California's Shaking Next Time

On this month's anniversary of southern California's last great earthquake, scientists ponder how bad the next might be

The ninth of January was the 125th anniversary of the great Fort Tejon earthquake of 1857. Every earthquake since then along the San Andreas fault in southern California has been but a quivering by comparison with that monstrous rupture. In spite of the perennial commotion about California's earthquakes, southern California is not overdue for its next great quake. But the anniversary does mark a milestone of sorts. Scientists believe that the fault needs at least 125 years, on average, to prepare for its next catastrophic failure. The rest of the wait could be a day or a century. When it does strike, southern California will suffer a disaster of vast proportions, but not the devastation conjured up by imaginative doomsayers.

One thing that could help ameliorate the effect of the impending earthquake is a clear warning. American scientists have not had much success with prediction (*Science*, 2 November 1979, p. 542), but they have some reason to think that the next great earthquake might not strike unannounced. According to historical research by geologist Kerry Sieh of the California Institute of Technology, at least four foreshocks struck California in 1857 in the 9 hours before the main shock, which came at 8:24 a.m. Residents from Santa Barbara to San Francisco felt the last two foreshocks, one at dawn and the other at sunrise. As best Sieh can tell, they occurred at or near the northern end of the 360-kilometer rupture of the San Andreas, in the vicinity of Parkfield and Cholame (see map).

If Sieh's tentative location is correct, these Parkfield-Cholame foreshocks probably triggered the great rupture that followed. That trigger has been pulled four times in this century, moderate earthquakes having broken the same 20-kilometer section of the San Andreas south of Parkfield in 1901, 1922, 1934, and 1966. Nothing else happened then, but researchers say that the San Andreas to the south of Cholame was probably not primed yet for a great earthquake. The priming is done by the slow motion of the Pacific and North American plates past each other. To the north of Parkfield, the opposite sides of the fault creep by each other unimpeded, which produces no great quakes. To the south, the fault locks up and refuses to move except in the infrequent, jerky movement of earthquakes. Many researchers now believe that a single irregularity on the fault, such as a bend or offset, can control the locking and rupturing of an entire section of the fault.

According to a model proposed by Sieh, the 1857 foreshocks may have been due to a sudden slippage of the San Andreas that broke through the irregularity, or asperity, at Parkfield and drove into an asperity at Cholame. The strain on that asperity may have become so large since the previous great earthquake that within a few hours it broke as well. Nothing stopped the rupture until it ran into a fork in the fault system (another possible asperity) northwest of San Bernardino. According to this model, the Parkfield quakes since then have been hammering on the same Cholame asperity like repeated sledge blows on a wedge—so far, without effect.

Any warning of the next great earthquake might be extended beyond a few hours by the kind of precursors associated with the 1966 Parkfield earthquake. Two weeks before the main shock, Clarence Allen of Caltech was showing off the San Andreas near Parkfield to a group of visiting Japanese scientists. On that trip, they found and photographed fresh cracks in the ground along a road. Only 10 hours before the main shock, a farmer's water pipe spanning the fault near Parkfield broke. These events were "pretty strong circumstantial evidence," says Allan Lindh of the U.S. Geological Survey (USGS) in Menlo Park, California, that the continuous slow creep on the fault near Parkfield had accelerated to perhaps ten times its normal rate before the quake. In the final 4 hours, the magnitude 5.6 main shock had its own set of smaller foreshocks.

Lindh is keeping a close eye on the Parkfield-Cholame area, but this convenient chain of events may not be repeated before the next great earthquake. Other moderate earthquakes have generally not been so cooperative. The magnitude 5.7 Coyote Lake earthquake struck without warning south of San Francisco Bay in August 1979, even though the USGS had blanketed the area with instrumentation.

The San Andreas might further complicate prediction, as well as disaster planning, by not breaking next time along the same length as last time. Researchers divide the San Andreas in southern California into several sections. Sieh has found that the northern section of the 1857 break, from Tejon Pass at the bend in the San Andreas (a possible asperity) to Parkfield, slipped about 9 meters, while the southern section of the break slipped only 3 to 4 meters. Most researchers conclude that plate motion will add strain to both sections at equal rates, bringing the southern one back up to the breaking point first. That rupture has a 50 percent probability of happening within the next 30 years, Sieh says, if the fault's past behavior is any guide. He has studied the timing of the great earthquakes of the past 2000 years on the San Andreas by examining the disrupted sediments on the fault.

