News Releases

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Seismic experiments provide new clues to earthquake wave directionality and growth speed

PASADENA, Calif.--In recent years, seismologists thought they were getting a handle on how an earthquake tends to rupture in a preferred direction along big strike-slip faults like the San Andreas. This is important because the direction of rupture has a profound influence on the distribution of ground shaking. But a new study could undermine their confidence a bit.

Reporting in the April 29 issue of the journal Science, researchers from the California Institute of Technology and Harvard University discuss new controlled laboratory experiments using dissimilar polymer plates to mimic Earth's crusts. The results show that the direction of rupture that controls the pattern of destruction is less predictable than recently thought.

The results explain puzzling results from last year's Parkfield earthquake, in which a northwestward rupture occurred. A southeastward rupture had been predicted on the basis of the two past earthquakes in the area and on numerical simulations. Also, during the recent large earthquakes in Turkey, some ruptures have occurred in the direction opposite to what happened in the past and are thought to involve unusually high speeds along that direction.

The phenomenon has to do with the basic ways rupture fronts (generating seismic waves) are propagated along a boundary between two materials with different wave speeds--an area of research that is yielding interesting and important results in the engineering laboratory.

The reason this is important is that geophysicists, knowing the wave speeds of the materials in different tectonic plates and the stresses acting on them, could someday have an improved ability to predict which areas along a major fault might be more powerfully hit. In effect, a better fundamental knowledge of the workings of Earth's plates could lead to a better ability to prepare for major earthquakes.

In the experiment, Caltech's von Kármán Professor of Aeronautics and Mechanical Engineering Ares Rosakis (the director of the Graduate Aeronautical Laboratories); his cross-campus colleague, Smits Professor of Geophysics Hiroo Kanamori; Professor James Rice of Harvard University; and Caltech grad student Kaiwen Xia, prepared polymer plates to mimic the effects of major strike-slip faults. These are faults in which two plates are rammed against each other by forces coming in at an angle, and which then spontaneously snap (or slide) to move sideways.

Because such a breaking of lab materials is similar on a smaller scale to the slipping of tectonic plates, the measurement of the waves in the polymer materials provides a good indication of what happens in earthquakes.

The team fixed the plates so that force was applied to them at an acute angle relative to the "fault" between them. The researchers then set off a small plasma explosion with a wire running to the center of the two polymer plates (the "hypocenter"), which caused the two plates to quickly slide apart, just as two tectonic plates would slide apart during an earthquake.

The clear polymer plates were made of two different materials especially selected so that their stress fringes could be photographed. In other words, the waves and rupture fronts that propagate through the system due to this "laboratory earthquake event" showed up as clearly visible waves on the photographic plates.

What's more, if the rupture fronts are super-shear, i.e., faster than the shear speed in the plates, they produce a shock-wave pattern that looks something like the Mach cone of a jet fighter breaking the sound barrier.

"Previously, it was generally thought that, if there is a velocity contrast, the rupture preferentially goes toward the direction of the slip in the low-velocity medium," explains Kanamori. In other words, if the lower-velocity medium is the plate shifting to the west, then the preferred direction of rupture would typically be to the west.

"What we see, when the force is small and the angle is small, is that we simultaneously generate ruptures to the west and to the east, and that the rupture fronts in both sides go with sub-shear speed," Rosakis explains. "But as the pressure increases substantially, the westward direction stays the same, but the other, eastward direction, becomes super-shear. This super-shear rupture speed is very close to the p-wave speed of the slower of the two materials."

To complicate matters even further, the results show that, when the experiment is done at forces below those required for super-shear, the directionality of the rupture is unpredictable. Both waves are at sub-shear speed, but waves in either direction can be devastating.

This, in effect, explains why the Parkfield earthquake last year ruptured in the direction opposite to that of past events. The experiment also strongly suggests that, if the earthquake had been sufficiently large, the super-shear waves would have traveled northwest, even though the preferred direction was southeast.

But the question remains whether super-shear is necessarily a bad thing, Kanamori says. "It's scientifically an interesting result, but I can't say what the exact implications are. It's at least important to be aware of these things.

"But it could also mean that earthquake ruptures are less predictable than ever," he adds.

Contact: Robert Tindol (626) 395-3631

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