California Aftershock Hazard Forecasts

The first practical application for our model for real-time probabilistic hazard assessment (1) was provided by the 6 March 1989 M4.7 Obsidian Butte earthquake sequence in the northern Brawley Seismic Zone at the southern end of the Salton Sea, California (Fig. 1). The earthquake sequence was initially very active and included a relatively high proportion of large-magnitude aftershocks \((a = -0.5, b = 0.6)\). As a result, the model-estimated probability for a larger \((M \geq 4.7)\) earthquake during the first week in the sequence was relatively high—on the order of 0.30. Scientists familiar with the Brawley Seismic Zone generally felt that this estimate was reasonable. We did find, however, that other factors, in addition to those considered in the model, also warranted consideration.

One factor was the proximity (18 km) of the Obsidian Butte earthquakes to the intersection of the Brawley Seismic Zone and the San Andreas fault and the possibility that a great \((M \approx 8)\) earthquake might be triggered by the Obsidian Butte sequence. The consensus was that the distance to the San Andreas fault was too great to warrant an upward revision of the model probability estimate for a great earthquake.

Another factor was that the Brawley Seismic Zone may not be capable of producing very large earthquakes because it is composed of numerous small faults, rather than a continuous long fault. If we assume that the largest possible earthquake in the Brawley Seismic Zone is \(M 6.2\) (the magnitude of the largest known historic event), then the model-estimated probability of a \(M \geq 4.7\) earthquake decreases from 0.30 to 0.26.

The U.S. Geological Survey used the model to issue frequent public forecasts during the 17 October 1989 Loma Prieta earthquake sequence of probabilities of strong aftershocks within a day, a week, and 2 months. While this earthquake produced fewer aftershocks than expected for a generic \(M7.1\) earthquake, the final model parameters determined for it \((a = -1.67, b = 0.75, p = 1.19)\) all differ by less than 1 SD from their respective generic values (2, figure 1). We reported 24 hours after the earthquake that the chance of a \(M \approx 5\) aftershock in the next day was 0.13 (none occurred). One week later that probability had decreased to 0.05, while the probability of a \(M \approx 5\) aftershock over the next 2 months was 0.50 (none occurred). Forecasts were made first daily, and then less frequently, through 30 November 1989. These were issued to federal, state, and regional government agencies and were widely reported by Bay Area printed and electronic media. Public demand for and interest in aftershock forecasts was greatest immediately after the earthquake and remained high for about 2 weeks, decreasing as the felt aftershocks subsided.

Some local and regional government agencies requested model results particular to their needs during the first week of the sequence. The Port of Oakland requested estimates of probabilities for strong aftershocks in order to decide whether and when to reoccupy a damaged structure. The San Francisco Fire Department requested probabilities of strong shaking in the Marin and China Basin districts to guide decisions about equipment deployment and staffing levels in those damaged areas. Within the U.S. Geological Survey, scientists coordinating the regional deployment of strong-motion portable seismographs frequently consulted model results in planning their experiment design and field strategy.

Our experience with the Obsidian Butte sequence and the Loma Prieta sequence has shown that the model can provide important information for real-time hazard assessment for earthquake sequences. Sensible real-time assessment of the seismic hazard during future earthquake sequences in California should also take into account relevant regional factors, including proximity to stressed fault segments, fault complications or gaps, and possible regional limitation of the maximum possible earthquake size.

In the Loma Prieta sequence, we found that regularly released short-term forecasts of expected aftershock activity were useful in meeting the public demand for earthquake hazard information after a strong earthquake. We also saw that the press and public can easily misunderstand a probabilistic forecast; such public statements should be simple, clear, and consistent. Overall, however, we feel that our use of model probabilities to forecast the continuing

---

REFERENCES AND NOTES

2. Model parameters \(a, b\) and \(p\), defined in (1), describe the total number, magnitude distribution and time distribution of the aftershocks, respectively.
3. As defined in (1), \(M_L\) and \(M_S\) are, respectively, the lower and upper limits of a magnitude range, and \(S\) and \(T\) are, respectively, the lower and upper limits of a time interval, for which \(P\) is computed.
4. In practice, observation of earthquakes within the central and southern California U.S. Geological Survey networks is complete above approximately magnitude 1.5.

21 November 1989; accepted 30 November 1989

19 JANUARY 1990
earthquake hazard after the Loma Prieta earthquake was generally understood and widely accepted by the public, the press, and other government agencies.

Paul A. Reasenberg  
U.S. Geological Survey,

345 Middlefield Road,  
Menlo Park, CA 94025

Lucile M. Jones  
U.S. Geological Survey,  
525 South Wilson Avenue,  
Pasadena, CA 91106

REFERENCES AND NOTES


21 April 1989; accepted 30 November 1989

"We now know all the extraordinary changes the universe went through in its first second. After that, unfortunately, it turns out to be very monotonous."
California Aftershock Hazard Forecasts
Paul A. Reasenberg and Lucile M. Jones

Science 247 (4940), 345-346.
DOI: 10.1126/science.247.4940.345

ARTICLE TOOLS
http://science.sciencemag.org/content/247/4940/345

RELATED CONTENT
file://contentpending:yes

REFERENCES
This article cites 2 articles, 2 of which you can access for free
http://science.sciencemag.org/content/247/4940/345#BIBL

PERMISSIONS
http://www.sciencemag.org/help/reprints-and-permissions

Use of this article is subject to the Terms of Service