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DEVELOPING MULTIVARIATE MODELS FOR EARTHQUAKE CASUALTY ESTIMATION

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Introduction

Considerable emphasis has been given in recent years to the development of methodologies for use in earthquake loss estimation (c.f., Steinbrugge, 1982; Applied Technology Council, 1985; Spangle, et al., 1987; Panel on Earthquake Loss Estimation, 1989). While the results of these efforts are impressive, and while we now know considerably more about potential earthquake losses than we did ten years ago, this knowledge is still quite uneven and incomplete (Tierney, 1990). For example, we know much more about probable losses to the building stock than about other kinds of losses, and the data base lacks regional balance.

Moreover, some types of potential earthquake impacts have been given very little emphasis. The estimation of earthquake casualties is among these under-emphasized topics. In fact, it would not be too much of an exaggeration to characterize the present state of knowledge in the casualty estimation area as rudimentary.

Gross estimates of potential injuries and deaths under different earthquake scenarios have been in existence for quite some time. For example, the well-known FEMA/National Security Council report (1980) projected deaths and hospitalized injuries for major earthquakes on two Northern and two Southern California faults. However, these estimates were derived from expert judgments, not empirical research, and they were acknowledged at the time to be "uncertain by a possible factor of two to three." While extremely useful in terms of raising awareness and concern about the earthquake threat, such estimates are too general--and based on too little data--to be useful as policy or planning tools.

The reasons we don't have better earthquake casualty estimates are doubtless obvious to everyone at this workshop, but I'll state them anyway. First and foremost is the lack of an empirical base. Solid data do not exist in sufficient quantity to enable researchers to develop casualty estimation models. This dearth of data is related to the woefully inadequate funding for such research, as well as to the fact that, until recently, relatively few individuals have been attracted to this area of study. If over the years there had been even one-tenth the number of persons working on the problem of earthquake casualties as were working on building effects, real progress might have been made on casualty estimation; but that was not the case. Indeed, the Loma Prieta earthquake is the first event of which I am aware in which a really well-designed case control study is being undertaken by a qualified multi-disciplinary research team--and even that work is being done on a comparatively small scale.

A second and related reason why this aspect of earthquake loss estimation has lagged behind other areas is that earthquake mortality and morbidity are very complicated problems to unravel, because of the large number of causal factors that ought to be taken into account. Modeling earthquake effects and estimating damage for different types of buildings is quite difficult, but in my view this task is far less difficult than casualty estimation. Not only are a large number of cases needed for serious modeling efforts, but also, because societies differ on so many relevant dimensions, generalizing from one society to another is difficult. For example, a study by Glass, et al. (1977) related deaths and injuries in a Guatemalan earthquake to building types and victims' social characteristics. The data collected were interesting and useful, but the findings are not generalizable to developed societies.

Modern, industrialized countries like Japan and the U. S. have been quite fortunate, in that really large earthquakes, producing large numbers of casualties, have not occurred in recent decades. However, this also means that these countries have a relatively limited record on which to base future casualty projections.

Finally, research in this area has been hampered by a number of practical, organizational, and legal-ethical obstacles. I will discuss these issues briefly in the concluding section of the paper.

Variables Affecting Deaths and Injuries

Because deaths and injuries are the result of complicated causal chains, casualty estimation must involve the development of complex, multivariate models (Jones, et al., 1989; 1990). We are not completely in the dark about how to build such models; there is no shortage of candidate hypotheses, and the data on past earthquakes point to a number of variables that ought to be taken into account. A partial list of these factors includes (1) characteristics of the earthquake itself; (2) features of the built environment; (3) population and victim characteristics; (4) the presence or absence of secondary hazards; (5) community emergency response capability; and (6) situational factors. I will discuss each of these sets of factors briefly, and then move to a consideration of some of the other difficulties inherent in studying the problem.

