The role of dynamic friction in earthquakes

New research shows how dynamic friction changes during a spontaneously evolving earthquake.

IN DISCUSSING FRICTION, the assumption is that the application involves a specific industrial or automotive application where machinery is used. But friction also can be a factor in natural phenomena.

An example is the role that friction can have in the evolution of earthquakes. In a past TLT article, a relationship was found between dry friction and fracture during an earthquake.[1] A new study that recently appeared in Nature Communications[2] introduced new experimental observations of dynamic friction during earthquakes in the laboratory. The measurements were enabled by a new full-field imaging technique.

Earthquakes occur as frictional ruptures along pre-existing faults in the Earth's crust. The researchers simulated earthquakes in the laboratory by producing dynamic ruptures along a pre-existing interface of two quadrilateral plates of a surrogate material, Homalite, a polymer. The experimental setup is shown in Figure 3.

Dr. Vito Rubino, research scientist for the Division of Applied Engineering and Applied Sciences at the California Institute of Technology in Pasadena, Calif., says, "During earthquake propagation, friction evolution controls how ruptures unzip faults in the Earth's crust and release waves that can cause destructive shaking."

As the earthquake is triggered, friction continuously evolves. Rubino says, "From theoretical and numerical studies, it is clear that friction needs to weaken for earthquake rupture to nucleate and proceed, but the detailed nature of appropriate friction laws is an active area of current study. It is important to get the picture right because assumptions about dynamic friction can markedly change the interpretation of earthquake observations, leading to different conclusions about the physical mechanisms controlling the rupture process."

Previous experimental studies did not consider spontaneous rupture propagation as they imposed the slip velocity history externally and assumed uniform sliding along the slipping surface.

New research has now been reported to evaluate how dynamic friction changes during a spontaneously evolving earthquake in the laboratory. This research was done using a unique facility that enabled earthquakes to be produced in a laboratory and to be monitored locally, which means along the interface where dynamic rupture propagates.

KEY CONCEPTS

- Dynamic ruptures were produced along a pre-existing interface of two quadrilateral plates of a surrogate material to simulate earthquakes in the laboratory.
- Slip velocity, a measure of how rapidly the two sides of a fault move past each other, most affected dynamic friction.
- During the dynamic ruptures, an initial increase in friction occurred as the slip rate increased, then friction decreased as the slip rate continued to increase in the next stage and, finally, friction reached a nearly constant, residual level while the slip rate reached a steady state level.

'During earthquake propagation, friction evolution controls how ruptures unzip faults in the Earth's crust and release waves that can cause destructive shaking.'

SLIP VELOCITY

Friction evolution is controlled by rupture parameters such as slip, the relative displacement between opposite sides of the fault, and slip velocity. Rubino and his colleagues determined through laboratory experiments that dynamic friction is most affected by the slip velocity, which is a measure of how rapidly the two sides of a fault

Goats have rectangular pupils to give them a wider field of vision.

move past each other as well as by other effects. This conclusion was found after analyzing laboratory earthquakes produced using the experimental setup shown in Figure 3.

Rubino says, "The inclined interface is prestressed, both in shear and compression due to a far-field vertical load applied to the sample. A nickel-chromium wire fuse is then activated in the fault to initiate the artificial earthquake. Digital images of the earthquake were taken using high-speed photography at a rate of two million frames per second and were analyzed using digital image correlation to produce a sequence of full-field maps of displacements, velocities and stresses. To study friction evolution, we tracked the time history of the ratio of shear to normal stress along the interface—which gave the friction coefficient—together with those of slip and slip rate."

