Assessing the Risk of Eastern U.S. Earthquakes

While geophysicists ponder new theories of eastern earthquakes, engineers are developing new seismic design standards

Geologists, seismologists, and engineers gathered in Knoxville last month* to discuss earthquakes in the eastern United States. The geologists and seismologists took some pride in finally understanding a few eastern earthquakes, such as the devastating New Madrid (Missouri) quakes of 1811–1812. These scientists were the first to admit, however, that they could not predict the size or location, much less the timing, of the next major eastern earthquakes. That made the engineers distinctly uneasy. They would have liked to know exactly what to expect. But even in the face of such uncertainty, the engineering community is moving ahead, slowly and amid controversy, with guidelines to standardize and tighten the procedures for designing earthquake-resistant buildings.

Scientists are most certain about the eastern earthquakes in the vicinity of New Madrid, where Arkansas, Tennessee, Kentucky, and Illinois crowd around the southeast bootheel of Missouri. During the winter of 1811–1812, three major earthquakes, each the size of the one that struck San Francisco in 1906, shook the area. They caused the land to sink tens of feet in places, drained some lakes and created others, and sent tons of sand spouting into the air. Those shocks, plus their numerous aftershocks, released as much seismic energy in 3 months as all the earthquake activity in the country normally does in 50 to 100 years, according to Otto Nuttli of Saint Louis University.

Despite the violence of that winter, geologists had never found any rupturing of the surface where the slippage of a fault might have broken through (*Science*, 15 September 1978, p. 1001), as the San Andreas so obviously does in California. The best seismologists could do was point to a highly suspicious zone of present-day microearthquake activity that zig-zags through the area of the 1811–1812 events.

Now researchers are claiming that they have found the faults responsible for the New Madrid earthquakes, although no geologist has yet found any visible fault. Instead, a group of U.S. Geological Survey (USGS) researchers led by Mark Zoback of the Menlo Park, California, office and Robert Hamilton of the Reston, Virginia, office have probed beneath the surface using seismic reflection profiling, an oil exploration technique that bounces acoustic signals off the boundaries between different rock units. They found a set of parallel faults that reached within a few hundred meters of the surface near Ridgely, Tennessee. These faults fall within the zone of greatest current seismicity. They also identified a major fracture zone beneath 1 kilometer of sediments along the far end of the southern leg of the seismic zone in northeast Arkansas.

These newly discovered faults are not only located in the active seismic zones, but they are also apparently responding to the crustal stresses that are thought to drive earthquakes in the central United States. Mary Lou Zoback and Mark Zoback of the USGS in Menlo Park compiled all of the available measurements of crustal stress in the continental United States and found that crustal rocks between the Rockies and the Appalachians are being compressed in a roughly southwest-northeast direction. That compression is close to the east-northeast compression that is tending to push the opposite sides of the faults of the southern zone past one another horizontally, as observed in the microearthquakes of that zone by Robert Herrmann of Saint Louis University.

The New Madrid fault zones have not always behaved the way they do today, noted David Russ of the USGS in Denver. The displacement along one of the faults shows that about 75 million years ago tensile stress was pulling it apart and only later did the stress reverse and begin to compress it. Russ said that such observed reversals and the periodic injection of magma into the crust in the area suggest that the faults have responded to alternating compressive and

USGS Earthquake Information Bulletin

The 1886 Charleston earthquake

**Earthquakes and Earthquake Engineering: The Eastern United States*, meeting held 13 to 16 September 1981 in Knoxville, Tennessee. Proceedings available from Earthquake Engineering Research Institute, 2620 Telegraph Avenue, Berkeley, Calif. 94704. Two-volume set, $39.95.

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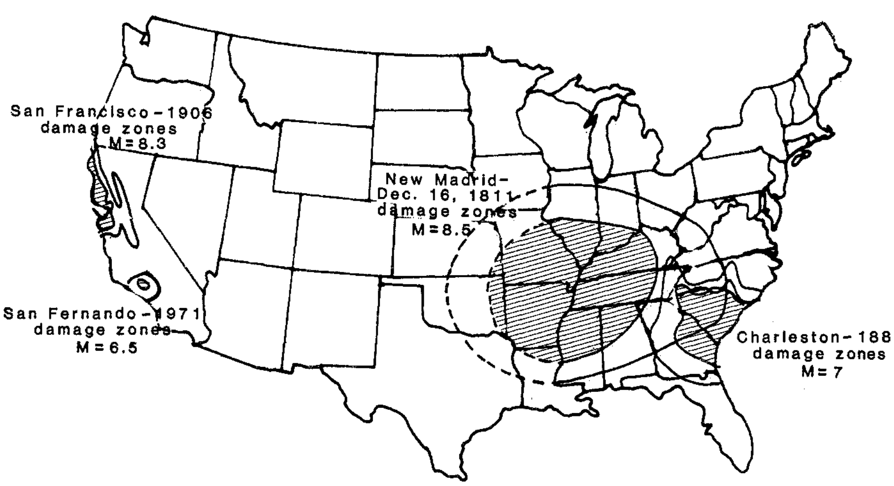

Greater damage in the East

Although the magnitudes of the earthquakes have been comparable, areas of equal damage have been larger in the East than in the West. Within the hachured areas, there was very strong shaking and buildings suffered noticeable damage. Within the open bands, damage was generally limited to overturning and falling objects. Although the given magnitudes are somewhat uncertain in the East, the New Madrid earthquakes (there were three of this size) and the 1906 San Francisco earthquake are generally considered comparable, as are the Charleston and San Fernando earthquakes. [*Adapted from a map by Robert Hamilton*]

tensile stresses since stretching of the crust formed the first of them about 500 million years ago. That was probably at the time when the proto-Atlantic, the ocean that preceded the present Atlantic, was being formed to the east by the tearing open of the continental crust. The crust of the New Madrid area felt the same stress and pulled apart slightly to form a narrow, sunken rift that now runs down a sediment-filled depression called the Mississippi Embayment. Ever since, Russ suggested, the New Madrid fault zones have felt a squeeze whenever North America banged up against another moving crustal plate and a stretching when continents have split open to form oceans.

Scientists now believe that the present compression, caused perhaps by the drag of the continent over the mantle, has caused the New Madrid faults to slip catastrophically every 500 to 1000 years in recent times. Russ has found two episodes of faulting and earthquake-generated sand blows in a trench dug near the fault zone. They occurred in the 2000 years before the 1811–1812 events. This recurrence time of 600 to 700 years compares well to one of 600 to 1000 years derived by Nuttli. He extrapolated the rate of occurrence of smaller earthquakes to one for large earthquakes.

The New Madrid faults do not seem to be the only ancient faults that have been reactivated by today's stress field. Gil Bollinger of the Virginia Polytechnic Institute and State University reported that the location of recent earthquakes define a possible fault zone in Giles County in southwest Virginia, the site of a moderate earthquake (magnitude 5.8) in 1897. Eight recent microearthquakes detected since 1978 by Bollinger's local seismometer network fell within the same 10- by 40-kilometer zone as four larger earthquakes that occurred between 1958 and 1976. James Dewey and David Gordon of the USGS in Denver precisely located the latter events in the course of an independent study. The zone is oriented northeast-southwest, cutting across the more westerly trend of the southern Appalachians of the area. In fact, the seismic activity, which occurs between 5 and 25 kilometers beneath the surface, does not appear to be associated at all with the thin surface layer of rock that overlies the region. Called the Valley and Ridge province, it was warped and crumpled as rock was thrust over the continent hundreds of millions of years ago. Bollinger suggested that the apparent fault zone in the older rock below this layer could also have formed during the opening of the proto-Atlantic and been reactivated by the present stress field. The area of the active surface of the fault suggests that it may be capable of generating an earthquake as large as magnitude 7, he said.

Elsewhere in the East, things are considerably more muddled. In Charleston, South Carolina, the other site of a major 19th-century earthquake, researchers have failed to identify the responsible fault or to determine with precision the direction of slippage caused by today's microearthquake activity. John Armbruster and Leonardo Seeber of Lamont-Doherty Geological Observatory told the audience that most researchers may have been looking for the wrong sort of fault beneath Charleston. Instead of a nearly vertical fault, as in the New Madrid area, they favor a nearly horizontal fault separating an upper, thin sheet of rock from the crust beneath the fault.

This thin sheet would be the same one that crumpled the Valley and Ridge province to the west when the closing of the proto-Atlantic thrust it onto the continent. Seismic reflection profiling interpreted by Frederick Cook of Cornell University does indicate that the thrust sheet overlies such a fault 300 kilometers to the west of Charleston in the Piedmont province. Whether the sheet extends beneath the coastal plain surface sediments as far east as Charleston is considered a matter for speculation by most researchers, but Armbruster and Seeber favor such an extension. They argue that the most violent effects of the 1886 Charleston earthquake covered too large an area to have resulted from a break on a nearly vertical fault. A break on a horizontal fault, on the other hand, could have directed its seismic energy over a much larger area of the surface, they said. A horizontal break could be caused by a tendency of the thrust sheet to backslide off the continent, which is consistent with the northwest-southeast compression assigned to the eastern seaboard by Zoback and Zoback.

The contrasting views of two other speakers emphasized the continuing uncertainty of earthquake hazard assessment in the East. Carl Wentworth of the USGS in Menlo Park argued that the most likely sources of eastern seaboard earthquakes are the faults paralleling the coast that formed during the opening of the Atlantic and that are now being compressed. Because such faults would be scattered up and down the coast, the earthquake threat would also be widespread and diffuse, as Armbruster and Seeber would predict from their theory. Patrick Barosh of Boston College took the other view—that the threat to the eastern seaboard is localized in those places along the coast where lowlands are sinking over the old edge of the continent, such as in southwest Georgia and the Saint Lawrence Valley. If Barosh is right, today's low-level seismic activity probably outlines all of the areas at risk. But most listeners agreed with Wentworth when he said, "It's going to be very difficult to figure out what's going on from the Appalachians east."

That kind of scientific uncertainty did not surprise the engineers present, but it was not what they wanted to hear. They would have liked to have been told where the earthquakes will occur and how hard the ground will shake; given that, they could adjust the usual design process to protect those and only those buildings that need protection. A plethora of local building codes, which are derived from a variety of regional and national standards, guide the engineer in making these adjustments. Because the shaking of an earthquake affects a building differently than do the wind forces that engineers normally consider, adjustments to increase seismic resistance involve more than adding strength to the building.

An engineer encounters numerous obstacles between the guidelines of a code and the completion of a seismically designed building, Thomas Tarpy of Stanley D. Lindsey & Associates, Ltd., of Nashville told his listeners. Most of the time, he said, local building officials in the southeast tell him that the earthquake provisions of the local code, such as they are, will not be enforced. No one will put that in writing, however. Then he must convince building owners and architects that the additional costs of seismic design, which can run as high as 15 percent, are worth it. And finally, subcontractors must be reminded that the execution of a seismic design requires careful attention to detail.

Tarpy reported mixed success in his attempts to incorporate seismic resistance in eastern buildings. If the engineer argues for it, the owner will usually go along with increasing the building frame's resistance to the expected shaking, Tarpy said. But other questions, which are ignored or only vaguely discussed in the present codes, create more conflicts. How much jostling of people and equipment by the building's shaking should be allowed? How resistant should mechanical, plumbing, and electrical systems be to the shaking? How well should the rest of the structure be anchored to the frame? How far should engineers allow architects to go in creating innovative, intriguingly shaped buildings whose design might actually amplify the seismic forces that it must resist? In the case of hospitals, which should not only be standing but usable after an earthquake, owners and architects take these questions seriously, Tarpy said. Office buildings do not usually receive such consideration, he noted.

If a recently developed approach to these problems catches on, engineers in both the West and the East will find more moral support and sophisticated guidance to seismic design in their local codes. The new approach is embodied in a set of tentative guidelines called ATC-3-06 after the Applied Technology Council, a private organization that directed its development with federal funding. Eighty-five professionals brought together by the ATC produced these updated seismic design standards in 1978 so that the standards might be incorporated, after further review and refinement, in local codes anywhere in the United States. Roland Sharpe of Engineering Decision Analysis Company of Palo Alto is the managing director of ATC.

One particular advantage of the ATC-3-06 approach, he said, is that it provides explicit guidance in critical areas of seismic design that are only vaguely addressed in present codes and poorly understood by some engineers. For example, codes assume that, for design purposes, less violent shaking will occur than most scientists would expect. The difference between the design shaking and the actual shaking is assumed to be absorbed by the distortion of the structure itself, whatever the particular design. ATC-3-06, on the other hand, starts with the real shaking forces and then adjusts them downward depending on the condition of the soil and rock at the site, the type of structural frame used, and how the building vibrates in response to an earthquake.

Other provisions of ATC-3-06 direct the engineer's attention to some of the details of design that do not contribute so much to the brute-strength resistance of a building as to its ability to hold itself together. ATC-3-06 requires that all buildings, even in low-risk zones, be "tied together." Beams and girders must be securely connected to their supports that will be resisting lateral shaking forces. Each section of a building, a smaller wing for example, must be able to transmit the forces created by its shaking to the part of the building that is providing resistance. The intent is that a building should resist earthquake forces as a unit and not be shaken into smaller pieces that cannot resist so well.

Henry Degenkolb of H. J. Degenkolb Associates in San Francisco, a prominent seismic engineer for many years, held a sobering slide show during the meeting's final panel discussion to point up the importance of going beyond simply building strength into a structure. He showed the 8-year-old, code-designed Imperial County Services Building that was torn down as a total loss following a moderate southern California earthquake in 1979 because its stylish open ground floor weakened it (*Science*, 29 August 1980, p. 1006). The old masonry courthouse across the street suffered no damage. He showed several buildings in downtown Managua after the great earthquake there. All were still standing, but the one designed to resist the greatest shaking suffered the most damage, while the one with no seismic design suffered the least damage. "Doesn't this tell us that perhaps we're on the wrong track?" Degenkolb said. "The real guts of earthquake engineering is not contained in present codes. We don't fully understand the tie-in between what we measure [severity of shaking] and damage." ATC-3-06 provisions that emphasize the details of engineering design are helping to shift the emphasis toward better engineering practices, he said.

Not everyone has been pleased with ATC-3-06. The various building materials trade associations have been prominent detractors. Some of them have objected strongly to the heavy penalties for using certain materials such as masonry and precast concrete. The considerable expense required by ATC-3-06 to reinforce these materials in earthquake-prone areas seems excessive to them. Trade associations had their chance last year to recommend changes during a National Bureau of Standards review. Those engineers involved in the ATC process still want to subject the modified standards to design tests for practicality and cost effectiveness, but the needed federal funding remains uncertain.

Even in its present form, ATC-3-06 is beginning to have an effect on design. AT&T, IBM, and Proctor and Gamble are using it as a guide in standards for their own buildings. San Francisco is incorporating it in its new city building code. And the forthcoming revised guidelines of the American National Standards Institute, which many local codes cite, include much of ATC-3-06's philosophy. How much of it will be practiced, especially in the East, remains to be seen.—RICHARD A. KERR

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