<u>Earthquake Characteristics and Resultant Seismic Hazards.</u>

Starting with the most basic considerations, it almost goes without saying that earthquake magnitude will have an impact on overall casualty rates. Existing data suggest that, other things being equal (and this is, of course, a very important qualification), we would not expect an earthquake under M 6.0, striking an area where structures are properly built to code, to produce significant numbers of casualties, except perhaps in relatively localized areas. In areas where seismic codes are in force, these magnitudes are not sufficient to produce the kinds of shaking intensities, structural damage, and nonstructural effects that are thought to lead to death and injury. Earthquakes between M 6.0 and M 6.9, of which the 1983 Coalinga event is a good recent example, represent more of a threat to life-safety, but still affect people in a relatively small area. The 1971 San Fernando earthquake was a somewhat comparable event: some very serious local effects were observed, such as the serious damage and life loss at the Veterans Administration Hospital, but the impact on the Los Angeles region was, comparatively speaking, rather small.

At M 7.1, with some very strong localized shaking, the Loma Prieta earthquake probably represented the lower end of the "high-casualty-producing" spectrum. Earthquakes greater than M 7.5 or 8.0 will affect a much wider area and will consequently produce many more injuries. We have no actual basis from which to extrapolate, but my guess is that the relationship between magnitude (or shaking intensity) and casualty rates is **not** linear.

Magnitude is not important in and of itself, but rather is significant because of its relationship to the various effects that are produced. Ground shaking is foremost among these hazards; deaths and injuries are likely to be more a function of shaking intensity than of Richter magnitude. Although a 6.0 or 6.5 earthquake can produce very strong localized shaking, unless there are very high concentrations of poor structures or very high population densities in these high-shaking areas, overall casualty rates are not likely to be high for moderate-sized earthquakes. We need to be more concerned about earthquakes that produce heavy sustained shaking over a wide area, not only because of the higher number of casualties they will likely create, but also because of the negative effect they will have on response capability (see discussion below).

Other hazards besides shaking must also be taken into account in casualty estimation. Structures built in areas with ground-failure and liquefaction potential are likely to be high-casualty-producing sites. Landslide zones are probably inherently more hazardous from a life-safety standpoint than stable areas. Areas of actual fault rupture are likewise likely to be dangerous from a life-safety standpoint. Like liquefaction and landslide areas, fault rupture zones are likely to be areas in which damage is quite high, and in which secondary hazards like fire are more prevalent.

In areas where building codes are not in force, or where design and construction standards are poor, deaths and injuries may be widespread even in smaller earthquakes. For example, the M 5.4 1986 earthquake in El Salvador killed approximately 1,500 persons and injured 10,000; an estimated 30% of the fatalities occurred in engineered buildings that experienced partial or total collapse (Durkin, 1987). The lack of seismic resistance in many structures in the Central United States is one of the main reasons for concern about the consequences of a future New Madrid event.

The Built Environment. Earthquakes act on structures in various ways, but it is the structures themselves that constitute the vectors by which earthquake deaths and injuries occur. Theoretically, we can greatly reduce or even eliminate earthquake casualties by making structures safer. Features of the built environment thus constitute a very important set of intervening variables that ought to be considered in the development of casualty estimation models.

Virtually everyone involved with the earthquake problem agrees that unreinforced masonry buildings and other "collapse-hazard" buildings present a major life-safety hazard. There is likewise universal concern with buildings not constructed to earthquake-resistant codes, such as much of the building stock urbanized areas in the Central United States.

The relationship between building **collapse** and negative life-safety impacts is obvious, as demonstrated in Tangshan, Mexico City, San Salvador, Armenia, and the Philippines. Earthquake death tolls are highest where the incidence of building collapse is greatest. The relationship between building **damage**, deaths, and injuries, although less straightforward, is still likely to be strong. Thus, the general expectation is that, other factors being equal, deaths and injuries will be more widespread in areas where the building stock is more vulnerable to damage. Assuming population densities are roughly comparable across areas in a community or region, we would expect death and injury rates to be correlated with both building collapse and building damage, but especially with collapse. Logically, then, if we are able to identify areas where there are concentrations of both people and unsafe buildings, we have a general idea of where the casualties will be concentrated.

Merging data on building stock with census data is one way to approach this problem. Information on residential density and various population characteristics can be related to housing characteristics for purposes of identifying high-risk areas or populations. I did this in a very simplified way with census and housing data in Los Angeles, in an effort to determine whether disabled and elderly persons are more likely than able-bodied persons to live in hazardous structures (Tierney, Petak, and Hahn, 1988). The development of sophisticated geographic information systems and mapping tools makes it possible to begin relating seismic hazards, housing characteristics, and census data in new, potentially productive ways.

