SEISMOLOGY

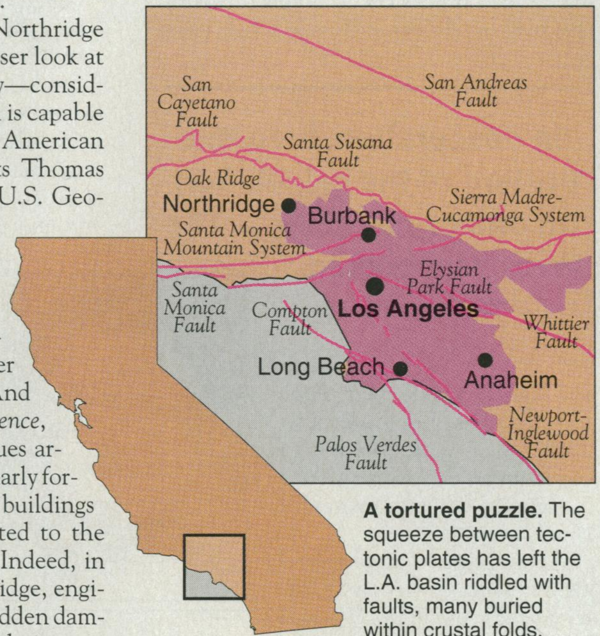
Bigger Jolts Are on the Way For Southern California

When it comes to earthquakes, the news in southern California is usually bad. First it was the mighty San Andreas fault. The San Andreas passes Los Angeles at a distance of more than 40 kilometers, but the realization in the early 1980s that the next great quake there may be due at any time was sobering. Then the 1987 Whittier Narrows earthquake and last January's highly destructive Northridge quake underscored an additional threat: quakes on smaller faults directly beneath the Los Angeles basin. Now, seismologists are warning that those faults can be even more destructive than they had seemed.

In spite of the devastation Northridge residents endured a year ago, a closer look at the quake suggests they got off easy—considering what the fault beneath them is capable of. At last month's meeting of the American Geophysical Union, seismologists Thomas Heaton and David Wald of the U.S. Geological Survey (USGS) in Pasadena, California, pointed out that the fault rupture focused its destructive energies in the sparsely populated Santa Susana Mountains, well north of the epicenter beneath the city of Northridge. And on page 206 of this issue of *Science*, Heaton, Wald, and their colleagues argue that the near-miss was particularly fortunate, because tall steel-frame buildings are more vulnerable than expected to the worst that a quake can dish out. Indeed, in spite of the lucky break in Northridge, engineers have recently ferreted out hidden damage in steel-frame buildings whose design was intended to allow them to weather earthquakes like Northridge's unscathed.

Northridge's narrow escape is bad news for the future—"a double whammy," as Heaton puts it. Even if the next L.A. basin earthquake is no bigger than the magnitude 6.7 recorded in Northridge, "the ground motions will be larger than the design [allows for], and the buildings will be weaker than the design [intended]." And Northridge may have been only a foretaste of what the shifting crust under Los Angeles has in store. In two other papers in this issue (pp. 199 and 211), researchers warn that the L.A. basin has probably been in an earthquake lull over the past 200 years. The calm will likely be broken by a barrage of Northridge-size earthquakes, by a single, far larger quake, or some combination of the two.

Angelenos might well ask how anything could be much worse than Northridge—after all, residents of that city were sitting directly over the earthquake's epicenter. But Heaton and Wald point out that the highest ground velocity in that earthquake—and the highest ever recorded in any quake—was felt 10 kilometers north of the epicenter in the mountains. For a moment, the ground there moved at a velocity of 6 kilometers per hour, the pace of a brisk walk, and shifted by up to half a meter. Those ground motions were up to two to three times more severe than those near the epicenter in Northridge, where the buildings are.



SOURCE: DOLAN ET AL. ILLUSTRATION: C. FABER SMITH

A tortured puzzle. The squeeze between tectonic plates has left the L.A. basin riddled with faults, many buried within crustal folds.

This intense shaking, say Heaton and Wald, was focused to the north of the epicenter, because in that direction—along the fault that slopes up to the north beneath the city—the earthquake's energy was concentrated in one pulse. When the fault began breaking upward from the deep end, explains Heaton, the rupture sent seismic waves rushing away in every direction, but along the fault they were only fast enough to stay just ahead of the rupture. Much like the sound waves ahead of a jet at Mach 1, these seismic waves piled up in front of the rupture to deliver an extra-strong punch north of the epicenter. That punch is evident in seismic records as a "quick jerk," which delivered up to 80% of the earthquake's total kinetic energy, says Heaton.

