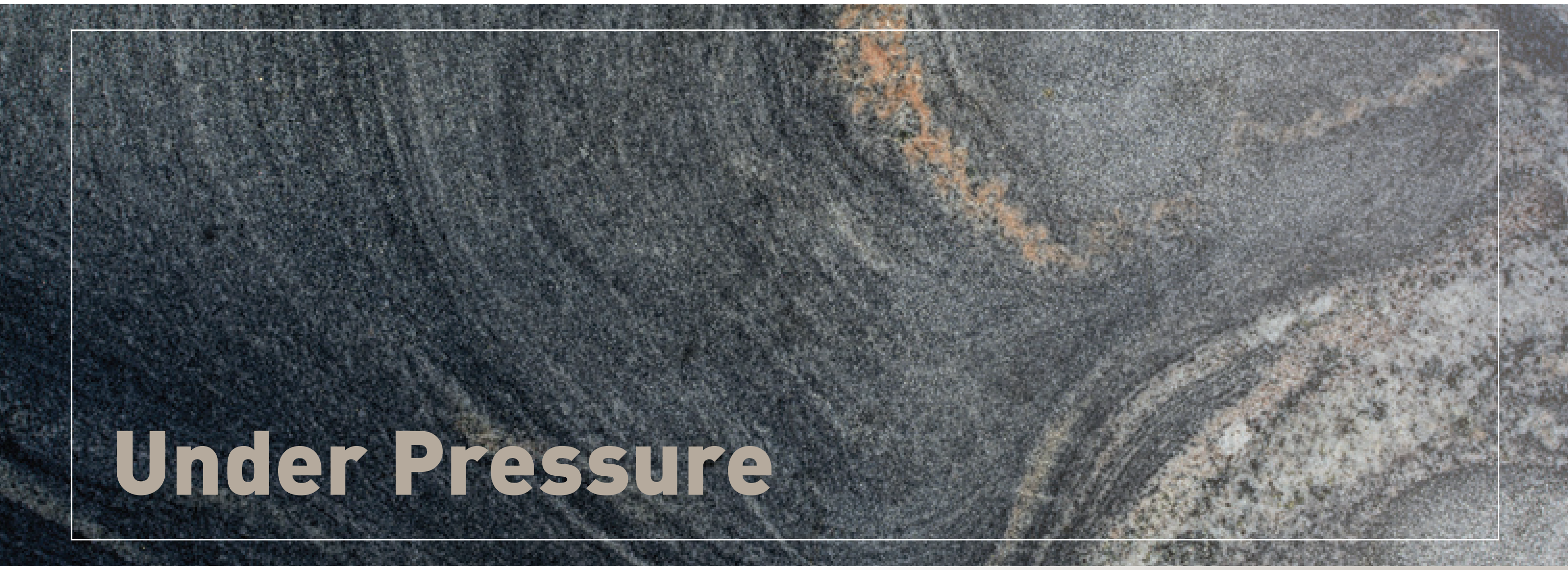
PHANTOM

2019
CASE STUDY



Under Pressure

To learn more about current fracking practices, MIT researchers are analyzing how high-pressure fluid cracks rock with the help of a Phantom high-speed camera.

Hydraulic fracturing, or "fracking," is a hot-button topic these days. The process involves drilling into the ground and then directing high-pressure water at the rock to release the gas inside. While fracking has had a major impact on the energy industry, many critics have environmental concerns—particularly regarding earth tremors and potential groundwater contamination.

With the help of a Phantom high-speed camera, researchers at the Massachusetts Institute of Technology (MIT) Earth Resources Laboratory (ERL) have been trying to understand the fracking process better. The lab uses the camera to observe how cracks initiate and propagate in various types of rock—including gypsum, marble, granite and shale—under different loading conditions. Since propagation happens very fast, the high-speed cameras are indispensable to the analysis.

Most recently, the team has been studying hydraulic fracturing—relying on fluid pressure to generate the load. "In particular, we're exploring how the hydraulic fracturing process is affected by the shape of the pressurized opening and the penetration of the injected fluid into the matrix of the rock," says Ignacio Martin Arzuaga Garcia, graduate student. "These two factors play an important role in the pressure required to break the rock."

