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CASUALTY PATTERNS IN THE 1994 NORTHRIDGE, CALIFORNIA EARTHQUAKE

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ABSTRACT

The Northridge earthquake was directly or indirectly responsible for at least 72 fatalities and thousands of injuries and medical problems. This paper describes the factors contributing to these fatalities and discusses the results of preliminary health service utilization studies to characterize the number, distribution and type of earthquake injuries.

Structural failure contributed to about one third of the 72 Northridge earthquake fatalities. The performance of nonstructural elements and systems was linked to an additional ten percent. Other causes, ranging from falls to heart attacks, accounted for the remaining sixty percent of the deaths. This proportion includes 30 heart attacks classified by the Coroner's office as indirectly earthquake-related.

Retrospective earthquake injury investigations reveal that nonfatal injuries ranged from crush injuries and heart attacks requiring hospital care to self-treatable cuts and bruises. Post earthquake hospital utilization data suggests that as many as 11,800 people sought hospital treatment soon after the earthquake with emergency rooms experiencing a sharp increase in injuries. The spatial distribution of both nonfatal injuries and injury severity corresponds to the relative distribution of earthquake damage and shaking intensity. Utilization data also suggests that the bulk of hospital-treated injuries and medical problems were relatively minor. About ten percent of these injuries or medical problems required hospitalization. Although the health care system in the affected area was disrupted by internal facility damage and external problems such as utility outages, local and regional health resources were extensive enough to handle the casualty demand.

KEYWORDS

Earthquake injuries; casualties; Northridge Earthquake; epidemiology

FATALITIES

Although estimates vary, our review of available data suggests that the earthquake contributed, either directly or indirectly, to the deaths of 72 people. This section briefly describes the factors contributing to these fatalities.

Structural Performance

Twenty-two or one third of the fatalities were due directly or indirectly to structural collapse. Of the twenty-two fatalities resulting entirely from structural failure, sixteen perished in the partial collapse of a three-story apartment building; four died in the collapse of three separate wood-frame, single family homes; one reportedly died in a mobile home collapse; and a policeman perished when he drove his motorcycle off the end of a collapsed freeway overpass.

Nonstructural Performance

The performance of nonstructural elements and building contents accounted for one tenth of the fatalities. A twenty-eight year old man died of heart failure after sustaining head injuries from a microwave oven when his mobile home collapsed. The performance of nonstructural elements, in the absence of structural collapse, including utilities, contributed to an additional six fatalities. Two were crushed and asphyxiated when buried under hundreds of pounds of books, model trains, and other collectibles in their home. One hospital inpatient

Table 1. Fatalities by structural type and other causes.

Cause	Fatalities	Percent of Total
Structural Failure		
Buildings		
Wood frame		
Apartment Building Collapse	16	.22
Single family residential	4	.05
Mobile Home		
Mobile Home Collapse	1	.01
Other Structures		
Freeways		
Collapsed Freeway Overpass	1	.01
Total Related To Structural Failure	22	.30
Nonstructural Elements/ Contents		
Microwave Oven/Heart Attack	1	.01
Collectibles	2	.03
Respirator Failure	3	.04
Electrocution	1	.01
Total Related To Nonstructural Elements/Building Contents	7	.10
Other Causes		
Falls	5	.07
Automobile Accidents	3	.04
Fire	1	.01
Suicide	1	.01
Exposure	2	.03
Heart Attacks	30	.42
Total Related To Other Causes	43	.60
Total Fatalities	72	1.00

and two at home users succumbed when their respirators lost power and stopped. Finally, a twenty-five year old man was electrocuted when he tried to remove a power line from his car.

Other Causes

Falls contributed to five fatalities. A forty-nine year old man died when he fell or jumped from the sixth floor window of a downtown Los Angeles hotel. A seventy-four year old women perished from an aneurysm which ruptured when she fell out of bed during the earthquake. An eighty-eight year old man fell during the earthquake and fractured his hip thus triggering a fatal heart attack. Three others died of a combination of head injuries and heart attacks that the coroner's office felt was earthquake related. In each case it was unclear whether the fall preceded or followed the heart attack. Two separate fatal accidents happened at intersections where traffic signals had been disabled by power failures. A third person died when her car overturned after hitting an earthquake-caused street break. An earthquake-related fire claimed one victim. In this case a ninety-one year old woman died of smoke inhalation when his mobile home was knocked off support jacks by the earthquake which ruptured a gas line a started a fire. A 50 year old Ventura County Businessman apparently committed suicide when his uninsured business was destroyed by the quake. Two died of exposure. An 87 year old male contracted pneumonia after spending several hours in the cold after evacuating his home. Heart attacks accounted for 40% of the total fatalities. The largest single loss of life resulted from the collapse of a single, engineered building. Sixteen persons died in the collapse of portions of the three story, Northridge Meadows apartment complex located close to the epicenter.

