UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PROCEEDINGS OF CONFERENCE XLIX

A MEETING OF THE U.S. AD HOC WORKING GROUP ON:

"EARTHQUAKE RELATED CASUALTIES"

July 13, 1989
Baltimore, Maryland

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Sponsored by:

Federal Emergency Management Agency
Office of U.S. Foreign Disaster Assistance
National Science Foundation
U.S. Geological Survey

OPEN FILE REPORT 90-244

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Reston, Virginia 22092

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Reston, Virginia
1990

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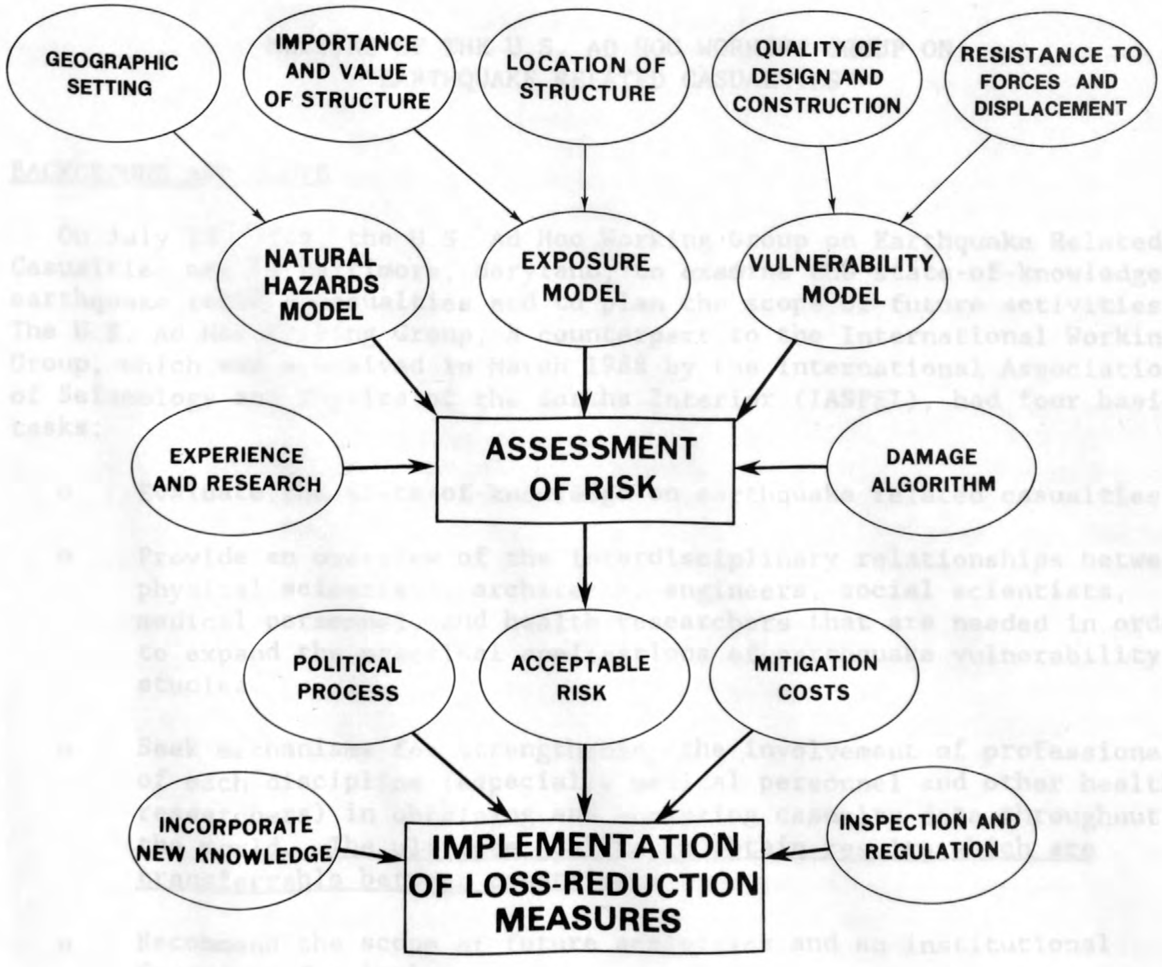

The working group on earthquake-related casualties proposes detailed investigators of the wide range of complex elements involved in the assessment of earthquake risk and the implementation of loss-reduction measures shown in this schematic illustration.

EXECUTIVE SUMMARY

MEETING OF THE U.S. AD HOC WORKING GROUP ON
"EARTHQUAKE RELATED CASUALTIES"

BACKGROUND AND SCOPE

On July 13, 1989, the U.S. Ad Hoc Working Group on Earthquake Related Casualties met in Baltimore, Maryland, to examine the state-of-knowledge on earthquake related casualties and to plan the scope of future activities. The U.S. Ad Hoc Working Group, a counterpart to the International Working Group, which was conceived in March 1988 by the International Association of Seismology and Physics of the Earths Interior (IASPEI), had four basic tasks:

- Evaluate the state-of-knowledge on earthquake related casualties.
- Provide an overview of the interdisciplinary relationships between physical scientists, architects, engineers, social scientists, medical personnel, and health researchers that are needed in order to expand the practical applications of earthquake vulnerability studies.
- Seek mechanisms for strengthening the involvement of professionals of each discipline (especially medical personnel and other health researchers) in obtaining and analyzing casualty data throughout the world. The ultimate goal is to obtain results which are transferrable between countries.
- Recommend the scope of future activities and an institutional framework for implementation.

SYNERGISM WITH THE INTERNATIONAL WORKSHOP

The U.S. Ad Hoc Working Group was able to take advantage of the synergism provided by the "International Workshop on Earthquake Injury Epidemiology for Mitigation and Response," which was held at the Johns Hopkins University in Baltimore, on July 10-12, 1989. Because it involved some of the same people as well as a broad crossection of people having the desired multidisciplinary skills and varied experiences, the schedule of the meeting was arranged so that all members of the U.S. Ad Hoc Working Group could participate in the workshop. Adoption of this strategy made both meetings more productive and cost effective.

PARTICIPANTS

Algermissen, S.T. (through correspondence)	U.S. Geological Survey
Andrews, Richard	Governor's Office, State of California
Aroni, Samuel	UCLA
Cheu, Donald H.	Permanente Medical Group
Coburn, Andrew	Cambridge Architectural Research Limited
Durkin, Michael E.	Durkin and Associates
Filson, John R.	U.S. Geological Survey
Freeman, Calvin	California EMS Authority
Giesecke, Alberto	Regional Center for Seismology for South America
Hays, Walter W.	U.S. Geological Survey
Jones, Nicholas P.	Johns Hopkins University
Krimgold, Frederick	Virginia Technical Institute and State University
Lagorio, Henry J.	University of California
McClure, Frank E.	Lawrence Berkeley Laboratory
Noji, Eric K.	Johns Hopkins University
Roth, Richard J.	California Department of Insurance
Smith, Gordon S.	Johns Hopkins University
Steinbrugge, Karl V.	Structural Engineer
Tierney, Kathleen J.	University of Delaware

The participants contributed to the deliberations of six work sessions, which were organized as follows:

I. Background
 Karl V. Steinbrugge
 Walter W. Hays

II. Summary of the "International Workshop on Earthquake Injury Epidemiology for Mitigation and Response"
 Frederick Krimgold
 Nicholas P. Jones
 Eric K. Noji
 Gordon S. Smith

III. Viewpoints of the Ultimate User
 Richard Andrews, Chairman
 Donald H. Cheu
 Calvin Freeman
 Richard J. Roth, Jr.
 Kathleen J. Tierney

IV. Interfaces Between Disciplines: Science/Design Professionals
 Frank E. McClure, Chairman
 Samuel Aroni
 John R. Filson
 Alberto Giescke
 Walter W. Hays
 Henry J. Lagorio

V. Viewpoints of Medical/Health Care
Eric K. Noji, Chairman
Michael E. Durkin
Gordon Smith

VI. Wrap-up: Where We Go From Here
Karl V. Steinbrugge

LOMA PRIETA EARTHQUAKE

In July 1988, the U.S. Geological Survey (USGS) advised public officials in California of:

- o A 50 percent probability for a magnitude 7.0 or greater earthquake in northern California.
- o A 30 percent probability for a magnitude 6.5 or greater earthquake on the Santa Cruz segment of the fault.

On Tuesday, October 17, 1989, at 5:04 p.m., local time, a 40 km-long segment of the San Andreas fault zone in the Santa Cruz Mountains ruptured. More than simple strike-slip faulting was involved in the rupture which had a significant (70°) nonvertical fault dip and a thrust component to the slip. The model derived from a combination of geodetic (geodolite and GPS) and seismological observations had the following parameters.

- o Strike - N 48°
- o Dip - 70° Southwest.
- o Slip - 1.7 m right lateral, 1.3 m reverse.
- o Depth of Focus - 18.24 km.
- o Fault Length - approximately 40 km.
- o Fault Width - approximately 13 km (down dip).
- o Fault Depth - approximately 5 to 18 km.
- o Magnitude - M_s 7.1 (18 stations).
- o Geodetic Moment - 3.5×10^{19} Nm. (assuming slip uniformity).

The earthquake triggered hundreds of landslides in the epicentral area which ground shaking levels reached 65 percent of gravity. The initial estimates of the economic impacts, deaths, and injuries were:

- o At least $8.3 billion in direct losses (direct losses are estimated to be a factor 2.5 greater).
- o 62 confirmed deaths (as of November 29, 1989), including 41 in the Cypress Street structure collapse of Interstate 80.
- o 3,000 injured.
- o 14,000 homeless.
- o Approximately 116,882 damaged buildings with the majority (more than 104,000) being in San Jose and Santa Clara Counties.

LOMA PRIETA EARTHQUAKE CASUALTIES

The Loma Prieta earthquake provided an opportunity to reassess casualty and fatality prediction estimates. Current methods based on historic records have proved to be inadequate from the lack of medical input. Due to the limited experience in the United States dealing with the occurrence of damaging earthquakes in major metropolitan centers, every opportunity to develop adequate data bases to verify the impacts of earthquakes results on public health and safety should be taken. The urgency of the problem on a national scale requires that a close look be taken of this earthquake now before fragile field data disappears.

We propose an interdisciplinary national effort which has the goal of reducing morbidity and mortality. The objective is to promote and coordinate the interdisciplinary study of earthquake-related casualties. Appropriate and coordinated data gathering is the basic element.

The focus of our national efforts should include:

1. Fostering interagency cooperation among all levels of government.

2. Establishing a catalytic role in the gathering, reviewing, and disseminating of data and research results.

3. Providing suggestions on the direction, objectivity, and balance of the on-going related research programs.

4. Providing recommendations for a proper mix of scientific disciplines, medical health expertise, design professions, emergency management, and relevant others.

5. Assisting in the creation of public/private research partnerships.

6. Identifying future research needs and methodologies.

The USGS, the Federal Emergency Management Administration (FEMA), the National Science Foundation (NSF), the Center for Building Technology (National Institute of Standards and Technology), and the Centers for Disease Control should play significant roles in carrying out the proposed effort, which should start as soon as practicable.

Initial tasks should include consideration of where the detailed gathering of the data and the carrying out of the work plan should be housed (e.g., in a State or local agency such as the State of California's Office of Emergency Services (OES)). Using this State agency as an example, their Bay Area Regional Earthquake Preparedness Project (BAYREPP) can provide a local address and vehicle for obtaining data. Another important consideration is staff support from the participating agencies. The USGS, for example, could provide seismological, engineering seismology, geology, and earthquake engineering expertise. FEMA, with its existing relationships to California's OES, could provide support for day-to-day operations. NSF could provide liaison with researchers. The Center for Building Technology could provide research in earthquake engineering. The Centers for Disease Control, the State of California's Emergency Medical Services Authority, and other State departments with medical/health responsibilities could provide medical staffing and/or expertise to assure that the medical and epidemiological aspects are given proper consideration. All of these agencies should coordinate their data acquisition activities to meet the goals of the proposed national efforts.

RECOMMENDATIONS

The participants recommended that a interdisciplinary national panel on earthquakes related casualties should be formed. The program of the International Decade for Natural Disaster Reduction in the 1990's was identified as one mechanism for gaining institutional support for activities. Planning to realize this objective should be initiated as soon as possible in order to take advantage of the window of opportunity presented by the Loma Prieta earthquake and the Decade. Funding and long-term multiagency support should be identified through the participating organizations.

Karl V. Steinbrugge
Chairman, U.S. Ad Hoc
Working Group on Earthquake
Related Casualties

Walter W. Hays
Secretariat, U.S. Ad Hoc
Working Group on Earthquake
Related Casualties

ACKNOWLEDGMENTS

The financial support of the National Science Foundation, the Federal Emergency Management Agency, and the Agency for International Development's Office of U.S. Foreign Disaster Assistance is gratefully acknowledged.