At the same time, the Loma Prieta earthquake provided very clear evidence that people die and are injured in earthquakes in many different ways, and that collapsed and damaged buildings only constitute part of the problem. The majority of people who died in that earthquake were killed in the collapse of the Cyprus structure, not in buildings.[1] From what I have heard about the injury epidemiology research being conducted in Santa Cruz by the team based at Johns Hopkins, it appears that many of the injuries were not related to any particular building types or components. Individuals were injured more as a result of the shaking itself. For example, they lost their footing during earthquake impact and were injured in falls. One death occurred when a workman fell off a tower. Thus, while it makes intuitive sense to concentrate on certain categories of buildings as causes of death and injury, the real picture is much murkier.

Population and Sociodemographic Factors. Since the risks of other types of injury are not uniform throughout the population, it seems reasonable to assume that earthquake casualties are also related to sociodemographic variables. On the regional or community level, injury rates are likely to be a function of both absolute numbers and population density. We are more concerned with the likelihood of earthquake casualties in San Francisco's Chinatown than in Marin County, not only because of differences in building types and vulnerabilities, but also because of Chinatown's population size and dense residential patterns. At any given time, there are simply larger numbers of people at risk from a given set of hazards in a densely populated urban setting of this type.

At the individual level, age is probably a significant risk factor. Glass, et al. (1977), in the study discussed earlier, found that, among adults, rates of serious injury increased continuously with age.[2] Ohashi and Ohta (1984), who analyzed data on casualties in several recent Japanese earthquakes, found that rates of both serious and minor injuries increased with age, and

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[1] It should also be noted that the majority of people who were killed by damage to unreinforced masonry buildings were not actual building residents. Several persons killed in San Francisco by collapsed masonry walls were not building occupants, but rather people who happened to be outside, close to the building the time of earthquake impact. The Santa Cruz structure in which most people lost their lives was a commercial establishment, rather than a residential building. We tend to concentrate a lot of our attention on unreinforced masonry structures as unsafe places in which to live, but in fact they pose a hazard to the general population as well.

[2] It should be noted that these researchers found that mortality rates were high for both young children and elderly persons. Among younger victims, mortality rates were highest for the second-to-youngest child in the family. They attribute this pattern to the fact that youngest children tended to be sleeping with their mothers at the time of earthquake impact and were thus more likely than the next-oldest children to receive life-saving assistance.

Durkin, Aroni, and Coulson (1984), in their study of injuries in the 1983 Coalinga earthquake, found evidence of the same relationship.[3]

The Disaster Research Center has been assisting researchers at the San Francisco Public Health Department's Emergency Medical Services Agency with a study of the medical and health-care aspects of the Loma Prieta earthquake. Part of this work involves analyzing the records of persons who sought treatment at hospital emergency departments at the time of the earthquake. Preliminary analyses of data from San Francisco hospitals suggest that injuries were related to age; persons sixty-five years of age and older appear to have been more likely than other age groups to go to the hospital for their injuries. Males and females went to the emergency room in approximately equal numbers.

Although to my knowledge no one is studying the relationship, an argument can also be made that social class and income levels may be related to earthquake injuries. Looking cross-culturally, disasters are significantly more devastating in poor countries than in better-off societies. Within the U. S., poor people are more likely than people with higher incomes to live in the kinds of structures that will collapse or be severely damaged in the event of an earthquake. For example, in California's urban areas, unreinforced masonry buildings constitute a significant segment of the low-cost rental housing stock (Comerio, 1989). Poverty is also associated with larger household size and higher residential density, which also may translate into higher casualty rates.

Earthquake preparedness programs place considerable emphasis on trying to tell community residents how they should behave during and after earthquake impact, e. g., getting under tables, staying away from heavy furniture and window glass that might shatter. The assumption underlying such programs is, of course, that people can learn how to avoid engaging behaviors that result in death or injury. Little work has been done to systematically examine the relationship between behavior and subsequent death and injury, but some findings are suggestive. Archea and Kobayashi (1984), who studied the behavior of building occupants in the off-Urokawa

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[3] Empirical findings like these underscore the complexity of the phenomenon. At a given shaking intensity, older persons may be more likely than their younger counterparts to fall down and to be seriously injured as a result of falling. But it may also be the case that older people are more likely than younger people to live in the types of structures that collapse or sustain serious damage in earthquakes. On the other hand, older people may know less than younger members of the population about how to protect themselves in earthquake situations, or may be less capable of doing so. Finding out that age and injury are related is not the same as understanding why.

earthquake of 1982, found that people had a tendency to move about a good deal during the shaking period and that those were most active were the most likely to be injured. They also found that efforts to keep household articles like stereo equipment from being damaged sometimes resulted in injury.

