Chapter 2

CASUALTY IN EARTHQUAKES

By
Nicholas P. Jones, Eric K. Noji, Gordon S. Smith, and Robin M. Wagner

ABSTRACT

Significant resources in research support and effort have been expended on the problem of earthquake hazard mitigation over the past twenty years. Most of this research effort has been directed toward questions of geophysical research and structural engineering. While this expenditure of effort has been appropriate in terms of advancing scientific understanding of the underlying phenomena responsible for earthquake losses, the tragic fact is that earthquakes continue to injure and kill human beings. The specific mechanisms of death and injury in earthquakes have not yet been the subject of extensive study. This chapter critically reviews past efforts in the study of earthquake-induced morbidity and mortality, outlines the lessons learned from past events, and offers some suggestions for future research in this area and utilization of current knowledge in the Central and Eastern United States.

INTRODUCTION

Over the past several decades, significant resources in research support and effort have been expended - in this country and elsewhere - on the problem of earthquake hazard mitigation. Most of this research effort has been directed toward questions of geophysical research and structural engineering. While this expenditure of effort has been entirely appropriate in terms of advancing scientific understanding of the underlying phenomena responsible for earthquake losses and the development of improved strategies for the mitigation of losses in future events, the tragic fact remains that earthquakes continue to exact a toll on human lives. The specific mechanisms of death and injury in earthquakes and the development of strategies to effect their reduction have not yet been the subject of extensive study.

Despite their often overwhelming and destructive effects, death-and injury-producing earthquakes are still relatively rare events. In fact, most earthquakes cause few or no serious injuries despite often extensive property losses: Over 70% of the approximately 1.3 million earthquake-related deaths since 1900 have occurred in 12 single events (Table 1). One single earthquake - the 1976 Tangshan earthquake in China - was responsible for close to 20% of all earthquake fatalities in this century.

Table 1: Major Casualty Earthquakes 1900-1988 (Smith, 1989.)

Mortality	Place	Date
242,500	Tangshan, China	1976
200,000	Kansu, China	1920
142,800	Kanto, Japan	1923
66,800	Ankash, Peru	1970
58,000	Messina, Italy	1908
40,900	Tsinghai, China	1927
32,700	Erzincan, Turkey	1939
32,600	Avezzano, Italy	1915
28,000	Chillan, Chile	1939
25,000	Quetta, Pakistan	1935
24,900	Armenia, USSR	1988
23,000	Guatemala City	1976
382,800	Others Combined (29%)	
1,300,000	TOTAL	

The estimated 1.3 million people killed in the period 1900-1988 represent an average of about 15,000 deaths each year over an 89 year period. While this number may seem large, when considered in relative terms, it corresponds to a rate of only 0.34 per 100,000 population per year. Even China has reported only about 500,000 deaths since 1900, just double the overall rate (0.60 per 100,000 population per year using the 1980 estimated population for calculations). More detailed studies which look at mortality rates for smaller geographic areas have not been performed but would likely show much higher rates in high risk areas. By comparison, the 1980 all-cause world annual mortality rate was 1,000 per 100,000 population and the motor vehicle mortality rate in the United States is 19.4 per 100,000 population. However, while the mortality rate from earthquakes overall is relatively low, the potential for massive, overwhelming numbers of casualties and injuries within a very concentrated time and place has made them an important focus of the International Decade for Natural Disaster Reduction.

In the United States, only an estimated 1,600 deaths have been attributed to earthquakes since colonial times (Stratton, 1989) with over 60% occurring in California. The most serious event in terms of loss of life was the 1906 San Francisco earthquake and fire which killed an estimated 700 persons (Stratton, 1989) and only 3 others killed more than 100 persons: 173 deaths in Unimake Island, Alaska (1946), 131 deaths in Prince William Sound Alaska (1964), and 116 in Mona Passage, Puerto Rico (1918). More recent events continue to exact smaller - but significant - tolls: 64 in the 1971 San Fernando earthquake, and most recently, 67 in the 1989 Loma Prieta earthquake. No events involving significant casualty have occurred in the Central and Eastern United States since the New Madrid events of 1811-1812; reliable morbidity and mortality figures for those events are not available.

The above statistics are based on a small number of high-impact events. While these data are of some use in assessing the overall impact of earthquakes for comparison to other causes of injury, they are of little value in developing a more detailed understanding of mortality (i.e., deaths) and morbidity (i.e., nonfatal injuries) patterns and mechanisms in earthquakes, or in the development of effective interventions at the various phases of these disasters. However, early work by epidemiologists suggests that efforts to reduce earthquake-related fatality and injury may indeed benefit from more disciplined study (Western, 1972; Glass, et al., 1977; Lechat, 1974). Subsequent work by architects and engineers has pointed to the possibility of more rigorous data gathering in the aftermath of major earthquakes (Durkin and Ohashi, 1988; Jones, 1989; Krimgold, 1989; Durkin and Thiel, 1991).