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REPORT OF THE WORKING GROUP ON

EARTHQUAKE RELATED CASUALTIES

Draft date: June 23, 1989

Origin and Mission

The Working Group on Earthquake Casualty Estimates was conceived in March of 1988 after the International Association of Seismology and Physics of the Earth's Interior (IASPEI) showed increased interest in practical applications of earthquake risk studies. It was clearly evident that medical studies have significantly lagged the interdisciplinary work by physical scientists, engineers, and social scientists in earthquake risk evaluation and hazard reduction. There is a great need for improvements in death and injury estimation methods and their applications in earthquake disaster response planning. The Working Group has the mission of examining and reporting on interdisciplinary approaches to correcting these imbalances.

Tasks of The Working Group

The first task of the Working Group is to provide a brief overview of the interdisciplinary relationships needed for vulnerability studies, with particular emphasis on the greater involvement of the medical disciplines.

A second task is to seek methods to strengthen the involvement of medical personnel and other health researchers in obtaining and studying casualty data. The objective is to obtain results which are transferable to other countries. By "transferable" is meant that the information can be applied to needs such as vulnerability studies. United States historic data are inadequate, and transferable world-wide information is vital. The current work by Johns Hopkins University and Hospital has the potential for a major forward step.

The third task is to make recommendations, if any, for national as well as international needs and cooperation. In the background is the forthcoming International Decade for Natural Hazard Reduction.

Research needs within disciplines are not emphasized, rather, examples of interdisciplinary research requirements and potential studies are looked at.

Figure 1 is an oversimplified flow diagram of all-inclusive earthquake vulnerability studies. The first three boxes summarize the products from disciplines which prepare the more usual vulnerability study. The subjects in the fourth box have seen little attention, are uneven in their content, and often are developed outside of the context of vulnerability studies. The last box lists the kinds of end users. The impacts of vulnerability studies have often suffered when the end users have not participated from the beginning.

Overview of the Current Status

By and large, vulnerability studies have emphasized building damage and impairments to community lifelines (public utilities). Losses therefrom normally have been estimates of type of damage, of time to repair lifelines, on the number of homeless and loss of housing, and with estimates of the number of deaths and injuries.

Casualty figures stated in United States earthquake vulnerability studies are of low credibility for a variety of reasons, principally for the lack of American experience data and the failure to use medical diagnostic criteria and reliable, valid measures of the severity of injuries. Injuries are often described as "serious", but without definition as to the type and extent of medical needs. Hospital disaster response plans, however carefully done, can not be expected to meet the needs of earthquake victims unless and until those needs are clearly understood from both quantitative and qualitative perspectives. It is not appropriate public policy to give better attention to property damage and economic losses than to casualties.

This serious deficiency is now beginning to be addressed by the medical community. Post-disaster medical studies conducted after the 1988 Armenia, USSR, earthquake are major beginning steps towards rationally quantified casualty estimates.

Expected damage to buildings, public utilities, and other construction types have reasonable credibility. Far less attention has been paid to the economic consequences of earthquake deaths and injuries; it is not evident that many private and public medical and health plans, including workers compensation, will be able to provide the post-earthquake financial support expected of them. In fairness, the data necessary for credible estimates are largely lacking.

Monetary resources for post-earthquake medical and health care needs, particularly long term resource needs, must be shared with other components of long term community recovery. Damage repair costs and costs due to the loss of function can be only crudely approximated since post-earthquake public policy is uncertain. Tax bases are reduced, thereby reducing a community's capability to reconstruct. This, in turn, throws a burden on higher governmental agencies which are often deficit ridden. Experience suggests that a great earthquake in a major population center will require years for full recovery.

FIGURE 1

PRE-EARTHQUAKE VULNERABILITY ESTIMATION

1. RISK EVALUATION -- GEOPHYSICAL DISCIPLINES

1. Earthquake probability vs. magnitude, focal depth, fault information, etc.
2. Local characteristics: surficial geology (potential for ground failure such as liquefaction, landslide, etc.), motion amplification as function of soils, duration of damaging shaking, spectra, etc.

↓

2. HAZARD EVALUATION -- ENGINEERING AND ARCHITECTURAL DISCIPLINES

NOTE: Estimates must consider life hazard separately from loss of function. Also building contents and equipment for vital occupancies.

1. Buildings/structures: Damage patterns by class of construction, dams.
2. Community lifelines: Damage patterns for utilities (water, electric power, telephones, sewage, etc.)
3. Critical facilities: hospitals, fire and police stations, etc.
4. Ensuing fire. Tsunami.
5. Homeless.

↓

3. HAZARD EVALUATION -- MEDICAL DISCIPLINES

NOTE: Inputs to medical include hazard evaluations by engineers and architects.

1. Death and injury estimates as functions of occupant loads in and about structures, and as a function of time of day.
2. Loss of medical response capabilities: personnel, hospitals, supplies, etc.
3. Effects of toxic materials (gas clouds, liquids spills).

↓

4. INTERRELATED CONSEQUENTIAL ECONOMIC IMPACTS

NOTE: Quantify dimensions of economic consequences -- examples listed.

1. Medical:
   A. Resources required to rebuild/replace both public and private hospitals, health care facilities, etc.
   B. Health/injury insurance response capabilities, including workers compensation.
2. Governmental:
   A. Aggregate property loss estimates for governmental roles in disaster loans and grants.
   B. Impacts on tax base (property damage, income loss, other).
3. Private: Ability of property insurance companies to pay their losses.

↓

5. RESPONSE PLANNING

1. Public response agencies: Federal, state, and local.
2. Private response agencies: Red Cross, Salvation Army, other.
3. All other: government, companies, private organizations, and individuals.

Examples of Interdisciplinary Research Needs And/or Applications

Editorial note: Each of the following was submitted by Working Group member(s) in response to the request in the April 22, 1989 draft of the "Working Paper".

All submittals will be agenda items at the July 13, 1989, Baltimore meeting. Each author is invited to be the discussion leader for their submittal.

All authors are requested at this time to review their submittals in the context of other submittals, and revise/expand them if this seems desirable.

Revisions must be in Steinbrugge's hands by June 10, 1989, to be included in the working draft to be submitted to all Working Group members.

TRANSFER OF CASUALTY INFORMATION AMONG DISCIPLINES

Karl V. Steinbrugge

Consider a scenario where post-earthquake medical information gathered in Country "A" is to be transferred and applied for response planning in Country "B". Assume as a part of the data that a number of multistory reinforced concrete buildings in Country "A" are located close to each other, in a similar geologic environment, and with similar design and construction characteristics. Further assume that some have been partially or totally destroyed. Medical personnel have categorized the causes and kinds of injuries and deaths by each building: i.e., collapsed, damaged, or survived -- or on a more accurate basis with engineering help. Occupant load in each building at the time of the event was determined or estimated. Deaths and injuries then can be stated as a percentage of occupant load for each building by building class or type, including undamaged.

It is reasonable to assume that geophysical studies will be made of the area after the earthquake, including strong motion instrumental recordings of aftershocks. Also, buildings will be examined by structural engineers. The medical, geophysical, and engineering data can be correlated.

Next is the desirability to apply this information in Country "B". Vulnerability studies in Country "B" should include the geographic distribution by class or subclass of multistory reinforced concrete buildings and their expected damage patterns. In Country "B" under similar geophysical conditions or reasonable extrapolations thereto, the occupant load casualty percentages will be similar to those in Country "A" since the modes of building failure are usually similar or predictable. (Failure modes of concrete frame buildings are different from shear wall buildings, but engineers can readily detect this.) Thus in general terms, the percentages are transferable using the collective judgments of the medical, engineering, and geophysical disciplines.

The same kind of process can be applied to other building types such as unreinforced unit masonry bearing wall structures. Construction variables within this class include wood partitions in United States and masonry partitions in other countries. These differences will result in differing medically related percentages.

Methods sketched here have significant potential for large errors, but represent major improvements over present techniques. It should also be evident that the methodology to implement even the rudiments will take time to achieve.

Status of Medical Inputs to Vulnerability Studies Conducted by U.S. Federal and State Agencies

Henry J. Lagorio

In the U.S., earthquake vulnerability studies sponsored by Federal and State Agencies for metropolitan centers located in areas of high seismic risk are a relatively recent development. These studies typically determine the estimation of: (1) Damage/functional impairment to critical emergency services and lifelines, (2) Dollar loss, (3) Homeless, and (4) Deaths and injuries, following a major seismic event. In the U.S., the first attempt to develop a comprehensive vulnerability study, "A Study of Earthquake Losses in the San Francisco Bay Area", was initiated in 1971 by the National Oceanic and Atmospheric Administration (NOAA) for the Office of Emergency Preparedness (OEP), and published in 1972. Since then, at least 19 additional vulnerability studies have been sponsored by Federal and State agencies for other selected regions throughout the U.S., while two others sponsored by FEMA are in preparation for the areas of Boston and St. Louis. (See Bibliography Index attached.)

While damage estimates for buildings and lifelines are at an acceptable level, it is generally agreed that in all vulnerability studies issued to date figures derived for deaths and injuries are of low credibility primarily because of the lack of medical input. In some cases, hospitalized injuries were simply established at a 4 t0 1 ratio of deaths based on historic records, while some of the studies developed more recently do not even include estimations of casualties, principally due to lack of medical back-up, sufficient performance data, and accurate building inventories. Table 1 presents a compilation of casualty data, or lack of, reported in 20 vulnerability studies conducted by U.S. Federal and State agencies and the sources for such data.

Based on these findings, it is recommended as a major step forward in the development of future vulnerability studies that appropriate members from the medical profession at be involved in the study and derivation of casualty data. Compared to other countries, 1976 Tangshan earthquake with 250,000 deaths, 1985 Mexico earthquake in Mexico City with 20,000 deaths, and 1988 Armenia earthquake with 25,000 deaths, historic data in the U.S. are inadequate and require the sharing and transferability of world-wide intelligence on the development of an earthquake casualty data-base for input into future vulnerability studies.

To carry-out the advancement of vulnerability studies at the international level, it is further recommended that a suitable delegation: (1) Assess compatible methods to include input from the medical profession, (2) Propose appropriate international guidelines for the development of such studies, and (3) Establish a comprehensive data-base record of all casualties reported.

Table 1

ESTIMATES AND DATA SOURCES OF EARTHQUAKE DEATHS AND INJURIES REPORTED IN U.S. VULNERABILITY STUDIES BY U.S. FEDERAL AND STATE AGENCIES

Source	Year	Study Area	Fault Zone	Casualties* Deaths	Casualties* Injuries
NOAA	1972	SFO Bay Area, CA	San Andreas	10,360	40,360
			Hayward	6,650	24,900
NOAA	1973	LAX Co. Area, CA	San Andreas	11,190	44,760
			Newport-Inglewood	18,858	75,432
		Orange Co, CA	San Andreas	1,195	4,780
			Newport-Inglewood	1,870	7,480
MATCOG/MDDD	1974	3 State Area, MW(1)	New Madrid Belt, etc.	1,100	4,400
USGS	1975	Puget Sound, WA(2)	Seattle Epicenter	2,170	8,680
			Olympia/Tacoma Epic.	2,030	8,120
USGS	1976	Salt Lake City(3)	Wasatch	1,930	7,720
			Magna	1,872	7,488
SSAC	1979	State of Utah(4)	Wasatch/Cache Valley	19	289
NSF	1979	Midwest Res.	New Madrid	646	64,567
FEMA	1979	State of Hawaii	All Islands	86	345
ADES	1980	Anchorage, AK(5)	Knik, Castle Mt.++	35	265
FEMA	1980	Anchorage, AK(6)	Knik, Castle Mt.+++	144	176
FEMA	1980	State of Calif.	North San Andreas	11,000	44,000
			Hayward	8,000	30,000
			South San Andreas	14,000	55,000
			Newport-Inglewood	23,000	91,000
USGS	1981	SFO/LAX/Orange, CA	North San Andreas	11,370	44,340
			Hayward	3,380	10,550
			South San Andreas	12,495	49,980
			Newport-Inglewood	20,755	83,020
DMG	1982	LAX Area, CA	San Andreas	(Not Reported)	
FEMA	1982	Oahu/Honolulu, HI	In Zone 2 Area	375	775
DMG	1982	SFO Bay Area, CA	San Andreas	(Not Reported)	

Table 1 (continued)

FEMA	1985	Central U.S.(7)	New Madrid	4,907	19,590
USGS	1985	LAX Region, CA	(All Potential)	(Not Reported)	
DMG	1987	SFO Bay Area, CA	Hayward	4,400	13,200
FEMA	1988	Charleston, SC(8)	Woodstock/Ashley, etc.	2,143	8,574
DMG	1988	LAX Area, CA	Newport-Inglewood	(Not Reported)	

NOTES:

* Exclusive of dam failure, casualty figures based on: (1) maximum estimated casualties, (2) maximum credible postulated earthquake for the study area, and (3) most critical time of day and/or night. Injury data indicate hospitalized (major) injuries only.

(1) 3 State Midwest Study Area: Mississippi (DeCoto Co.), Arkansas (Crittenden Co.), (Shelby Co.) Tennessee.