Fatalities in the Northridge Meadows Apartment Collapse

Northridge Meadows was a three story, 164 unit apartment complex consisting of connected buildings surrounding a central area. A two story, reinforced concrete parking structure made up the west edge of the project. These buildings were essentially a "soft-story" configuration of primarily wood frame construction. The complex's ground floor perimeter consisted of double and single rows of wood frame garden apartments surrounding a central courtyard. Many of these units were backed, along the exterior edges, by carports whose steel columns and beams supported the upper floors. The building's wood frame second and third floors housed apartment units along double loaded corridors.

Durkin Associates' ongoing, historical cohort investigation determined that the earthquake caused first floor portions of the apartment complex to collapse in the following manner. The north, south and east portions of the complex fell approximately ten feet to the north, while the west section collapsed to the south. Twenty-six of the thirty-six ground floor apartments collapsed completely. The remaining ten units did not collapse. All of those killed lived in first-floor apartments in those building areas that completely collapsed. However, not all first floor residents died in the collapse. The collapse pattern of the building enabled some occupants to escape. Typical of observed building performance in other earthquakes, the collapse created void spaces which contributed to the survival of some first floor occupants (Shinobu et al., 1990; Noji et al 1990; Durkin et al., 1991a; Johns Hopkins University, 1989). Because the size and configuration of these void spaces differed for different parts of the complex, so did the survival rates. In addition, occupant behavioral patterns contributed to the fatality rate (Durkin and O'hashi, 1989).

NONFATAL INJURIES AND MEDICAL PROBLEMS

The Northridge earthquake was responsible for thousands of injuries and medical problems ranging from crush injuries and heart attacks requiring hospital care to self-treatable cuts and bruises. This section presents preliminary results from five investigations of health service utilization, dealing with the number and type of cases seen at hospitals, especially those with emergency rooms over a specified time interval.

Number and Spatial Distribution of Earthquake-related Injuries and Medical Problems

Los Angeles County Emergency Operations Center and Hospital Council of Southern California Hospital Surveys. The Los Angeles County Emergency Operations Center (LAEOC) and the Hospital Council of Southern California both periodically communicated with Los Angeles County hospitals to keep a running tabulation of the number of injuries and medical problems that hospitals were treating. As of January 22, the LAEOC and the Hospital Council reported that since the earthquake, 7,192 patients had been treated and released from hospital emergency rooms and 1,419 patients had been treated and admitted to hospitals, for a total of 8,611 non-fatal injuries and medical problems. However, these surveys did not include injuries in neighboring counties such as the heavily damaged Ventura County, nor did they make a systematic attempt to differentiate between earthquake-related and non earthquake-related cases.

American Red Cross Survey Of Earthquake-related Injuries and Medical Problems. The American Red Cross also surveyed Southern California hospitals to determine earthquake-related casualty counts. Data was partially collected through telephone contact with individual hospitals. However, in most cases the Red Cross relied on an individual hospital to compile its own results. Although some reporting inconstancies are possible (Hospital A reports all cases up to January 31 while Hospital B reports all cases up to February 6), the Red Cross survey results represent largely those cases treated during the two week period following the earthquake.

Preliminary Analysis of Red Cross Data. Our analysis of the reports from the 133 Los Angeles, Ventura and Orange county hospitals contacted, found a total of 11,846 non-fatal casualties. The one hundred and two responding area hospitals reported treating a total of 11,846 earthquake-related injuries and medical problems. Of this number 10,802 cases were treated and released and 1,044 cases were serious enough to require hospital admission. Not surprisingly, since this was the area of most intense shaking and heaviest damage, San Fernando Valley hospitals treated the largest number of cases. San Fernando Valley hospitals treated 5,938 or 78% of the total cases. Seven Ventura County hospitals reported treating 1,284 injuries and medical problems which was about eleven percent of the three-county total and twelve percent of the Los Angeles County cases. Our further analysis found that treatment was localized in specific communities. Surprisingly, Santa Monica hospitals reported treating relatively few casualties even though this community was heavily damaged.

As in other recent US earthquakes, the bulk of hospital-treated injuries and medical problems apparently were not severe enough to require hospitalization. The overall ratio of non hospitalized to hospitalized treatments was about ten to one in the three county area, in Los Angeles County, and in the San Fernando Valley. As with the spatial distribution of nonfatal casualties, the distribution of injury severity corresponds to relative damage and shaking intensity. About ninety percent of the cases requiring hospitalization were treated at San Fernando Valley hospitals. Less than one percent of hospitalizations were at Ventura County hospitals.