A COMPLETE PICTURE

For one set of experiments, Garcia tested gypsum—a soft sulfate mineral. He placed a 4 x 2 x 1-foot specimen in a biaxial loading frame under 4.5 megapascals (MPa) axial load and 1 MPa lateral load. Then, he hydraulically pressurized a concentric opening in the rock until it fractured—tracking the internal pressure inside the opening and the volume of the injected fluid using a data acquisition (DAQ) system.

Because the fracturing process is very fast, Garcia recorded the process at 2,000 frames per second (fps) using a Phantom v2511 high-speed camera, which helped him determine the moment of fracture initiation and resulting fracture pattern. The DAQ unit synchronized the high-speed video with pressure-volume curves during the fracturing process.

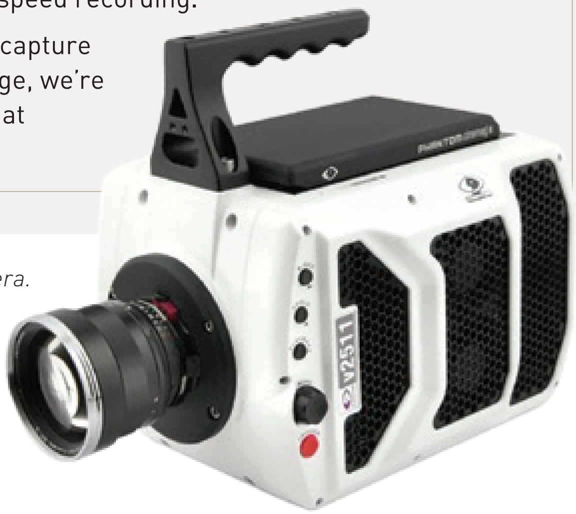
What makes the ERL team's research particularly interesting is the fact that it generates a complete picture of the fracturing process. Most research groups studying rock mechanics analyze the fracturing process only after it's done. "But lots of cracks open up during the process," explains Omar Al-Dajani, doctoral candidate. "As some open, they end up closing earlier cracks. If you don't see the full process, you'd base your analysis only on the fractures left at the end. For this reason, we're capturing things no one else has seen so far."

SUPERIOR RESOLUTION AND MEMORY

The ERL researchers have been using high-speed cameras in their lab for several years. "They've advanced a lot in that time—especially when it comes to memory and resolution," says Al-Dajani. In the past, he and his colleagues were limited by the small amount of internal camera memory—leading to very short recording windows. Concurrent with this, the sensor resolution of previous high-speed cameras was not high enough to decipher the finer details of the fast fracturing process.

The Phantom v2511 overcomes these issues. It features up to 96 gigabytes of high-speed memory—equating to 33-second recording times at 10,000 fps and 1280 x 800 resolution. Without sacrificing image quality or speed, it achieves 25,000 fps recording speeds at full 1-megapixel resolution and up to one million fps at lower resolutions. Depending on the material under study, various frame rates were utilized including 10,000–15,000 fps for granite and 1,000–3,000 fps for shale. The camera also integrates a custom CMOS sensor with 28-micron pixel sizes for high light sensitivity—overcoming the typical lighting pitfalls associated with high-speed recording.

"The longer recording windows and high-resolution images enable us to capture the cracking process in very high detail," says Al-Dajani. "To my knowledge, we're the only group that runs these hydraulic fracture experiments in a way that creates a full picture of what's happening."



The Phantom v2511 camera.