Instructions on appropriate behavior stress the notion that people should not attempt to run out of a building during earthquake shaking. Such advice was derived from scattered findings suggesting persons who flee from buildings can be killed or injured outside those buildings by falling bricks and other building materials. One very serious injury occurred in this manner in the 1983 Coalinga earthquake. In the 1987 Whittier Narrows earthquake, one of the individuals killed was a relatively recent immigrant from Central America who died in a fall as he hurriedly attempted to exit from his apartment building.

While it certainly seems reasonable to assume that individual behavior makes a difference in the earthquake situation, many of the generalizations made about the relationship between behavior and life-safety are based on anecdotal accounts and non-systematic data. The relationship may be more complicated than we think. Perhaps certain behaviors are important in some physical settings, or in some earthquakes, but not in others. Much more work is needed before we can discuss with any degree of confidence how injury and behavior are related.

Secondary Emergencies. As the 1906 San Francisco and 1923 Kanto events illustrate vividly, post-earthquake fire can be a major life-safety hazard. Potential ignition sources include broken natural gas lines, spills of oil, gasoline, and other flammable materials, and electrical appliances. Charles Scawthorn's work (1987) suggests that post-earthquake fire, and even conflagration, is a real possibility in a major California earthquake, particularly in San Francisco. It is likely that fire would be an even greater problem in other parts of the country, such as the New Madrid Fault Zone and the Charleston area. Because of the extremely high residential densities in urbanized areas, Japanese planners are also very concerned about fires following earthquakes.

In industrialized areas, the potential also exists for post-earthquake hazardous materials releases. Airborne releases of hazardous materials such as chlorine and ammonia (both of which are relatively common in U. S. communities) could pose a serious life-safety hazard, particularly given the fact that, following an earthquake, warning the public would be even more difficult than usual.

Once again, we can only observe that very little systematic work has been done to estimate the contribution of these kinds of secondary hazards to death and injury rates in earthquakes.

Scawthorn's work is the most comprehensive study to date on post-earthquake fire potential in U. S. cities, but the study focused on potential property losses, rather than life-safety hazards. Some colleagues and I recently worked on developing an approach to modeling post earthquake hazardous chemical releases and to estimating the size of the population at risk in Greater Los Angeles (Tierney, et al, 1990), but this was only a modest preliminary effort.

<u>Emergency Response Capability.</u> In the late 1960's, shortly after the implementation of Federal emergency medical services legislation, quite a bit of publicity was given to the fact that, if a person were unfortunate enough to suffer a heart attack, he or she would be much better off doing so in Seattle than in most U. S. cities. An individual's chances of surviving were greater there, because the Seattle emergency medical services (EMS) system was better prepared and more capable of handling cardiac emergencies than many other urban EMS systems. Similarly, trauma physicians speak of the "golden hour" during which, if sufficient resources are brought to bear, a seriously injured person's survival chances are greatly enhanced; if the system does not respond rapidly enough, the patient's condition deteriorates quickly. Both these examples illustrate the important influence community and societal response capability have on mortality and morbidity.

Some earthquake victims are killed outright, due, for example, to massive trauma brought about by building collapse. Nicholas Jones (personal communication) argues correctly that these deaths are appropriately conceptualized as failures of hazard mitigation, rather than failures in the emergency response system. Even an instantaneous response would not have prevented their deaths. However, for a large number of earthquake victims, the immediate local response capability probably does make a difference. Thus, post-earthquake medical outcomes such as deaths, complications arising from earthquake-generated conditions, length of hospitalization, and short- and long-term disability are likely to be affected by a range of social and organizational factors. Among the factors that may be important are: professional and volunteer rapid search-and-rescue capability; the capacity of EMS systems to respond to earthquake-related injuries and health problems; the availability (and survivability) of trained personnel, medical-care facilities, and other important resources; and the overall capacity of affected communities to respond effectively to victims' needs in the post-impact period.