(2) 6 County Area, Washington: Snohomish, King, Pierce, Thurston, Mason, Kitsap.

(3) 4 County Area, Utah: Weber, Davis, Salt Lake, Utah.

(4) 100-year death and injury figures limited to hospital and nursing home populations only.

(5) Casualty figures limited to local medical facility populations, and include potential activity on Aleutian Megathrust Fault Zone.

(6) Casualty figures represent all injuries, and include any potential of acivity on Aleutian Magathrust Fault Zone.

(7) Six cities: Carbondale, Evansville, Little Rock, Memphis, Paducah, and Poplar Bluff.

(8) Tri-County Area, S. Carolina: Charleston, Berkeley, Dorchester

BIBLIOGRAPHY INDEX OF VULNERABILITY STUDIES
BY U.S. FEDERAL AND STATE AGENCIES
(Listed in Chronological Order)

<u>Source</u>:	<u>Title of Publication</u>:
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CASUALTY RATES VS.
CLASSES OF BUILDING CONSTRUCTION

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As a result of the 1971 San Fernando earthquake, The Regents of the University of California adopted a University of California Seismic Safety Policy in 1975. This Policy led to a survey of University buildings in 1978 to evaluate the seismic performance of these buildings. The seismic performance ratings for over 44 million square feet of 1978 University buildings on the nine campuses were (by percentage of area): Good 34%, Fair 45%, Poor 13% and Very Poor 8%.

When the University went to the State Legislature for funding to reconstruct the Poor and Very Poor buildings, the Legislature asked the State of California Seismic Safety Commission to develop a methodology to prioritize the reconstruction of University buildings based on "life safety." The Seismic Safety Commission established a Committee on the Test Program of Evaluating the Seismic Hazard of State Owned Buildings, chaired by Karl V. Steinbrugge. The Committee prepared a report, "Evaluating the Seismic Hazard of State Owned Buildings, State of California Seismic Safety Commission, Report 79-10, dated January 1, 1979. This report presents a methodology for prioritizing the funding and reconstruction of State owned buildings (approximately 3/4 of University of California buildings are State owned) based on "life safety," using a "benefit-cost" methodology.

The "benefit-cost" methodology compares the number of lives to be saved in each building against the cost to reconstruct the building. Buildings with the potential for saving the most lives per dollar of reconstruction have the highest priority for funding and reconstruction.

This "benefit-cost" methodology is expressed by the following equation:

$$\text{Benefit Cost Ratio (BCR)} = \frac{(\text{LSR})^{*}\,(\text{ECO})^{*} - (\text{LSRG})\,(\text{ECO})^{**}}{10{,}000\ (\text{RC})}$$

*denotes prior to reconstruction
**denotes after reconstruction

BCR: Benefit Cost Ratio, being the number of postulated lives saved per reconstruction dollar.

LSR: Life Safety Ratio, being the postulated number of fatalities per 10,000 for a particular class of building construction when subject to the earthquake under consideration.

ECO: Equivalent Continuous Occupancy, being the theoretical estimated number of persons continuously occupying the structure on a 24 hour basis, 365 days per year.

LSRG: Life Safety Ratio Goal, being the attainable life safety goal that could be achieved by strengthening the building. Based on experience, Table 1 (appended) contains the estimates of attainable life safety goals for various classes of buildings.

RC: Reconstruction Cost: being the cost to rehabilitate a given type of building so as to reduce the life hazard to the Life Safety Ratio Goal specified for the particular class of building in question.

To apply the methodology it was necessary to establish the LSRs for each class of building construction. These LSRs are presented in the appended Table 1 of the Report, "Life Safety Ratios and Goals for Buildings in Zone A." The LSRs vary from a low of 2 per 10,000 for Building Class IA, small wood frame structures, to 5,000 per 10,000 for Building Class F, adobe or hollow tile construction.

These data necessary to correlate the casualty rates (LSRs) with various classes of building were almost non-existent. Therefore, the three authors of the above Seismic Safety Commission Report, who were earthquake engineers and had observed earthquake damage in the field and have retrospectively studied reports of earlier earthquakes, researched the 1978 earthquake damage literature for data on the number of deaths and injured in previous earthquakes. They used the data in the 1972 NOAA Report "A Study of Earthquake Losses in the San Francisco Bay Area," and the 1973 NOAA "A Study of Earthquake Losses in the Los Angeles Area," prepared by Karl V. Steinbrugge et al. These reports have very comprehensive and detailed discussions of how to predict the deaths and injuries from large California earthquakes.

Considerable earthquake engineering judgment was used to establish the LSRs. The LSR of 2 per 10,000 was based on the earthquake performance and the deaths and injuries reported in California small wood frame structures. The LSR of 5,000 per 10,000 was based on data from foreign earthquakes presented in the aforementioned 1972 and 1973 NOAA reports.

The above "benefit-cost" methodology used a term, Equivalent Continuous Occupancy, which represents the theoretical estimated number of people continuously occupying the structure on a continuous 24 hour basis, 365 days per year. The Equivalent Continuous Occupancy was used to normalize the number of occupants at risk for various different occupancy uses. For example, a hospital would have a higher ECO than a school or office building of the same area because the hospital is occupied 24 hours a day compared to 8 or 9 hours for a school or office building. For studies of earthquake casualty estimates, the actual number of occupants in each class of building construction at a given time under construction should be used rather than the ECO.

As a first preliminary estimate of the number of casualties in the event of a scenario earthquake in a given country, the size of the earthquake must be estimated and the LSRs revised to take into account the difference in the size of the scenario earthquake from earthquakes which were used to predict the LSRs. Also the LSRs must be revised to account for the differences in earthquake resistance of buildings in the same building classification in the given country from the earthquake resistance of the buildings used to establish the original LSRs.

It is suggested that the revised LSRs by class of building construction be applied to the number of occupants postulated to be in each class of building construction at the time of the scenario earthquake to calculate the number of deaths. From the number of deaths, the hospitalized injuries and non-serious injuries can be estimated using the data in previous studies. The ratio of hospitalized injuries and non-serious injuries to death given in the NOAA Reports of 4 to 1 and 30 to 1, respectively, are suggested until further research can verify or change these values.

Preliminary reports have indicated that the 1988 Armenian earthquakes have ratios of hospitalized injuries to deaths less than 4. In other words, because of the type of "pancake collapses" of the buildings, most of the people in the Armenian collapsed buildings died and there were fewer people who were only injured.

The 1989 Report "Estimating Losses from Future Earthquakes" by the Panel on Earthquake Loss Estimation Methodology, Committee on Earthquake Engineering, National Research Council, stressed the need to collect data from a large number of earthquakes with the type and degree of injury related to the physical damage that causes the injuries. If these data were collected by class of building construction, it would help validate the LSR's presented in the appended Table 1. Hopefully, the data from the 1988 Armenian earthquakes might still be available to contribute to these needed data. Unfortunately, it would be somewhat more difficult to obtain similar data from the 1985 Mexico earthquakes reports due to the passage of time.

TABLE 1

LIFE SAFETY RATIOS AND GOALS FOR BUILDINGS IN ZONE A*

BUILDING CLASS		SUMMARY DESCRIPTIONS (Detailed definitions are attached)	LSR'S FOR BLDG. DESIGNED FOR EARTHQUAKES **		LSR'S FOR BLDG. NOT DESIGNED FOR EARTHQUAKES	ATTAINABLE LIFE SAFETY GOALS (LSG) GOAL
I.	A	Small wood frame	2		4	2/10,000
	B	Large wood frame	5		10	5/10,000
II.	A	Small all metal	2		4	2/10,000
	B	Large all metal	8		15	8/10,000
III.	A	Steel frame, poured concrete walls	5		10	5/10,000
	B	Steel frame, curtain walls	15		40	10/10,000
	C	Steel frame, better than III. B	10		25	5/10,000
	D	Steel frame, weak diaphram & walls	25		50	15/10,000
	E	III. A for auditoriums, long spans, etc.	25		50	15/10,000
	F	III.B for auditoriums, long spans, etc.			1500	15/10,000
			Non-ductile Concrete	Ductile Concrete		
IV.	A	Concrete frame & walls	50	25	100	15/10,000
	B	Concrete frame, floors, curtain walls	300	75	1000	25/10,000
	C	Better than IV. B	200	50	500	25/10,000
	D	Precast or lift slab	500	75	1500	25/10,000
	E	Concrete frame, weak walls & diaphrams	800	100	2000	25/10,000
	F	IV. A for auditoriums, long spans, etc.	75	50	200	35/10,000
	G	IV. B,D,E for auditoriums, long spans, etc.	1000	200	2500	35/10,000
V.	A	Small mixed dwellings & similar	10		200	10/10,000
	B	Mixed superior tilt-up	15		800	15/10,000
	C	V.B. with ordinary control features	20		1000	15/10,000
	D	Mixed Concrete, precast reinforced	40		2000	15/10,000
		masonry			4000	15/10,000
	E	Unreinforced masonry, wood, etc.			5000	15/10,000
	F	Adobe, hollow tile				

* Should be adjusted for Seismic Zone B.

** In conformance with earthquake lateral force provisions in building codes in force at the time of their construction.

Epidemiology of Injuries Following Building Collapse

There is a need for a sound research program on earthquake epidemiology, particularly with regard to injuries and deaths following building collapse. Multidisciplinary teams should be formed to coordinate research activities from both the engineering, epidemiology, acute care, and search and rescue perspective. Some of the important aspects to be addressed by such a research program include:

1. Development and validation of means to assess the number of fatalities and likely number of injured survivors. A simple field tool for assessing severity of injuries sustained is needed that could be used to predict the immediate health care and search and rescue needs. Analyses should be conducted of previous earthquakes and a study protocol developed to collect data prospectively in the next major earthquake. The protocol should be developed in consultation with existing experts in the field.
2. Better survey instruments must be developed to assess the health impact of earthquakes. This should include development of the most appropriate sampling techniques in the field. How can reliable data on injuries be collected under difficult field conditions? An extensive review should be conducted of previous research on casualty estimation. The work should be critically evaluated by engineers, architects, epidemiologists, and physicians with training in emergency medicine.
3. More research is needed on factors related to the survival of those rescued following building collapse. Why did some survive and others were killed? What is the relationship to building structure design or to non-structural components in the building? What is the most appropriate place to be in a building that will increase the chance of survival? Is it possible to predict likely places where survivors could be located and thus better direct search and rescue efforts?
4. How effective was the medical response and how could it be improved? What factors were responsible for reducing the effectiveness of the response? What is the most appropriate treatment for the entrapped victim?
5. What are the weak links in the search and rescue effort?
6. How applicable is data obtained from many different countries to earthquakes and search and rescue efforts in the U.S.? Can we learn from earthquakes in other countries? What differences must be taken into consideration?
7. How important is it to mount a large primary data collection immediately following the earthquake? Is it possible to go back retrospectively and collect reliable data?
8. What is the relationship of occupant behavior and subsequent injuries or entrapment?
9. How does building design contribute to injuries in the search and rescue effort?
10. Can knowledge of injury patterns lead to the following:

(a) Alter current building design practices in earthquake- prone areas (prevention/mitigation implications)

(b) Aid in planning (knowledge of types and severity of injuries should be able to guide type of acute medical care required)

(c) Aid in emergency medical response (knowledge of injury patterns in given type of building structure, design should help guide types of external aid delivered)

(d) Aid in evaluation of response (post-disaster evaluation of efficacy of health response. Eg. compare predicted number and severity of injuries with actual morbidity and mortality).

(e) Implementing changes in community disaster planning in response to recommendations of above evaluation.

11. Rescue operations management: Models of spatial distribution of casualties identified by building context and injury severity need to be created in order to develop specific management directives. These need to include:

    (a) Manpower and equipment demand
    (b) Mobilization and logistics
    (c) Resource allocation over time of rescue operation
    (d) Medical response and facilities allocation.

12. Little information is available on the relationship between mortality in casualties and the time that elapses before extrication from debris, and treatment (e.g., time trends for morbidity and mortality).

13. Should factors postulated to influence injury severity assume a variety of values or weights depending on their importance, as well as uncertainties in the data and/or various interpretations of the data?

14. Application of quantitative injury severity scores (e.g., ISS, AIS, CRAMS, etc.) to victims of building collapse in order to determine salvageability of victims, resuscitation potentials and for evaluationb of efficacy of search and rescue and medical response.

15. Are there a number of late deaths following earthquakes or do most deaths occur within a very short space of time? Could many of the deaths have been prevented by better emergency services, or better long-term definitive care.

16. "Real time response modeling" That is, the development of a casualty estimation system for optimization of rescue activities. Such a real-time casualty estimation system will also serve a major function as an educational tool and as an element in risk communication. A realtime casualty estimation system is principally an effort to bring together research results from a number of different disciplines to develop useful operational directives for disaster response. If it is successfully developed, it will constitute a major step forward for effective research application and implementation.

