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 [38, 39], 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, intensity, distance from the epicenter, time of day and season), geological and topographic conditions (e.g., soil type, cliffs or

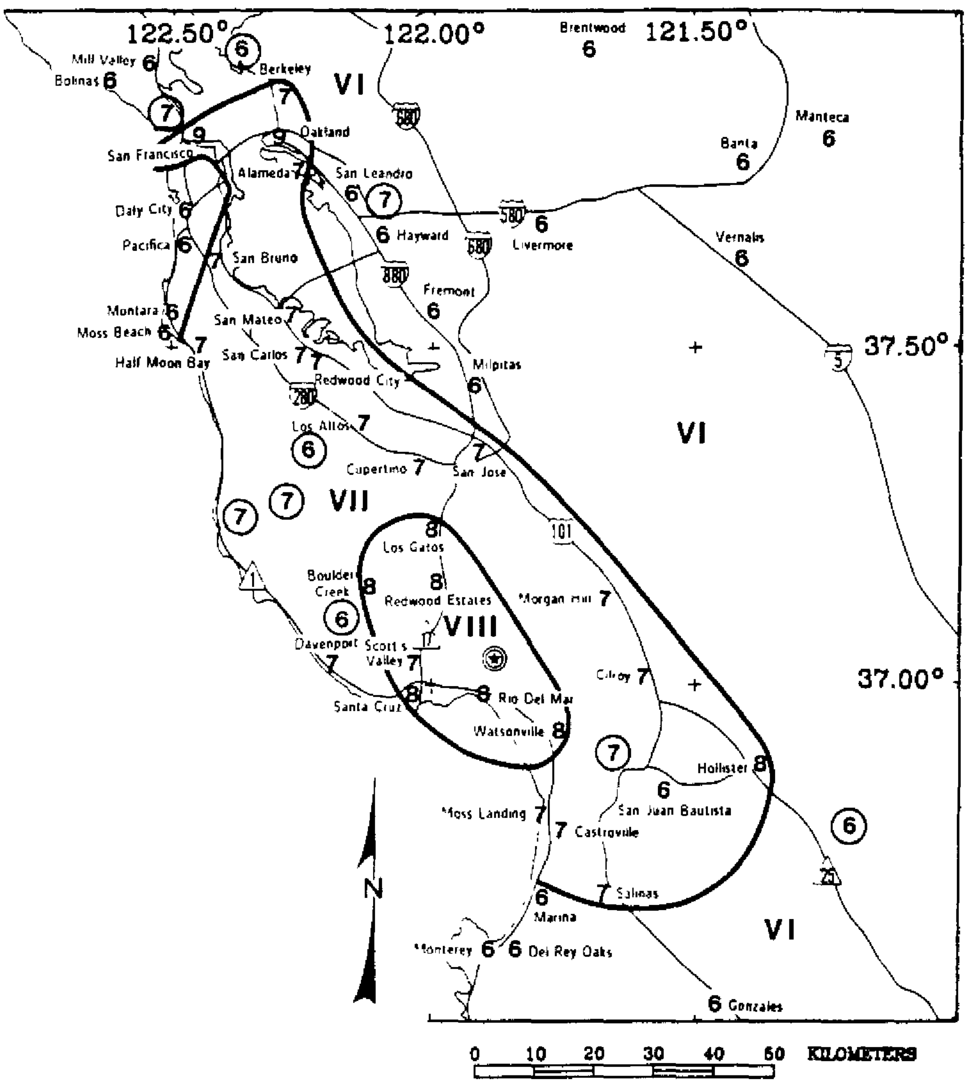

Fig. 1. Distribution of Modified Mercalli Intensity for Loma Prieta earthquake [50].

mountains), post-earthquake weather (e.g., rain which may cause landslides, 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 [48, 49].

There is consensus among epidemiologists and engineers that built environments pose the single greatest physical injury risk to people in earthquakes. Table 1 presents some of the relevant results of the six analytical epidemiology studies. In this table, the "odds ratio" is defined as the ratio of the odds of injury in individuals exposed to a particular risk factor to the odds of injury in those not exposed, and is closely related to the rate ratio for 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 [12, 13, 37]. 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 [16].

