One mineral that Meade and Jeanloz squeeze in their diamond anvil cell is a hydrated form of olivine called serpentine. It forms on the upper surfaces of the ocean slabs when they are exposed to seawater. Under the relatively mild pressure conditions of the upper part of a descending slab, serpentine produced acoustic emissions that Meade and Jeanloz associate with water loss by the serpentine. The water thus released could fill the cracks in the mineral and counteract some of the pressure pushing them shut, Meade says, thus allowing them to slip and generating a mini-earthquake in the diamond anvil cell.

But a second kind of deep earthquake mechanism may be operating at higher pressures and in a broader range of temperatures, Meade says. Under those conditions, he and Jeanloz detect another set of acoustic emissions that are associated with the conversion of crystalline serpentine to its glassy, amorphous form. By inference from known transitions of this sort, some at up to 70 gigapascals, Meade and Jeanloz conclude that the atomic motions produced as crystal gives way to non-crystal might produce an earthquake-like signal from a slab.

Meade and Jeanloz are the first investigators to produce seismic-like emissions from minerals under deep-Earth conditions, so they are encouraged. They also think that the properties of their laboratory "quakes" can make sense of the observation that there are two types of deep earthquakes—those between 100 and 300 kilometers, which might be explained by the dewatering mechanism, and those between 300 and 680 kilometers, which might be driven by decrystallization.

But they are not ready to declare victory. "Just because we have acoustic emissions in serpentine doesn't mean [the same mechanism] produces deep-focus earthquakes," says Meade. "Our results are consistent with that, however. There's still a big leap of faith from the lab experiment to explaining deep-focus earthquakes."

But seismologist Frohlich warns that leap may be being made too early. "Both approaches have weaknesses. What worries me is the enthusiasm, the 'Aha, the problem has been solved' attitude." It might not be too surprising that the initial results of the these studies conflict because the two groups have taken quite different approaches to learning how deep rocks can fail suddenly in earthquakes. But now at least geophysicists have produced mechanisms that they can test further. "We're in the enviable position of trying to decide if we have the right one, rather than whether it can happen in the lab at all," as Frohlich puts it.

■ **Richard A. Kerr**

Quick Fix for Freeways

Thanks to a team of fast-working engineers, some good has come of the tragic collapse of the double-decker freeway in Oakland during the 17 October Loma Prieta earthquake. On a 170-foot stretch of freeway that remained standing, engineers from the University of California at Berkeley created a temporary laboratory to test methods for strengthening similar structures against future earthquakes. The results are now in, and they proved to be a pleasant surprise—the most effective method may be as simple as a well-placed bolt.

To simulate earthquake stresses, Jack Moehle and his Berkeley colleagues outfitted the freeway section with six hydraulic jacks, braced by A-shaped steel frames anchored to the bases of the columns that support the roadway. With the jacks, they could subject the upper roadway to 4 million pounds of horizontal force, similar to the stresses it would experience from a magnitude 7 earthquake on the nearby Hayward fault.

Marcia Barinaga

Stressing the freeway. *A hydraulic jack supported by an A-shaped frame is used to put force on the upper deck.*

The experiment would not qualify as a "fake quake," because the hydraulic jacks couldn't create the rapid back-and-forth motion of an actual earthquake. But Moehle said their slow increase of force, over about an hour, provided a reliable test of how the freeway would perform in a quake.

The engineers first used the jacks to stress the freeway with a force approaching what it experienced in the Loma Prieta quake. And sure enough, they saw signs of the same type of diagonal cracks in the support columns that brought the roadway down on 17 October. Then before the cracks got worse, they released the strain, reinforced each column pair with one of three retrofit methods, and applied the strain again, this time far exceeding the force of Loma Prieta.

One retrofit plan that came highly recommended by consulting engineers was to strengthen the concrete support columns with 10-inch steel I-beams. But this method has a problem, Moehle says, because it is nearly impossible to strap the beams tightly enough to the concrete columns to make them bend as one. The experiment bore this out: while the I-beams strengthened the columns significantly, they did not work as well as the other two methods.

A second method involved wrapping steel jackets around both the upper columns and the vulnerable area at the level of the lower roadbed where the fatal cracks develop. This approach seemed to work, but the engineers had not removed the jackets by the time *Science* went to press and so had not yet determined if the columns suffered hidden damage. And that illustrates an inherent drawback with this technique, Moehle said. "If you have another earthquake, you can't look and see how the column fared."

The scheme that seems to have worked best was deceptively simple. Several steel bands were wrapped around the upper columns, and 8-foot-long bolts called "rock anchors" were inserted into holes drilled through the column and into the lower roadbed, spanning the region where the diagonal cracks formed. The bolts provided reinforcement in precisely the spot where it was lacking in the original column design, and the bands gave added support where the upper columns are also prone to form cracks. That simple fix not only protected the columns from collapse, but also left them open to easy inspection. Moehle said he will probably recommend the method as a quick and reliable way to retrofit the three double-decker freeways in San Francisco that have been closed since the earthquake.

■ **Marcia Barinaga**