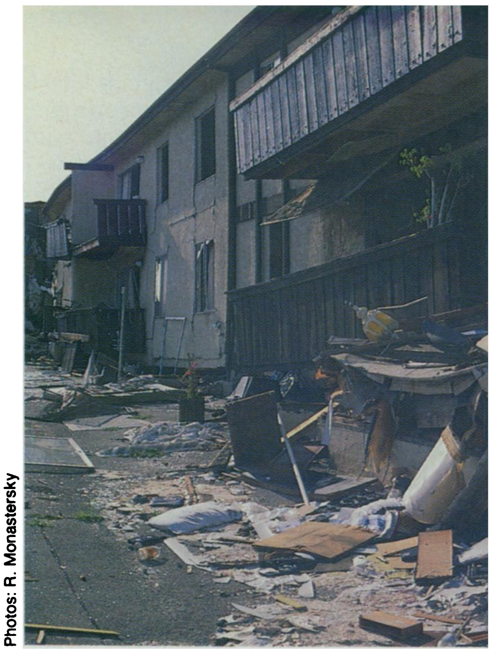
The Fatal Fling

A maverick earthquake theory spells trouble for tall buildings

By RICHARD MONASTERSKY



Photos: R. Monastersky

The weak first floor of the Northridge Meadows apartment complex collapsed, while the second and third stories remained essentially intact.

Even in her dreams, Shannon Jones couldn't escape the faint buzz emanating from the television across the room. The college senior finally dragged herself out of bed at 3:00 a.m. to turn off the set, figuring that maybe now she could get some rest. But even as she drifted off to sleep that morning, a long-dormant fault deep beneath her apartment building started to reawaken.

Twenty kilometers under California's San Fernando Valley, the rock layers had reached their breaking point. At one minute past 4:30 a.m. on Jan. 23, a crack shot up through the crust, releasing stress that had accumulated over decades.

The sudden movement sent waves of seismic energy racing at 21,000 km per hour toward Jones' first-floor apartment in the Northridge Meadows complex. They slammed against the building, hitting it repeatedly until the three-story structure gave way.

A piece of the ceiling dropped on Jones, and she ran toward the bedroom door. Then she hesitated. Turning around, the barefoot student raced in the opposite direction, stepping on broken glass to jump through her shattered window. Moments later, the building buckled, collapsing the very hallway toward which Jones had originally run. Sixteen of her neighbors in first-floor rooms perished as their ceilings caved in upon them.

With its $15 billion in damages, the Northridge quake enters the record books as the most costly U.S. earthquake yet. But like any large tremor, it has provided important lessons about how Earth moves and how best to prepare for coming disasters.

The recordings of ground motion collected during the Northridge quake and a quake 2 years ago are now convincing many seismologists and engineers that earthquakes carry a previously unappreciated hazard, a type of motion that some call seismic fling.

Unlike the typical vibrations, which rattle both near and far regions, the fling effect only occurs close to the earthquake source. But because it literally pulls the ground out from under structures, then yanks it quickly back again, this phenomenon has the potential to topple some of the most seismically resistant buildings in the United States.

While those who draft building codes are only now recognizing the hazard of seismic fling, hints of this phenomenon surfaced in earthquakes as far back as 1966. But the previous examples were not obvious, and few people focused attention on this type of movement.

"They were seen, but people did not understand their significance at the time," says seismologist Thomas H. Heaton of the U.S. Geological Survey in Pasadena, Calif., who has investigated the problem for many years and recently started drawing attention to its dangers.

Heaton shuns the term "fling" because it gives the impression of starting in one place and ending in another. He uses "displacement pulse" to describe how the ground rapidly shifts a significant distance in one direction and then back.

In the past, Heaton's mathematical simulations of earthquakes showed that displacement pulses should occur. But it wasn't until June 28, 1992, when a magnitude 7.3 quake struck near the town of Landers in the Mojave Desert northeast of Los Angeles, that scientists captured a truly clear example in nature.

Engineer Wilfred D. Iwan of the California Institute of Technology in Pasadena found evidence of a dramatic displacement pulse while examining records taken only 2 km from a fault in the Mojave. As the fault broke during the Landers quake, the ground underneath the seismometer shifted 60 centimeters away from the fault and then back in less than 5 seconds.

