Eos, Transactions, American Geophysical Union, Vol. 80, No. 41, October 12, 1999, Pages 482–483

Extensive Research on Loma Prieta Improves Understanding of Earthquakes

Research on the 1989 Loma Prieta, California, earthquake, probably the most thoroughly documented in American history, has dramatically improved our understanding of the complexity of earthquakes and of how society can reduce risk and improve response in connection with large natural disasters. The magnitude 6.9 earthquake was the largest and most damaging to strike an American urban area since the 1906 San Francisco earthquake. Loma Prieta's 10th anniversary is October 17.

Loma Prieta began without immediate foreshock activity about 100 km southeast of San Francisco (37°03.6'N, 121°88.3'W) on October 17, 1989, at 5:04 p.m. PDT (00:04:15.2 UTC., October 18). The quake killed 63 people, and another 350 were hospitalized. Estimates of total property losses range from $6 billion to $10 billion. Its dramatic timing, interrupting the World Series in San Francisco, and its striking images—a pancaked freeway, a fallen span of a major transbay bridge, and burning collapsed apartments—piqued public interest. It also prompted the U.S. Congress to authorize supplemental funding to the National Earthquake Hazards Reduction Program (NEHRP) agencies—USGS, National Science Foundation, Federal Emergency Management Agency, and National Institute of Standards and Technology—to support research in order to learn from the tragedy.

Loma Prieta was the largest quake near a metropolitan area since the enactment of NEHRP in 1977 and it occurred in a well instrumented region. Physical scientists, engineers, and social scientists were able to scrutinize it intensely.

Documentation of the 1989 event has led to answers to many questions. But, in the area of forecasting, it has raised almost as many questions as answers. The event occurred on a complex geologic structure and was not a simple strike-slip event as many forecasters had assumed.

The earthquake also renewed interest in the interaction of faults. Ironically, this research led to a forecast of the August 17, 1999, Izmit, Turkey, earthquake as scientists took note of the sequential westward migration of earthquakes along the North Anatolian fault.

The 1989 event also significantly influenced how seismologists and engineers estimate strong ground motion. The earthquake demonstrated the importance of amplification phenomena by soft soils, the significance of the azimuth of a site relative to the sense of expansion of the seismic rupture, and the relevance of deep crustal structure to strong ground motion with its well defined Moho "bounce."

Four volumes of recently published U.S. Geological Survey papers address these topics and a number of others related to Loma Prieta [*Bakun and Prescott*, 1998; *Holzer*, 1998a, 1998b; *Mileti*, 1998] and are now available at federal depository libraries. They supplement an already extensive literature [e.g., *Benuska*, 1990; *Hanks and Krawinkler*, 1991].

Commemorating the 10th anniversary, the 1999 AGU Fall Meeting will hold a half-day Union session on Loma Prieta, highlighting what has been learned through the research. More information on the sessions is available from the AGU Web site (http://www.agu.org), Ruth A. Harris (E-mail: harris@usgs.gov), or Thomas L. Holzer (E-mail: tholzer@usgs.gov).

Some of the most intriguing seismological research documented in the USGS report pertains to earthquake forecasting. The fault segment that ruptured approximately coincides with a segment of the San Andreas fault identified by a group of Earth scientists in 1988 as having a 30% probability of generating a magnitude 7 earthquake in the next 30 years [*Working Group*, 1988]. Although the forecast was assigned a low confidence level, it prompted many later reports that the 1989 earthquake had been anticipated. This was one of more than 20 relevant forecasts that were made in the 83 years before the earthquake. It was not even the most accurate in terms of magnitude and location of the ruptured segment. An earlier forecast by Lindh [1983] came remarkably close to identifying the Loma Prieta earthquake rupture segment.

Was the earthquake truly forecast, or was it just a coincidence? The crux of the issue is that none of the forecasts can be rigorously tested because they are incomplete. The earthquake did not follow all of the specifications set out by any of the forecasters. It occurred deeper than expected and with significant reverse-slip displacement. It also is not clear that it occurred on the principal strand of the San Andreas fault in this area. If it was not the earthquake anticipated in the forecasts, is the seismic hazard in the Santa Cruz Mountains still high or has the strain been released?

The Loma Prieta earthquake also has refocused attention of researchers on interactions among earthquake faults. Immediately following the 1989 event, some investigators took note of four seismic events in the 1800s that were inferred to be on the Hayward and San Andreas faults and that were paired 2 to 3 years apart. These investigators warned about the possibility of additional seismic activity on the Hayward fault along the east side of San Francisco Bay.

