Bouncing quake waves theory complicates prediction efforts

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One reason the October 1989 earthquake shook the San Francisco Bay Area so severely may be because seismic waves "bounced" off a rock layer about 15 miles deep.

U.S. Geological Survey scientists have lent support to the bounced-wave theory by studying seismic waves from microquakes triggered by intentional explosions in the Marin Headlands, San Juan Bautista and the Santa Cruz Mountains.

If verified, their findings could "seriously complicate" seismologists' efforts to predict where quakes will cause the most damage, said one of the geophysicists, Rufus Catchings.

Researchers have been puzzled by how much the 1989 quake damaged the Bay Area, considering its great distance from the epicenter in the Santa Cruz Mountains.

Much Bay Area damage was caused by liquefaction of loose fill in the Marina District and East Bay. Still, experts found it hard to believe that landfill had caused all the Bay Area shaking.

In early 1990, Paul Somerville and Joanne Yoshimura of Woodward-Clyde Consultants in Pasadena, proposed a possible explanation: Some seismic waves from the quake epicenter may have traveled deep into the Earth and bounced off the Mohorovicic or "Moho" layer, about 15 miles deep.

Then (their theory goes) the waves bounced back to Earth's surface and clobbered the San Francisco area – a double whammy. The first "whammy" would have been the seismic waves that travelled directly to San Francisco, in a straight line from the epicenter (actually, the subsurface "hypocenter" where the quake occurred, many miles beneath Earth's surface); the second whammy would have been the reflected waves, arriving several seconds later.

The Moho layer was named after its discoverer, Andrija Mohorovicic, an early 20th century Yugoslavian geophysicist. The Moho layer marks the boundary between the continental crust and the upper part of Earth's mantle, the 1,800-mile-thick shell that covers the super-hot planetary core.

To assess the Somerville-Yoshimura theory, Catchings, Gary Fuis and Will Kohler of U.S. Geological Survey analyzed charts of seismic waves generated by explosions of 3,000-pound explosives detonated 200 feet underground along the San Andreas Fault.

For example, one detonation triggered a 1.5-magnitude quake that was all but imperceptible to human beings. Seismic waves from the blast rippled for dozens of miles through Earth's crust.

The waves were recorded by a dense array of 400 instruments stretching some 120 miles along the fault from the Santa Cruz Mountains to Marin County. The instruments are so sensitive that they show vibrations caused by cars, construction and other "cultural noise" in the Bay Area.

They found the intensity of ground shaking declined fairly steadily across the Bay Area until San Francisco – then it surged suddenly. The surge, or "bump" as Catchings calls it, is easily visible on a chart.

For now, the "bump" seems easiest to explain as the result of seismic waves reflecting off the Moho, Catchings said. He said he's unaware of any significant alternative explanation, although he's withholding final judgment pending further study.

Their finding pleases Somerville, who says it reinforces his and Yoshimura's theory about Moho reflections.

"It's very clear evidence that the reflections from the Moho are strong and probably were strong during the Loma Prieta earthquake," Somerville said in a phone interview.

Moho reflections could have "very significant" impact on efforts to forecast where quake damage will be worst, Catchings says.

Because the new theory suggests a way quake waves could "bounce" a long distance, it suggests one may be endangered even if one lives far from a quake epicenter.

"Conventional theory was that if you get far enough from a quake, there's nothing to worry about," Catchings said. "This could require some rethinking."

For example, if Moho reflection is truly significant, then "you could have an earthquake outside the LA area that could still cause tremendous damage inside the city," Catchings said.

Another complication could be the Moho layer's varying depth. It ranges from 6 to 7 miles under the oceans and up to 30 miles under the continents, according to one estimate. Because the depth varies, the angle at which seismic waves hit the Moho layer could be important: For example, if the waves strike a sloping portion of the Moho layer, then the waves could be bent at an especially steep angle and travel a greater distance back to the surface.

Catchings recalls that when he discussed Moho reflections with structural engineers, they said it could cause them "tremendous headaches" in determining which areas are likely to suffer the worst quake damage.

The USGS scientists' next step is to create a computer model that simulates seismic wave movements – including Moho reflections – across the Bay Area after the 1989 quake.

Catchings and Fuis hope to do a similar study of Moho reflections in the Los Angeles area later this year.

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