Earthquakes: Pattern For Prediction

Since February 9, 1971, scientists have learned a lot about the possibility of predicting earthquakes. At Caltech, six seismologists have been using the avalanche of information about the thoroughly recorded San Fernando quake to look for telltale signs that might precede such events. In particular, they have been looking at the phenomenon of "dilatancy" and its effect on the primary (P) and secondary (S) waves generated by earthquakes.

Dilatancy is a curious process in which a material under stress expands when it is near its breaking strength because of the formation of cracks. It is what happens when you press your foot into wet sand and the sand lightens in color. The stress of the foot rearranges the grains of sand, increasing the space between them, which makes the sand appear dryer. While under stress, the sand is firmer and less apt to shift.

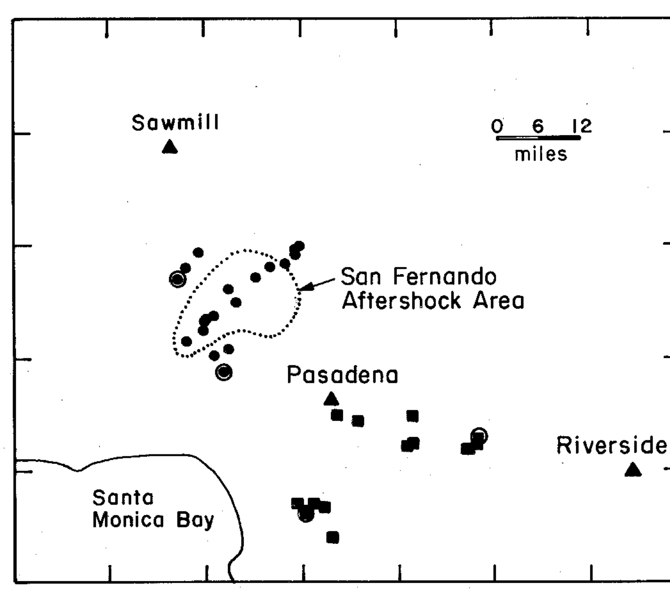
On a much larger scale, something of the same sort takes place in the earth's crust. The rocks under stress in the ground strengthen temporarily, but their strength decreases again as water and steam flow into the newly opened cracks. The dilatancy theory was generalized by Don Anderson, professor of geophysics and director of the Seismological Laboratory, and his colleagues.

Dilatancy explains phenomena that were detected by seismologists when they started reviewing seismic recordings for earthquakes in the San Fernando Valley for the ten years before the 1971 earthquake. These records showed that until three and a half years before the quake, the seismic wave velocities were relatively constant. Then, suddenly, they dropped sharply and began moving slowly back up until they reached their previous "normal" level a few months before the quake hit Sylmar. Similar results had been found by Soviet seismologists in the Garm region of the USSR.

In comparing the way the P and S waves change velocity when passing through a seismically active zone, the Russians found that when the P-wave speeds were divided by the S-wave speeds and plotted on a chart, the curve that resulted followed a curious path. Beginning at a relatively constant normal value, the ratio of the two speeds dropped sharply and then slowly rose until it reached its original level. Shortly thereafter an earthquake occurred.

This pattern is remarkably similar to what happened in 1971, and it led James Whitcomb, research associate in geophysics, and Jan Garmany, research assistant, to take a closer look at the P- and S-wave components in the seismic records of 19 other earthquakes in southern California between 1961 and 1970. These quakes were chosen because their epicenters fell on a more or less straight line between two Caltech recording stations at Pasadena and Riverside, making it possible to measure P- and S-wave velocities with some precision, as well as the velocity ratio.

Comparison of the two kinds of waves in these records showed patterns similar to those observed by the Russians. By measuring both waves separately, the two



Nineteen earthquakes whose seismic waves passed near the epicenter of the 1971 San Fernando Valley quake (dots) between 1960 and 1970 have been analyzed by Caltech seismologists. The old records reveal a pattern that might possibly have been used to predict the 1971 disaster. Analysis of another 12 quakes whose seismic waves passed *through* the epicenter between 1966 and 1970 (squares) shows they followed a similar pattern.

researchers found that it was the P wave that was changing velocity rather than the S wave, as some scientists had previously thought. And the only theory that satisfactorily explains a change in the P-wave velocity is dilatancy.