That quick jerk wasn't a peculiarity of the Northridge earthquake, Heaton and his colleagues note in their *Science* paper. They examined 27 other seismic records from 10 earthquakes around the world that happened to catch the shaking near the fault. In almost every case the records reveal a concentration of seismic energy in the direction of the fault rupture. "The lesson is—we can expect strong shaking in close to large earthquakes," says Heaton, stronger than buildings suffered in Northridge.

To see what kind of toll might result from a future quake that aimed its seismic pulse at buildings in Los Angeles, Heaton and Wald teamed up with engineers John Hall and Marvin Halling of the California Institute of Technology (Caltech). They simulated in a computer model how a 20-story steel-frame building would react to a pulse of seismic waves from a magnitude 7.0 quake. Their quake took place on a hypothetical fault much like the Elysian Park fault that underlies downtown Los Angeles, and it "shook" a steel-frame building meeting the standards of the California Building Code of 1991. The result: That code—the standard for the country—may not be good enough.

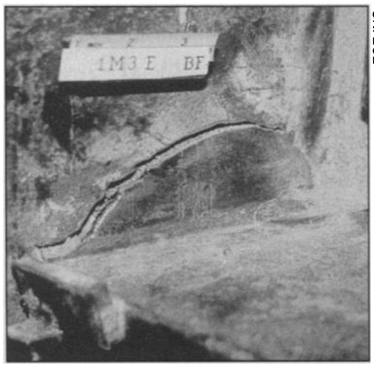
Steel-frame buildings readily meet the code because they are thought to be inherently earthquake-resistant: In moderate shaking, they are supposed to sway like a tree in the wind. Stronger shaking should permanently bend and stretch the steel beams and columns, absorbing much of the quake's energy and saving the building from collapse.

Exposed to the strong pulse of shaking from the hypothetical quake, the model building did bend without collapsing, but only because its creators gave it no means of failing. When the full brunt of the displacement pulse hit, it swayed 35 centimeters between its first and second stories—three times more sway than is generally considered "severe." How such extreme swaying would damage a building is difficult to simulate in a model, but when the modelers allowed it to fracture one column in a subsequent run, the model building collapsed.

When Heaton and Hall tested a different kind of construction—three-story buildings built on a rubber pad to damp the shaking, the current standard for crucial facilities like hospitals—the results were equally disheartening. In the computer simulation, these buildings, too, were shaken beyond their design limits. The severe shaking from a seismic pulse poses "a fundamental problem" not just for ordinary steel-frame buildings, but for other types of construction as well, says Heaton. "The solution is not obvious."

Not all earthquake engineers agree that the danger is as great as Hall and Heaton suggest. "Engineers are always a little bit skeptical of the seismologists when they come up with larger and larger ground motions," admits Hall. And Andre Reinhorn of the University of Buffalo thinks the capability of steel-frame buildings to resist severe shaking has not yet been fully explored.

Still, he and other engineers acknowledge that the Northridge earthquake provided an unplanned test of how well steel-frame construction weathers a nearby earthquake. "A significant number of buildings of modern steel construction were subjected to very strong ground motion for the first time," says seismic engineer John Shipp of EQE International Inc. in Irvine. And even though the test was not as tough as it might have been, "they performed poorly."



EQE INC.

A nonfatal flaw. The Northridge quake cracked joints in steel-frame buildings, although none collapsed.

None of the buildings identified—more than 100, at distances of up to 25 kilometers from the epicenter—collapsed, but they suffered numerous breaks at connections between the horizontal beams and the vertical columns that form their steel framework. Why these buildings cracked instead of swaying harmlessly isn't clear yet, says Reinhorn, but he and other engineers are considering whether the recent trend toward relying on a few big beams and columns to absorb most of the strain from an earthquake may have been a mistake. The strategy requires unusually large welds, difficult to perform properly under construction-site conditions.

New kinds of steel-frame construction might eliminate such welds, bettering the odds in the next Northridge-sized quake. But that may not be enough, as worse quakes could be in store for the Los Angeles basin. In their paper in this issue, geologist James Dolan of Caltech and his colleagues associated with the Southern California Earthquake Center, headquartered at the University of Southern California, argue that when it comes to major earthquakes, the city has some catching up to do.