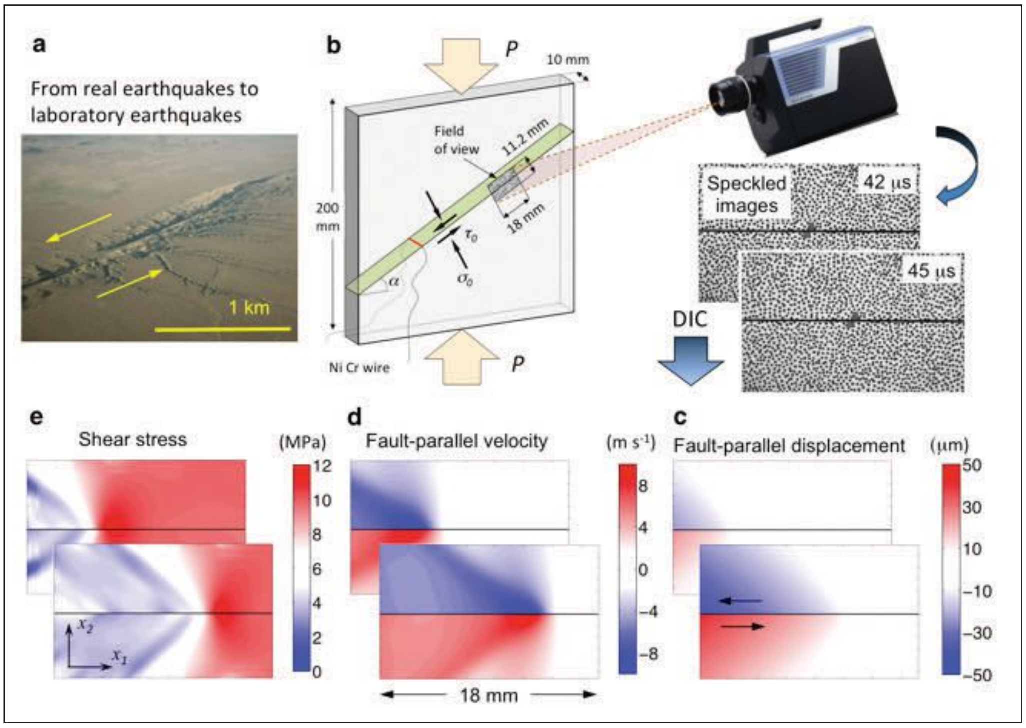

Figure 3 | **Testing has been developed to simulate earthquakes in the laboratory.** *(Figure courtesy of the California Institute of Technology.)*

An evaluation of dynamic friction versus slip for a number of experiments indicated a non-unique dependence of friction versus slip.

In evaluating the dynamic friction as a function of slip rate, the researchers found a complex relationship between the two parameters with an initial increase in friction as the slip rate increased, followed by a reduction in friction as the slip rate continued to increase. Eventually friction reached a nearly constant, residual level as the slip rate attained a steady state level.

Furthermore, the researchers found that friction has a pronounced decrease with slip velocity at a steady rate. Their measurements are consistent with friction formulations known as "flash heating," in which contacting asperities heat up and weaken. Rubino says, "Interestingly the flash-heating formulation was initially proposed in the tribology community to interpret dry friction in metals and was subsequently adopted in earthquake science as a candidate mechanism contributing to friction evolution during earthquake propagation. Our measurements on a polymer showed that this mechanism can actually be responsible for the pronounced weakening of friction and showed the generality of the flash-heating formulation."

The sample was prepared from a thermoset polymer plastic known as Homalite that has similar mechanical properties compared to rock, yet it presents several advantages over natural materials. Rubino says, "We used Homalite as a model material because it has a shear modulus that is approximately 20 times lower than rocks, enabling us to work with samples that have significantly smaller relevant length scales. We can observe well-developed ruptures in the tens of centimeters range with Homalite as opposed to needing several meters if we had used natural rocks."

For the future, Rubino believes the researchers will build on what they learned in this work. He says, "We can use our novel experimental approach to measure dynamic friction to study the effects of complexities, which could play an important role in a natural setting, such as damage in the bulk, rock gouge along the interface and multiple ruptures propagating on the same interface."

Additional information on this research can be found in a recent paper[2] or by contacting Rubino at **vito.rubino@caltech.edu.**

REFERENCES

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2. Rubino, V., Rosakis, A. and Lapusta, N. (2017), "Understanding dynamic friction through spontaneously evolving laboratory earthquakes," *Nature Communications*, Article Number: 15991, DOI: 10.138/ncomms15991.

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