17. **Building stock characterization: Need to develop a set of global categories to distinguish gross grouping of urban development patterns as related to vulnerability and casualty rates. Need to gather existing building stock data for prototype development. Need to develop criteria for future data acquisition for refinement of algorithms.**

18. **Damage estimation models for the global vulnerability classes.**

19. **Development of casualty estimation models based on damage estimation for principal building types and principal occupancies. These casualty estimation models will include injury severity discrimination.**

20. **Global risk assessment: An assessment of earthquake casualty data in the context of other public health concerns.**

21. **The risk horizon: the individual perspective. This should attempt to place earthquake and natural hazards in perspective as potential causes of death and injury for various representative individuals from various parts of the world with varying socio-economic standing and various natural hazards exposure.**

22. Categorization of urban vulnerability: (Units of useful generalization). Building materials, practices vary significantly around the world as do patterns of building use. Research should attempt to determine the appropriate groupings of urban construction/social patterns for the pooling of data and sharing of algorithms.

23. Prediction of collapse potential: Research should reevaluate vulnerability functions with a specific focus on the "high- end" damage as it relates to death and injury. So far, most research, particularly in the U.S., has focused on "low-end" damage and on economic issues like repair cost. This will result in a set of vulnerability functions which emphasize aspects of severe damage and collapse in terms relevant to occupant safety.

Submitted by: Jones/Krimgold/Noji/Smith
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HAZARD EVALUATION -- MEDICAL DISCIPLINES

As has been state previously in the opening statements, Tasks, and Overview of the Working Group, there is a total lacking of medical data on casualties resulting from any earthquake. We do have gross numbers of injuries resulting from various world wide earthquakes, but these have not really been broken down into specific types. Nor has there been any published data on the correlation of the types of injuries with the type of structures these injuries occurred in. An attempt was made following the Whittier Narrows Earthquake to analyze the Emergency Department logs of the hospitals in the Los Angeles City and County, but as far I know, the collection of this data was never accomplished. There appears to be a real reluctance of Countries, county, and local officials to release the injury data. Thus an early task of the Working Group may be to convince Governments to release or allow this type of data to be gathered and to convince these Governments and their agencies that the data is to be studied for humanitarian causes and not political reasons.

Another step that has to be taken prior to the Working Group going out and collecting data has been indicated earlier, and that definitions of casualty types need to be established. Should we group casualties in the usual manner of **Major** and **Minor**, or is there possibly an improved and logical fashion to classify the injuries. Within the greater categories, we will need to break down the conditions into specific types of injuries such as fractures, head injuries, thoracic and abdominal wounds, penetrating and blunt injuries, vascular injuries, and medical problems.

Why do we need this type of data ? With the stimulus of the Governor's Earthquake Task Force, there has been an increasing effort by State, county, and local agencies, and hospitals to plan for the **Great** earthquake. However, these plans are built on exceedingly weak foundations, because there is no creditable data regarding the exact nature and numbers of casualties that can be expected in any given location for any specific magnitude earthquake. Most of the planning in California is based on the NOAA studies of Southern and Northern California and as has been stated, these figures have a factor of plus or minus three (3). Or another example, in the 1971 San Fernando temblor, some 20% of these receiving medical care were listed as having some type of cardiac condition. Is that an accurate fact ? Does this mean that at 4:30 PM in the Bay Area with an magnitude 8.3 quake, there will be 8,800 victims with cardiac problems ? Based on this type of data, there are those who would want to provide cardiac monitoring at the Casualty Collection Points.

Without firmer casualty data, it is nearly impossible to know the quantity and types of medical supplies we should be planning to supply the impacted areas.

To accomplish the medical aspect of the tasks assigned to the Working Group, medical personnel should be allow into impacted areas as soon as feasible after the earthquake to record the types, numbers, and location of the injured. Their goal will be one of recording the events rather than the traditional role of providing medical care at the scene. The teams should have with them data sheets developed before the response to standardize the type of information to be gathered. The development of the data collection forms will require the joint efforts of different disciplines to cover the many aspects that need to be studied.

Finally, there should be an effort to learn from other countries on how best to treat those who have been trapped for long periods of time before being rescued, especially if they have any type of crush injury.

Submitted by: Donald H. Cheu, M.D., F.A.C.S.
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Suggested topic: Social and Organizational Factors Affecting Medical Outcomes

Characteristics of the built environment, such as age and type of building stock, have a significant influence on the rates and the severity of earthquake-related injuries. However, medical outcomes (deaths, presence or absence of additional complications resulting from injury, short- and long-term disability) are also affected by a range of social and organizational factors. Potential influences on mortality and morbidity following earthquakes include: the capacity of emergency medical service systems to respond to earthquake-related medical needs (e.g., the speed and skill with which search and rescue, triage, and emergency care are provided); the available supply of trained personnel, medical-care facilities, and other important resources; and the general capacity of the affected jurisdiction(s) to respond effectively following an earthquake.

Societies clearly differ on these dimensions. It is also likely that, within the U. S., intercommunity differences also exist that could affect medical outcomes. At the present time, no research has been undertaken attempting to relate social and organizational factors to earthquake casualty data. Initial steps in this direction could consist of (1) reviewing the medical and health-care literature to identify what factors besides the nature and severity of victims' initial medical conditions appear to determine medical outcomes; and (2) developing indicators of medical system performance that are applicable to earthquake casualty studies. Such work should ideally be undertaken by interdisciplinary teams comprised of medical and health-care researchers as well as specialists in various aspects of health care service system organization and processes.

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May 29, 1989

Some Ideas On

Earthquake Injury Epidemiology for Mitigation and Response

The Interdisciplinary Aspect: Why? What? Who?

This is both an important and urgent subject. Although earthquake studies are of recent historic origin, much progress has been made on the scientific and physical aspects. The emphasis on death and injury, their prediction, field study, economic impacts, and planning for direct mitigation and prevention have visibly lagged behind. Thousands of human lives are at stake as well as billions of dollars. Progress in this area will take time, and time here is both lives and money.

Probably more than in most other earthquake related areas of study we are dealing here with a subject that requires an effective interdisciplinary approach. Not only are a great number of separate disciplines involved, with quite distinct and varied paradigms, but the need is for integrated cooperation and emphasis rather than just input from the various fields. The problem of "earthquake injury", beyond considerations of physical injury and death and their medical consequences, involves questions of seismology, the engineering of the built environment, the nature of both the physical and the sociological environments, aspects of personal and group psychology and behavior, economic short and long term issues, as well as many planning and preparedness aspects. Injuries are both physical and psychological and by their numbers have a significant impact on the particular community and society. The interdisciplinary team must not only contain representatives from the various disciplines but must be trained and capable to work together effectively and with a common base of agreement on objectives and methods.

The interdisciplinary nature of this problem is reflected in the details of its many activities. Examples include the following:

- Vulnerability studies, estimates of predicted risks before the event, require the cooperation of many specialists and suffer significantly from the lack of hard and reliable data on some aspects in the chain of events. As these become available, vulnerability studies will need to be iterated and upgraded.
- Collection of earthquake injury data and its analysis and interpretation need the collective efforts of researchers from a number of disciplines. A conceptual model is required reflecting the many concerns and a systems approach. Data

collection from many earthquakes is needed in order to understand the influence of changes in physical location, cultural and societal variables, and the characteristics of earthquakes including the time and season of their occurrence.

• The planning and execution of injury mitigation efforts are again activities requiring interdisciplinary cooperation. Their effectiveness will depend to a great extend on the quality of such cooperation.

• Since behavior during an earthquake, irrespective of the environment in which one finds oneself, can be a decisive factor in either causing or preventing injury, education and training can play a significant role. These should be based on an interdisciplinary input reflecting an understanding of likely behavior under different circumstances, their likely consequences and the means of achieving desired behavior modification.

• Planning for adequate disaster response with respect to injuries requires close collaboration between the providers of medical care after the event and those disciplines engaged in studying the likely characteristics of the earthquake and its various consequences.

• In order for search and rescue operations to be most effective they should be both planned and executed in a comprehensive manner and with full interdisciplinary input. For example, knowledge of the prior training and the likely behavior of people in a particular earthquake and physical environment may enhance the likely success of a rescue operation.

• A variety of earthquake policy issues related to injuries, which require governmental actions, need the involvement and cooperation of the full spectrum of relevant disciplines.

Many disciplines need to be involved in this problem. It requires both specific specialty and the desire and ability to cooperate as members of a large team with many overlapping smaller groups. Some of the key players include the following:

• Seismologists and earth scientists deal with their own basic research and at the same time may be called upon to respond to some special questions raised by others.

• Epidemiologists and medical practitioners play an obvious role. So do people in emergency medicine who need to apply their expertise to the special problems related to earthquakes.

• The design professionals, engineers, architects and interior designers, create the built environment which may contribute to injury and death. Beyond the obvious role of structural engineers in designing seismically safe structures, the work of other engineering specialties, mechanical, electrical, etc., influences potential earthquake injuries. All designing professionals can contribute to a built environment which decreases the probability of injury and maximizes the chances of survival and rescue if a failure should occur. This can be best achieved by suitable interdisciplinary endeavors.

- Economists and financial experts dealing with the general economic impact of injuries, as well as with the specific impact on medical facilities, services, and insurance institutions can play a significant role in both planning for an earthquake disaster and in influencing appropriate public policy.

- Behavioral scientists, sociologists, psychologists and educators, have a lot to contribute in predicting, explaining, and possibly modifying undesirable behavior which may lead to death and injury.

- Planners, experienced in dealing with large physical and societal systems as well as those with more specific interests, are very valuable in sometimes providing the glue that brings together various participants in an interdisciplinary endeavor.

In conclusion, it seems that the important challenge of saving lives and decreasing injury in earthquakes requires significant interdisciplinary work and makes each particular single profession essential but otherwise unimportant.

Professor Samuel Aroni

CONCEPTUAL FRAMEWORK

The comprehensive problem of earthquake injuries, understanding the details of the etiology of these injuries, and the various actions needed for their prevention and mitigation, is a very complex one. It involves many aspects and a number of disciplines. The need exists for some model, or conceptual framework, which is at the same time comprehensive, simple, and flexible. Such a conceptual framework is shown in Figure 1, inspired by a similar matrix proposed by Haddon[21,22] for the problem of prevention of motor vehicle crash injuries.

FIGURE 1: Conceptual Framework for Earthquake Injuries

	FACTORS			
PHASES	Human	Physical	Socio-Economic	Circumstantial
Pre-Earthquake				
Earthquake				
Recovery				
Long Range				

The model uses four fundamental phases of general applicability to earthquakes: the pre-earthquake, earthquake, recovery, and long range phases. Within each phase, in focusing on injuries, we can consider four groups of factors which influence injuries in various ways; namely human, physical, socio-economic, and circumstantial factors. Each of the 16 phase-factor interactions represents an area of specific sets of concerns within the comprehensive picture of the matrix as a whole. The phases also remind us of the "continuing" aspect of earthquake injuries. Beyond the obvious injuries during the earthquake, injuries can and do occur during the recovery period that are earthquake-related, and there is evidence of long range psychological and emotional injury, as well as some physical ones. The long range phase merges into the pre-earthquake phase for the next event, with particular significance when a seismic gap is identified, or another reason arises for an earthquake warning or prediction.

Hopefully, the conceptual framework will serve some useful purposes in that it should facilitate identifying the various roles the interactions play in mitigating and preventing injury. Let us exemplify some interactions by discussing a number of issues.

The human factors include personal characteristics such as age, sex, state of health, etc. At the pre-earthquake phase they affect personal preparedness planning and receptivity for training towards greater protection from injury. During the earthquake they influence behavior and the probability of either greater safety or increased likelihood for injury. For example the starting and propagation of fires, with subsequent injuries, during both the earthquake and early recovery phases, are due to a combination of both human and other factors. Human factors during the recovery phase would impact the medical problems of the homeless, another aspect of earthquake related injuries. Also, human factors, including curiosity and lack of discipline, contribute to tsunami losses, sometimes at great distances from the epicenter. One example is the 11 deaths at Crescent City, California, in 1964, due to the tsunami generated by the Alaskan earthquake hours earlier. A long range-human factors interaction, influenced by physical and circumstantial histories, is, for example, the prevailing attitude that exists about specific earthquake dangers. While fires have occurred during U.S. earthquakes,[23] with 1906 San Francisco being a major example, the predominant fear is of building and other collapses. This is in contrast to Japan, where the fear of earthquakes is dominated by the fear of fire.[24] An obvious explanation for the Japanese reaction is their past repeated experience, for example the Kanto earthquake of 1923, when the majority of the 90,000 deaths were caused by fire.[24]

Physical factors include all the characteristics and variability of the built environment, as well as those of local and regional seismicity. These factors obviously have a major impact on injuries and for the considerations appropriate for each of the four phases. Included in the physical factors are non-structural elements, as well as building contents.