Despite its apparent simplicity, obtaining reliable and accurate estimates of casualties associated with earthquakes has posed serious challenges in the past. Such estimates have varied, in part, because there is no universally accepted definition of earthquake-related deaths and injuries. Furthermore, documentation of injuries has generally taken a lower priority than rescue and treatment activities in the face of disaster. Even the recent Loma Prieta earthquake was no exception. Initial press accounts put the total death toll in the hundreds (Shilts et al., 1989a; Shilts, et al., 1989b), an overestimate by a factor of 3 to 4, and even the scientific literature could not agree on the actual count, offering a range of 60 to 67 deaths (e.g., Anon, 1990; McNutt, 1990; CDC, 1989; and USGS, 1989). One year after the event there was still no reliable quantitative information on injury counts associated with the earthquake (Jones et al., 1990b). This uncertainty still exists at the time of writing.

Until recently, there has been no effective or coordinated program of research into earthquake injury epidemiology. While there have been a few preliminary studies from individual researchers in several disciplines, this topic has suffered the fate of many transdisciplinary problems. It has been dealt with peripherally by several disciplines, but not accepted as the central responsibility of any particular research group. The topic is difficult to approach from any narrow disciplinary background, as it requires the collaboration of several disciplines. First, it is necessary to understand the mechanisms of physical failure in earthquakes (engineering.) Second, it is necessary to understand the process of human injury in earthquake-induced building failure. The implications of building/occupant interaction are the critical issue in prevention of life loss and injury (medicine, architecture, social science). Third, it is necessary to develop an analytical framework for the analysis of injury patterns and the relationship between specific causative agents and their negative consequences (epidemiology) (Smith, 1989; Alexander, 1989; Armenian, 1989; Coburn et al., 1989; Coulson, 1989; Durkin, 1989).

While there have been clear advances in recent decades in most of the disciplines listed above, it is clear that it is the epidemiological dimension which has only recently begun to be explored. Recent efforts have confirmed the assertion that there is much to be learned from the detailed analytical study of earthquake casualty. As society endeavors to reduce the consequences of natural disasters, appropriately directed and focused efforts are required. In the earthquake injury field, these efforts can be identified most readily through comprehensive and detailed epidemiologic study of events as they occur.

This chapter will begin with an assessment of the need for casualty data: **Why are the data needed, for whom, and for what purpose?** A brief summary of some past studies on earthquake casualty will be given, concentrating on the relatively few studies where comprehensive and rigorous data collection procedures have been implemented. In addition, brief reference will made to other studies which have contributed knowledge to the field. A discussion of the implications of these results will be made, outlining some of the important issues which remain unanswered, both in general, and in the context of the Central and Eastern United States situation. Finally, suggestions for future research issues in the casualty field will be offered. A comprehensive, but not exhaustive, bibliography of much of the recent research on the topic is included.

WHAT IS EARTHQUAKE INJURY EPIDEMIOLOGY?

Earthquake injury epidemiology can be defined as the study of the distribution of death and injury in earthquakes and the causes of fatal or nonfatal injury. The causal mechanisms are difficult to elucidate precisely, as are the appropriate variables and indicators describing them. It is necessary to consider building construction types, and their performance during earthquakes, the influence of nonstructural components of buildings and building contents, occupancy and occupant behavior, emergency and rescue response, and medical treatment provided. These areas have not traditionally been the responsibility of any single field, but require the *interaction* of several disciplines.

A rigorous epidemiological approach to the study of earthquakes is based on the study of diseases/injury in whole populations, rather than studying a limited number of individual patients and their treatment (Last, 1983; Lilienfield, 1980). As such, it seeks to determine risk factors or predict disease outcomes that can then be used to develop sound principles for disease/injury prevention. Central to the epidemiologic approach to injury prevention is the matrix developed by Haddon (1980) who describes three phases of an injury producing event where injury prevention can be achieved (Table 2.)

While nothing can be done to prevent earthquakes from occurring, avoiding high risk areas can reduce losses to me built environment and to those exposed to risk (Noji and Sivertson, 1987). Engineering interventions have largely been directed to increasing the ability of buildings to withstand ground shaking. The traditional health approach to earthquakes has been largely directed at the post-event phase; seeking to reduce the health consequences of an earthquake once it has occurred through better search and rescue methods, and more effective medical care. Researchers are now studying the event and pre-event phases to determine how epidemiology and public health can assist in a more primary mode of prevention.

Table 2: Phases of earthquake where injuries can be prevented

Phase	Strategy
Pre-event	Prevent earthquake from occurring, or ensure people do not experience its effects by avoidance strategies and building codes.
Event	Reduce injures during earthquake (earthquake-resistant building design.)
Post-event	Reduce consequences of injury following building collapse (rapid search and rescue.)

Unfortunately, detailed epidemiologic studies of injuries in past events have not, in general, occurred. Thus, it is not clear exactly where prevention and treatment efforts and finances should be focused. If it is found, for example, that most severe injuries or deaths are resulting from inappropriate responses on the part of the victims, then education should be targeted as a priority item. If the interaction between building contents and occupants is causing high rates of injury, then more action needs to be taken to ensure proper anchorage of these contents. If a large number of people are dying because they are not being extricated quickly enough from collapsed buildings, then extrication techniques or rescue equipment need improvement. If a large number of people are dying after successful extrication from severely damaged or collapsed structures, then it is necessary to improve emergency treatment procedures.