Limitations of Hospital Survey. This approach also has several limitations. First, the lack of uniform training of individual hospital informants might have resulted in data collection errors. Second, the lengthy Red Cross updating process, between January 31 and February 15, might under-report the actual case numbers and skew the case distribution among hospitals. Despite its limitations, the Red Cross data provides a useful first look at the frequency and spatial distributions of "earthquake-related casualties" within the three-county affected area.

Pre and Post-earthquake Comparison of Emergency Room Utilization.

Another way to estimate the Northridge earthquake's impact on health services, as well as the kinds of injuries caused, is to compare use of certain health care system organizational units before and after the earthquake. Beginning on January 21, LA County Public Health Workers, as part of their communicable

disease surveillance program, began a pre and post earthquake review of emergency room logs at 15 San Fernando Valley Emergency Rooms (Los Angeles County Department of Health Services, 1994).

This study's preliminary data analysis yielded the following three important results:

1. Immediately after the earthquake, the subject emergency rooms experienced a substantial increase in the volume of services rendered as evidenced in overall patient visits. In the seven days before the earthquake, patient visits were at a steady range of between 700 and 800 visits per day. However, on January 17, the overall number of patient visits jumped three-fold to about 2,300.

2. Immediately after the event, ER's saw significantly more injuries as opposed to other types of medical problems. Soft tissue and orthopedic trauma such as lacerations and fractures averaged about 120 per day during the pre-earthquake period. On the day of the earthquake, the number of injuries treated increased tenfold to 1,500. The volume of injuries seen dropped to 500 per day on January 18, and to 250 per day on January 19. Over the next ten days, this rate gradually tapered off bringing the injury rate to slightly above the pre-quake rate by January 30th.

3. About one week after the earthquake, emergency rooms saw more patients with gastroenteritis. Infectious diseases averaged about 80 per day during the week before the earthquake. They remained at the same level for the first six days after the quake. However, the infectious disease rate jumped from 80 to 200 per day on January 23 rd., due mostly to gastroenteritis cases, but returned to the pre-earthquake rate the next day.

Contribution of Earthquake-related Injuries and Medical Problems by Type

Table 2 illustrates the distribution, by general type, of injuries and medical problems seen by a cross-section of area emergency rooms immediately after the earthquake. This table provides a percentage breakdown showing the relative proportion of six major injury and illness groups (Soft Tissue and Orthopedic, Cardiovascular, Neuropsychiatric, Respiratory, Gastrointestinal, and Obstetrics/Gynecological) seen at six major hospitals located in or close to the most heavily damaged areas. The figures in Table 2 are derived from our review of the emergency room records, at each hospital, for the first twenty-four hours after the earthquake. All six hospitals are acute care general hospitals. Hospitals A and B are private hospital located near the earthquake epicenter in the west San Fernando Valley. Hospital C is a private hospital located in west Los Angeles. Hospital D, also a private hospital, is situated in an area of heavy damage in Santa Monica. Hospital E is a public hospital in the east San Fernando Valley. The sixth hospital (Hospital F) is a public hospital just east of downtown Los Angeles. The percentages, presented in Table 2 are derived from a preliminary analysis of cases seen at the emergency room of each hospital during the twenty-four hour period following the earthquake.

This analysis shows that soft tissue and orthopedic injuries including lacerations, contusions, sprains, burns and fractures formed the overwhelming majority of the immediate cases treated at five of the six hospitals studied. Such injuries comprised sixty percent of all cases treated at the six hospital emergency rooms. The percentage of soft tissue and orthopedic injuries treated at each hospital ranged from forty-nine to seventy-five percent at the five hospitals.

Cardiovascular conditions such as chest pain, dysrhythmia, hypertension and full cardiac arrest made up eleven percent of the total cases. Neurological and psychiatric complaints like anxiety and seizure constituted four percent of the cases. Respiratory problems, specifically asthma, toxic inhalation and respiratory infection, were responsible for six percent of the complaints. Gastrointestinal problems were also six percent. Obstetrics and gynecological episodes, namely threatened abortion, pre-term labor, and labor, comprised four percent of the events. Other medical problems such as replacing lost medication or simply lacking sufficient detail to assign the case to a particular category accounted for four percent of the total. And finally, two

hospital had insufficient data in emergency room records to categorize, by type, an additional forty five cases with medical problems. Such classification awaits a further medical record review.

Table 3: Distribution, by general type, of all injuries and medical problems treated at five hospital emergency rooms for first 24 hours after earthquake.

	Hospital A N=291		Hospital B N=125		Hospital C N=60		Hospital D N=103		Hospital E N=96		Hospital F N=165		All Cases N=840	
Injury or Medical Problem Groups	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Soft Tissue/Orthopedic	171	59	86	69	45	75	66	64	56	58	81	49	505	60
Cardiovascular	24	8	8	6	8	13	14	14	13	14	25	15	92	11
Neuro/Psych	5	2	2	2	5	8	2	2	6	6	16	10	36	4
Respiratory	17	6	8	6	0	0	7	7	9	9	12	7	53	6
Gastrointestinal	7	2	10	8	1	2	8	8	0		27	16	53	6
OB/GYN	11	4	2	2	1	2	3	3	12	13	2	1	31	4
Other	13	4	7	6	0	0	3	3	0	0	2	1	25	3
Insufficient Data*	43	15	2	2	0	0	0	0	0	0	0	0	45	5
Total	291	100	125	101	60	100	103	101	96	100	165	99	840	99

Source: Data from a preliminary analysis of hospital emergency room data from the Northridge earthquake currently being conducted by Durkin Associates.

* *Emergency room records were insufficient to categorize these medical problems at the present time.*

Breakdown of soft tissue and orthopedic injuries treated. Since Soft Tissue and Orthopedic injuries constituted the bulk of injuries treated at the six hospital emergency rooms, we further analyzed the five hundred and five injuries treated in these six settings and found the following: 1) Lacerations made up fifty-two percent of the total, 2) Twenty-three percent were sprains with shoulder dislocations contributing another three percent, 3) Fractures accounted for only ten percent of the soft tissue and orthopedic injuries, and finally, 4) Contusions were only ten percent of the injuries. Surprisingly, given the numerous fires after the earthquake, only one burn injury was treated at the five hospitals during the twenty-four hour study interval.

Additional limitations of previous studies

The previous studies offer valuable insights about the number, spatial distribution, and type of injuries and medical problems treated after the Northridge earthquake, as well as demands placed on area hospitals and their emergency rooms. However, the results of hospital emergency room assessments, by themselves, provide an incomplete picture of overall casualty patterns in the Northridge earthquake. First, such studies don't encompass the total range of organizational settings such as hospital outpatient units, physician's offices

and clinics where injuries and medical problems are commonly treated in an earthquake's aftermath. For example, a recent study of Loma Prieta, work-related injuries found that sixty percent of the cases were treated in nonhospital-based settings or were self-treated. Although serious casualties requiring hospital admission would normally be reflected in hospital surveys, the hospitalized only comprise about ten percent of the Northridge hospital caseload. Second, while yielding important information about the volume of medical services rendered, these investigations don't tell us which injuries and medical problems were earthquake-related. Most hospital records, especially those completed immediately after a disaster, lack sufficient detail to enable either determining whether or not the medical condition was earthquake related or to document and evaluate the risk factors contributing to the casualty.

Finally, we were interested in estimating the emergency room case proportion that was potentially earthquake-related, so we reviewed the emergency room records, in four of the six hospitals, looking for evidence that would eliminate specific cases from further consideration. We found that the earthquake-relatedness proportions varied among injury categories. While ninety-five percent of the Soft Tissue and Orthopedic, ninety-seven percent of the Cardiovascular, and eighty-three percent of the Neuropsychiatric cases were potentially earthquake-related, only fourteen percent of gastrointestinal and eleven percent of the respiratory problems were potentially so. We also found that about fifty-three percent of the OB/GYN and sixty percent of the Other conditions were not earthquake-related.

DISCUSSION, CONCLUSIONS AND IMPLICATIONS FOR INJURY REDUCTION

So far, the Northridge earthquake's casualty patterns seem similar, in several ways, to those observed in the 1971 San Fernando and 1989 Loma Prieta earthquakes. First, there were relatively few fatalities in each event. The Northridge earthquake had 72 fatalities (42 if we exclude heart attacks), the San Fernando earthquake had 67 deaths (NOAA, 1973), and the Loma Prieta earthquake had 63 deaths (Durkin et al., 1991b). Second, the fatality rates were similar and relatively low when compared with earthquakes worldwide. The gross fatality rate for the Northridge event was 5.5 deaths per 100,000 population. The fatality rate for San Fernando was 5.2 per 100,000. The fatality rate for Loma Prieta was 1.3 per 100,000 population. Excluding heart attacks from this analysis yields fatality rates of 3.2, 4.5, and 1.3 per 100,000 population for Northridge, San Fernando and Loma Prieta respectively (The Earthquake Project, 1993). Third, the fatalities related to structural performance occurred in a small number of damaged structures. For instance, the collapse of buildings in the Northridge Meadows apartment complex accounted for 16 of the 22 (or 72 percent) of the Northridge, collapse related deaths. 47 of the 58 (or 81 percent) San Fernando earthquake deaths happened in the collapse of buildings at the Veteran's Administration San Fernando Hospital. Finally, 42 of the 57 (or 73 percent) Loma Prieta deaths, related to structural failure, took place in the Cypress Viaduct collapse.