If only the southern section broke, it would still produce a great earthquake of magnitude 8 on the part of the San Andreas nearest to Los Angeles, Sieh notes. This section has also been the site of the Palmdale bulge (*Science*, 18 December 1981, p. 1331), an easing of the squeeze on the fault in 1979 (*Science*, 15 February 1980, p. 748), and an unusual swarm of microearthquakes in 1977. These are the sorts of phenomena usually mentioned as likely precursors of the next great earthquake.

A fault break shorter than that of 1857 may be the most plausible outcome, but possibilities exist for even more widespread destruction. Like the Parkfield earthquakes, the 1857 rupture rammed into and stopped at an asperity, says Lynn Sykes of Lamont-Doherty Geological Observatory. In that case the asperity is formed by the branching and rejoining of the San Andreas fault between Palm Springs and San Bernardino, he says. If Sieh's studies at Indio hold for the entire section of fault between this asperity and the Salton Sea, no great earthquake has ruptured the asperity for at least 600 years. Accumulating strain appears to have gone unrelieved there, Sykes says, while at least three great

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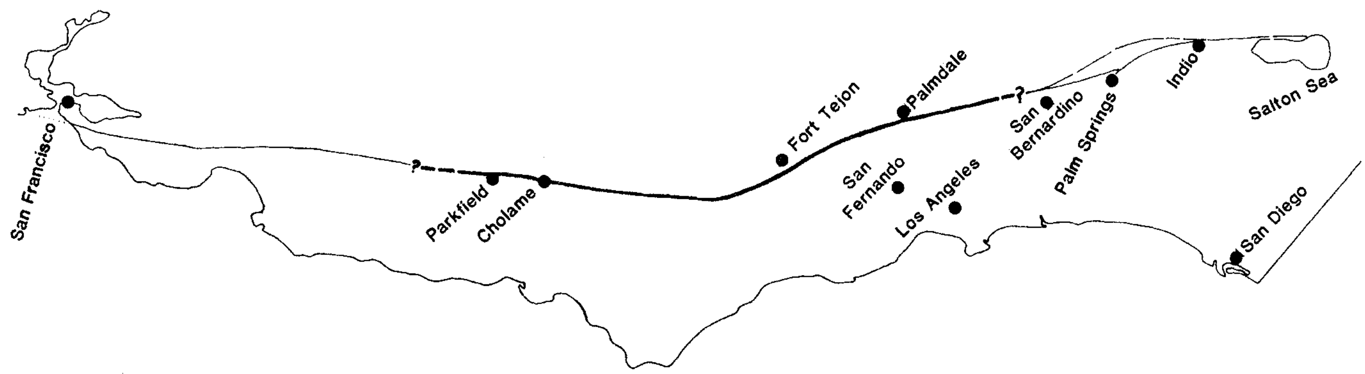


The 1857 rupture of the San Andreas fault

The bold line is the section that slipped in 1857. The section south of San Bernardino seems to have been locked for at least the past 600 years.

earthquakes occurred to the north. That much strain, when released along the 200 kilometers of that section, would produce an earthquake at least as large as any known in California, Sieh notes. If the San Bernardino asperity failed during rupture of the San Bernardino–Salton Sea section, the southern half of the 1857 break could be added to that great quake as well.

Paradoxically, the ground shaking from even the greatest of these possible quakes would last longer but would not feel much stronger to Los Angelenos than the shaking they experienced in 1971 from the magnitude 6.5 San Fernando earthquake. One reason for this is that the shaking increases with the size of the earthquake, but only up to a point. An earthquake of magnitude 7 shakes the ground harder than one of magnitude 6, but the shaking of a great earthquake (magnitude 8 or larger) feels no greater; the longer fault rupture of a great earthquake simply shakes a larger area. Another reason is that the shaking attenuates with distance from the fault, much as sound fades with distance. In California, the earth is particularly efficient at deadening the shock, so that few persons on solid ground in San Francisco even felt the 1857 quake, and it went unreported from towns east of Sacramento.

Fortunately for the 9 million residents of the area, downtown Los Angeles lies 50 kilometers from the San Andreas, the sparsely populated San Gabriel Mountains accounting for the first 35 kilometers. By searching contemporary accounts of the 1857 earthquake, Sieh found that it badly frightened the people of what is now downtown Los Angeles, but caused no severe damage there. The same seemed to be true for San Bernardino and Santa Barbara, although the reported shaking was somewhat stronger in the San Gabriel and San Fernando valleys.