THE NEED FOR COMPREHENSIVE CASUALTY DATA

Applications of Epidemiologic Data on Earthquake Casualty

The results of epidemiologic studies of injuries in disasters - in this case, earthquakes - can be used to effect casualty reduction by improving both mitigation and preparedness and response activities. For the Central and Eastern United States, where lack of attention to the earthquake threat has led to a significant potential vulnerability, the implementation of efficient and cost-effective mitigation strategies and conduct of appropriate response and recovery planning is essential. **Where should funds be spent to effect the greatest potential reduction in casualty when the 1811-1812 events recur: Retrofit (pre-event)? Education (event)? Search and rescue capability (post-event)?** Results of past and future analytical epidemiological studies can be used to assist in answering this question.

An overall objective of collecting data after earthquakes is to measure and describe the health effects of earthquakes and the factors that contribute to these effects, with the goals of: (1) assessing the needs of earthquake-affected populations; (2) matching resources efficiently to needs; (3) preventing further adverse health effects; (4) evaluating earthquake relief effectiveness; and (5) making future earthquake contingency plans. Data collection after earthquakes and analysis of these data can also be linked to an emergency decision-making process. In addition, **earthquake casualty researchers have an important role to play in providing informed advice about the probable health effects which may arise in a future earthquake, in establishing**

priorities for action, and in emphasizing the need for accurate information as the basis for relief decisions.

Epidemiology has made major contributions to the planning of more effective relief efforts after disasters. For example, the assessment of health needs and disease surveillance after earthquakes have occurred. Studies of attendance at clinics following the 1976 earthquake in Guatemala, for example, showed that by the time international medical disaster assistance arrived, new trauma admissions had fallen off dramatically (Seaman, et al., 1984; de Ville de Goyet, 1976). This finding has led to the realization that efforts should be made to increase the local capacity to respond to disasters rather than rely on outside assistance. Well-designed epidemiologic studies have also shown that contrary to popular belief, major outbreaks of food or water-borne diseases rarely follow natural disasters (Spencer, et al., 1977).

Decisions faced by emergency managers and planners depend on which phase of an earthquake disaster they are considering. Thus, at the pre-event phase the decisions are concerned with delineating the at-risk populations, assessing the level of emergency preparedness, and training of personnel. For emergency managers and city planners, data collected by earthquake injury researchers can be used in community vulnerability analyses. Vulnerability analysis involves the collection and assessment of information on communities at risk from earthquakes, including data on the performance of structures and lifeline systems during past earthquakes (e.g., utilities such as water, electricity and gas, health facilities, etc.). During the event phase, characteristics of the affected population and the need for emergency services have to be assessed quickly. In the post-event phase, data are needed to evaluate the effectiveness of health intervention programs and to serve as the basis for planning strategies to reduce future event-related morbidity and mortality.

Hospital and emergency medical services (EMS) personnel will also need information regarding the types of casualties to expect in earthquake disasters. In the light of the Loma Prieta earthquake, it is clear that hospitals are a key, if not the most vital part, of the immediate response to an earthquake. Unfortunately, most hospital administrators and health care personnel have no idea what to expect when an earthquake strikes or what sort of building and occupant damage may occur. Clearly, this lack of readiness must change. During the two most damaging recent United States events, the 1971 San Fernando and the 1989 Loma Prieta earthquakes, health care facilities suffered significant damage and, in San Fernando, most of the deaths occurred in hospitals.

Consider, as an example, the medical aspect of the relief phase. This aspect can be broken down into on-site medical assistance, transportation, hospital treatment and, if appropriate, post-hospital care. Identification of a weak link in the "medical process", e.g., transportation delays, can be important to enhancing survival or improving recovery. The medical response must be somehow incorporated into the total response operation. It is important to identify where problems may have occurred in this operational structure in the past, and to make efforts to establish procedures to minimize these in future events.

The development of important preventive strategies has also followed epidemiologic studies of disasters. More complete discussions of the use of epidemiology in disasters are available in several reviews of the subject (Logue, et al., 1981; Seaman, 1984; Lechat, 1975, 1976, and 1979; Western, 1972; Lechat, 1990).

Another significant potential application of earthquake injury epidemiology studies is the use of the data to develop educational programs which may enhance occupant survival. Past educational programs have tended to be general; it is possible that a more site-specific approach is needed. A question exists, however, as to whether prior training does actually effectively change behavior under stress. More research needs to be done in this area, and in the development of more effective teaching tools. It is likely that it is easier to teach behaviors such as checking for gas and water leaks after the earthquake than to teach appropriate behaviors for the event phase.

Casualty Estimation Modeling

One of the important uses for casualty data which deserves special attention is casualty estimation modeling: This represents the framework into which the outcomes from individual studies may fit. The close relationship that exists between earthquake injury epidemiology and casualty modeling is important: However, they are indeed distinct, and this distinction is also critical. Loss estimation models are frequently used by planners and public officials in preparedness activities. "Loss" may refer to property and economic losses, or to casualties. One of the important potential uses for the data collected through earthquake injury epidemiologic studies is as a database with which casualty estimation models may be developed or refined. While the focus of this chapter is not specifically the modeling issue, or the evaluation of current casualty estimates and the procedures used to derive them, this topic represents a very special application of the data and its inclusion is essential.