The socio-economic factors are a large group, including institutional factors, cultural aspects, and the variability of circumstances of families, communities and regions, all of which affect issues of injuries at the different phases. During the pre-earthquake period, they are relevant for considerations of planning, preparedness and education. The performance of social organizations, for example hospitals, and the various industrial and work environments, during all earthquake phases, can have a major impact on injuries. Social roles and relations, as well as human characteristics, among those in the same location during the earthquake phase, may account for one person being injured and another not. For instance, in the Coalinga earthquake, a husband who left his living room to exit the house directly through the front door was uninjured, while his wife who left the same living room to exit circuitously through the kitchen was injured by broken glass. The wife was seeing to her children who were in the backyard playing. In the recovery phase, socio-economic factors are also important in providing the needed organization and resources, including those for the homeless, and in making a difference to the health of individuals.

Finally, the group of circumstantial factors, for example the time and season of the earthquake, can have a profound influence. In the United States, so far, we have been very lucky with respect to the timing of damaging earthquakes. The 1933 Long Beach earthquake, which caused extensive damage to pre-Field Act school buildings, occurred at 5:45 in the afternoon when the schools were empty.(25) The 1964 Alaska earthquake, although 8.4 in magnitude, struck a sparsely populated area in the late afternoon of Good Friday, when offices and commercial establishments were closed in the heavily damaged downtown Anchorage. The death toll of the 1971 San Fernando earthquake certainly would have been considerably higher if the event had occurred three hours later when between 100 and 300 staff would have occupied the first-story area of the Olive View Hospital Psychiatric building, which was crushed during the earthquake, and in the areas of the main hospital building, which were destroyed by the collapsed stairway towers.(26) As far as the season of the earthquake is concerned, major secondary sources of injury and damage associated with California earthquakes are landslides and dam failures (primarily in winter or spring) and uncontrolled fires (primarily in summer and fall).(3)

Our own study is mainly concerned with the earthquake and part of the recovery phases, and deals primarily with the human and physical factors. Much work needs to be done, in many earthquake prone countries, to provide the understanding and empirical data required to answer the many questions raised by the conceptual framework.

EARTHQUAKE INVESTIGATIONS

We shall present and discuss next results of our current study of injury and behavior of four earthquakes, namely the 1978 Santa Barbara, 1979 Imperial County, and 1983 Coalinga, all in California, and the Chile earthquake of March 1985. Some relevant details of these earthquakes are given in Table 2. Our results are preliminary since not all interviewing and analysis have been completed.

TABLE 2: Details of the Earthquakes Investigated

Earthquake	Magnitude	Maximum Intensity (Modified Mercalli)	Date	Time	Dead	Injured
Santa Barbara	5.7	VIII	August 13, 1978 (Sunday)	3:55 P.M.	---	85
Imperial County	6.6	VII	October 15, 1979 (Monday)	4:16 P.M.	---	78
Coalinga	6.7	VIII	May 2, 1983 (Monday)	4:42 P.M.	---	211
Chile	7.8	VIII	March 3, 1985 (Sunday)	7:47 P.M.	180	2,572+

Santa Barbara, California, 1978

Santa Barbara is a coastal community in southern California, some 160 kilometers northwest of Los Angeles. In 1978, together with neighboring Goleta, (where the University of California, Santa Barbara (UCSB) campus is located), it had a population of about 143,000. The August 13, 1978 earthquake struck on

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Earthquake Parameters and Effects: Their Relationship to Earthquake Casualties

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INTRODUCTION

The analyses of geophysical and geological factors associated with the occurrence of damaging earthquakes can provide important insight into the problem of earthquake related life loss and provide guidance for earthquake preparedness, planning and mitigation. Careful review of the characteristics of earthquakes in various seismicly active areas of the world shows that the earthquakes that occur in certain zones are most likely to result in large economic loss and casualties. This seems to be true even after allowance is made (as best as one can) for differences in building codes, materials and construction practices. The geophysical and geological factors of these earthquake zones which most affect earthquake-related losses can be roughly grouped as follows: (1) earthquake source parameters; (2) attenuation of seismic waves; (3) site response (the behavior of near surface materials beneath any given site when shaken by earthquake waves); (4) ground failure at the site (landsliding, liquefaction, etc.); and, (5) wave action resulting from earthquake ground motion (seiches, tsunami, etc.)

The following discussion is intended to provide some qualitative overview of the relationships among these geophysical and geological factors and earthquake related casualties.

Earthquake Source Parameters

The important earthquake source parameters are as follows: (1) geographical location (the epicenter); (2) depth of focus (the depth beneath the surface at which the earthquake originates; (3) style of faulting (the direction and mode of fault rupture); and (4) magnitude of the earthquake.

The location of the epicenter of an earthquake is obviously important since its proximity to urban areas often results in heavy damage and life loss even if the shock is not large.

Not so obvious is the fact that depth of focus is often a critical factor in producing earthquake damage and life loss. Examples are easy to find to illustrate this point. The Managua, Nicaragua earthquake of December 23, 1972, was of moderate magnitude (M_S=6.5) but caused life loss of over 10,000 (Lomnitz, 1974). A similar magnitude earthquake with nearly the same epicenter devastated the city in 1931 and caused similar life loss. A shock of magnitude M_S=5.4 on October 10, 1986 resulted in the deaths of about 1,500 people in San Salvador (Rios and others, 1986). On the other hand, a M_S=7.1 magnitude (ref. 41) located approximately beneath Seattle in 1965 caused damage and killed seven (four as a result of heart attacks). Each of these earthquakes occurred beneath the cities discussed. Why, then did the largest earthquake in this group cause negligible life loss? While there are obvious differences in design and construction in the three cities, buildings that were designed to be earthquake resistant were heavily damaged in Managua and San Salvador but not in Seattle. The important difference between the earthquakes is that both the Managua and San Salvador shocks occurred at depths of 5 km or less, while the 1965 earthquake that affected Seattle occurred at a focal depth of about 50 km. This is an important result since many damaging earthquakes of moderate magnitude repeatedly occur at very shallow depths, particularly, in the central valleys of Central America which are commonly large population centers. Conversely, no shallow earthquakes in the Puget Sound region of Washington are known to have caused widespread damage and life loss in historical times even though several earthquakes in the magnitude range of 6 to 7.1 have occurred. A number of other examples could be cited. A detailed study of earthquake focal depth, maximum magnitude and related life loss could provide important generalizing guidelines for earthquake preparedness and mitigation.

The direction and mode of faulting in earthquakes varies greatly from region to region and often within regions. The direction of fault rupture is, however, important since energy (and resulting damage) can be concentrated in the direction of rupture. Unfortunately, fault rupture directivity is difficult to estimate. By mode or style of faulting is meant the nature of the motion on the fault. Some faults rupture horizontally, others vertically and many at various other angles. Differences in the levels of ground motion associated with the different modes of faulting are believed to vary, but the amount of the difference is not thought to be large and probably does not vary enough to be important in determining possible life loss.

Earthquake magnitude, a measure of the energy release in an earthquake, is clearly an important parameter in forecasting life loss. Without consideration of focal depth, however, it is only a very general indicator of probable life loss.

Attenuation of Seismic Waves

Most earthquake damage, on the average, is caused either directly or indirectly by earthquake ground shaking (Algermissen and others, 1972). Ground shaking, in addition to directly causing building damage, is the cause of various kinds of ground failure, such as landslides and soil liquefaction. Tsunami and seiches are also caused by ground shaking.

Thus, the manner in which earthquake ground motion changes in amplitude and frequency content with distance from an earthquake may be an important consideration in estimating the area (and hence the number of fatalities) affected by dangerous levels of shaking during an earthquake. An an example, it is known that for earthquakes of the same magnitude, the area shaken sufficiently to cause severe building damage in earthquakes east of the Mississippi is of the order of 20 times greater than for earthquakes in California (Algermissen, 1972). The public is generally unaware of this east-west difference in strongly shaken areas because damaging earthquakes are much less frequent east of the Mississippi than in California. It is, however, important to take this factor into account in disaster planning and mitigation in the eastern and central United States.

Site Response

Site response is taken here to mean any change in the nature of ground shaking due to the nature or configuration of the rock and soil beneath or in the near vicinity of a site to a depth of several hundred meters. An excellent example of site response is the abnormally high and unusually long period of the damaging ground motion in Mexico associated with the 1985 earthquake which resulted in severe building damage and great life loss. Here, significant damage was caused by the resonance of the deep clays beneath the city and "in tune" with the natural resonance of certain structures built on sites over these clays. Another less well known example is illustrated in Figure 1 which shows a portion of the central Chilean coast around the city of San Antonio affected by a M_s=7.8 earthquake. The hospital in San Antonio (location shown in Figure 1) is a reinforced concrete frame building that was severely damaged in the earthquake and even today, after four years, has not returned to full operational capacity. The hospital is located on about 40 meters of largely unconsolidated beach terrace material. Only about one kilometer to the north, where dense igneous and metamorphic rocks outcrop at the surface (stippled in Figure 1), very little damage to buildings was observed. The difference in the level of ground motion in the two areas is believed to be largely a result of difference in site materials. Yet again, the considerable loss of life associated with the M_s=6.4 moderate earthquake that shook Caracas, Venezuela in 1967 is known to be in part a result of the site/building resonance due to the geotechnical properties and thickness of the soil and rock in the heavily damaged area of Caracas (Seed and others, 1970; Espinosa and Algermissen, 1972). Many other examples of the importance of site response can be given.

Ground Failure

Various types of ground failure caused by ground shaking can occur during an earthquake. The Huascarán debris avalanche in the Peruvian Andes triggered by the May 31, 1970, M_S=7.7, earthquake buried the village of Yunguy together with an estimated 18,000 inhabitants (Plafker and others, 1971). The earthquake epicenter was about 120 km from Yunguy. The size and duration of the earthquake triggered the landslide, even at this large distance.

Extensive soil liquefaction occurred with the 1964 earthquake in Alaska in a number of areas in Anchorage and caused extensive property damage but low life loss owing primarily to the low population. Ground failures of various types and magnitudes are a feature of most damaging earthquakes and they often produce disasterous life loss (as in the 1970 Perú earthquake). Potential ground failures are difficult to forecast and the resulting life loss can vary over a wide range. Often, something is known of the potential for ground failure in an area in advance of a destructive earthquake. For example, the residences of Yunguy, Perú were well aware of the frequent landslides from Cerro Huascarán. A Huascarán avalanche in 1962 <u>not</u> triggered by an earthquake killed about 4,000 inhabitants in a village near Yunguy. The low recurrence frequency of large earthquakes and the lack of understanding of the possible role of a large earthquake in triggering a major earth movement contributed to the 1970 disaster in Perú. Similarly, evidence of earthquake activated landslides associated with liquefaction were recognized in Anchorage well before the 1964 earthquake (Miller and Dobrovolny, 1959), but the significance was not fully understood at that time.

Tsunami and Seiches

Tsunami are sea waves generated by ground shaking or tectonic displacement associated with earthquakes. The waves have periods of about 5 to 60 minutes in the open ocean. As tsunami approach coast lines, that is, shallow water, the amplitude of the waves increase and the wave runs inland from the shore, often creating waves of considerable height. The wave height depends considerably on the geometry of the coastline. Tsunami are an important cause of life loss. A tsunami in Japan in 1896 killed more than 27,000 persons. Damaging waves are also caused by submarine landslides triggered by earthquakes and by wave action in lakes and other bodies of water (seiches) Significant tsunami are generally generated only by earthquakes with magnitudes of 7 or greater.

Discussion

The intent of the preceding cursory outline of the components of the earthquake process that affect earthquake related life loss is to show the exceedingly complex relationships that exist and the attendant difficulties in estimating life loss. The equally complex problem of relating building vulnerability to life loss has not been discussed. In order for progress to be made in the estimations of the potential for life loss, the numerous parameters in the earthquake process must be carefully studied and ranked in terms of their importance in causing life loss. The following approach to the problem is proposed.

SUGGESTED PROGRAM

It is easy to demonstrate in a qualitative fashion that the earthquake source parameters and resulting effects briefly reviewed here are all related directly to life loss resulting from earthquakes. Estimates of earthquake related casualties have been notoriously poor because of the many variables involved in their occurrence. Figure 2 illustrates in a general way, some of the complexities of the problem. In Figure 2 are shown dollar loss and fatalities for a number of earthquakes worldwide. The dollar losses have been crudely normalized to 1986 dollars. In view of the preceding discussion it is not surprising that the scatter in data is large. An interesting aspect of Figure 2 is that for earthquakes with similar economic losses, those that have occurred in the more industrialized countries of the world tend to group in the left half of the graph (decreasing life loss) whereas the earthquakes in developing countries tend to group towards the right half of the graph (increasing life loss). Industrialized countries usually have more advanced building codes and construction practices than those in use in developing countries. Largely for economic reasons, these codes place emphasis on protection against life loss rather than protection against economic loss. Figure 2 seems to show that the practice of achieving protection against life loss is relatively successful. This ilustrates very clearly the importance of design and construction practices in limiting earthquake losses and that earthquake source parameters and effects are important but are obviously only a part of a complex problem. Progress in understanding the most important causes of life loss can only be made by isolating each factor as far as possible, and the evaluating and ranking of the factors with respect to importance. This approach would seem to be a sound basis for earthquake disaster preparedness and mitigation. The problem has yet to be studied in a quantitative manner. The following program is proposed:

1. Upgrade the international data base relating specific earthquakes to revised (where necessary) estimates of life loss.