The expectation that most southern Californians would feel only moderate shaking during a repeat of the 1857 earthquake is supported by calculations made by engineer John Blume of URS/John A. Blume Associates of San Francisco. On the basis of the size of the shock, its propagation, and local soil conditions, such a great earthquake would shake Beverly Hills, Burbank, Glendale, Los Angeles, Pasadena, and Santa Monica no more than the San Fernando earthquake did. San Bernardino, just beyond the southern end of the 1857 rupture, would be shaken harder than downtown Los Angeles, but not as hard as San Fernando itself in 1971. Palmdale and other small cities close to the fault would be hit hardest, harder than San Fernando in 1971.

Although most predictions of felt shaking generally resemble Sieh's and Blume's, engineers have much more trouble agreeing on how much damage the shaking will do. Part of the problem is that although moderate and great earthquakes feel much the same to people, there are still major differences in their effects. For one thing, some buildings "feel" great earthquakes differently than people do. People feel seismic waves having periods of 1 second or less. The same waves set in motion buildings of about ten stories or less. Buildings of 20 stories or more feel proportionately longer waves, having periods of 2 seconds and longer, which are not generally sensed by people. Because longer-period waves experience less attenuation than shorter ones and are more efficiently generated by long ruptures, a great earthquake on the San Andreas would damage taller buildings more than the less distant San Fernando quake.

Another difference is that the shaking of a great earthquake lasts many times longer than that of a moderate one. Even traveling at 2.5 kilometers per second, the 1857 rupture would have taken more than 2 minutes to rip along the 350 kilometers of fault from Parkfield to San Bernardino. Most witnesses reported 1 to 3 minutes of shaking. The 13-kilometer rupture of the San Fernando earthquake produced only about 15 seconds of strong shaking. Unfortunately for those making damage predictions, construction practices typical of southern California today have not been tested by prolonged, strong shaking dominated by long-period waves.

Faced with these uncertainties, engineers readily admit that damage prediction is highly subjective—some call it an art rather than a science (*Science*, 29 August 1980, p. 1004). Published estimates include few specifics, predicted losses usually being expressed in terms of total dollars for a region or as statistical projections. A single estimate may have a stated error of a factor of 2 to 3, and separate estimates vary by as much as a factor of 10. Even so, leading earthquake engineers do generally agree on the kinds of buildings that are relatively safe and those that are most likely to fail.

In the Los Angeles area, most single-family houses of wood-frame construction should suffer little more than cracked walls and shattered glass, due to their durability and the attenuation of short-period waves. Likewise, engineers express faith in the tallest of the high-rises. Waves with periods of more than 3 seconds will sway buildings taller than 30 stories, but engineers expect that the design expertise lavished on these large construction projects will stand them in good stead. A great earthquake will jostle their contents (including people), crack plaster, and even cause yielding of some steel structural members, but the buildings should remain intact.

Engineers are deeply concerned about two types of buildings—older masonry structures and, surprisingly, modern midrise buildings. Downtown Los Angeles alone has more than 5000 unreinforced masonry buildings that were erected before 1933, when the disastrous performance of such construction in the Long Beach earthquake prompted changes in the building code. A 1973 report by the National Oceanic and Atmospheric Administration (NOAA) predicted that more than half of the 11,000 deaths expected during a workday repeat of the 1857 earthquake would occur in downtown Los Angeles, where pre-1933 masonry buildings are concentrated.

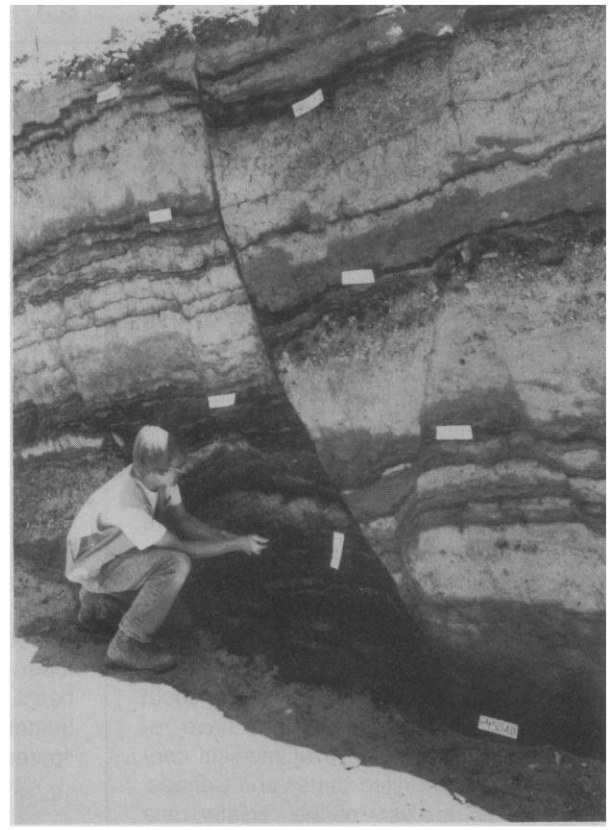
Unlike older masonry buildings, the 10- to 15-story buildings put up during the 1950's and 1960's met specific requirements of applicable codes for earthquake resistance. Although lower masonry buildings may be protected somewhat by the attenuation of short-period waves, the 1- to 2-second waves that shake these midrises will still be strong. Engineers fear that the concrete of these buildings was not reinforced in a way that will provide enough ductility to resist shaking without serious damage or collapse. They also regard many of the popular architectural designs of that time as suspect. Too many of them, they say, have open stories or structurally useless glass or flimsy panels where there should be stress-resisting walls. The misplacement by a few meters of a single wall on the open ground floor of the Imperial County Services Building apparently doomed it to being razed following a 1979 earthquake (*Science*, 29 August 1980, p. 1006). Changes in the building code in 1973 dealt specifically with the ductility problem. Codes still leave architectural configuration to the judgment of the architect and the engineer, a show of trust that many earthquake engineers regard as unwise.