The relevance of modeling for the Central and Eastern United States is critical: reliable estimates of future losses (both material and human) depend critically on not only data (appropriately collected and processed) from past events, but also the effectiveness of the predictive model into which they are incorporated. With little or no past damage or injury data from this region to depend upon, casualty modeling for these regions must be very carefully implemented through a well-conceived and designed procedure to avoid gross overestimates or underestimates being made. The lack of data places an even greater burden on the modeling philosophy used, and its implementation.

During the past two decades, considerable attention has been devoted to the general area of disaster loss estimation. However, little attention has been devoted to the more specific estimations of earthquake-related casualties. Yet casualties are of prime concern to those who commission loss estimations -public and private sector organizations whose responsibility is life safety. Disaster loss estimation projects should aim to provide a sound basis for development of comprehensive casualty estimation methodologies that combine the most efficient and effective casualty estimation techniques and the most current theories and data. In addition to improving our ability to estimate casualties in future earthquakes, this research will lead to 1) developing more realistic planning guidelines; 2) developing better response programs; 3) predicting disaster impacts on specific sub-populations for planning purposes; 4) planning for the allocation of supplies and medical resources in the immediate post-disaster environment; 5) developing more effective medical training, search and rescue (SAR) and self-help programs and 6) assessing feasibility and designing disaster appropriate warning systems.

Serious doubts exist as to the validity of existing casualty estimation models - both pre-event and post-event. While they often have been instrumental in motivating preparedness activities, their reliability is unknown, and, therefore, usefulness for detailed planning is generally limited. Most are based on engineering models with little input from medicine or epidemiology. It is common for post-event damage estimates, and, therefore, casualty estimates to initially be highly suspect. This is perhaps a fault which lies with the organization and implementation of rapid post-event reconnaissance. The problem is a difficult one: both the 1985 Mexico and 1989 Loma Prieta earthquakes exhibited localized areas of intense damage interspersed throughout large, relatively unaffected areas.

Exactly what a casualty estimation model is designed to accomplish must be carefully defined. **Are estimates of the breakdown of injuries given (e.g., orthopedic, lacerations, contusions, etc.)? Does the model predict final outcomes, or the initial distribution of deaths and injuries or injury severities before intervention? Does the model produce aggregate (e.g., regional) information, or structure-specific information?**

At the national level it is important to make reliable estimates of the dead and injured. This includes pre-event estimates, for preparedness and planning purposes, as well as post-event or response-phase estimates, which represent refinements to the pre-event planning model based on reconnaissance. The latter are necessary for the allocation of resources after the event (Lechat, 1989; Mahoney, 1989). At the local level, models predicting the search and rescue demand for particular structures are essential for effective responses.

Perhaps it is even possible to develop general models which are based on individual events or individual structures or blocks of structures. In addition to providing a rational method for casualty estimation, which is essential to planners, such models would enable the mechanism of injury in earthquakes to be elucidated through identification and observation of critical variables, and also provide a framework for data collection in future events (Jones, 1989).

One of the important features of such a model is the potential for identifying how the variables interact and how independent risk factors modulate the expected outcomes. Sensitivity of the model to small changes in the variables should be addressed. Spatial models would greatly assist in resource allocation planning both before and after an event. The development of probabilistic models is seen as an urgent need. Not only should expected numbers of casualties be given, but also the variances of the estimates, and the associated statistical moments for the various variables and indicators in the model. In this way, estimates can be improved (i.e., the variance of the estimate reduced) as more data become available. Pre-event predictions can be modified quickly after the event by performing reconnaissance activities.

Past Casualty Estimates in Vulnerability Studies

Previous research findings on casualty have been used loosely to project earthquake-related casualties in future events. Earthquake planning scenarios including casualty estimates have been performed over the last several decades for a number of regions in the United States, including Central and Eastern States. Estimates have been made for the **Los Angeles region** (e.g., NOAA, 1973; FEMA, 1981; USGS, 1981; DMG, 1982; USGS, 1985; DMG, 1988), the **San Francisco Bay Area region** (e.g., NOAA, 1972; FEMA, 1981; USGS, 1981; DMG, 1982; DMG, 1987), **Puget Sound, Washington region** (USGS, 1975), **Utah** (USGS, 1976; SSAC, 1979), **Alaska** (ADES, 1980; FEMA, 1980), **Hawaii** (FEMA, 1980; FEMA, 1982), **Charleston** (FEMA, 1988) and **New Madrid area** (Mann et al., 1974; Liu, et al., 1979; FEMA, 1985). Details of the estimates can be found in the cited references, while Lagorio (1990) gives a summary of the predicted mortality and morbidity figures.

Of interest are the figures for the central and eastern regions referenced above. These data are summarized in Table 3 (Lagorio, 1990).

Table 3: Loss Estimates - Central and Eastern United States

Reference	Region	Fault	Deaths	Inj'd
Mann et al., 1974	Mississippi,Arkansas, Tennessee	New Madrid	1100	4400
Liu et al., 1979	New Madrid	New Madrid	646	64567
FEMA, 1985	Six cities: Carbondale, Evansville, Little Rock, Memphis, Paducah, Poplar Bluff	New Madrid	4907	19590
FEMA, 1988	Charleston, S.C.	Woodstock /Ashley	2143	8574

It is difficult to compare these estimates, as the study areas and other parameters differ greatly. It is important to note, however, the difference in the structure of the estimates (e.g., ratio of deaths to injuries). Such estimates, while they consider a range of possible scenarios, are plagued by high degrees of uncertainty in both the modeling philosophy adopted and the data on which they are based.