2. Carefully revise the source parameters and effects for the earthquakes in the lists in (1) above.

3. Correlate each parameter or measurement of effect (ground acceleration, depth of focus, etc.) with life loss. It may be possible to devise a scheme of multivariant analysis that would recognize relationships among important variables.

4. Attempt to normalize variables, taking into account population density, building type and construction, time of day, etc.

5. Examine the results for forecasting capability.

It is hoped that this type of research program coupled with an improved understanding of building vulnerability and probability of collapse of buildings, occupancy density and life loss can lead to improved earthquake preparedness and mitigation.

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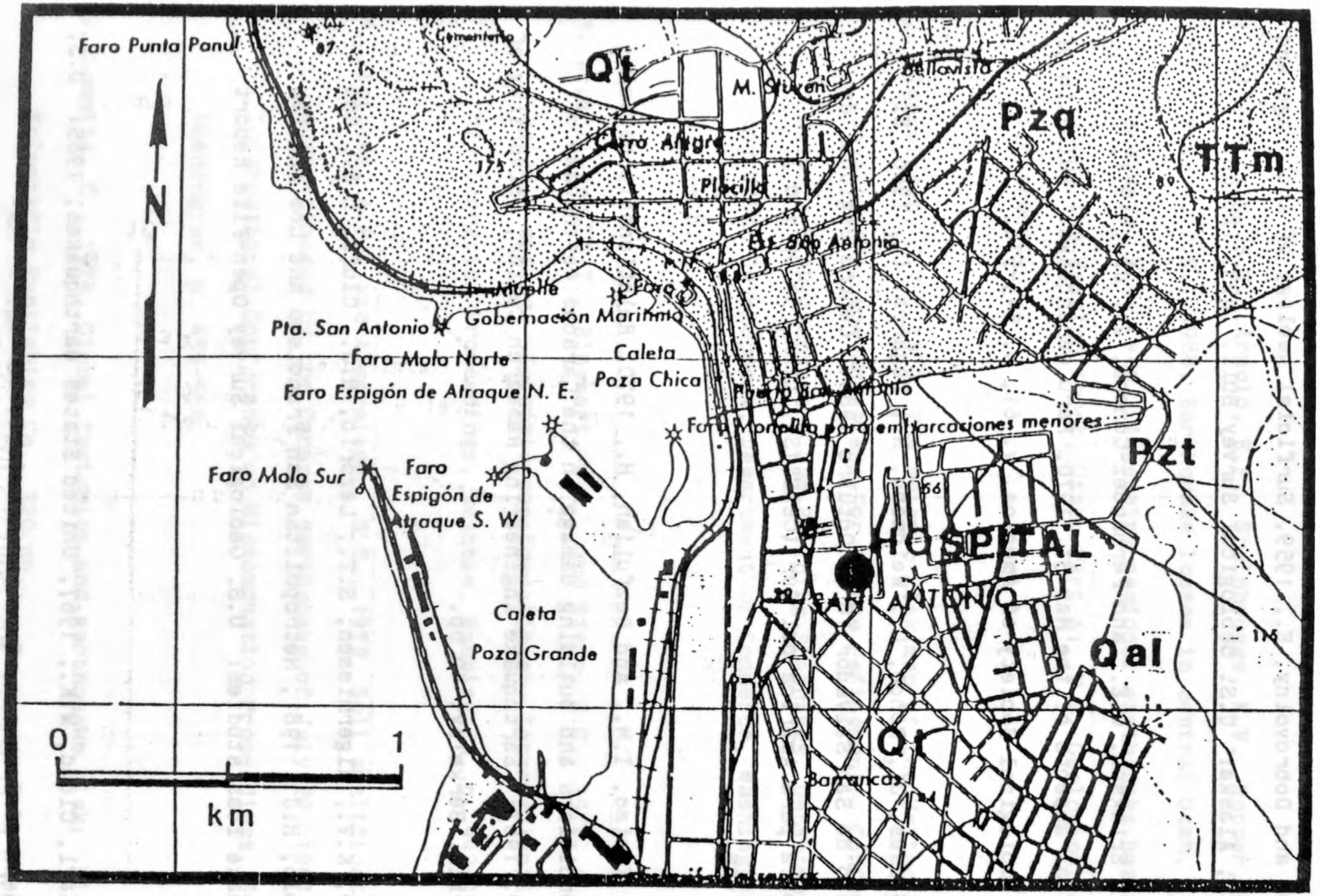

Figure 1. Coastal area of Central Chile in the vicinity of San Antonio. The hospital, which was heavily damaged in the March 3, 1985 earthquake, is located on about 40 meters of unconsolidated sand deposits. Damage to many other structures located on the sand was also considerable. The stippled area less than a kilometer to the north is underlain by dense metamorphic and igneous rocks. Structures in the stippled area generally had minimal or no damage.

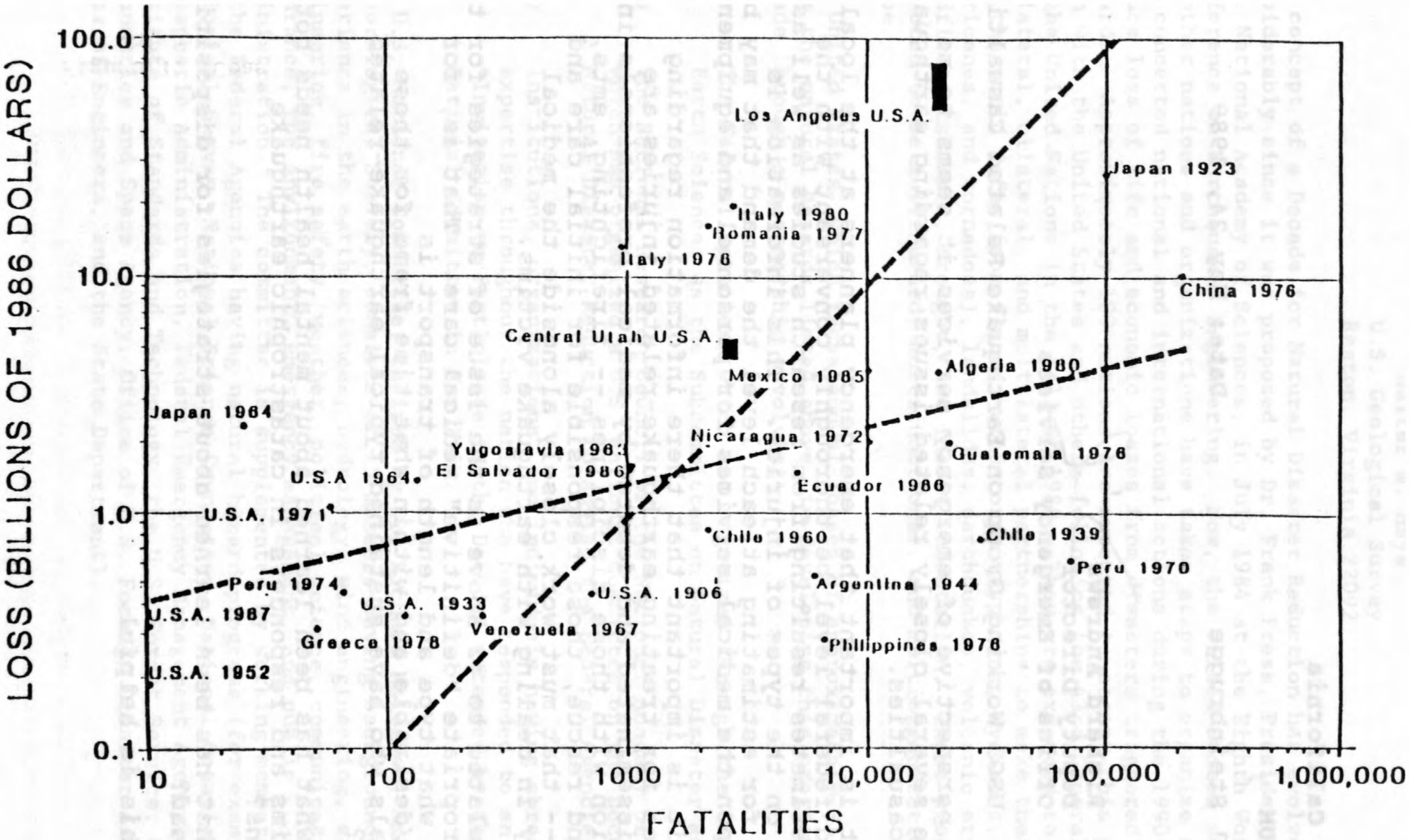

Figure 2. Earthquake economic losses and fatalities for some important earthquakes. The bars shown are estimates of possible loss in the two areas indicated (Algermissen and others, 1989 and Steinbrugge and others, 1981). The two dashed lines indicate least squares regressions assuming in turn that dollar loss or fatalities as the independent variable.

State of California

MEMORANDUM

To: Karl Steinbrugge **Date:** May 24, 1989

From: **Richard Andrews**
Deputy Director
Office of Emergency Services

Subject: USGS Working Group on Earthquake Related Casualties

From the perspective of emergency services it seems to me there are several closely related issues regarding earthquake related casualties.

First, it is important that emergency planners at the local, state and federal level be thoroughly conversant with the injury estimates resulting from research studies as well as the data on the types of injuries. This information is valuable for estimating at each level the demand that may be placed upon the medical services for personnel and equipment.

Second, it is important that there information regarding strategies for treating earthquake-related injuries are widely disseminated and debated by medical professionals in cooperation with those disciplines -- firefighting, emts, search and rescue, those responsible for initial care and shelter -- that must work closely alongside the medical community in dealing with earthquake victims.

Third, related to #2 above is the issue of strategies for the most appropriate "definitive" medical care. That is, for example, what type and length of transport is possible/desirable and within what time frame for those individuals who have sustained typical earthquake-related injuries?

Fourth, what has been learned about mental health needs both for victims and responders in catastrophic earthquake situations?

Fifth, what has been learned about strategies for disposition of the dead?

I hope this is helpful.

INTERNATIONAL DECADE FOR NATURAL DISASTER REDUCTION

By
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The concept of a Decade for Natural Disaster Reduction has evolved considerably since it was proposed by Dr. Frank Press, President of the U.S. National Academy of Sciences, in July 1984 at the Eighth World Conference on Earthquakes Engineering. Now, the United States and at least 28 other nations and organizations have taken steps to organize and plan for concerted national and international actions during the 1990's to reduce loss of life and economic losses from disasters triggered by natural hazards. Approximately 100 nations are expected to accept this goal and to join with the United States and others following the 43rd General Assembly of the United Nations in the fall of 1989. They are expected to forge unilateral, bilateral, and multilateral partnerships to make their country and the world safer from floods, windstorms (typhoons, cyclones, hurricanes, and tornadoes), landslides, earthquakes, volcanic eruptions, wildfires, tsunamis, drought, and insect infestation. These programs are expected to be multihazard, multifunctional, and multiorganizational in scope.

The United States, which faces annual losses of approximately $17 billion from the natural hazards listed above, is developing this program the Decade through a partnership involving:

- The Federal Agencies, which are organized through the Committee on Earth Sciences as the Subcommittee on Natural Disaster Reduction.
- The National Research Council of the National Academy of Sciences which has organized a U.S. National Committee on the Decade for Natural Disaster Reduction to advise the Federal Agencies.
- Institutions, organizations, and individuals having abroad range of expertise throughout the nation who have responded to an "Invitation to Participate in the Decade" extended by the U.S. National Committee in May 1989.

The U.S. National Committee, chaired by Dr. Richard Hallgren, American Meteorological Society, consists of 15 members having backgrounds and broad experience in the earth sciences, hydrology, wind engineering, earthquake engineering, fire safety, weather, political science, communication, insurance, the environment, emergency management, and public administration. The committee is supplemented by working members from and of the Federal Agencies having natural hazard programs (for example, U.S. Geological Survey, National Science Foundation, National Oceanic and Atmospheric Administration, Federal Emergency Management Agency, National Institute of Standards and Technology, the U.S. Forest Service, National Aeronautics and Space Agency, Office of U.S. Foreign Disaster Assistance, Corps of Engineers, and the State Department).

The Federal Agencies Subcommittee on Natural Disaster Reduction and the U.S. National Committee must deal with three critical problems in the development of a U.S. Decade program. The are:

- o Leadership,
- o Motivation, and
- o Funding.