Stress-change calculations for faults in the bay area after the Loma Prieta earthquake, however, indicated that the Hayward fault probably was relaxed in that event. This inference was subsequently supported by the slowing of fault creep at the surface on the Hayward fault. Calculated stress changes for most of the faults in the bay area were small. The absence of significant seismicity in the past 10 years is consistent with the calculations. These observations have increased international research on how active faults interact.

The Loma Prieta earthquake also affected how engineering seismologists estimate strong ground motion. Major elements of the San Francisco Bay area transportation system as distant as 90 km from the source region sustained major damage. Collapse of a 2.4-km-long section of the Interstate 880 Cypress Street Viaduct in Oakland caused 43 fatalities. Failure of a closure span in the East Bay Crossing of the San Francisco-Oakland Bay Bridge closed this major artery for a month.

Damage to remote transportation systems was consistent with unusually large property losses outside the source region. Approximately three-quarters of the total property loss occurred more than 42 km from the seismic source. Although concentration of loss outside the source region primarily resulted from the small amount of exposed property within the source region, several other factors contributed to anomalously large losses outside this region. The primary seismological factors were directivity in the radiated seismic energy, critical reflections of seismic energy off the Moho, and local amplification of ground shaking by soft, silty-clay soils.

All of these ground-motion amplification phenomena were well known before the earthquake, but their documentation by strong motion recordings in 1989 has prompted efforts to include them in earthquake modeling for ground motion estimation. The greatest impact on engineering practice has been from the recordings at soft soil sites. These recordings led to modifications of the 1994 NEHRP-recommended provisions for the development of seismic regulations for new buildings.

Although the 1985 Michoacan earthquake, which badly damaged buildings in Mexico City, reminded engineering seismologists of the amplification potential of soft soils during earthquakes, the Loma Prieta event provided a significant set of recordings of strong ground motion at sites underlain by saturated estuarine mud. Amplifications of peak horizontal accelerations at these sites typically were greater than 2.0. Because most of these recordings were made at considerable distances from the rupture zone, ground motions recorded on nearby exposed bedrock were generally uniform. Thus the observations provided robust estimates of strong-motion amplific ation factors for use in site-specific design spectra.

The USGS publications, Professional Papers 1550, 1551, 1552, and 1553, contain 162 papers totaling 2773 pages and are available at 618 federal depository libraries, many of which are at universities and colleges. Tables of contents for the papers are posted on the Web (http://quake.wr.usgs.gov/study/LomaPrieta Anniversary). Information on ordering individual chapters can be obtained by telephoning 1-888-ASK-USGS or by visiting the USGS Web site (http://greenwood.cr.usgs.gov/propaper.html).

Author

Thomas L. Holzer
U.S. Geological Survey, Menlo Park, Calif., USA

References

Bakun, W. H., and W. H. Prescott (Eds.), The Loma Prieta, California, earthquake of October 17, 1989: Earthquake occurrence, *U.S. Geol. Surv. Prof. Pap. 1550*, 853 pp., 1998.

Benuska, L. (Ed.), Loma Prieta earthquake reconnaissance report, *Earthquake Spectra, 6 (suppl.)*, 448 pp., 1990.

Hanks, T. C., and H. Krawinkler (Eds.), The 1989 Loma Prieta earthquake and its effects, *Seismol. Soc. Am. Bull., 81*, 1415-2166, 1991.

Holzer, T. L. (Ed.), The Loma Prieta, California, earthquake of October 17, 1989: Strong ground motion and ground failure, *U.S. Geol. Surv. Prof. Pap. 1551*, 1050 pp., 1998a.

Holzer, T. L. (Ed.), The Loma Prieta, California, earthquake of October 17, 1989: Performance of the built environment, *U.S. Geol. Surv. Prof. Pap. 1552*, 590 pp., 1998b.

Lindh, A. G., Preliminary assessment of long-term probabilities for large earthquakes along selected fault segments of the San Andreas fault system in California, *U.S. Geol. Serv. Open File Rep. 83-63*, 14 pp., 1983.

Mileti, D. S. (Ed.), The Loma Prieta, California, earthquake of October 17, 1989: Societal response, *U.S. Geol. Surv. Prof. Pap. 1553*, 280 pp., 1998.

Working Group, Probabilities of large earthquakes occurring in California on the San Andreas fault, *U.S. Geol. Surv. Open File Rep. 88-398*, 62 pp., 1998.