Results from more recent earthquakes in Coalinga (1983), Whittier-Narrows (1987), Loma Prieta (1989), Sierra Madre (1991), Ferndale

(1992), and Landers-Big Bear (1992) indicated that in these moderate-to large-magnitude (6.5 - 7.4) events, deaths were relatively uncommon and most injuries included only minor contusions, sprains, lacerations, or extremity fractures. **Note that this observation pertains (specifically) to California events, and may not be generalizable to regions such as the Central and Eastern United States.**

PAST RESEARCH AND FINDINGS IN CASUALTY DATA COLLECTION

General

A critical review of the scientific literature on the causes of earthquake-related deaths and injuries leads to the following general conclusions. First, there is a lack of epidemiological investigations of earthquakes, despite their great lethality (see Table 1). This dearth has arisen from inadequate funding and, until recently, from a relative lack of interest in the subject area by researchers (Tierney, 1990). Second, almost all of the published epidemiological studies on earthquake-related injuries are descriptive rather than analytical, precluding the ability to establish and quantify the magnitude of the relationship between significant risk factors and injuries. Only five analytical studies of earthquake-related injuries have been conducted to date (see Table 4).

Third, documentation of deaths and, in particular, non-lethal injuries is often incomplete in the aftermath of disaster, particularly in less developed countries. Fourth, injuries are often vaguely and inconsistently defined in the previous epidemiological studies. For example, the definition of injuries may include conditions other than physical trauma (Sanchez-Carrillo, 1989), as well as any affliction treated after the disaster, whether or not it was earthquake-related (de Ville de Goyet et al., 1976). Investigators often employ different schemes to classify injury severity levels (Coulson, 1989). Fifth, most previous epidemiological studies of earthquake populations have been conducted solely by health researchers, even though the topic calls for an interdisciplinary approach which draws on structural engineering, geology, architecture, epidemiology and emergency medicine.

Table 4: Analytical Epidemiological Earthquake Injury Studies

Authors	Location & Magnitude	Date
Glass, et al., 1977	Guatemala 7.5	Feb. 4, 1976
de Bruycker et al., 1983 de Bruycker et al., 1985	Campania, Italy 6.5-6.8	Nov. 23, 1980
Armenian et al., 1992 Noji, 1990	Armenia, USSR 6.8	Dec. 7, 1988
Jones et al., 1992 Wagner et al., 1992	Loma Prieta 7.1	Oct. 17, 1989
CDC, 1990	Luzon, Philippines 7.7	July 16, 1990

Risk Factors for Physical Injury

The majority of studies on the risk factors for earthquake-associated injuries actually appear in the earthquake engineering literature. These studies have generally been executed along strict disciplinary lines without input from health professionals. Thus, despite their quantitative approach, these engineering studies do not employ standard methods or meet minimal criteria generally required by epidemiologists to accurately and reliably assess risks. For example, some surveys of earthquake victims are not based on random, probability based samples of a clearly defined study population (Arnold, 1986; Durkin, 1985 (San Fernando earthquake); others do not report sufficient information to evaluate the sampling methodology (Mochizuki, 1988; Miyano and Mochizuki, 1988; Ohta and Omote, 1977; Ohta and Ohashi, 1980,); still others sampled highly select groups (Mochizuki et al., 1988), making it difficult to generalize the results to the rest of the population. Many of these studies either do not report or have unacceptably low case ascertainment or survey response rates, raising questions about the validity of the results. The survey instruments, when described, do not appear to measure well the stated variable of interest (Ohta and Omote, 1977; and Ohta and Ohashi, 1980), although in the cited cases this may have resulted from translation of the questionnaires from Japanese into English for publication.

Despite these limitations, the literature has identified a number of potentially important risk factors for injuries associated (either directly or indirectly) with earthquakes. These include characteristics of the earthquake itself (e.g., magnitude, epicentral intensity, distance from the epicenter, time of day and season), geological and topographic conditions (e.g., soil type, cliffs or mountains), post-earthquake weather (e.g., rain, which may trigger landslides, or extreme cold), the nature of the built environment (e.g., the degree of seismic resistance of buildings and other human engineered structures, such as bridges), the presence or absence of secondary hazards (e.g., fires, hazardous materials spills, tsunamis), sociodemographic features of the affected population (e.g., population density, age, sex), and human behavior during and after the event (Stratton, 1989; Tierney, 1990).

There is consensus among epidemiologists and engineers that built environments pose the single greatest physical injury risk to people in earthquakes. Table 5 presents some of the relevant results of the five analytical epidemiology studies. In this table, the "odds ratio" is defined as the ratio of the odds of injury in exposed individuals to the odds of injury in the unexposed, and is closely related to the relative risk of injury. Being trapped by collapsing structures was found to be the most significant risk for dying in the 1988 Armenian and 1980 southern Italian earthquake (Noji, 1990; de Bruycker et al., 1983; de Bruycker et al., 1985). Trapped persons were 68 to 107 times more likely to die, and 5 to 11 times to be non-lethally injured than non-trapped individuals. Similarly, all deaths and serious injuries that occurred in a village during the 1976 Guatemalan earthquake were caused by building collapse (Glass et al., 1977).

