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Caltech Researchers Reveal Three Distinct Modes of Dynamic Friction Rupture with Implications for Earthquake Behavior

PASADENA, Calif.-A new study by researchers at Caltech has revealed important findings about the nature of ruptures and sliding behavior, which could impact how we respond to earthquakes and other disasters.

In the modeling of earthquake ruptures, researchers have, for some time, proposed that three primary modes of rupture may occur at a faultline during an earthquake. The experimental visualization of these ruptures or sliding modes, including the "self-healing" pulse rupture, has for the first time been achieved and demonstrated in the Graduate Aeronautical Laboratories of the California Institute of Technology (GALCIT) using dynamic high-speed photoelasticity and laser vibrometry.

Ares Rosakis, Director of GALCIT and the Theodore von Karman Professor of Aeronautics and Professor of Mechanical Engineering at Caltech, says, "The discovery of these rupture failure modes has never been directly confirmed. We are the first to create the conditions in the laboratory to generate and visualize these rupture and sliding phenomena. Utilizing ultra high-speed optical instrumentation, we have been able to see these modes in a laboratory-which have produced some rather counter-intuitive results. The results of this research could have a significant impact on understanding earthquake behavior and ruptures, on validating existing theoretical and numerical methodologies currently used in seismology, and could one day help us to potentially mitigate massive earthquake damage."

In controlled laboratory conditions, Rosakis along with his collaborators, Guruswami Ravichandran, the John E. Goode Professor of Aeronautics and Mechanical Engineering, and George Lykotrafitis, their former PhD student and currently a postdoctoral scholar at MIT, created rupture models propagating along "incoherent" or frictional interfaces separating identical materials. Combining high-speed photography with a new technique called laser vibrometry, the team conclusively confirmed the existence of the rupture mode types, the exact point of rupture, the sliding velocity, and the rupture propagation speed. Ultra high-speed photography, providing up to two million photographs per second, and dynamic photoelasticity were combined with laser vibrometry, to give an accurate measurement of the sliding velocities and to reveal the various modes of sliding.

Specifically, to conduct the research, the GALCIT team compressed two sheets of a clear polymeric material called "Homalite." They then shot projectiles at various velocities into one of the two sheets. The high-speed camera and the interferometers were simultaneously triggered. Two laser vibrometers measured both the horizontal and the vertical particles velocities just above and below the sliding interface, thus providing a time record of the relative sliding and opening speeds as the dynamic rupture went by with speeds in excess of 1.0Km/sec. They also controlled the parameters of impact speed, confining pressure, and the surface roughness to measure the dynamic sliding.

Theoretical models have predicted that shear ruptures assume either a sliding crack rupture mode; a pulse-like mode; a wrinkle-like opening pulse mode; or a mixed rupture combination of these

modes. In earthquake faulting, a sliding crack mode would occur where a large section of the interface slides behind a fast-moving rupture front and continues to slide for a long time. In the "self-healing" slip pulse mode (first proposed by Professor Thomas Heaton, professor of geophysics and professor of civil engineering at Caltech in the early nineties) the rupture will actually slide or "crawl" along the fault in a pulse-like motion and the fault will then re-compress or "self-heal" behind the pulse. In this pulse-like sliding mode, the slip is confined to a finite distance behind the propagating rupture front, while the fault behind it relocks. The third mode, the wrinkle-like opening pulse mode, is similar to the sliding pulse but would actually create a vertical opening across the fault plane followed by self-healing (something like a ripple on a carpet). Through this new laboratory research technology, these phenomena were actually "seen" and verified.

This research may eventually provide new insights into how we view, react-and prepare for earthquakes. Team member Professor Ravichandran comments, "In studying seismology and the physics of earthquakes, there is no way to internally visualize the Earth's crust. In the lab, we have now confirmed the existence and behaviors of crack-like sliding, self-healing pulse-like sliding, and wrinkle-like opening pulse sliding. This research can provide vital information to help determine the behavior of earthquake ruptures and sliding. Now we have a way to 'see' these behaviors, which can provide new avenues of understanding for these occurrences."

This technology also has potential applications for any composite structure containing both coherent or incoherent interfaces; for example, the durability of the new generation of high speed naval vessels that are constructed with layered structures in their hulls and are subject to dynamic wave slamming or underwater threats can be studied by such techniques. Professor Ravichandran is the director of a newly established MURI sponsored by the Office of Naval Research at GALCIT whose purpose is the study of such phenomena as they pertain to the reliability of the new generation of naval structures.

The findings from the GALCIT team are being published in the September 22 issue of the journal *Science*. The title of their article is "Self-Healing Pulse-Like Shear Ruptures in the Laboratory."

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