Each of these complex problems is being addressed cooperatively. The goal of the cooperative efforts is to:

- o Develop a <u>vision</u> of where we go as a Nation during the decade.
- o Identify a <u>rallying point</u> that all participants in the Decade throughout the Nation can associate with (for example: a) zeal for protecting our planet from the disastrous consequences of natural hazards, b) personal pride in protecting our homes, families, and workplaces, c) national pride that comes from gaining a position of preeminence in the world in natural hazards research or in disaster prevention, and d) the challenge of working together to make the world safer and more productive).
- o Create <u>partnerships</u> at all levels throughout the Nation to carry out programs to accomplish the vision (for example: a) Federal-Federal, b) Federal-State, c) State-State, and d) Federal-regional partnerships).
- o Attack complex programmatic issues one step at a time(for example: a) the linkage between researchers and practitioners, and b) the interface between disciplines).
- o Work <u>smarter</u>, not just harder (for example: a) take advantage of the exiting body of fundamental knowledge on natural hazards developed through research, and b) utilize modern technology such as geographic information systems, satellites, and computer networks).
- o <u>Communicate</u> (for example: a) use a nationwide speakers bureau to communicate the vision of the Decade to everyone, b) use a national news letter, c) improve the capability of credible sources of hazards and risk information to use all of the available channels to reach decisionmakers and policymakers and their constituencies with a meaningful message).
- o <u>Simplify</u> (for example, some loss reduction techniques for each natural hazard can be applied to another natural hazard).
- o <u>Evaluate</u> (for example: a) use the anniversary dates of past notable disasters as a time to take stock of progress and to examine gaps in knowledge or capability and b) use each new disaster as a window of opportunity to exiting capability).

These seven actions are expected to provide solutions to the problems associated with leadership, motivation, and funding.

The U.S. Committee, which met for the first time on June 21-22, 1989, will produce a comprehensive report in 1990 containing model programs and recommendations on how to implement them. These programs will call for:

- o <u>Pilot projects</u> to build local, State, regional,and national partnerships,

- o <u>National projects</u> to accelerate the application of loss reduction measures, and

- o <u>International projects</u> to share the technology for hazard mitigation with other nations, especially developing countries.

The overall goal is to save lives and to reduce economic losses in the United States. The particular thrusts of the U.S. Decade programs will be on achieving:

- o Coordination and integration of the natural hazard programs of the Federal Agencies, State and local governments, academia, and the private sector.

- o Development of hazard warning and prediction systems.

- o Creation and sharing of multihazard databases and mitigation techniques.

- o Implementation of post disaster data acquisition,data analysis, and data sharing programs.

- o Execution of research to close critical gaps in fundamental knowledge on topics such as extreme events and the implications of regionally and temporally varying natural hazards occurring singularly or in combinations.

- o Provision of education and training throughout the Nation to increase awareness of natural hazards and to enhance the capability and skills of professionals to deal with their adverse societal impacts.

- o Improvement of existing systems to communicate natural hazards and risk information, especially to public officials, policymakers, and professionals who can provide leadership for hazard mitigation.

The U.S. National Committee on the Decade for Natural Disaster Reduction will join with the committees and entities of other nations and the United Nations in carrying out the overall Decade program. The United Nations, which will have a major role in facilitating the Decade program, started their planning in March 1988 by forming a 25-member International Ad Hoc Group of Experts on the Decade. Chaired by Frank Press, this group delivered a report to the Secretary General of the United Nations on June 1, 1989, containing model programs and recommendations for an organization to implement them. The proposed organization for the United Nations consists of:

- o A Board of Trustees to marshall political support and to seek funds.

- o A program committee to solicit, develop, evaluate, and recommend programs to individual nations for the Decade.

- o A secretariat drawn from existing UN organizations to carry out operational requirements.

The report also recommended that a trust fund be established to provide resources to assist program development, especially for developing nations. The trust fund and the funds available to each national committee or national entity would constitute the resources for the Decade program.

The challenge of the International Decade for Natural Disaster Reduction in unprecedented. If the past is an indication of what will happen in the 1990's and afterward, the United States and the world will once again face potential disasters from:

- o Earthquakes, such as those that occurred in Alaska in 1964, Algeria and Italy in 1980, Chile and Mexico in 1985, and Armenia, SSR, in 1988.

- o Volcanic eruptions, such as those that occurred in Mount St. Helens, Washington in 1980, Nevado del Ruiz, Columbia in 1985, and Izu-Oshima, Japan in 1986.

- o Floods, such as those that occurred in Florence, Italy in 1966, Nagasaki City, Japan in 1982, and Bangladesh in 1988.

- o Typhoons, cyclones, and hurricanes, such as those that occurred in Japan from typhoon Isewan in 1959, in Pakistan from a cyclone in 1970, on the eastern seaboard of the United States from hurricane Agnes in 1972, and in Jamaica and other Caribbean countries from hurricane Gilbert in 1988.

- o Tornadoes, such as the Palm Sunday outbreak that struck Iowa, Illinois, Indiana, Michigan, and Wisconsin in 1965; and the super outbreak of tornadoes that struck 11 Midwestern States and Canada on April 3, 1974.

- o Landslides, such as those that occurred in Alaska in 1964 in conjunction with the Prince William Sound earthquake, in Peru on the west bank of the Manatro River in 1974, in Puerto Rico in 1983, in Ecuador in 1987, and in Tajekistan, SSR in 1989.

- o <u>Tsunamis</u>, such as the Showa Sanriku earthquake-tsunami that struck Japan in 1933, the Chilean earthquake-tsunami which struck Hawaii and affected the coast of almost all of the countries of the Pacific rim on May 22, 1960, and the Mindanao earthquake-tsunami that struck the Philippines on August 7, 1975.

- o <u>Wildfires</u> - such as those that broke out in the Great Khingan Range in northern China on May 5, 1987 and the great Yellowstone wildfires of 1988 in the Western United States.

- o <u>Drought</u> - like the Dust Bowl drought on the 1930's that persisted in the Great Plains States of the United States for 10 years, and the long-term drought beginning in 1968 in the Sahel countries of West Africa.

- o <u>Insect infestation</u> - such as the invasions of pilgrim locusts which have occurred often in many places in Africa.

The goal of the Decade is to keep recurrences of these natural hazards from becoming disasters. The concerted actions of all nations working together in the 1990's can make this goal a reality.

Earthquake Casualty Estimation and Response Modeling

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Introduction

Earthquake Casualty Estimation and Response Modeling is a part of the mobilization of the research community to respond to the appalling loss of life in recent earthquakes. The world has been shocked to witness the massive fatalities caused by the catastrophic failure of large, modern, engineered structures in Mexico City in 1985 and in Armenia in 1988.

A program of research on earthquake injury epidemiology and search and rescue in collapsed buildings. The focus of work has been on the improvement of survival rates after building collapse.

In the pursuit of that work one face the problem of attempting to understand the relationships of building damage and occupant casualty. One is soon faced with the problem that there is very little useful data available on the mechanism of injury in building collapse and there are very few cases of comprehensive injury investigation following earthquakes. Such data has been very difficult to collect because it must be collected in the immediate post impact period when conditions are most chaotic and all qualified manpower is directed to the primary lifesaving effort.

While the events with which we are concerned are too frequent and too serious to be tolerated, they are still too unpredictable and too infrequent to offer themselves for ample study. We must make use of all available global experience. We must develop the means to make useful and accurate transfer of experience between events taking into account differences in seismology, building practice and social and economic factors.

The problem of earthquake casualty reduction necessarily involves several disciplines. We must consider both aspects affecting the physical performance of buildings and factors affecting the physiological status of building occupants. Further, in terms of operational response, we must consider the factors which affect organizational capacity in post-collapse search and rescue, transportation and treatment.

To address this complex set of issues, we have attempted to assemble a multidisciplinary group of people from around the world who have distinguished themselves by taking initiatives in the study of some aspect of the building collapse/casualty problem.

Though earthquake damage estimation and earthquake loss estimation have been considerably elaborated over the past twenty years, the topic of earthquake casualty estimation is relatively new and less developed. In this group we hope to develop some consensus on:

- The current definition of the topic earthquake injury epidemiology

- definition of the principal problems of the field

- review of recent work, sharing those descriptive and analytical models which have been developed to date

- sharing references and access to relevant data which is in very short supply

Before this meeting is over we hope to develop some agreement on research priorities for the advancement of the field.

Earthquake Casualty Estimation

Casualty estimation in earthquake may be used in a variety of ways. In pre-earthquake mitigation planning:

a. As a part of general loss estimation. Measurement - the quantification of death and dollars: material and life loss estimates have proven to have a critical function in the provision of political motivation to initiate pre-disaster mitigation activities. For the most part, general estimates based on judgement with little specific reference to the mechanism of death and injury in buildings have been adequate.

b. As a part of "life safety" based mitigation measures, as in the case of the University of California System. Prioritization of retrofit measures on the basis of life safety requires an understanding of the lethality of particular structural types and the relationship of lethality to occupancy. This application also relies heavily on judgement. The estimation of collapse potential is still very premature. In spite of all of our contempt for URM, unreinforced masonry, in normal times, it does not appear to have been the major culprit in recent severe earthquakes in Mexico and Armenia.

c. As a part of emergency response planning and response exercise scenarios. This is a more recent development. Specific organization of structural search and rescue capability has only begun to develop as a major concern in the U.S. since the Mexico City earthquake in 1985.

In post earthquake response, we face a much more severe test. While an error in estimates for mitigation planning may lead to some inefficiency in resource allocation, errors in response organization and execution cost lives. Casualty estimation in the response phase is not just a function of building type. Relevant factors affecting search and rescue must be considerably more elaborated. Factors affecting survival of collapse victims include:

1. initial injury severity score
2. individual pre-collapse health status
3. discovery time
4. extrication difficulty
5. fade-away time
6. effective rescue manpower
7. time of extrication
8. site stabilization status
9. transport time

These factors affecting survival involve a complex interweaving of physical factors relating to building collapse environment and physiological factors relating to the health status of the victim. There are also critical variables relating to the organization of response capabilities of search, rescue and medical services.

The modeling of earthquake casualty mechanisms has the benefit of making explicit the relationship of key variables. It allows us to better understand the significance of new information and allows us to assemble what may initially be fragmentary information in a constructive way to facilitate appropriate response.

Principal uses of casualty estimation modeling in the post disaster phase are:

1. Estimation of manpower and equipment needs for search, rescue and medical treatment - gross

2. Optimization of initial deployment of SARTAT response over affected area

3. Dynamic optimization of active SAR period as resources increase and opportunities for rescue decrease.

Modeling of Response

To date only fragmentary information is available on the critical factors which affect the survival rate of victims in collapsed buildings. There is very little systematically collected data which allows the comparison of building damage and resulting occupant injury. Data collection has been ad hoc and rarely preplanned. There has been no commonly accepted model of the process of building failure, occupant injury, search and rescue and medical treatment. As a result, we lack comparable observations from different events. Variables relating to building type, environmental factors, and rescue operations are not typically adequately distinguished to make cross event or event multiple site (from the same event) comparisons feasible.

It is necessary to develop a model in which key variables are identified and plausible relationships of these key variables are represented. The development of such a hypothetical model of the building collapse/rescue process is helpful in attempting to make sense of data collected in past events and it may be helpful in organizing the protocols for collection of data from future events.

While pre-event casualty estimation modeling is focused on the potential loss from the entire population affected by an earthquake, response modeling is focused on the operational unit of response which is typically the collapse site. This is particularly true of recent major urban earthquakes where casualties and rescue efforts have been concentrated in large, high occupancy buildings. The pre-collapse input variables to the site response model include attributes relating to the building and the occupancy:

Building attributes: Type of construction
Size (floor area and number of floors)

Occupancy attributes: Number of people
Age
Sex
Mobility
Function
Distribution

The immediate post-collapse variables include:

Collapse Pattern: Volume loss
Floor area compromised

Occupant Status: Injury severity (animation score)
Extrapolation status (extrication difficulty)
External environmental factors

These variables will not be typically subject to on-site observation. Immediate on-site observation is typically not feasible. However, a hypothetical determination of victim status immediately following the collapse (t_o) is important in estimating the optimum feasible search and rescue operation. It is in theory possible to estimate the time that a victim may survive in the rubble on the basis of the following variables:

Pre-collapse victim health status
Animation score
External environmental factors
Entrapment status

Rescue operations may be represented by a set of variables relating to the following factors:

Time of arrival
Volume of manpower
Effectiveness (training and equipment)

Victim status can be estimated at several critical points during the rescue process:

Point of detection
Point of access
Point of extrication
Point of transport
Point of definitive care
Point of release from health care

This tracking of building occupant status through the process of collapse, injury, rescue and subsequent care allows the analysis of relationships of a number of factors from building attributes to rescue response and medical treatment to ultimate patient outcomes.

The elaboration of this model of site response will help in the clarification of the process of occupant injury as a function of building attributes and victim attributes. Such information will contribute to prioritization of building modifications for earthquake safety. It also may lead to possible reassignment of occupancies to reduce injury exposure. Improved understanding of the distribution of injury and severity and associated fade-away time may help optimize the applications of rescue resources in the post-collapse period. Tracking of victims through the extrication, stabilization, transport and definitive care stages is also very important in order to evaluate the ultimate value of measures applied to particular categories of victims.