Being inside a building when the earthquake began was associated with a 12 fold-risk of being seriously injured in the 1988 Spitak, Armenia, earthquake (Armenian et al., 1992). Construction materials, height and age of the building, as well as the individuals' location in the building and behavior during shaking proved to be significant risk factors for casualties. Hazardous buildings were generally made of unreinforced masonry or concrete (v. wood), and were relatively tall and old (Armenian et al., 1992; CDC, 1990; Glass et al., 1977). Persons located on higher floors of multistory buildings suffered more casualties than those on lower floors in the Armenian, Italian and 1990 Luzon, Philippine earthquake (Armenian et al., 1992; de Bruycker et al., 1983; and CDC, 1990). In the Armenian and Italian earthquakes where many buildings collapsed or were severely damaged, those who stayed indoors during the shaking had a higher risk of being injured than those who ran outside (Armenian et al., 1992; de Bruycker et al., 1985).

Table 5: Building and structure-related risk factors for injury: analytical studies.

	Odds Ratio (95% CI)***	Author
Inside building v. not inside	12.20 (3.62-63.69)	Armenian et al.(1992)
	3.31 (2.11-5.53)	Jones et al.(1992)
For those inside a building		
Construction materials Adobe brick v. non-adobe houses	26.8*,**	Glass et al., 1977
(mostly wood frame) Concrete/mixed matls v. wood	3.4 (1.1 - 13.5)	CDC, 1990
Age of building ≥ 8 yrs old v. ≤ 8 yrs old	3.21*	Glass et al., 1977
Number of floor levels ≥ 5 floors v. ≤ 5 floors	3.45 (1.76 - 6.74)	Armenian et al. (1992)
≥ 7 floors v. ≤ 7 floors	34.7 (8.1 - 306.9)	CDC, 1990
Location on floor Located on floors 2-4 v. 1	2.60 (1.42 - 4.75)	Armenian et al.(1992)
Located on floors ≥ 5 v. 1	4.02 (1.08 - 14.9)	Armenian et al.(1992)
Located in mid-level v. bottom or top	2.3 (1.3 - 4.2)	CDC, 1990
Stayed indoors v. ran outdoors	4.82 (2.34 - 10.0)	Armenian et al.(1992)
Entrapment		
Being trapped v. not trapped (mortality)	107.24*,** 67.3* (49.7 - 91.3)	de Bruycker et al., 1983 Noji, 1990
Being trapped v. not trapped (morbidity)	5.17*,** 11.4* (10.2 - 12.7)	de Bruycker et al., 1983 Noji, 1990
Duration of entrapment: ≥ 1 hr. v. ≤ 1 hr.	2.79 (1.52 - 5.13)	Noji, 1990

* Relative Risk, not odds ration
** Calculated from information provided in the publication
*** CI = Confidence interval

In addition to the built environment, age has been shown to be a significant risk factor for earthquake-related deaths and injuries in epidemiological investigations. Mortality was highest in children and the elderly (de Ville de Goyet et al., 1976; Glass et al., 1977) whereas morbidity increased continuously with age (Glass et al., 1977).

County of Santa Cruz Case-Control Study

As an example of the detailed insights that can be obtained from an analytical epidemiological study, some preliminary results are given from a case-control study of the risk factors for sustaining physical injuries in the County of Santa Cruz (SCC) associated with the Loma Prieta earthquake. This study was recently initiated by the authors to study how the physical environments and personal behaviors of residents of SCC contributed to their risk of being physically injured or killed in SCC during the shaking of the main earthquake and in the subsequent 72 hours (Jones et al., 1992; Wagner et al., 1992.) The complexity of the issue is well demonstrated in the relatively few data that are presented, and implications for scenario development for the Central and Eastern United States evident.

This study is the first case-control study of earthquake-related injuries in a region in which many buildings have been designed or retrofitted to resist seismic forces. Thus, in contrast to the few earlier studies which have concentrated on lesser developed nations, the results of this investigation are likely to be generalizable to future earthquakes in California, the United States in general, and industrialized nations, such as Japan, which have adopted and enforced well-conceived seismic design provisions of building codes.

This information should be valuable since there is a probability of approximately two-thirds that an earthquake at least as strong as the Loma Prieta earthquake will strike California in the next 30 years (USGS, 1990b). However, it is emphasized that these findings may not be generalizable to the Central and Eastern United States, where construction codes and practices relative to earthquake-reistant design have been (and in many cases still are) quite different from those in the Western States. This point underscores the need for researchers to study a variety of physical environments in order to describe injury risks and devise appropriate intervention strategies. It may indeed be suggested that data from the lesser-developed nations may be more appropriate for the Central and Eastern United States situation. More investigation of this topic is required.

In the Loma Prieta study, information on both injuries and risk factors was obtained through a structured telephone interview of cases and controls, or their proxies if necessary. Injury information on cases was also obtained from emergency department and inpatient medical records and autopsy reports. Further details of the study and its design can be found in Jones et al. (1992), Wagner et al., (1992), and Jones et al., (1993).