Societies clearly differ on these dimensions. Countries such as those in the developing world that cannot provide basic health care for members of the population on an everyday basis will not be able to launch an adequate emergency medical response to save lives and deal with serious injuries in a major earthquake. Recent earthquakes illustrate this point. The members of the reconnaissance team who studied the care of victims in the 1988

Armenian earthquake and who were aware of the situation in other recent major earthquakes worldwide observed that in many cases emergency care providers were unable to administer even basic forms of treatment that could have kept victims' conditions from deteriorating. The team members concluded that, rather than being attributable only to injury severity, many cases of death and long-term disability in recent earthquakes have been due to the lack of an adequate response on the part of local emergency health care systems (Wyllie and Filson, 1989).

In contrast, the 1985 Mexico City earthquake was a very significant disaster, but by and large, the health-care system responded quite adequately, given the level of demand. A large proportion of the health-care resources of the country are concentrated in the Federal District, and even though three hospitals collapsed, necessitating the relocation of nearly 5,000 patients, there was no shortage of hospital beds or medical supplies (Dynes, Quarantelli, and Wenger, 1990).

Besides intersocietal differences in response capability, we can also expect important differences among communities within the same society. Improvements in EMS systems in the United States have not been uniform, and EMS systems still vary considerably in their ability to provide treatment in medical emergencies (Dawson, 1985). When we also take into account the fact that hospitals and other EMS system components in many parts of the U. S. are quite vulnerable to earthquake damage, the importance of the community response component becomes even more apparent.

It is quite ironic and sobering to consider the fact that those societies and communities in which earthquake damage and victimization are likely to be more widespread are also the ones in which the emergency response is likely to be less effective. The concern about a major earthquake in the urbanized areas of California is entirely appropriate. However, we also need to keep in mind that many structures in these areas--including most hospitals and many of the structures that house emergency response organizations--have a high degree of earthquake resistance, and that local emergency responders and health-care systems are well-prepared for earthquakes. Other things being equal, Californians are probably more likely to survive a major earthquake than residents just about anywhere else in the world--with the possible exception of Japan.

Situational Factors. In addition to the five sets of variables discussed above, some of the variation in mortality and morbidity will be a function of situational factors. Time of day is likely to be one such factor. The 1980 FEMA/NSC report assumes that the "safest" time a California earthquake could occur would probably be during the night, while the highest-risk period would be in the late afternoon/early evening when many people are on the streets returning from work. Because the routines of social life differ worldwide, periods of relative safety and risk may well vary across societies.

The 1988 Armenia earthquake illustrates the impact seasonal variations can have on mortality and morbidity. With respect to that event, Smith (1989: 69) notes that "it is believed that some people who could otherwise have been rescued may have perished due to the intense cold." Depending on the time of year, earthquake victims in the Central United States might also be subject to very low temperatures; depending on the length of the exposure, this could be an additional risk factor. At the other end of the scale, extremely hot weather could create a different set of problems for victims.

Problems With Studying Earthquake Deaths and Injuries

The foregoing discussions contained several suggestions about how one might go about unraveling the complex causal chains that result in earthquake-related mortality and injuries. With sufficient funding and enough knowledgeable, trained, motivated researchers, theoretically we ought to be able to make considerable progress in model development in this area.

Unfortunately, before we can do so, we also need to acknowledge and develop ways of overcoming a number of practical obstacles--obstacles that have hampered past research efforts and limited the usefulness of the data that have been collected. In this concluding section, I will note a few of these, without dwelling at length on any particular problem.

Establishing Who Was Injured. The first obstacle, which is quite fundamental, has to do with our ability to identify and measure the dependent variable--that is, casualty rates and types. Finding out this information might seem easy from a common-sense perspective, but in many cases it is rather difficult to identify who was actually injured--and, for that matter, who was killed--as a result of a disaster. Disaster researchers have pointed out for quite some time that numbers of this type are not only hard to obtain but occasionally somewhat arbitrary.

