Wave generation and formation in the air by under-water explosions

Mie Ichihara[1]; Katsumi Tanaka[2]; Akio Goto[3]; Hiromitsu Oshima[4]; Hiromitsu Taniguchi[3]

[1] ERI, U. Tokyo; [2] AIST; [3] CNEAS, Tohoku Univ; [4] Usu Volcano Observatory, Hokkaido Univ.

The Research Group on Volcanic Explosion conducted under-water explosion experiments at Lake Toya, Hokkaido, in 2001 and 2002. We installed acoustic and seismic sensors on the land, and blast sensors in the lake. At the same time, the water motion was monitored by high-speed video cameras. In this study, we analyze the experimental data and discuss the mechanism in which air-waves are generated and formed by an explosion in the liquid. Our ultimate goal is to know what is going on at the eruption source from the observation of air-waves. This study is intended to improve our basic knowledge required to achieve the goal.

Air-waves generated by active volcanoes are expected to bring a useful information from the crater. However, technique to decode the information has not been developed sufficiently. On the other hand, the under-water explosion itself has been one of the subjects of intensive studies, partly because it is concerned with military affairs. Nevertheless, the incidental air-waves have drawn little attention and their generation process is not understood well. The process includes difficult problems from mathematical and computational points of view, such as wave transfer through the water-air boundary with a large impedance contrast, large displacement and fragmentation of the water, and ejection of the gas produced by the explosion. Therefore, detailed observations and analyses of the phenomena are required to solve the problem.

We used dynamite in the experiments. The explosive was suspended in the water by a raft at 86 m from the lake shore. The scaled depth, which is defined as the depth divided by the cubic root of the explosion energy, was taken as the experimental parameter. Two blast sensors were installed at the horizontal distances of 12 m and 45 m from the explosion center and 5 m below the water. A high-speed video camera was set at the lake shore, and the acoustic and seismic sensors were installed at the same place and in an array with 40-m intervals. The timing of all the signals was correlated with an accuracy of 1 ms.

The observed pressure waves were noted with the following features. (1) The blast wave associated with the explosion is followed by a series of pulses. (2) Pressure waves generated by explosions of an identical scaled depth have similar waveforms, even though the depth and the energy are different respectively. (3) Pressure waves in the water and in the air are considerably different. The feature (1) has been explained as the successive pulses are generated by the oscillation of the bubble formed by the explosion. Here, the focus is put on the features (2) and (3).

We assume a system consisting of the water and the air separated by an infinite planner boundary. The wave field produced by a point source in the water is calculated using the linear-wave theory. The source time function is inferred from the under-water pressure data. The analyses are conducted on the first pulse, which is not influenced by the reflection from the bottom of the lake. The observed air-waves are explained well by the calculation in the cases with relatively large scaled depth, while those associated with the smaller scaled depth have larger amplitude than the corresponding calculation and are characterized by an M-shape in contrast with the one-peak pulse obtained by the calculation. The discrepancy becomes larger as the scaled depth is smaller.

Next, we compare the motion of the water surface and the corresponding air-wave. Shockwave transmission from the water to the air is visually recognized as sudden change of the color and fragmentation of the water surface. As the scaled depth becomes smaller, the motion of the water surface becomes more violent involving a water jet and immediate emission of the gas generated by the explosion. We are going to investigate the contribution of such large motion of the water surface to the air-wave.

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