To be eligible for the case-control study, participants had to have been living and present in SCC at the time of the earthquake. The case group consisted of those killed by the earthquake, and those seen at a SCC hospital or flown by helicopter out of County for treatment of earthquake-related injuries. For comparison, a population-based random sample of current SCC residents was selected using a random digit dial of listed and unlisted residential telephones. The sample was divided into two groups: non-injured controls; and, injured controls, i.e., individuals who incurred an earthquake-related injury but were not treated at a SCC hospital or flown by helicopter to a hospital outside SCC. The non-injured controls were frequency matched to hospital and dead cases on general area of residence at the time of the earthquake.

Physical environments are characterized broadly as being inside a building; in or on a vehicle; or outside (in close proximity to a building or away from buildings entirely). Risk factors specific to each environment are also being explored. Buildings are broadly classified as residential, commercial, industrial/farm, and public/institutional. For practical reasons (e.g., relying on reports from laypersons), the only attempt made through the questionnaire to infer structural type was through description of building materials; this aspect requires field follow up. Within the building environment, hazards from structural and non-structural components of buildings are distinguished from dangers posed by building contents. Behaviors of interest include the protection and rescue of oneself and other people, pets, or things, as well as clean-up activities in earthquake-damaged areas. Sociodemographic characteristics examined include age, sex, level of education, occupation, access to health insurance, etc.

The outcomes of interest are earthquake-related physical injuries that occurred during the shaking of the main earthquake (the event phase) and the subsequent 72 hours (the post-event phase) when aftershocks are occurring frequently. Injuries are characterized by their type, affected body parts, cause, and level of severity. Injury outcomes are defined in two ways: 1) presence or absence of injuries of any severity level; and 2) injury severity level using the Injury Severity Score (AAAM, 1990).

Using the interview data as a source of information, a building survey was conducted by structural engineers in the county in the summer of 1992. Addresses were obtained (from the case interviews and injured controls) and validated through a careful evaluation of the (sometimes inconsistent) interview data. In all, a total of 543 sites were visited over a ten-day period. Structures were coded with a form which attempted to collect information compatible with the interview forms used in the case-control study and with ATC-13 classifications (ATC, 1985). These data will be used to estimate risk factors as related to building type.

The hospital/dead case population consisted of 580 persons (or their proxies) targeted for interview. Of these attempted interviews, 483 (83%) were successfully completed, 31 (5%) were refusals, and 66 (11%) were lost to follow up. Of the 483 successful interviews, 357 were eligible for the case-control study.

In obtaining the random population sample of controls, contact was attempted with 1823 households. Of these, only 7.5% refused to cooperate with the study. This low refusal rate among hospital/dead cases and the controls is important, as it indicates that both study groups are likely to be representative of the populations from which they came. In all, 701 households were eligible for the case-control study.

The data indicate that a significant proportion (106/701) of the population sample of controls actually sustained some form of injury associated with the earthquake, even though they did not visit one of the SCC hospitals. This background rate of injury not reported to a hospital is of importance for disaster preparedness, as it must be factored into overall casualty estimates.

Table 6 compares the breakdown of time of injury for the hospital/dead cases to that for the population sample. It is evident that while most of the injuries occurred during the main shock, a reasonable number (42%) also sustained an injury in the 72 hours after the event. Table 7 presents a summary of the first detailed data from the study which form the basis for initial estimates of risk factors. The table summarizes the numbers of hospital/dead cases and non-injured controls by location.

Table 6: Earthquake-related injury by time period.

Time Period	Hosp/Dead Cases	Injured Controls
During mainshock	219	50
72 Hrs after mainshock	114	46
Both time periods	24	10
Total	357	106

Table 7: Respondent location (when main shock began) for hospital/dead cases injured during main shock and non-injured controls

Location at t(eq)	Hosp/Dead Cases	Noninjured Controls
Building	218	419
Vehicle	1	69
Other	24	102
Total	243	590

From a further analysis of the data in Table 7, stratified by the participants' residential location at the the time of the earthquake, the odds ratios (which represent the relative odds of being injured during the mainshock associated with being in a building when the shaking began) can be computed (Jones et al. 1992). The result of the analysis, adjusted for residential location, is that persons were 3.32 times as likely to be injured or killed during the mainshock (95% confidence interval = (2.11,5.53)) if they were in a building when the earthquake began compared to those who were not. While this number perhaps "confirms the obvious" to many readers, its numerical value and those of its more risk-factor-specific counterparts (currently being estimated) are important values for incorporation into casualty models.

It is important to note that because of the relatively few (5) earthquake-related fatalities in the County among SCC residents, the results presented are weighted heavily toward non-fatal injury. It is expected, therefore, that future analyses will reveal causative agents for injury other than total building collapse or severe damage which have shown in the past to have played a major role in fatality.

