Krakatau eruption.