Being inside a building when the earthquake began was associated with a 12 fold-risk of being seriously injured in the Armenian earthquake [5]. 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 (versus wood), and were relatively tall and old [5, 10, 16]. Persons located on higher floors of multistorey buildings suffered more casualties than those on lower floors in the Armenian, Italian and 1990 Luzon, Philippine earthquake [5, 10, 12]. 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 [5, 13].

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 [14, 16] whereas morbidity (non-fatal injuries) increased continuously with age [16].

7. The Loma Prieta case-control study

7.1. The Loma Prieta earthquake

On Tuesday, October 17, 1989 at 5:04 PM Pacific time, a magnitude 7.1 earthquake with an epicenter 10 miles northeast of Santa Cruz struck the northern California region. The quake caused extensive damage to the Marina district of the City of San Francisco, one span of the Bay Bridge fell from its support, a 1.5 mile section of Interstate 880 (Nimitz Freeway) in Oakland (Cypress Section) collapsed and major structural damage was reported from a number of locations in the County of Santa Cruz. The Loma Prieta event is regarded as one of the most financially destructive earthquakes in the history of the United States.

The County of Santa Cruz (see Fig. 1) was hard hit by the quake though it did not get the media attention of San Francisco and Oakland. The damage sustained warranted the assignment of the second highest intensity level assigned to this earthquake, i.e., Modified Mercalli Intensity (MMI) VIII, to much of the County (only two small areas, both outside the County, were assigned a higher intensity of MMI IX).

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 was initiated 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.

7.2. Specific aims

The specific primary aims of this study are:

(1) To assess the relative risk for physical injury associated with different physical environments (e.g., buildings, vehicles, outside), entrapment, and personal behaviors in the disaster and post-disaster phases of the Loma Prieta earthquake.

(2) To assess the relative risk for other potential risk factors for physical injury including pre-existing medical conditions and mobility, drug and alcohol use, and sociodemographic characteristics.

(3) To estimate the absolute risk of physical injury mortality and morbidity associated with the Loma Prieta earthquake in SCC.

(4) To provide input data for casualty and loss estimation procedures for California (in particular the Bay Area), and other areas of the U.S.

A secondary aim of this study is to determine if physically injured cases who sought treatment at a hospital were different from those who did not seek such care. For example, examined selection factors for treatment include injury severity, possession of health insurance, and sociodemographic characteristics.

7.3. Study methods

The case-control study examines how the physical environments and personal behaviors of SCC residents contributed to their risk of being physically injured or killed in SCC by the Loma Prieta earthquake [52].

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., knowledge limitations of laypersons), the only attempt made through the questionnaire to infer structural type was through material description; this aspect required field follow up after preliminary data analyses [22]. 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, and access to health insurance.

The outcomes of interest are earthquake-related physical injuries that occurred during the shaking of the main earthquake (the disaster phase) and the subsequent 72 hours (the post-disaster phase). 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 [7].

Information on both injuries and risk factors was obtained through a structured interview of cases and controls, or their proxies if necessary. Injury information on cases was also obtained from medical records and autopsy reports. Interviews were generally conducted by telephone. They were administered in English or Spanish.

Interviews are a standard tool in epidemiology [44]. They provide unique advantages over other methods of data collection for certain classes of information. For example, interviewing individuals is the best method currently available to investigate human behaviors during an unanticipated event (such as an earthquake) in a large-sized sample.

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 an SCC hospital or flown by helicopter out of County for treatment of earthquake-related injuries. For comparison, a population-based two-stage random sample of current SCC residents was selected using a modification of the random digit dial sampling of listed and unlisted residential telephones developed by Waksberg [53]. In stage one, an eligible household was randomly selected. In stage two, all eligible household members were listed and one of them was then randomly selected for an interview. 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 an 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, because residence was thought to be an important potential confounder. Three residential strata were defined by aggregates of contiguous zip codes in the County. Stratum 1 is the northern mountainous region of the County, stratum 2 is the coastal northern area of SCC (including the City of Santa Cruz) and stratum 3 is the southern part of the county (including the City of Watsonville).

The goal was to interview two non-injured controls for each hospital or dead case.

The injury status of the individuals from the population sample was not determined in advance of the interview. Injury information collected in the interview was used to assign persons post-hoc to the appropriate category. Based on the results of the pilot testing, 20% of the population sample was expected to have incurred an earthquake-related injury and thus qualify as injured controls. With such a background injury rate, it would be necessary to interview 2.5 members of the population sample for each hospital or dead case to achieve the desired 2:1 ratio of non-injured controls to hospital/dead cases. Injured controls will be studied separately from hospital and dead cases.

The relationship between risk factors and earthquake-associated injuries and deaths is being evaluated for each of two time periods:

(1) the disaster phase, the 15 second shaking period of the mainshock, and
(2) the post-disaster phase, defined as the next 72 hours.

Hospital and dead cases (or their proxies in the latter case) were interviewed from July 19, 1990 to March 31, 1991. Non-injured and injured controls were interviewed over the period of March 24, 1991 to August 31, 1991.

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 according to a form which attempted to collect information compatible with the interview forms used in the case-control study and with ATC-13 classifications [4].

The primary purpose of collecting the data was twofold:

(1) To provide an expert and valid measure of structure-related risk factors for earthquake-related injuries, and

(2) to enable comparison of the experts' assessment to the interviewees' (i.e., laypersons') responses to the structure-related questions in the interview.

The collected data are currently being coded for data entry. Three basic types of analyses will be performed. First, hospital and dead cases will be compared to non-injured controls to assess the significant risk factors for injury. Second, hospital and dead cases will be compared to injured controls to evaluate the selection factors for seeking medical care among the injured. Third, several descriptive studies will be undertaken to assess the total morbidity and mortality in SCC associated with the earthquake.

8. Results

The proceeding data should be regarded as provisional since the data are still being validated and edited. Final results will be published when available.

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 deemed eligible for the case-control study.

In obtaining the random population sample, contact was attempted with 1880 households. Of these, only 7.4% refused to cooperate with the study. This low refusal rate among hospital/dead cases and the population sample is important, as it indicates that both study groups are likely to

Table 2
Population sample: Injured vs non-injured controls by stratum

	Total	Injured	Non-injured	Unknown
Stratum 1	138	25	112	1
Stratum 2	318	39	278	1
Stratum 3	245	42	200	3
All strata	701	106	590	5

Table 3
Population sample. Injured controls by time period of injury (during and after the mainshock) and stratum

	Only during	Only after	During and after	Total
Stratum 1	10	13	2	25
Stratum 2	17	17	5	39
Stratum 3	23	16	3	42
All strata	50	46	10	106

Table 4
Earthquake-related injury by time period

Time period	Hospital/dead cases	Injured controls
During mainshock	219	50
72 hrs after mainshock	114	46
Both time periods	24	10
Total	357	106

be representative of the populations from which they came. In all, 701 households were deemed eligible for the case-control study

Table 2 shows a summary of the injury status of the population sample, i.e., those not in the initial case series, for the three strata. The data indicate that a significant proportion (106/701 or 15%) of the sample 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 3 gives a more detailed breakdown of that part of the population sample injured by time period of injury and by stratum.

Table 4 compares the breakdown of time of injury for the hospital/dead cases to that in the population sample. It is evident that while most of the injuries occurred during the mainshock, a reasonable number also sustained their injury after the event

Table 5 presents an example from this study of the level of detail and organization of data needed to calculate estimates of the relative risk for exposures in a case-control study. The

Table 5
Data set-up for analysis of respondent location (when mainshock began) for hospital/dead cases injured during mainshock and non-injured controls

Location at t_{eq}	Hospital/dead cases				Non-injured controls			
	Stratum				Stratum			
	1	2	3	Total	1	2	3	Total
Building	a	b	c	m_1	q	r	s	o_1
Vehicle	d	e	f	m_2	t	u	v	o_2
Neither	g	h	i	m_3	w	x	y	o_3
Total	n_1	n_2	n_3	N_1	p_1	p_2	p_3	N_2

table presents the set-up of data for hospital/dead cases and non-injured controls by two potential risk factors, physical location and residence stratum when the mainshock began.

In Table 5, the odds ratios for each stratum (which, in this example, represent the relative odds of being injured during the mainshock associated with being in a building when the shaking began) can be computed.

The "odds ratio" ψ, is defined as the ratio of the odds of injury in exposed individuals to the odds of injury in the unexposed. It is closely related to the rate ratio [44], and can be represented as

$$\psi = \frac{P(I \mid E)/P(\bar{I} \mid E)}{P(I \mid \bar{E})/P(\bar{I} \mid \bar{E})} = \frac{P(E \mid I)/P(\bar{E} \mid I)}{P(E \mid \bar{I})/P(\bar{E} \mid \bar{I})}$$

where E represents exposure (in this case to a building), $\bar{E}$ nonexposure, and I, $\bar{I}$ represent injury and non-injury, respectively. The first term is the odds ratio sought, while the second represents quantities measurable in a case-control study; the two are equal by Bayes' Theorem. For stratum 1,

$$\psi = \frac{a/n_1 \times (t+w)/p_1}{(d+g)/n_1 \times q/p_1} = \frac{a \times (t+w)}{(d+g) \times q}.$$

If the stratum-specific odd ratios are constant across strata, then it is appropriate to calculate a summary statistic. This is frequently accomplished using the Mantel–Haenszel estimate, a weighted average of the stratum-specific odds ratios [31]. If the stratum-specific odds ratios are not constant, then it is inappropriate to combine them. Instead, they should be presented separately with the interpretation that there is an interaction between the two risk factors (e.g., stratum and location at the moment the earthquake began).

9. Discussion

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 fatalities.

The relatively high percentage of injured controls found in the population sample demonstrates the need to develop and apply standardized criteria for injury severity. Controls who reported an earthquake-related injury in the study interview did not seek medical treatment. A preliminary review of the data shows that while the majority of the controls appeared to have minor injuries, a significant proportion of hospital cases also had minor injuries. Thus, utilization of medical services should not be used as the sole measure of injury severity.

There is also a need to separate injuries by time of occurrence, i.e., during the mainshock and in the post-shaking period. Not only did post-shaking injuries occur in significant numbers, they appear to have been caused by different mechanisms than injuries produced during the mainshock. Subsequent analyses will explore these differences with the goal of tailoring injury prevention strategies for each time period.

Injury epidemiology can play a critical role in assessing the impacts of disasters and the development of intervention strategies to address them. The example presented herein is applied to *one* earthquake; more events need similar study. The fact that an appropriate instrument has already been developed for this study will certainly lessen this burden in a future effort. It is also suggested that this methodology be more frequently applied to other disasters (e.g., hurricanes) to improve the understanding of the public health consequences of such events.

The engineering community — even in making assessments of structural performance after a disaster — can learn much from epidemiologists in terms of technique. In most cases, engineers perform descriptive (case) studies of damage. The advantages offered by performing analytical studies are evident: studying in building populations both those structures which failed *and* those which did not can certainly provide valuable information relative to a variety of applications, e.g., retrofit priorities, loss estimation procedures, and insurance assessment. Seldom have these studies been performed.

10. Conclusions

This paper provides a comprehensive overview of epidemiology and describes efforts since the Loma Prieta Earthquake to apply epidemiologic methods to assess, both qualitatively and quantitatively, the morbidity and mortality associated with that event. When complete, this study will not only provide useful information relative to this specific event, but will also augment substantially the literature available in disaster — specifically earthquake — epidemiology. While being in a building seems an obvious risk factor for injury, this study provides quantitative risk information for use in improved casualty estimation models. As the research is still in progress, the material and data presented herein must be considered preliminary only (some subjects are still being reviewed for possible inclusion in the study). Since most of the efforts to date have focused on study design, data collection and coding, only a few quantitative data are presented herein for illustrative purposes at this stage, but those which are available are still of significance. It is anticipated that more complete, definitive data will become available.

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 U.S. in general, and industrialized nations, such as Japan and New Zealand, which have well-conceived and enforced seismic 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 [51].

Ongoing work is investigating other factors relative to casualty in earthquakes, such as the magnitude of the risk posed by non-structure hazards, e.g., building contents, sociodemographic-related vulnerability, and inappropriate personal behaviors.

11. Acknowledgments

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Drs. Kirsten Waller, Alex Kelter and Roger Trent are the DHS's principal personnel involved with the study. Jim Schneider and Lisa Angell, emergency medical care specialists, organized and directed the medical abstraction of hospital case records and provided ongoing advice and consultation to the study.

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