Medical Consequences

Previous work has shed light on the spectrum of health outcomes associated with earthquakes. Among those physically injured, most will sustain combination injuries, such as pneumothorax in addition to an extremity fracture. Other major medical complications that should be expected include hypothermia, secondary wound infections, gangrene requiring amputation, sepsis, adult respiratory distress syndrome (ARDS), multiple organ failure and crush syndrome. Crush syndrome results from prolonged pressure on limbs causing disintegration of muscle tissue (rhabdomyolysis) and release of myoglobin, potassium, and phosphate into the circulation. Systemic effects include hypovolemic shock (from loss of blood volume), hyperkalemia (excess potassium in the blood), renal failure, and fatal cardiac arrhythmias. Patients with crush syndrome may develop kidney failure and require dialysis. In Armenia following the 1988 earthquake, thousands of people developed kidney failure, which completely overwhelmed the region's capacity to deliver such high technology care.

Among trapped victims, heavy dust from collapsing buildings may create a life-threatening hazard due to asphyxiation and upper airway obstruction. Asbestos and other particulate matter in the dust could also pose both subacute and chronic respiratory hazards to entrapped victims as well as to rescue and cleanup personnel, depending on the characteristics and toxicity of the dust.

There may also be an increased incidence of certain medical conditions brought on by earthquake-related stress, such as myocardial infarction and hypertensive crisis as well as psychological problems, such as severe anxiety and depression.

Rescue and Medical Response Issues

One non-controversial fact in earthquake medicine is that response time for search and rescue is absolutely critical. Observations made in Italy after the 1980 Campania-Basilicita earthquake, the 1988 Spitak, Armenia earthquake, and the 1976 Tangshan earthquake show that the proportion of people found alive declines rapidly with increasing delay in extrication. In the Italian study, a survey of 3619 survivors showed that 93% of those who were trapped and survived were extricated within the first 24 hours.

Moreover, 95% of the deaths recorded in Italy were among those trapped in rubble who had not yet been extricated. Although there are "miracle" reports of one or two persons rescued alive one to two weeks after an earthquake (e.g., Mexico, Armenia and most recently in Erzincan, Turkey), estimates of survivability among entrapped victims buried under collapsed earthen buildings in Turkey and China indicate that within 2 to 6 hours, less than 50% of those buried are still alive. Although it cannot be determined whether a trapped person died immediately or survived for some time under the debris, it is known that more people might have been saved if they had been extricated sooner.

Although the mortality time trends described above cannot be extrapolated entirely to other events (e.g., a central or eastern United States earthquake) due to differences in construction types and search-and-rescue capabilities, it will be quite likely that after two days, the probability of rescuing entrapped people alive will be very low. One week following the earthquakes mentioned above, hospitals were no longer receiving earthquake-related casualties.

When a building collapses, whether due to an earthquake, a terrorist bombing, or structural failure, a variety of challenges confront rescue and medical personnel. Trapped survivors pose serious problems with limb compression and dust inhalation. Some of these persons will require in-field amputation in order to be extricated. In the field, medical care will have to be austere, and conditions rarely will allow for definitive care of minor or moderate injuries. Any field medical intervention should be oriented toward life-saving extrication such as limb amputation, stabilization of immediate life threats (e.g., maintenance of airway patency, management of external hemorrhage) and relief of severe pain. Therefore, search and rescue combined with effective emergency medical care are essential for successful lifesaving efforts.

Despite the necessity for rapid medical intervention, in recent major earthquakes such as Armenia, the Philippines, Iran, and Turkey basic medical care was only rarely administered to persons actively being extricated from the debris. Although these patients were successfully located and accessed by rescue personnel, very few of them received intravenous fluids, stabilization of the neck with cervical collars, or maintenance of patent airways. The institution of these very basic procedures, particularly intravenous fluids, may go a long way toward reducing the morbidity and mortality related to building collapse, particularly in preventing the development of crush syndrome with its attendant kidney failure and cardiac arrhythmias.

Despite these observations, few rescue personnel are trained in intravenous techniques. Even when trapped persons are discovered, their extrication may take several hours - plenty of time for them to develop severe muscle damage and secondary kidney failure. Safar (1986), studying the 1980 earthquake in Italy, concluded that 25% to 50% of victims who were injured and died slowly could have been saved if initial life-saving first aid had been rendered immediately.

Potential Data Sources from Past Events

The usefulness of existing data from past (generally historical) events is difficult to assess in general terms; it depends on the methodology that was used and questions that were asked in the collection. As an example, there often has been no distinction made in the time period following an earthquake whether hospital admissions are earthquake-related or not: they often just have been assumed to be earthquake-related. Often the definition of injury has been unclear and has given no indication of severity (de Ville de Goyet, 1976). Discrimination requires a detailed follow-up study. In most instances, a reasonable amount of data have been available with respect to structural performance, but not on injuries. Even fewer cases exist where the relationship between injuries and structures at the individual (vs. population) level is available.

It is clearly important to study as many past events as possible to glean lessons about preventative strategies for future events, and to assist in the formulation of data collection methodologies. This task is very labor intensive: techniques such as record searching or questionnaire distribution require much effort. As time moves on, these events become progressively more difficult to investigate.

There is a significant difference in the risk factors and health outcomes between earthquakes affecting urban and rural areas. Extrapolation of data from rural to urban environments is thus inappropriate and misleading. For example, application of the results from the Glass study of injuries following collapse of rural village houses in Guatemala (Glass et al., 1977) to planning for an urban impact would be erroneous.

An example of the possible use of past earthquakes as sources of data is the recent significant effort to compile data from the 1906 San Francisco earthquake, using newspaper accounts, letters, coroner's records