Casualty estimates used by public officials show considerable variation, and the inclusion or exclusion of a particular case is often a judgment call. Counts of deaths and injuries in recent U. S. earthquakes have included cases such as the following: an individual in an earthquake-damaged area who was bitten by a dog (Coalinga); a relief worker injured while making earthquake repairs (Coalinga); several heart-attack victims whose conditions were judged to have been made worse by the earthquake (Whittier); a person who was shot while directing traffic in an earthquake-related blackout and a person who was killed on the highway the night of the earthquake when his truck ran into several horses set loose when their corral collapsed (Loma Prieta). These deaths and injuries would likely not have occurred if it weren't for the earthquake, but the actual causal connections are difficult to unravel.

Hospital records constitute one important source of data on deaths and injuries. However, these data are not without problems. For one thing, it is not always possible to tell from records alone whether or not the symptoms that brought an individual to the hospital were earthquake-caused. Sometimes the emergency department record identifies a problem as earthquake-related, and sometimes it does not; the researcher is thus faced with having to interpret a vague or incomplete set of data. There is also some possibility that it is hospital personnel, rather than the patients themselves, that link the patient's symptoms to the disaster event; heart pains, anxiety, asthma, and many other complaints can be interpreted in a variety of ways. Added to these problems is the fact that in disaster situations, keeping complete records tends to be viewed as less important than during normal times.

Tapping the Range of Treatment Settings. People who are injured in an earthquake may or may not go to a hospital. We can assume that, in a given earthquake, there will be a number of individuals (probably those with less serious injuries) who will either receive informal first aid from family members or neighbors or go to some other setting for care. Red Cross shelters are one such setting. With the recent proliferation of stand-alone emergency care units--the so-called "Doc-in-the-Box" phenomena--we can expect that these kinds of facilities will also be involved in providing care to earthquake victims. Thus, collecting a valid listing of who was actually injured in an earthquake from various facilities, as well as ruling out double-counts and questionable cases, becomes a major endeavor in itself.

Confidentiality. Data from hospitals, the Red Cross, and other facilities are typically treated as confidential material, which is entirely appropriate. Health care facilities should do anything and everything they can to ensure that the privacy of their patients is respected. Unfortunately, patient privacy occasionally comes into conflict with the needs of research. This is particularly true with projects such as those being discussed here, which would necessarily involve not only using hospital records, but also contacting the victims themselves for information. In societies like the U. S., in which legal concerns tend to shape organizational activity and policy, hospitals are understandably reluctant to get involved in work of this kind. Researchers need not only considerable skill and patience, but also a degree of luck, to surmount these kinds of obstacles.

Obtaining Comparable Data Across Events and Societies. If we as researchers are genuinely interested in developing models to explain earthquake deaths and injuries, it will be necessary for us to formulate and agree upon methods for collecting comparable types of data across different earthquake events. However, the present state of affairs is that individual investigators or groups of researchers each develop their own methods, approaches, and data-collection instruments. As a result, findings from different studies are neither comparable or cumulative. At minimum, there needs to be agreement on a common set of variables on which to collect data, a common data-collection instrument, and a common approach to sampling cases.

Engineers are able to find out a great deal about how buildings performed and how damage occurred in an earthquake merely by observing those buildings after impact. Investigating earthquake mortality and morbidity is not quite that straightforward; it necessarily involves having contacts with individuals who were present in a setting during an earthquake and making detailed inquiries about what occurred. Work of this kind is not only labor-intensive; it also requires those involved in research to have knowledge not only of the languages spoken but also of the particular cultural settings in which the work is being done. Researchers from many countries should be included in data-collection efforts, and those collecting the data should be thoroughly trained and well-supervised in the field.

Conclusions

Having discussed the problem of earthquake casualty estimation at some length, I'll very briefly recapitulate my major points:

(1) There is a shameful dearth of good data on earthquake-related deaths and injuries.

(2) Learning more about these phenomena is likely to be a labor-intensive but worthwhile effort.

(3) We have enough general and anecdotal data at this time to undertake model development and hypothesis testing.

(4) To have maximum payoff, the research undertaken should use a common set of data-collection instruments and strategies, rather than proceeding in a haphazard way as it has in the past.

(5) Empirical studies should be cross-national, multi-cultural, and multi-disciplinary.

REFERENCES

Applied Technology Council. 1985. Earthquake Damage Evaluation Data for California. Redwood City, CA: Applied Technology Council.