Nonfatal injury patterns were also similar in that, in each case, injuries were widespread but relatively minor (Durkin et al., 1994). For instance, the crude hospitalization rate for hospital-treated injuries appears to be about 10% for Northridge, 8% for San Fernando, and 17.5% for Loma Prieta (The Earthquake Project, 1993) . Conversely, one important distinction of the Northridge earthquake is that many fatalities were concentrated in the collapse of "soft-story," predominately, wood frame structures rather than reinforced concrete structures: the site of most San Fernando and Loma Prieta deaths. This finding, coupled with the poor seismic performance of other similar structures suggests the need to include this building type in earthquake hazard reduction activities, and to incorporate resulting casualty coefficients in earthquake casualty estimations.

What do some of these preliminary observations mean? For emergency planning they suggest that there are two principal patient-demand sources. The first is from structural collapse that yields concentrations of serious, life-threatening injuries. The second is from the normal injury mix from low to moderate building damage - that is, non-building collapse and collateral causes. These injuries and medical problems are probably distributed proportionally to the population and do not create excessive demands on most health-care systems, because there are not likely to be massive numbers of severe casualties concentrated in a local

area. This suggests that the primary emphasis of emergency medical planning should be first in areas where there are large numbers of high-hazard, structures and second where there are collapse-hazard structures, often widely distributed within a community (Durkin and Thiel, 1992).

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REFERENCES

Durkin, M. E. and C. C. Thiel, Jr. (1992). Improving measures to reduce earthquake casualties. Earthquake Spectra. 8(1), 95-113.

Durkin, M. E., A. Coulson, M. Hijar, J. Kraus, and H. Ohashi. (1991a). The survival of people in collapsed buildings. Disaster Chronicles, No. 3: Earthquake In Mexico, September 19 and 20, 1985. Washington, D.C.: Panamerican Health Organization, 55-70.

Durkin, M. E. and H. Ohashi. (1989). Casualties, survival and entrapment in heavily damaged buildings. Proceedings Of The Ninth World Conference On Earthquake Engineering, Kyoto, Japan. Tokyo: Maruzen Co., Ltd, 977-982.

Durkin, M.E., C.C. Thiel and J.E. Schneider (1994). Casualties and emergency medical response. In: The Loma Prieta, California, Earthquake of October 17, 1989: Loss Estimation and Procedures, U.S. Geological Survey Professional Paper 1553-A. United States Printing Office, Washington, A9 - A38.

Durkin, M.E., C.C. Thiel, J.E. Schneider, J.E. and T. De Vried (1991b). Injuries and emergency medical response in the Loma Prieta earthquake. Bulletin of the Seismological Society of America, 81, no. 5, 2143-2166.

Los Angeles County Department of Health Services (1994). Hospital ER Survey, January 10 - January 30, 1994. Los Angeles County, Department of Health Services, Disease Control Programs.

National Oceanic and Atmospheric Administration (1973). Individual and Organizational Dimensions. In: San Fernando, California Earthquake of February 9, 1971. U.S. Department of Commerce, NOAA, Washington, D.C., pp 261-291.

Glass, R.I., J.J. Urrutia, S. Sibony, H. Smith, B. Garcia and L. Rizzo (1977). Earthquake injuries related to housing in a Guatemalan Village. Science, 197, 638-643.

Johns Hopkins University (1989). Proceedings, International Workshop On Earthquake Injury Epidemiology For Mitigation And Response. The Johns Hopkins University, Baltimore, Maryland.

Noji, E.K., H.K. Armenian, A.P. Oganessian (1990). Case-control study of injuries due to earthquake in Soviet Armenia. Ann. Emer. Med., 19, 449.

Shinobu, S., A. Coburn and R. Spence (1990). Human Casualties in Building Collapse: Literature Review. The Martin Center for Architectural and Urban Studies, University of Cambridge, Cambridge, England.

The Earthquake Project (1993). The Loma Prieta Earthquake: Impact on Local Emergency Medical Services and Patient Care. Emergency Medical Services Agency, Department of Public Health, City and County of San Francisco.