Although engineers generally avoid discussing possible damage to particular buildings, several reports have attempted to draw on past earthquake experience to predict damage from a repeat of the great 1857 earthquake. The toll taken by such an event would probably be unprecedented in the history of the United States, these studies find, but it could not approach the losses suffered in other countries where construction practices meet lower standards. According to the NOAA study of Los Angeles and Orange counties, 3000 people would die if the earthquake struck at 2:30 a.m., when most people are in relatively safe homes. Eleven thousand would die if it struck at 2:00 p.m., when many are downtown. In contrast, at least 240,000 Chinese died in 1976 when a quake struck directly beneath Tangshan, collapsing their unreinforced masonry homes.

Disruption of public services would be widespread, the NOAA study found.

The main trace of the San Andreas fault

An excavation by Kerry Sieh (pictured) at Pallet Creek, near the southern end of the 1857 rupture, reveals the main fault trace associated with the past five earthquakes on the fault there. The beds on the lower left side were laid down in about A.D. 200 and those near the top left in about A.D. 600. Beds that were once continuous have been offset more than a meter, the right side moving downward relative to the left.



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The pipelines, rail lines, and aqueducts crossing the San Andreas would be cut. The shaking would break water mains at 1200 different places and gas lines at 1500 places. It would knock out 50 percent of electrical transmission lines and 50 percent of sewage pumping and treatment plants. Almost 400 old masonry buildings might collapse, littering the streets with 44,000 tons of debris. Landslides would block mountain roads. Forty-six thousand persons would be homeless for a week or more due to damage or loss of utilities, according to the report.

A 1980 update of the NOAA report by the Federal Emergency Management Agency (FEMA) placed a $17 billion price tag on such a disaster. That does not include damage to transportation or communication systems, dams, or military bases. Although only a moderate event on the edge of the Los Angeles metropolitan area, the San Fernando quake caused a loss of $0.5 billion (1971 dollars). By comparison, tropical storm Agnes caused damage of $3.5 billion (1972 dollars), the largest economic loss in U.S. history. The $17 billion figure and the casualty estimates could be too high or too low by a factor of 2 to 3, the FEMA report concedes. In contrast, Blume's study produced a loss estimate almost ten times lower, which is probably the lowest of all estimates. There is little agreement about the reasons for the large difference.

The coming great earthquake should not be the only concern of Californians. Although a great earthquake on the San Andreas has a probability "as large as 2 to 5 percent" of striking in any one year, according to the FEMA report, an earthquake of magnitude 7.4 has a 1 percent annual probability of striking on the Haywood fault east of San Francisco Bay. There is a 0.1 percent chance of the Los Angeles section of the Newport-Inglewood fault producing a magnitude 7.5 shock. Unlike a repetition of the 1857 earthquake, both of these would slice through heavily populated areas. The Los Angeles earthquake could kill almost twice as many as an 1857 repeat and cause four times the economic loss, according to the report.

Such moderate quakes have been occurring on subsidiary faults in southern California since a post-1857 quiescence came to an end in the 1920's, say William Ellsworth and Barbara Moths of the USGS in Menlo Park. Such earthquakes will continue to occur there, they say, and could soon begin appearing in northern California as stress continues to build following the 1906 San Francisco earthquake.—RICHARD A. KERR

Additional Reading

1. *A Study of Earthquake Losses in the Los Angeles, California Area* (National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Boulder, Colo., 1973).
2. *An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken* (Federal Emergency Management Agency, Washington, D.C., 1980).