Archea, J. C. and M. Kobayashi. 1984. "The Behavior of People in Dwellings During the Off-Urakawa Earthquake of March 21, 1982." In Proceedings of the Eighth World Conference on Earthquake Engineering. Englewood Cliffs, N. J.: Prentice-Hall.

Comerio, M. C. 1989. Seismic Costs and Policy Implications: The Cost of Seismic Upgrading in Unreinforced Masonry Residential Buildings and Policy Implications for Maintaining an Affordable Housing Stock. San Francisco: George Miers and Associates.

Dawson, D. 1985. State Emergency Medical Services: A National Survey. Helena Montana: National Association of State Emergency Medical Services Directors.

Durkin, M. E. 1987. "Casualties, Search and Rescue, and Response of the Health Care System." **Earthquake Spectra** 3: 621-633.

Durkin, M. E., S. Aroni, and A. Coulson. 1984. "Injuries in the Coalinga Earthquake." In The Coalinga Earthquake of May 2, 1983: EERI Report. El Cerrito, CA: Earthquake Engineering Research Institute.

Dynes, R. R., E. L. Quarantelli, and D. Wenger. 1990. Individual and Organizational Response to the 1985 Earthquake in Mexico City, Mexico. Newark, DE: University of Delaware, Disaster Research Center. DRC Book and Monograph Series #24.

Federal Emergency Management Agency. 1980. An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken. Washington, D. C.: Federal Emergency Management Agency.

Glass, R. I., J. J. Urritia, S. Sibony, H. Smith, B. Garcia, and L. Rizzo. 1977. "Earthquake Injuries Related to Housing in a Guatemalan Village." **Science** 197: 638-643.

Jones, N., E. Noji, G. Smith, and F. Krimgold. 1989. Proceedings of the International Workshop on Earthquake Injury Epidemiology for Mitigation and Response. Baltimore, MD: Johns Hopkins University.

Jones, N. P., F. Krimgold, E. K. Noji, and G. S. Smith. 1990. "Considerations in the Epidemiology of Earthquake Injuries." **Earthquake Spectra** 6: 507-528.

Ohashi, H. and Y. Ohta. 1984. "Importance of Indoor Environmental Performance Against an Earthquake for Mitigating Casualties." In Proceedings of the Eighth World Conference on Earthquake Engineering. Englewood Cliffs, N. J.: Prentice-Hall.

Panel on Earthquake Loss Estimation Methodology. 1989. Estimating Losses from Future Earthquakes. Washington, D. C.: National Academy Press.

Scawthorn, C. 1987. Fire following Earthquake: Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco. Oak Brook, ILL: All-Industry Research Advisory Council.

Smith, G. S. 1989. "Research Issues in the Epidemiology of Injuries Following Earthquakes." In Jones, et al., Proceedings of the International Workshop on Earthquake Injury Epidemiology for Mitigation and Response. Baltimore, MD: Johns Hopkins University.

Spangle, W. E., R. L. Meehan, H. J. Degenkolb, and M. L. Blair. 1987. Pre-Earthquake Planning for Post-Earthquake Rebuilding. Pasadena, CA: Southern California Earthquake Preparedness Project.

Steinbrugge, K. V. 1982. Earthquakes, Volcanoes, and Tsunamis: An Anatomy of Hazards. New York: Skandia America Group.

Tierney, K. J. 1990. "Loss Estimation and Public Policy: Cautionary Words from a Social Science Perspective." Paper prepared for the National Research Council Forum on Economic Consequences of a Catastrophic Earthquake. Washington, D. C.: August 1-2.

Tierney, K. J., W. J. Petak, and H. Hahn. 1988. Disabled Persons and Earthquake Hazards. Boulder, CO: University of Colorado, Program on Environment and Behavior. Monograph #46.

Tierney, K. J., H. A. Seligson, and R. T. Eguchi. 1990. Chemical Hazards, Mitigation, and Preparedness in Areas of High Seismic Risk: A Methodology for Estimating the Risk of Post-Earthquake Hazardous Materials Releases. Draft report prepared for the National Science Foundation and the National Center for Earthquake Engineering Research.

Wyllie, L. A., Jr. and J. R. Filson (Eds.). 1989. Armenia Earthquake Reconnaissance report. **Earthquake Spectra** Special Supplement. El Cerrito, CA: Earthquake Engineering Research Institute.