A series of complex events takes place beneath the earth's crust just before an earthquake:

Far below the surface of an active fault, where two massive land blocks strain against each other, there are small, hairline, water-filled cracks in the rock layers. As the rocks grind against each other, these microscopic cracks begin to expand; the water no longer fills them. And as the volume of the partially filled cracks increases, the velocity of the P waves begins to fall off and the ratio of P to S drops.

More water and steam percolate into the zone and fill the enlarged cavities. As this happens, the velocity of the P waves bottoms out and starts increasing. When the velocity is back to normal, it means that the cracks have filled completely with water. And because the cracks are now larger and hold more water than they did before, the rocks are weakened and are less able to stand the unrelenting pressure of the opposing blocks. Eventually, the rocks shatter, and an earthquake rips through the crust above.

Anderson, Whitcomb, and Garmany have found a correlation between the length of time it takes for the P wave to return to its normal value and the magnitude of the ensuing temblor. It also appears that by plotting the variations in P-wave velocities it may be possible to predict the day or week an earthquake is likely to strike.

One question that needs to be answered, however, is whether rocks change in this manner in all seismic areas, or whether the change is peculiar to thrust-fault regions such as those of the east-west ranges like the San Gabriel Mountains in southern California. During a quake in a thrust-fault region, two land blocks are locked head to head, and as one block tries to vault up and over the second block, the second is trying to slip under the first.

The 1971 San Fernando Valley quake occurred in this kind of region. During quakes in strike-slip fault regions, such as along the San Andreas fault, the two blocks are trying to slide past each other. It is not yet clear whether earthquakes in strike-slip fault regions give off the same kind of warning signals as those in thrust-fault regions.

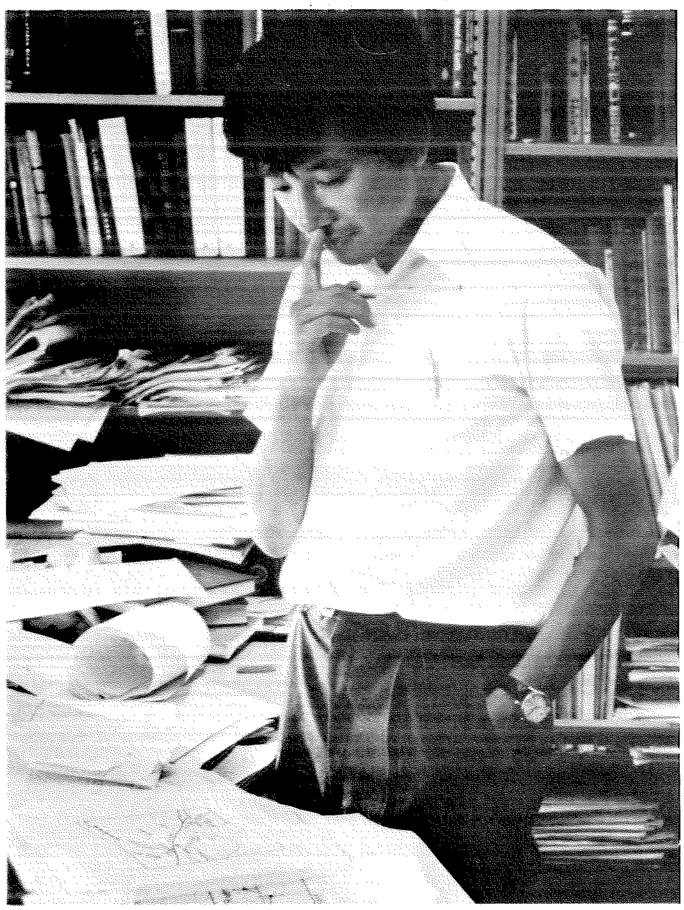
Seismological Laboratory scientists are now looking over records collected during the past 30 years on Caltech's southern California seismograph network. They want to see if dilatancy and precursory phenomena occurred before other earthquakes, and to look for abnormal patterns that may exist right now.

There may be such an abnormal pattern occurring beneath the city of Riverside. The seismic wave velocity in the earth's crust there has been changing for several years, and Hiroo Kanamori, professor of geophysics, is attempting to determine whether it is due to earthquake-related activity, to changes in the flow and distribution of underground water, or to something else.

Kanamori discovered the variations by measuring the changes in the velocities of seismic waves under the Riverside area produced by nuclear explosions in the Aleutian Islands in 1965, 1969, and 1971; by dynamite blasts in a cement quarry in the neighboring city of Corona; and by distant earthquakes. Using old seismic records, he measured the velocity of the waves produced from these sources by comparing the time it took them to activate various southern California seismographs.

He found that the recorded velocities had not changed

Seismologists James Whitcomb, Don Anderson, and Tom Hanks review the records of one of the many earthquakes monitored by Caltech seismometers—this particular one from Chile. Recent detailed analysis of such records reveals the existence of warning signals that may precede quakes.



Hiroo Kanamori, formerly professor of geophysics at the Earthquake Institute of Tokyo University, joined the Caltech faculty in November 1972. In Japan his most recent work was on the mode of strain release associated with major Japanese earthquakes, particularly as it relates to quake prediction. He is now conducting similar research along the San Andreas fault near the city of Riverside.

significantly over the years at any of the stations except the one at Riverside. The seismic velocities were constant between the 1965 and 1969 nuclear explosions, but at the Riverside station the waves from the 1971 detonation had increased in velocity about 14 percent. The records of waves from dynamite blasts and distant quakes corroborated the finding. In addition, seismic records from these two sources show that since 1971 the seismic wave velocities in the Riverside area have returned to "normal." Kanamori is also studying the change in velocity of surface waves that cross this region.

Of course, it is possible that the velocity change takes place without any association with an earthquake. Underground water can move around, and seismic waves passing through it react in the same way they do in a quake-prone area. But if the velocity change is related to a possible future earthquake, the dilatancy phenomenon may be common to all quakes and not just to those occurring in thrust-fault areas. (Riverside is near the southern end of the central segment of the San Andreas fault, which is in a strike-slip fault area, but it is still subjected to compressive stresses as well because it is so close to the big bend in the San Andreas fault.) To determine if dilatancy is the cause of the velocity changes, Kanamori is now measuring the seismic waves at different angles across the fault. If the measurements indicate some directional change of seismic waves with respect to the fault, it would strongly imply dilatancy, as shown theoretically by Anderson and two graduate students, Bernard Minster and David Cole.

Two other Caltech seismologists—Thomas Hanks, research fellow in applied science and geophysics, and graduate student James Hileman—have approached the prediction problem on a slightly different tack. Rather than reviewing records of past quakes, they are looking for an area with a high probability of earthquake activity in the future. They will then set up equipment to study what goes on underground prior to an expected earthquake.

Two likely sites for their study are Lytle Creek, northwest of San Bernardino, and Anza, northwest of Borrego Desert. Both are on the San Jacinto fault, in a strike-slip fault region that extends for more than 200 miles southeast from Lytle Creek in the San Bernardino Mountains, through Hemet, Borrego Springs, Anza, and Mexicali, and then to the Gulf of California. Small quakes of about magnitude 4 have shaken the Lytle Creek and Anza areas frequently in the past 40 years, and the seismic habits along this branch of the San Andreas fault indicate that larger temblors—of magnitude 6 or greater—are likely to occur where smaller quakes are active.

Even before this vital research is finished, Caltech and the U.S. Geological Survey are taking steps to set up an earthquake prediction system. In a cooperative project they will install a large number of seismographs within the next two years in southern California; many of them will be placed along the San Andreas and San Jacinto faults. Seismic recordings from these stations will be continuously transmitted to the Caltech Seismological Laboratory. About 40 seismograph stations now ring southern California. But with this limited number, there are only certain places where dilatancy can be detected and used to spot potential earthquakes. If the Caltech-USGS project is successful, however, within five years seismologists may be able to predict earthquakes in areas that are heavily instrumented to monitor seismic activity. □