The development of an elaborated model of the collapse response process also makes possible more appropriate reference to experience from other parallel activities such as mine rescue operations and aircraft crash investigations. Detailed field investigation and data collection procedures have been developed in both these areas which can readily be adapted to the purposes of earthquake injury epidemiology. It is now important that the initiative be taken and that we agree on the most effective means to expand our collective understanding of the factors affecting survival in earthquakes.

Future development of earthquake casualty estimation should address the following questions:

1. To what extent can the initial estimate of manpower needs be made automatically - that is based on minimum event information. Is an automatic mobilization or call-out possible on the basis of magnitude and location data?

2. To what extent can a casualty estimation model serve to optimize immediate post event reconnaissance? To identify specific collapse sites and to generate detailed estimates of victim distribution in terms of injury severity, and extrication difficulty.

3. To what extent can a casualty estimation model serve to evaluate the value of specific inputs. What is the value of added rescue and medical capability at various points during the rescue period in terms of victim survival.

Reducing Earthquake Casualties: New Considerations for Engineers

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Abstract

For most of this century, engineers have been aware of the effects of earthquakes on constructed facilities. The development of building codes has reflected the concern for the threat to public safety resulting from the severe damage or collapse of buildings and other structures. In the past several decades, great advances have been made in techniques for the analysis, design and construction of new buildings, resulting in a generally safer product. However, as recent earthquake events have shown, there is still the possibility, in the U.S. and elsewhere, for great loss of life and injury from inadequate structures. Earthquake engineering must reflect the broader context which addresses more directly the public safety issue, and where necessary, the search and rescue problem. This paper discusses the multidisciplinary field of earthquake injury epidemiology, and outlines suggestions for a global framework into which the disciplines of earthquake engineering, architecture, medicine and epidemiology may fit to reduce the large potential losses in future earthquakes.

Introduction

Since ancient times, societies, however primitive, have been aware of the effects of earthquakes on their habitat, even though the source of the shaking and the mechanism of the destruction were often not understood. The Corinth, Greece earthquake of 856 AD is estimated to have killed 45,000; the Shensi, China event of 1556 about 830,000; the 1737 Calcutta, India earthquake: 300,000 (Bolt 1978). Most of these victims were killed by low-rise, poorly-constructed structures which had little or no lateral load resistance.

The effect of major earthquakes on large urban areas in the industrialized world was really first felt in the earthquake and subsequent fire in San Francisco in 1906. While the death toll of 700 was small in comparison to historical events, and actually many subsequent events in the 20th century, the potential for a larger disaster in terms of loss of life and economic consequences was evident. Contrasting the historical events, society questioned the adequacy of the structures in which it worked and lived, and engineers were called upon to produce structures which could resist earthquakes in a manner which reduced economic loss and improved life safety.

The development of building codes which reflected the lateral loads of wind and earthquake was started around that time as a result of the 1906 earthquake, and new codes reflect the seismic loads on new construction in a realistic and risk-consistent manner.

A similar trend has occurred with what are commonly called secondary systems and nonstructural items. Secondary systems generally include large pieces of mechanical equipment which are attached to the building, or primary structure, in some way, but are not required for structural support. Dynamic interaction between these systems and the primary structure has often led to extensive damage, which often is, at least potentially, life threatening. The effect of nonstructural walls and cladding on modifying the performance of the primary structure has long been a concern. More recently it has been recognized that building contents also pose a threat to life and limb and appropriate steps should be taken to secure them appropriately.

While current codes and suggested provisions (e.g., FEMA (1988), ICBO (1988)) estimate the seismic loads that new buildings are designed to withstand quite realistically (which includes allowances for building function, type of structural system, foundation effects, as well as the inherent dynamic properties of the structure and the location-specific seismic risk), there are still a number of unresolved areas which are of relevance here.

In this country and abroad, there are a large number of what may be termed "precode structures" which in some cities house a large proportion of the population. These buildings were constructed before the codes in effect at the time required consideration of seismic loads, and therefore offer little or no resistance to these lateral loads. The structural forms and the construction materials used are often highly unsuitable for seismic areas.

There are in some cases ambitious plans afoot to strengthen or remove these hazardous buildings (for example in California which has a "five-year plan.") However, there is often great economic, social and political pressure which hinders these actions. The result is that in this country, and throughout the world, there are thousands of buildings which are likely to collapse in moderate to major earthquakes. The recent examples in Mexico City, 1985 and Armenia, 1988 graphically demonstrate the hazard, and underscore the large human tragedy which results.

Also highlighted by the events mentioned above is the fact that when a building does collapse, for whatever reason, we are still not in a position to be able to effectively rescue trapped victims from the rubble. Systems for location of building inhabitants abound, but most are adaptations of technology developed for other applications, and virtually all are only marginally effective. Likewise, methods for the "delicate dismemberment" of a collapsed structure and the extrication of located victims are not well developed.

Understanding the precise mechanism of injuries and deaths in earthquake-induced collapse and severe damage is a multidisciplinary field. Multidisciplinary implies that the required research is both interdisciplinary, pooling the resources of the various relevant professions to investigate problems of common interest, and intradisciplinary, in which the professions work essentially independently, but with significant interaction with other fields. Examples of both will be given later.

The purpose of this paper is to highlight the engineering aspects of the problem in a framework which addresses its multidisciplinary nature. Summarized are some suggestions for specific research thrusts which will improve our capability to locate and rescue trapped persons in future building collapses, and thereby reduce the high cost – in terms of human life and suffering – of future earthquake events.

Problem Definition

Figure 1 presents a flowchart which outlines globally the "earthquake process" in an attempt to identify the critical issues and clarify the potential contribution of a broadened definition "engineering for earthquakes." Indicated in the diagram are the professions involved in the analysis or study of the various stages in the process, as well as the relevant inputs required.

The figure may be divided into three basic phases:

1. the earthquake and its consequences,

2. the response to the earthquake at a particular location, and

3. the recovery after the event.

The first phase, given by the top line, presents what has traditionally been the earthquake engineering process. Included are contributions from seismologists, geologists and geotechnical engineers who, working together, estimate a realistic level of expected ground acceleration at a site. The geotechnical and structural engineer then translates this information into a design load; analysis is performed and the structure designed accordingly. In many cases, these steps are handled in a simplified manner by the building codes and the services of a seismologist, geologist and sometimes even earthquake-specializing geotechnical engineer are not required.

Commonly, the job of the engineer is complete at this stage, save the supervision of the construction process. While due consideration has usually been given to the basic principles of seismic-resistant design[3], the engineer does not normally consider the possibility of collapse and the resulting consequences for occupants. For modern structures, this optimism may be justified but, as outlined earlier, collapse or severe damage of some older construction must be considered a certainty when a major earthquake affects an urban region.

[3]That is: (1) the structure should suffer no structural and only minor nonstructural damage in a "minor" earthquake; (2) the structure may suffer nonstructural damage and minor, repairable structural damage in a "moderate" earthquake; (3) the structure may suffer significant damage but should not collapse in a "major" earthquake. While the definitions of "minor," "moderate," and "major" are variable depending on location, type of structure, type of facility, etc., the basic "three-level" design principle is fairly well established.

Perhaps due to this "positive" attitude on the part of engineers with regard to their new construction (which is somewhat justified considering the performance of many newer buildings in both U.S. and worldwide earthquakes) that little study has been done which considers the actual collapse of structures. While the causes of earthquake-induced collapse have been identified in many structures over the years, and improvements in earthquake-resistant structural design resulted from their study, very little research has been directly aimed at investigating the ultimate failure modes of structures, and the resulting effects on inhabitants. The recent heightened awareness of the threat posed by older structures has led to a big push to implement evaluation and strengthening programs. Little thought has been given, however, to prioritize structures for retrofit based on a detailed study of their expected lethality (Krimgold 1990), except in the most general sense, or to how to deal with such collapses should a major event occur *tomorrow*.

Referring back to Figure 1, this observation is represented as the split box for "effect on structure". While the basic response of a structure to earthquake loads is well understood, collapse – particularly of older structures – and collapse patterns, and the direct relationship between type of collapse and morbidity and mortality, have received little attention. It is, however, study of this type which is needed to begin to understand box 5: the effects of structural damage on occupants.

As indicated in the figure, this understanding of human effects cannot be accomplished by structural engineers alone. While the engineer can make contributions in analysis and prediction of response, damage potential, and collapse potential and patterns, classification of the structural form and materials, and so on, factors best understood by other professionals are also important. For example, these include:

- Architects, to study building layout, occupancy, egress patterns, population distributions, usage patterns, etc. and how these factors relate to the location of survivors in a collapsed structure.

- Medical personnel, to identify and study where necessary the precise causes of death and injury of trapped victims, including the deterioration with time corresponding to particular circumstances of entrapment and appropriate treatments for such situations (Noji 1989).

- Epidemiologists, to relate the observations and factors obtained above in such a way as to enable substantive conclusions to be drawn and recommendations made for the management of and response to future events, and the determination of the relationship between the structural/architectural factors and the medical/health consequences (Smith 1989).

The second phase indicated consists of the response phase, and is concerned with the delivery of relief, rescue and treatment activities after the event. Of prime concern is the location and extrication of trapped victims in the rubble of collapsed buildings. Paralleling and following this activity is the appropriate medical treatment, both on site and off site.

At this stage, the necessity for effective emergency management is apparent. In most significant events over the past decade, it has been clear that there was a lack of an organizational capability not only in the affected region, but also on site. The reasons for this are manyfold. The infrastructure is usually severely disrupted; local management capability is often minimal, and disorganized. International relief efforts are often not coordinated, and search and rescue activities often end up competitive, rather than cooperative. Even within a national team, an organizational structure is not apparent.

A major, and pertinent, reason for the management difficulties is, however, that there is really no disaster management role which is clearly defined and based on a solid body of research and past experience. Difficulties outlined above compound the problem. The results of studies in earthquake injury epidemiology can influence directly the management aspect. Training programs require establishment, ensuring adequately trained[4] personnel

[4] Adequately trained implies trained in principles of engineering, architecture, emergency medicine and epidemiology, as well as management aspects.

are available, at least at the national level, and perhaps ultimately at the international level also.

The third and final phase is the recovery from the event. This refers in this context to the long-term medical, engineering, architectural and societal recovery. Again, it is envisioned that studies in earthquake injury epidemiology will impact directly on many of these aspects.

Recovery can also be linked to prevention. Recovery from one event can lead to preparedness for another, not necessarily in the same location. For example, there is a significant effort to improve earthquake preparedness in Southern California in anticipation of a large event. We do not have to wait for the event to strike to learn our lessons!

A Broadened Role for Engineering:

It is clear from the discussion that the current scope of earthquake engineering is not sufficiently comprehensive. Presented below, in summary form, is a series of areas into which engineers must delve to assist in the enhancement of life safety in future earthquake events. Indicated on each item is the nature of the required research: interdisciplinary or intradisciplinary. While the whole field, as discussed, is multidisciplinary, and must include aspects of both, identified below is the major component.

1. What is the ultimate performance of an engineered structure? Given that the three-level design approach has been used, the possibility of collapse is should have been minimized. Should a sufficiently large event occur, however, what will be the collapse scenario for the structure? Can this information be used in the design to enhance the possibility of survival even if a collapse should occur (e.g., safe corridors, etc.?) I.e., can consideration of ultimate performance be factored in to the design process. (Intradisciplinary.)

2. How should we characterize structural collapse from an epidemiological standpoint? Is a simple, single-parameter measure such as volume fraction lost, etc., appropriate

as an indicator of survivability potential? Should the parameter be purely "structural?" An appropriate measure should perhaps include injury characteristics (Jones and Choudhury 1990). (Intradisciplinary, interdisciplinary.)

3. What are the most "lethal" building types from a structural engineering standpoint, in terms of both morbidity and mortality? Building on earthquake injury epidemiology studies, can we identify and those types of structure most likely to collapse in an "undesirable" manner and potentially killing or trapping large numbers of people? Information of this type can be used to assist in the prioritization of structures for retrofit procedures (Krimgold 1990). (Intradisciplinary, interdisciplinary.)

4. Can we successfully develop a conceptual framework for predicting morbidity and mortality in earthquakes in building collapse on the macro or micro scale? What are the unknown parameters or relationships to be determined? (Shiono and Krimgold 1989). (Intradisciplinary.)

5. What are the needs in search or location equipment? Can systems be developed which can penetrate the mixed environment of voids, concrete, masonry and steel to detect trapped victims. While some systems exist, none have been specifically designed for this environment, and as a result they are generally relatively ineffective. What are the specifications for such equipment? How should such equipment be calibrated and rated? (Intradisciplinary.)

6. How should a collapsed structure be "dismantled" or penetrated in such a way as to rapidly reach trapped survivors, yet not risk the integrity of the remaining structure nor threaten the security of the victims? What are the stability characteristics of the collapsed structure? