The Importance of Earthquake Modeling and Lab Experiments for Understanding Seismic Hazard

Nadia Lapusta, Professor of Mechanical Engineering and Geophysics, California Institute of Technology

Understanding earthquake behavior and developing resilient seismic design based solely on observations presents a host of insurmountable difficulties, as the existing observations provide an incomplete picture of seismic hazard. This is because the instrumented history is short compared to recurrence times of large events and can be misinterpreted using oversimplifying assumptions. For example, the extremely large and destructive 2011 Tohoku-Oki earthquake came as a great surprise, as the past earthquake history of the region consisted of much smaller events. Since the ground shaking during an earthquake is the result of rapid relative motions on faults deeper in the Earth, it is important to understand what controls the sudden motion of the earthquake source and how this motion is transmitted to the Earth surface by seismic waves.

Two approaches to earthquake source modeling will be presented that can help us identify the broader range of potential earthquake scenarios and their societal implications. In the first approach, detailed physics-based models of earthquake-producing faults are constructed using observations and laboratory rock studies, and then interrogated with computer simulations. As an example, we will show that the unexpected characteristics of the great Tohoku-Oki earthquake can be reproduced in a computer model with the state-of-the-art fault friction laws and parameters based on laboratory studies of materials from the fault zone that produced the 1999 Chi-Chi earthquake. The obtained insight into the physics of the process can help us explore the range of potential future behaviors on faults in Japan and around the world.

In the second approach, miniature earthquakes are produced in the laboratory using analog materials and observed in great detail with high-speed imaging tools. Such experiments have been used to demonstrate the phenomenon of earthquake rupture propagation at supershear rupture speeds, which was first discovered in theoretical models. The propagating fronts of such ruptures feature a Mach-cone of shear “shock waves” similar to that of supersonic aircraft, often trailed by a Rayleigh disturbance. This aspect is not typically accounted for in standard methods for interpreting earthquake observations and can greatly amplify the resulting ground shaking. A closer look at well-recorded large (magnitude Mw > 7) strike-slip earthquakes has indicated that nearly all of them may have had at least some supershear propagation. Seismic hazard analysis for similar events should incorporate the possibility of supershear propagation, particularly when predicting extreme credible earthquakes for critical facilities that have close to zero-risk tolerance.