Iwan bolstered his case by checking the instrument that recorded the pulse. In his lab last summer, he recalibrated the sensor, ensuring that it had correctly measured the ground motion. Iwan presented his findings in April at the annual meeting of the Earthquake Engineering Research Institute.

"This provides everybody now with something that says we really measured the effect. It's not just a theoretical fault model anymore. It's something we measured in the field, and we have to be concerned about it," says Iwan.

Iwan recently detected displacement pulses in the records of the Northridge earthquake as well. But because the faulting did not reach the surface, that quake presents a more complex situation than the one at Landers. Some of the pulses recorded in January may equal, if not exceed, the size of those measured during the Landers earthquake, Iwan says.

With future work, engineers and seismologists can potentially link the displacement pulses to particular regions of damage. The stations that recorded the pulses during the Northridge quake are located north of the epicenter in the Santa Susana Mountains and the Santa Clarita Valley beyond.

Because this same area suffered significant damage, Iwan wonders whether the displacement pulses are to blame. "There's a suspicion, at least, that there is a correlation. But that hasn't been verified yet," he says.

Heaton's explorations of displacement pulses have led him to adopt an unconventional theory of faulting, which he believes explains how earthquakes can produce this type of motion.

His maverick model takes issue with the standard image of an earthquake, in which a fracture spreads like a zipper opening a jacket. According to the traditional theory, a crack starts out small and then spreads until it eventually unlocks a long stretch of fault. Once freed, rock on one side of the fault can slip past rock on the other side. So if an earthquake breaks a 50-km-long fault, the crust along this entire length will be moving by the time the rupture reaches its stopping point 20 seconds later.

Heaton, however, argues that an earthquake doesn't unlock a long stretch at once, but rather creates a small break that moves. A crack measuring a kilometer or two in length propagates along a fault like two zippers traveling together, one behind the other. The leading edge of the rupture frees the fault, then the rear of the crack seals the rock together only a second or two later. Heaton calls this a self-healing fracture.

This novel vision of faulting, if true, would change theories about how earthquakes work and deflate hopes for predicting quakes (see sidebar). At the same time, the self-healing fracture model also suggests that sites near a fault will experience displacement pulses, says Heaton. According to his calculations, as a crack passes a particular spot, it causes nearby land to shift away from the fault and then back toward the fault. The larger the earthquake, the greater the displacement.

While many experts now accept that the ground can move fast and far during quakes, they don't necessarily buy Heaton's theoretical arguments about the cause. Although no one has explored the idea yet, some believe that the traditional theory of fault rupture may also explain seismic fling. "I strongly expect that the standard model will show a similar effect," says James R. Rice, who studies faulting at Harvard University.

James H. Dieterich, a researcher with USGS in Menlo Park, Calif., also remains skeptical about Heaton's theory. "What Tom is saying is possible," Dieterich says. "But in my opinion, it's quite a ways from being demonstrated and I'd rather stick with conventional physics for now."

Whether or not Heaton succeeds in rewriting seismological theory, he is spurring engineers to redraft seismic safety codes to account for the hazard of displacement pulses.

Heaton and Caltech engineer John F. Hall recently demonstrated how this phenomenon could cause acute problems for high-rise buildings, even those built to the stringent safety codes of Los Angeles. The researchers discovered these weaknesses while modeling how a 20-story building would respond to a hypothetical magnitude 7 earthquake located 10 km away.

In their calculations, the ground beneath the building shifted to the southwest by more than 1.6 meters (5.2 feet) and then slid back to its original position

A severely damaged apartment building in Northridge. After the quake, inspectors declared unsafe approximately 3,000 buildings in the Los Angeles area.

in roughly 5 seconds. Because the building is tall and flexible, however, it couldn't withstand that motion.

Imagine the base of the building shifting to the southwest while the top floors lag behind. By the time the top floors start swinging to the southwest, the bottom of the building is moving in the opposite direction. The result: a structure headed rapidly toward the horizontal.

"If you move the base of a building a large distance, basically you're knocking the legs out from underneath it. It's very important in a tall building that the columns stay vertical. If they tilt very much, they're in trouble," says Heaton. Indeed, Hall calculates that this hypothetical 20-story structure would topple if subjected to such movement.

(As if the displacement pulse would not do enough damage, the Northridge quake also revealed other problems. Numerous steel buildings developed cracks in connections between beams and columns, greatly reducing the strength of these structures. Engineers do not yet know how well steel buildings will stand up to a stronger quake.)

