Profile of Mortality from the 1989 Loma Prieta Earthquake using Coroner and Medical Examiner Reports

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Mortality patterns from earthquakes in the United States may differ from those observed in other parts of the world. We reviewed coroner and medical examiner records for all investigated deaths from seven California counties for 15 days following the Loma Prieta earthquake of October 17, 1989 (N = 327). Data on the circumstances surrounding death were used to classify each case as directly earthquake-related, indirectly earthquake-related, or not earthquake-related. Fifty-seven deaths were judged as directly earthquake-related. Six other deaths were indirectly related. Ten circumstances accounted for all directly earthquake-related deaths, with the collapse of an elevated freeway accounting for 40 of these deaths. Forty-six (80.8 per cent) of the 57 directly earthquake-related deaths occurred in motor vehicles on public roadways. Fifty-three (93.0 per cent) of the directly earthquake-related deaths occurred within seconds or minutes of injury. Future earthquake deaths in the United States may best be prevented by identifying and modifying seismic hazards in earthquake-prone regions, particularly transportation structures.

With a magnitude of 7.1 M_s, the Loma Prieta earthquake of October 17, 1989, was the largest earthquake to strike the San Francisco Bay region since 1906 (United States Geological Survey, 1989). Rupture of the Earth's crust at 5:04 p.m. Pacific Daylight Time along a segment of the San Andreas fault 60 miles southeast of San Francisco released 1,022 ergs of seismic energy, equal to about 500,000 tons of TNT or one thermonuclear bomb. Ground shaking lasted 15 seconds and was felt over an area of 400,000 square miles (United States Geological Survey, 1989).

Estimates of the number of deaths from the earthquake have ranged from 62 to 66 (Rogers et al., 1990). More than 3,700 injuries were associated with the event (Bolin, 1990). In addition, more than 18,000 homes were damaged (Ward et al., 1989), 367 businesses were destroyed (Benuska, 1990), and some 13,000 persons were left homeless (Bolin, 1990). Three major highway structures collapsed, and 10 others were closed due to massive structural damage (Benuska, 1990). With total economic losses ranging from $6 to $10 billion, the earthquake was one of the

costliest natural disasters in U.S. history (United States Geological Survey, 1989; Fairweather, 1990).

Previous earthquake mortality studies, all from outside the United States, have relied largely on door-to-door surveys by the investigators or by local health officials (e.g. Noji et al., 1990; Glass et al., 1977; De Bruycker et al., 1985). Most deaths reported in these studies had occurred among persons trapped in collapsed residential structures. As the first large earthquake in decades to strike a heavily populated area of the United States, the Loma Prieta earthquake provided an opportunity to examine earthquake mortality patterns in this country for the first time. This study was undertaken to investigate the circumstances surrounding each death in the Loma Prieta earthquake by using data from coroner and medical examiner (C/ME) reports. To our knowledge, C/ME reports had only been used once previously to examine deaths from a natural disaster (Centers for Disease Control, 1989a). A telephone survey of C/MEs in late October 1989 had uncovered a total of 63 deaths believed by the C/MEs to be related to the earthquake (Centers for Disease Control, 1989b). A second objective of the current study was to verify this count of earthquake-related deaths and to evaluate this method of obtaining a rapid accounting of deaths in a disaster.

METHODS

California statutes require that county C/MEs investigate all deaths occurring in their jurisdictions that are sudden or unusual, unattended, or due to injuries, both intentional and unintentional (Combs et al., 1990). C/ME reports for all investigated deaths occurring between October 17 and October 31, 1989, were collected from seven northern California counties: Alameda, Monterey, San Benito, San Francisco, San Mateo, Santa Clara, and Santa Cruz. Though 10 counties had been included in the federal earthquake disaster area, earthquake-related injuries had been reported in only these seven counties (Office of Emergency Services, 1989). The dates and counties chosen paralleled those used in the post-earthquake telephone survey of C/MEs. Completeness of records collected was assured by checking the records obtained against each C/ME log of investigated deaths and by comparing names given in the reports with those of coroner-certified cases listed in state vital records.[1]

Of 421 C/ME reports obtained, two were excluded because they involved investigations of stillbirths, not deaths of live persons. Ninety-two additional records were excluded because they provided only fragmentary data on deaths that had been reported to C/MEs in four of the counties. These deaths had not been investigated, and nearly all of them had not been certified by the C/MEs. None of the excluded deaths appeared to be earthquake-related.

Five trained investigators abstracted up to 106 items of data from each C/ME report. Abstracted data included demographic characteristics of the deceased, descriptive information about the circumstances of death, toxicologic data, and several assessments of the completeness of the reports. Abstractors assigned a single underlying cause to nearly every death, using criteria from the International Classification of Diseases, 9th Revision (ICD-9, United States Department of Health and Human Services, 1989). Causes were grouped into 19 categories for analysis. For deaths due to accidents, additional data were collected on the circumstances of injury. Abstractors assigned each of these deaths an ICD-9 external cause code. These codes were grouped into 13 categories for analysis. For deaths coded E909 (resulting from accidents due to 'cataclysmic earth surface movements') further

information on the circumstances of injury was obtained.

Abstractors reviewed and assigned each death to one of four categories. (1) Directly earthquake-related: death was due to injuries sustained during ground motion or immediately thereafter from hazards caused by the earthquake. Directly earthquake-related deaths would include, for example, those due to crush injuries received in the collapse of a building. (2) Indirectly earthquake-related: death appeared to result from circumstances created by the earthquake and probably would not have occurred at that time had there not been the earthquake. Examples would include stress-related heart failure in a person with cardiovascular disease or fatal injuries occurring hours after the earthquake resulting from earthquake damage. This category included a spectrum of events, some probably more earthquake-related than others. (3) Not earthquake-related: death resulted from circumstances independent of the earthquake. (4) Insufficient information in the report: unable to determine if death had been earthquake-related.

Most analysis was limited to calculating frequencies for variables of interest. When comparisons were made, directly earthquake-related deaths were compared with other C/ME-investigated deaths due to unintentional injury from the study counties during the study period. This comparison group was selected for convenience and may not represent the population at risk of death in the earthquake. Statistical tests used in the analysis of the data included odds ratios and 95 per cent confidence intervals.

RESULTS

As shown in Table 1, 1,504 deaths occurred in the seven-county region during the 15-day study period.[2] Of these, 327 deaths (21.7 per cent) were investigated by county C/MEs. The investigation rate by county ranged from 14.3 to 40.0 per cent. More than 80 per cent of the investigated deaths were not related to the earthquake. Of the remainder, 57 deaths were considered directly earthquake-related, with six others judged indirectly related. The C/ME reports for two additional deaths had inadequate information to determine if the deaths had been associated with the earthquake. Vital statistics records indicated that one of these two deaths, that of 'Victim A', was definitely an earthquake fatality. Since our study was based exclusively on C/ME records, data on 'Victim A' are excluded from the analysis reported here.

Circumstances surrounding the 57 directly earthquake-related deaths are summarized in Table 2. Ten circumstances accounted for all the deaths, with one circumstance — collapse of an elevated freeway in Oakland — responsible for 40 deaths, more than two-thirds of the total. Circumstances of death for the six indirectly related cases were as follows: (1) carbon monoxide poisoning of a 60-year-old man from a portable generator used in his home after the earthquake caused a power outage; (2) a heart attack in a 77-year-old man at 5:05 p.m. as he talked with a neighbor on his driveway about earthquake damage to his home; (3) a fall by a 59-year-old alcohol-intoxicated man on a quake-damaged stairway four hours after the tremors; (4) the death of a 27-year-old man in a motor vehicle collision with three horses that may have wandered onto the highway because of the earthquake six hours earlier; (5) the death of an 88-year-old woman from an unattended heart attack at home within 90 minutes of the earthquake; and (6) the death on October 18 of a 66-year-old woman with gastrointestinal bleeding who could not be admitted to a hospital the night of the quake because the hospital was filled to capacity with patients suffering from

TABLE 1
Earthquake related deaths from reports of coroner/medical examiner examinations, seven-county disaster area, California, 17–31 October, 1989

County of Occurrence	*Total[a] Deaths*	*Total C/ME Investigations*	*Earthquake-Related Deaths*		*Non-Quake Deaths*	*Not Enough Info.*
			Direct	*Indirect*		
Alameda	456	133	40	1	91	1[b]
Monterey	92	18	2	0	16	0
San Benito	5	2	0	0	2	0
San Francisco	337	72	10	1	60	1
San Mateo	204	42	0	1	41	0
Santa Clara	343	49	1	2	46	0
Santa Cruz	67[c]	11	4	1	6	0
Total	1504[c]	327	57	6	262	2

a By county of occurrence. Source: California Department of Health Services, Health Data Statistics Branch, vital statistics computer tape files.
b This death in Alameda County is known, from other sources, to be a direct earthquake fatality, but is excluded from the total of earthquake deaths because the coroner/medical examiner report lacks sufficient information for proper determination of its earthquake relatedness.
c Includes one investigated death not listed in vital statistics computer tape files.

earthquake-related traumas.

Demographic characteristics of individuals with directly earthquake-related deaths are shown in Table 3. For comparison, demographic characteristics also are given for the 49 persons investigated by the C/MEs who died from non-earthquake-related, unintentional injuries in the study counties during the study period. As the numbers of deaths are small, none of the differences between the two groups are statistically significant. As a group, the earthquake victims were more likely to be female and were older than accident victims in the comparison group. The majority of earthquake victims were non-Hispanic whites, but minorities, particularly Hispanics and Asians, accounted for a larger share of the earthquake-related deaths than of the other unintentional injury deaths. A larger proportion of the earthquake victims were known to be married, but marital status data were often missing from the C/ME reports.

Twenty-nine (50.9 per cent) of the 57 directly earthquake-related deaths occurred outside the county in which the individual resided (Table 4). More than 30 per cent of the 57 deaths occurred among persons residing outside the seven-county area. The county whose residents made up the third largest number of earthquake-related deaths was Contra Costa, which is outside the study area.

Forty-six (80.8 per cent) of the 57 directly earthquake-related deaths resulted from injuries in motor vehicles on public roadways, as shown in Table 5. Death occurred at the scene in all but one of the roadway injuries. Only four of the 57 deaths occurred in hospitals, all within a few hours of injury. The other 53 deaths,

TABLE 2
Circumstances surrounding directly earthquake-related deaths (N = 57), seven-county disaster area, California, 17–31 October, 1989

County of occurrence	*Circumstances*	*Direct quake-related deaths*	*% of county quake deaths*	*% of all quake deaths*
Alameda	Collapse of I-880 elevated freeway, Cypress Section, Oakland.	40	100.0	70.2
Monterey	Collapse of wooden water tank tower near residence.	1	50.0	1.8
	Loose bricks falling from building onto sidewalk, Watsonville.	1[a]	50.0	1.8
	Total (2 circumstances)	2	100.0	3.5
San Francisco	Collapse of unreinforced brick facade onto cars on 6th street	5	50.0	8.8
	Collision of vehicle with damaged section of Bay bridge roadway.	1	10.0	1.8
	Collapse of 4-storey apartment building in Marina District.	3	30.0	5.3
	Smoke inhalation from residential fire in Marina District.	1	10.0	1.8
	Total (4 circumstances)	10	100.0	17.5
Santa Clara	Collapse of church tower at St Joseph's College, Los Altos.	1	100.0	1.8
Santa Cruz	Collapse of retail business at Pacific Garden Mall, Santa Cruz.	3	75.0	5.3
	Collapse of earth embankment at Bonny Doon Beach, near Davenport.	1	25.0	1.8
	Total (2 circumstances)	4	100.0	7.0
	Total (10 circumstances)	57		100.0

a Injured in Santa Cruz County but taken to Monterey County for medical treatment. Pronounced dead in Monterey County.

TABLE 3
Demographic characteristics of directly earthquake-related deaths (N = 57) and non-earthquake, unintentional injury deaths (N = 49), seven county disaster area, California, 17–31 October, 1989

Characteristic	*Directly Earthquake-Related Deaths (N = 57)*		*Non-Earthquake Unintentional Injury Deaths (N = 49)*	
Sex:				
Males	34	(59.6%)	34	(69.4%)
Females	23	(40.4%)	15	(30.6%)
Age:				
0–19 years	3	(5.3%)	6	(12.2%)
20–39 years	29	(50.9%)	24	(49.0%)
40–59 years	21	(36.8%)	10	(20.4%)
60+ years	4	(7.0%)	9	(18.4%)
Race/Ethnicity:				
White, Non-Hispanic	32	(56.1%)	36	(73.5%)
Black, Non-Hispanic	8	(14.0%)	6	(12.2%)
Hispanic	8	(14.0%)	1	(2.0%)
Asian	6	(10.5%)	2	(4.1%)
Other	1	(1.8%)	3	(6.1%)
Not Ascertainable	2	(3.5%)	1	(2.0%)
Marital Status:				
Married	25	(43.9%)	11	(22.4%)
Divorced	4	(7.0%)	3	(6.1%)
Never Married	5	(8.8%)	3	(6.1%)
Widowed	4	(7.0%)	3	(6.1%)
Single, Unspecified	4	(7.0%)	4	(8.2%)
Not Ascertainable	15	(26.3%)	25	(51.0%)

about 93 per cent, occurred at the scene, seconds or minutes after the time of injury.

Of the 57 directly earthquake-related deaths, C/MEs tested body fluids for drugs or alcohol in 11 cases. Three of the 11 tests showed detectable levels of alcohol or street drugs. As a comparison, positive tests were found in 22 of 40 non-earthquake-related C/ME accident cases from the study counties during the study period that were tested for alcohol and drugs. (Odds ratio = 0.31, 95 per cent confidence interval = 0.05, 1.56.)

Sixty of the 63 earthquake-related deaths that had been reported from the telephone survey of C/MEs were counted again here, either as directly or indirectly earthquake-related deaths. Two of the deaths that had been included in the results of the telephone survey were judged to be not earthquake-related here, upon review of the C/ME reports. They were the death of a 68-year-old female

TABLE 4
Directly earthquake-related deaths occurring within and outside deceased's county of residence (N = 57), seven-county disaster area, California, 17–31 October, 1989

County of Occurrence	*Number of Persons Dying Within County of Residence*		*Number of Persons Dying Outside County of Residence*		*Total*
Alameda	17	(42.5%)	23	(57.5%)	40
Monterey	1	(50.0%)	1[a]	(50.0%)	2
San Benito	0	(0.0%)	0	(0.0%)	0
San Francisco	7	(70.0%)	3	(30.0%)	10
San Mateo	0	(0.0%)	0	(0.0%)	0
Santa Clara	0	(0.0%)	1	(100.0%)	1
Santa Cruz	3	(75.0%)	1	(25.0%)	4
Total	28	(49.1%)	29	(50.9%)	57

a Injured in Santa Cruz County but taken to Monterey County for medical treatment. Pronounced dead in Monterey County.

tourist who apparently fell in her San Francisco hotel about three hours after the earthquake, and the death of a 37-year-old man from a gunshot wound on the night of the earthquake, also in San Francisco. The other death that had been included in the telephone survey results but was excluded here was that of 'Victim A', who died in the collapse of the elevated freeway in Oakland.

Three indirectly earthquake-related deaths not reported in the telephone survey were uncovered only by this examination of all C/ME reports from the study period. These deaths were the two heart failures occurring close to the time of the earthquake and the death from gastrointestinal bleeding in the woman who could not be admitted to the hospital on the night of the earthquake.

DISCUSSION

This study of C/ME reports from a seven-county area in the 15 days following the Loma Prieta earthquake provides a detailed picture of mortality patterns in a particular natural disaster. We have identified 57 deaths due directly to the earthquake and six others indirectly related to the disaster. This total excludes an unknown number of deaths that may have been associated with the earthquake but were not investigated by the seven C/MEs. It also excludes deaths not investigated adequately to determine earthquake involvement — such as that of 'Victim A' — or deaths occurring after October 31, 1989, from injuries received at the time of the earthquake. From news media accounts we know of two earthquake-associated injuries for which death occurred after the study period. One death was due to the elevated freeway collapse, and one resulted from injuries suffered from earthquake damage at home.

Mortality from this event was the sixth highest of any earthquake in U.S. history (National Safety Council, 1989), but was small compared to earthquake mortality elsewhere in the world. During 1990 more than 52,000 persons worldwide died in earthquakes, most from a single event in western Iran (Person, 1991). An earth-

TABLE 5
Location of injury and death for directly earthquake-related deaths (N = 57), seven-county disaster area, California, 17–31 October, 1989

	Place of death	
Place of Injury	*At scene*	*Hospital*
Public roadway:		
— I-880 elevated freeway, Oakland	40	0
— 6th Street, San Fransisco	5	0
— Bay Bridge	0	1
Residence of deceased:	2	1
Other residence:	2	0
Institution or business:		
— Stores, Pacific Garden Mall, Santa Cruz	3	0
— Commercial sidewalk, Watsonville	0	1
— St Joseph's College, Los Altos	0	1
Other place:		
— Bonny Doon Beach, near Davenport	1	0
Total	53	4

quake of a magnitude similar to that of Loma Prieta killed an estimated 25,000 persons in Soviet Armenia in 1988 (Noji et al., 1990). More than 600,000 persons died in an earthquake in China during 1976 (Person, 1991). Adherence to strict building codes in earthquake-prone areas may be responsible for dramatically reducing mortality from earthquakes in the United States. No engineered structure built according to the latest codes collapsed in the Loma Prieta earthquake (United States Geological Survey, 1989). Earthquake mortality surveys in Guatemala and southern Italy found that most deaths were associated with the collapse of houses (Glass et al., 1977; De Bruycker et al., 1985), but in this study only five directly earthquake-related deaths occurred in or around residential structures. Falling debris from other buildings was involved in 10 other deaths.

Despite the relatively low mortality from the Loma Prieta earthquake, earthquakes do pose an ongoing threat to public health in particular areas of the United States. Had an event of magnitude 7.4 M_s struck the Hayward fault, 50 miles to the north, deaths would have ranged from 3,000 to 8,000 (Federal Emergency Management Agency, 1980). There is a probability of 0.67 for one or more large earthquakes ($\geq$7.0 Ms) there or elsewhere in the San Francisco Bay area by 2020 (United States Geological Survey, 1990). Lessons learned from mortality in the Loma Prieta earthquake may help reduce mortality in the next earthquake.

Three findings in this study have policy implications that merit further discussion.

(1) Nearly all deaths in the earthquake occurred within seconds or minutes of injury, at the scene of the injury. Of the 57

directly earthquake-related deaths included in this study, less than 7 per cent of the victims survived to reach a hospital, and all of those died rapidly despite resuscitative efforts. This suggests that intensified efforts to rescue trapped persons and provide on-site medical care to earthquake victims with serious injuries would not have yielded significant reductions in mortality. In California, with its long history of antiseismic construction, further reductions in earthquake mortality may better be achieved by identifying and modifying persistent hazards in the physical environment that are likely to incur sudden and severe damage during ground motion. This involves identifying locations where ground conditions may amplify shaking in an earthquake, avoiding future development on land that is vulnerable to earthquake damage, and strengthening existing structures that are likely to collapse, such as unreinforced masonry buildings. Unlike many other injury control programs that aim to modify individual behavior, public health efforts to reduce deaths from earthquake-related injuries may need to concentrate on creating a seismically safe environment.

(2) Four out of five deaths in the Loma Prieta earthquake occurred in motor vehicles on public roadways. As in non-earthquake situations, where motor vehicles account for more than half of unintentional injury deaths (National Safety Council, 1989), occupants of motor vehicles appear to have a special risk of fatal injury in an earthquake. In this study, a single circumstance, the collapse of the Cypress Viaduct of Interstate 880 in Oakland, accounted for 40 deaths. Designed in 1951 and completed in 1957, this reinforced concrete viaduct was California's oldest double-deck freeway structure (Benuska, 1990; Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake, 1990). With four lanes of traffic on each deck, it carried 50,000 vehicles per day along 2.5 miles through an industrial area of Oakland. The northern two-thirds of the structure, the major portion that collapsed in the earthquake, was founded on artificial fill overlying a tidal marsh composed of soft bay mud. Limited seismic retrofitting of the viaduct was done in 1977. Analytical methods available at that time would have predicted failure of the retrofitted structure under ground motion like that of the Loma Prieta earthquake, but no such tests were performed (Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake, 1990). Freeway overpasses have also collapsed during two other recent California earthquakes. In the 1971 San Fernando earthquake, three interchanges of the Golden State Freeway in Los Angeles were destroyed, killing two persons (Jennings, 1971). Five persons were injured when an overpass on U.S. Highway 101 collapsed in the Eureka earthquake of 1980 (Simon, 1981).

Many of the 22,000 highway bridges in California are at risk of severe damage or collapse in a major earthquake (Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake, 1990). Any plan for earthquake hazard mitigation in a seismically active area such as California should give highest priority to the systematic retrofitting of transportation structures.

(3) About half of the people who died in the Loma Prieta earthquake died outside their county of residence. The mobility of contemporary populations demonstrated by this finding suggests that statistics on injury incidence are better classified by county of occurrence than by county of residence. This finding also suggests that seismic safety is not merely a local issue, but should be a regional or national concern. Local decisions about land use, building code enforcement, and the retrofitting of potentially hazardous buildings and highways have impacts on earthquake mortality that extend beyond the boundaries of local jurisdictions.

States, counties and cities in earthquake-prone areas should not be expected to assume the full costs of hazard mitigation.

Finally, this study has shown that a telephone survey of C/MEs in the first weeks after an earthquake can provide a rapid and nearly complete ascertainment of disaster-related deaths. Though the telephone survey missed three indirect deaths found only in this study, it found all known directly earthquake-related deaths from the study period, including one directly related death that was not evident from this review of the C/ME reports. The telephone survey method could be used again to measure mortality in future earthquakes and other natural disasters.

Announcement

Notes

C/ME reports were provided by Charles Plummer, Sheriff-Coroner, Alameda County; David B. 'Bud' Cook, Sheriff-Coroner, Monterey County; Harvey S. Nyland, Sheriff-Coroner, San Benito County; Boyd G. Stephens, MD, Chief Medical Examiner-Coroner, San Francisco County; Paul B. Jensen, Coroner, San Mateo County; John E. Hauser, MD, Chief Medical Examiner-Coroner, Santa Clara County; Alfred F. Noren, Sheriff-Corner, Santa Cruz County. We also acknowledge assistance from: S.A. Brenner, MD, and Eric K. Noji, MD, of the Centers for Disease Control and Prevention; Lynn R. Goldman, MD, Susan K. Cummins, MD, Martin Kharrazi, PhD, Richard A. Kreutzer, MD, Alexander Kelter, MD, Roger B. Trent, PhD. and Kathleen H. Acree, MD, of the California Department of Health Services. The project was funded by the California Department of Health Services.

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1. California Department of Health Services, Health Data Statistics Branch. Vital statistics computer tape files for 1989.
2. Source: California Department of Health Services, Health Data Statistics Branch. Vital statistics computer tape files for 1989.

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