HIGH-SPEED VIDEO AND DATA ACQUISITION

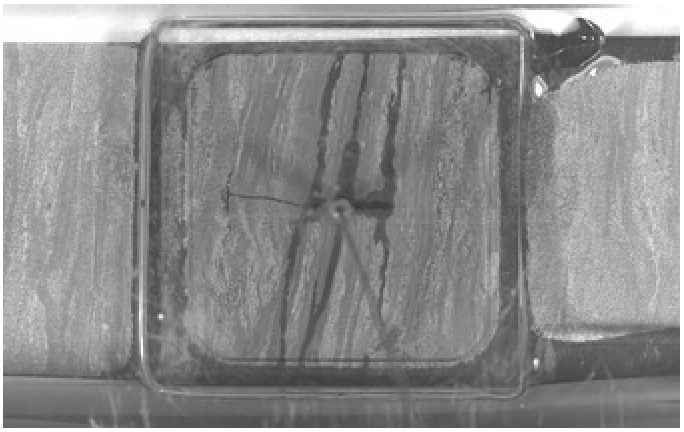
Combining high-speed imaging and data acquisition (DAQ) systems is valuable for any researcher studying fast-moving events. Linking Phantom high-speed cameras with popular off-the-shelf DAQ units lets you easily collect analog data and video data simultaneously. You can then visualize the synchronized video and analog data side by side within the Phantom Camera Control (PCC) software—improving workflow efficiency and leading to new insights about the process at hand.

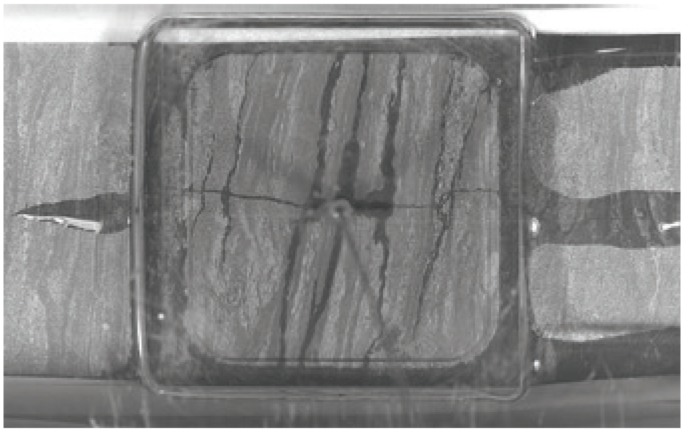
"The outputs on the back of the Phantom camera let us easily run other acquisition equipment," says Qiuyi Bing Li, MIT alumnus and PhD. "We wanted to know when in time the video was corresponding to the pressure, load or seismic energy coming out of the rock. This gave us very precise results on what was happening."

DRAWING CONCLUSIONS

The results of the hydraulic fracturing experiments led Garcia to two conclusions. First, the shape of the pressurized flaw plays a significant role in the pressure required to initiate a fracture—that is, the breakdown pressure. Smoother openings, like circles or ellipses, require higher hydraulic pressure than openings with sharper boundaries, such as a circle with notch. The longer the notch, the lower the breakdown pressure.

Second, the injected fluid to penetrate into the matrix of the rock lowers the breakdown pressure. While these results are not new, the experiments introduce an innovative, high-speed testing procedure that successfully verifies past conclusions.





The Phantom v2511 enabled the MIT team to capture the hydraulic fracking process—including when a crack starts and how it spreads. Note the crack's progression from the first image to the second.

“Thanks to the Phantom camera, we can determine the exact instant a fracture initiates, including the pressure and location” Garcia says. “Because it can keep up with the fast fracturing process, it also gives us the exact frame where two fractures coalesce—representing a very important piece of the puzzle when describing fracture propagation.”

Understanding the exact geometries of produced hydraulic fractures can help inform the design and implementation of fracking practices in the oil and gas industry.

OTHER RESEARCH METHODS

High-speed data acquisition isn’t the only experimental method used by the ERL researchers. MIT alumnus Qiuyi Bing Li, for example, employed digital image correlation (DIC)—a non-contact technique that uses high-speed cameras and special software to optically measure deformation, displacement and strain. Specifically, he analyzed individual pixels of rock from the high-speed recordings in order to quantify their displacement during fracturing. Al-Dajani has also used DIC. “I’m looking into quantifying the damage radius in the fracture process zone—a key question in oil and gas applications,” he says.