Even before the high-rise experiment, Heaton had started worrying about the consequences of displacement pulses. Those thoughts first came while he visited the basement of a base-isolated building — a design that uses rubber pads or springs to separate the building from the foundation.

A carpet-layer's guide to earthquake theory

Do earthquakes follow some predictable pattern, or do they obey the whim of chaotic forces within the Earth? The answer depends on the way the crust breaks — a secret that seismologists have yet to unlock.

The traditional concept of an earthquake holds that stress gradually increases in the crust until it exceeds the friction pressing two sides of a fault together. At first a small patch of rock starts to slide. Then the rupture grows until it frees a large zone. As the blocks of crust slip, they release most of the pent-up energy that had accumulated for decades.

Because the stress on the fault increases by a steady amount each decade, this suggests that — in theory at least — seismologists could forecast the general timing of an earthquake. In fact, U.S. researchers have used the concept to gauge the long-term seismic risk for different parts of California.

But some measurements of faults and earthquakes have raised questions about the standard theory. Heat presents one problem. If friction on a fault really did reach expected levels, then slippage of rock during earthquakes should generate tremendous amounts of heat that would persist for millennia. But extensive measurements of ground temperatures near faults have come up cold.

Scientists also think that earthquakes release far less stress than the standard model would predict, says Thomas H. Heaton of the U.S. Geological Survey.

In thinking about these problems, Heaton and other seismologists have resurrected a different earthquake theory, proposed long ago but never accepted. According to this rival idea, stresses need not build to a set level before a fault can slip. Fluids in the crust or other factors can temporarily reduce the friction on a fault, enabling it to fail at any time. When it does start sliding, the fault does not slip all at once. Rather, a small gap runs down the fault, unlocking rock in front and sealing rock behind.

According to Heaton, it is much easier for rock to slide this way. He likens the two sides of a fault to a carpet sitting on a floor. Imagine trying to move the carpet several inches. Instead of dragging the whole piece at once, it would take less effort to introduce a small wrinkle and then push that wrinkle across the carpet.

The self-healing slip model would solve some of the problems raised by the standard theory. Because faults slip under much lower frictional forces, earthquakes would produce less heat. Unfortunately, the unconventional model also bodes ill for earthquake predictions. If true, scientists could not count on faults behaving regularly, with stress building up to a certain level before triggering an earthquake.

— R. Monastersky

Because it reduces shaking, this system is growing more popular in seismically active cities. Builders increasingly are using it in critical facilities such as hospitals or emergency services offices. To Heaton, however, the base-isolation design seems ill-suited to handle a large displacement pulse.

During the Northridge quake, the five base-isolated buildings already completed in the Los Angeles area rode through the vibrations quite well. But the closest structure, a wing of the University of Southern California Hospital, sat a comfortable 35 km from the epicenter.

If the same building had stood in Sylmar, much closer to the fault, it would not have fared as well, says Caltech's Iwan. The displacement pulse measured in Sylmar would have moved the hospital 40 cm during the quake. But the gap between the building and a surrounding concrete enclosure allows only 26 cm of movement, notes Iwan. The hospital would have crashed into concrete walls at a speed of 1.3 m per second. For comparison, consider walking at a brisk pace smack into a concrete wall.

"One would have to have serious concern about the performance of that structure had it been located in Sylmar," Iwan says.

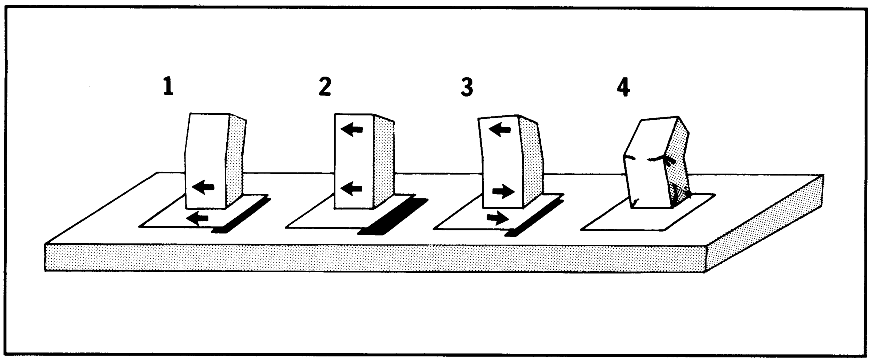
As chairman of the California Seismic Safety Commission, Iwan can do something about the new findings. After the Northridge earthquake, Governor Pete Wilson asked the commission to recommend needed changes in the building code. As currently written, the code deals primarily with the forces generated during an earthquake and therefore does not directly address the issue of rapid displacements that occur during seismic fling.

The issue of fling is not just a southern California concern. Scientists and engineers in the San Francisco Bay area must also grapple with this phenomenon, because several quake-producing faults underlie this region as well.

Iwan and others note that seismic fling doesn't threaten an entire area shaken by a quake, because large displacements only occur in the "near field" — the land closest to a fault. But he says researchers have not yet defined how far the near field area extends from a fault.

Answering the question "How close is too close?" is particularly difficult in the Los Angeles Basin, a region riddled with known and unknown faults.

"If you have the possibility of these earthquakes anywhere in the basin," asks Iwan, "do you zone the whole basin for this kind of motion? And if so, what does that mean? Does it mean restrictions on types of structures or heights of structures? I don't know the answer to that." □



Dan Skripkar

When a displacement pulse passes a tall building and pulls the lower floors to the left, the top floors remain stationary (1). Soon the upper stories catch up and the entire building moves to the left (2). Then the pulse reverses, pulling the lower floors to the right even as the top floors continue to the left (3). As the ground returns to its original position, the building deforms and may collapse (4).

Environment

Global warming: Beyond termites

Over the last dozen years, scientists have debated how much termites might contribute to the threat of global warming. These insects emit methane — a potent greenhouse gas.

In 1990, an international team of researchers quantified methane emissions for six species of Australian termites. Their conclusion: Such bugs probably cannot produce enough of the gas collectively to play an important role in what had been a steady growth in atmospheric methane (SN: 4/28/90, p.268).

Now, in the June 7 Proceedings of the National Academy of Sciences, two European biologists reopen the debate. Their study indicates that insects and their kin indeed "can contribute substantially to atmospheric methane." But to understand how, they add, requires looking beyond termites.

Working at the Catholic University of Nijmegen, the Netherlands, Johannes H.P. Hackstein and Claudius K. Stumm measured methane releases from 110 types of arthropods — a phylum of segmented animals that includes insects, spiders, and crustaceans. "We expected to find methanogens [methane-producing bacteria] in all arthropods," they say. Instead, only four classes — termites, millipedes, cockroaches, and scarab beetles — possessed the symbiotic microbes.

But even within these classes, not all species produced methane. Those that did tended to be tropical, suggesting that methane-producing symbionts might not survive colder climes.

Based on the new measurements, each of the three additional classes of arthropods "may contribute more or less the same amount of methane as do termites," Hackstein told Science News. He and Stumm now estimate that land-based arthropods produce at least 10 teragrams (trillion grams) — and perhaps as much 300 teragrams — of the roughly 500 teragrams of methane released into the global atmosphere annually.

Moreover, Hackstein points out, "tropical cockroaches caught in Africa have been reported emitting at least four times the amount that I measured in the lab and report here," while roaches collected outdoors in temperate regions produced no methane. "Our studies ... show that [temperate] cockroaches living in houses can produce tremendous amounts of methane — nearly as much as tropical ones." To err on the side of caution, he explains, the new estimates make no attempt to account for methane from indoor, temperate roaches.

Good news about some gray whales

On June 15, the Fish and Wildlife Service (FWS) removed the California gray whale from the federal endangered species list. Since the 1973 Endangered Species Act (ESA) became law, only 16 other species have been "delisted" — and all but three of those because they were presumed extinct.

Grays are one of 13 species of large whales, all of which had been considered threatened or endangered. There are now some 21,000 California grays, which migrate in the eastern Pacific from the Bering Sea to Baja California. Federal estimates indicate that this is probably as many grays as existed there in prewhaling days. The remaining, "Korean" stock — numbering perhaps a few dozen grays — will stay on the ESA list.

Two birds also show signs of recovery. Last fall, FWS proposed delisting arctic peregrine falcons. Within weeks, the agency also plans to propose reclassifying the bald eagle in part of its range from endangered to simply threatened.