By some simple accounting, seismologists have found that the number of earthquakes recorded over the last 200 years seems to fall well short of that expected. The Dolan group studied six major fault systems in the L.A. Basin to determine how much deformation they have undergone over thousands of years as the Los Angeles basin is squeezed by the collision of the Pacific and North American plates. Assuming all the deformation occurred during earthquakes, Dolan and his colleagues conclude the basin must have experienced earthquakes at an average rate much higher than that of the past 200 years. If the quakes were no bigger than Northridge, they must have come every 11 years on average—which would mean, says Dolan, that Los Angeles is long overdue for a spate of Northridges.

The more likely possibility, suggests Dolan, is that most of the slip occurs in a few much larger quakes, with magnitudes of 7.2 to 7.5, that occur every 140 years on average. And in the third paper in this issue, Susan Hough of the USGS in Pasadena lends support to this large-quake alternative. By extrapolating from the frequency of Southern California earthquakes of various sizes, she argues for a mix of moderate and large earthquakes—a half-dozen Northridge-sized ones and one magnitude 7.4 to 7.5 quake every 300 years or so.

The only escape from these grim implications is one explored in a long-awaited report from the Working Group on the Probabilities of Future Large Earthquakes in Southern California, to be released next week. The Working Group, funded primarily by the National Science Foundation and the USGS, considers the possibility that most of the strain on faults beneath the Los Angeles basin is being released quietly, by gradual slip (*Science*, 28 January 1994, p. 460). In that case, there would be no shortfall of earthquakes, and Los Angeles would have nothing worse to fear than it has experienced in recent decades. But now that a second look at Northridge suggests even the status quo is worse than it had seemed, that is likely to be cold comfort to jittery Angelenos.

–Richard A. Kerr

NEUROSCIENCE

A New Face for the Glutamate Receptor

When a baby is born, eager relatives immediately search its face for its father's dimple or its mother's eyes. And in much the same way, biologists examining a newly discovered protein keep a sharp eye out for structural features that may link the protein to its relatives. Such family similarities among proteins are much more than emotionally satisfying: They can be enormously helpful in determining how a protein works. But just as initial appearances among new family members can be deceiving, first impressions of a new protein may turn out to be misleading as well. That is just what happened recently in the case of the proteins that act as receptors for the amino acid glutamate, an important neurotransmitter in the brain.

Five years ago, researchers cloned the first glutamate receptor gene and found that the amino acid sequence of the protein made by the gene resembles those of the receptors for several other neurotransmitters. That led the researchers to predict that the glutamate receptor fits into the cell's outer membrane as those other receptors do, with the protein crossing the membrane four times. The sequence comparison "was all we had to go with at the time," says Stephen Heinemann of the Salk Institute, leader of the team that proposed the original model. But while that was a good working model then, he adds, "I think we were wrong."

Recent work, including findings described in two papers from Heinemann's group in the December issue of *Neuron*, suggests the glutamate receptor has three membrane-spanning segments, not four. If it's correct, this new model will turn the prevailing view of the glutamate receptor on its ear. And many in the field believe it is right. "I think it will be accepted," says Arthur Karlin, who studies receptor structure and function at Columbia University College of Physicians and Surgeons. Evidence against the old model has been accumulating, he says, and most is "consistent with this [new] idea."

In addition to providing a better understanding of the evolution and function of the glutamate receptor, which plays a key role in learning and memory, the new work could have clinical implications. Excess activity of the glutamate receptor contributes to brain damage during stroke and seizure; a better understanding of the receptor could aid in designing drugs to prevent this kind of damage. Beyond that, the about-face has a broader significance: It serves as a warning to protein researchers not to make too much of family resemblances until the baby's parentage has been conclusively established.

Heinemann's group cloned the first gene for a glutamate receptor in 1989 and shortly thereafter came up with their original model of the receptor structure by making use of a "hydropathy plot." This method, a standard for analyzing protein structures, involves searching for fat-loving stretches in a protein's amino acid sequence; such stretches may traverse the cell membrane when the protein assumes its normal configuration within the cell.

When the Salk workers performed a hydropathy plot on the glutamate receptor, they identified four fat-loving segments and therefore proposed that the protein crosses the membrane four times. This arrangement implied that both ends of the protein (the so-called amino- and carboxy-terminals) dangle outside the cell, where they would presumably form the glutamate binding site;