Where Do You Go When the Volcano Blows?

Fluid flow modeling aids Italian university researchers in characterizing the effects of explosive eruptions on nearby buildings.

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When a volcano erupts, the geological process that results often releases devastating amounts of energy from beneath the planet's surface through volcanic flows. Such flows are classified into two categories: well-known lava flows when the eruption is effusive, and pyroclastic flows when it is explosive. Explosive eruptions, like the ancient events at Mount Vesuvius in Italy and the modern ones at Mount St. Helens in the United States and Mount Pinatubo in the Philippines, represent the more hazardous of the two classes.

The explosions themselves can be caused either by magmatic fragmentation due to high stress on the subterranean molten rock (magma) or phreatomagmatic fragmentation, which is caused when magma shatters after interacting with water [1]. In both cases, a multiphase mixture of hot gas and solid (ash and pumice) particles is generated and is ejected out the volcano. If the mixture at the crater consists of a pressure-balanced jet, it expands only upward and generates a volcanic column; if it has a pressure greater than atmospheric pressure, it expands in all directions and generates a volcanic mushroom. When columns and mushrooms reach the maximum height allowed by the issuing flow rate against gravity, they then collapse, impacting the ground and generating pyroclastic flows.

Pyroclastic flows are extremely dangerous because they move rapidly down from the volcanic crater to spread over the surrounding terrain [2] and interact with buildings in populated areas through the dynamic pressure action on structures. Generally, a flow-building interaction zone, that is, a village or a city, is located far enough from the crater so that pyroclastic flows arrive diluted, turbulent and fully developed — characterizations supported by recent geophysical studies [3]. The multiphase behavior of pyroclastic flows is also very important both on the turbulence modulation and on the dynamic pressure. The flow currents are strongly stratified by velocity and particle concentration [4] so turbulence and pressure must account for the gas–particle coupling.

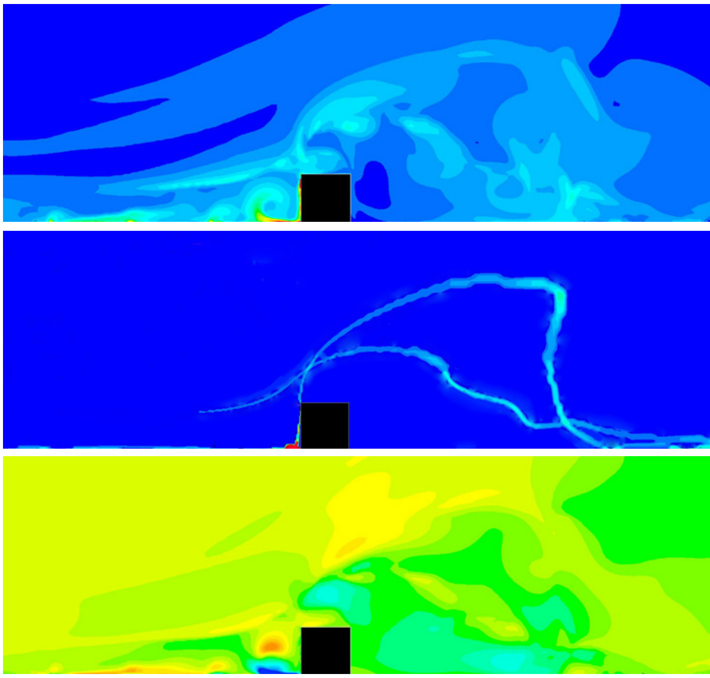
A volcanic column from the Mount St. Helens eruption in May 1980
Photo by Austin Post, USGS.

Based on this knowledge of pyroclastic flow behavior, researchers from the University of Bari in Italy used ANSYS FLUENT fluid flow simulation software to model the interaction between a pyroclastic flow and a single equilateral building. The team's goal was to calculate the local flow field to quantify the volcanic hazard in the interaction zone by accounting for the effects of turbulence.

To simulate the multiphase turbulent behavior of the dilute currents that propagate along the sides of a volcano at a certain distance from the crater, the research team performed 2-D steady-state simulations of pyroclastic flows in ANSYS FLUENT software. The modeled domain was 190 meters long by 50 meters high with a 10-meter by 10-meter building located 80 meters from the inflow. It was represented by a computational grid with 200,000 quadrilateral cells. To account for the effects of flow separation and recirculation near the building, the team chose the realizable k–ε turbulence model coupled with non-equilibrium wall functions. After ensuring appropriate mesh refinement near the building and ground, a turbulent boundary layer for velocity was applied at the inlet using a profile file with turbulence intensity and length scale inputs taken from literature values [5]. For the simulation of particles contained in the flow, the researchers applied the Euler–Lagrange discrete phase model in ANSYS FLUENT using a series of particle injections. These injection points followed a grain size distribution ranging from 0.06 millimeters to 2.8 millimeters [2] and a concentration profile that decreased moving upward along the inlet boundary to allow for stratification of the flow currents [3]. The outflow consisted of atmospheric pressure all around the domain with a no-slip condition applied along the ground and building walls.

Results from the fluid flow simulations are very interesting, indicating that strong variations in the flow field occur around the building because of the high Reynolds number, or strongly turbulent flow. The analysis also showed that the particle concentration was very high at the base of the building, which contributes to dynamic pressure [3] that would strongly impact the doors.

The findings from this approach using numerical simulation can be useful for studying the impact of pyroclastic flows, as well as generally dilute natural flows, on buildings and natural environments to determine the associated geological risk. In the future, the research team's goal is to compare the ANSYS FLUENT simulation results with recent experimental work that studied the interaction between scaled pyroclastic flows and buildings [6, 7] to develop a better understanding of the interaction dynamics resulting from such explosive volcanic eruptions. ■



Contours of turbulence intensity (top), particle concentration (center) and x-direction velocity (bottom). The inflow is advancing left to right. Increased turbulence intensity makes particles that would normally follow the flow currents be dispersed from those currents much more readily. With the notable exception of particles impeded by — and thus accumulating near — the base of the building, this turbulent dispersion locally decreases the average solid particle load and increases the velocity.

References

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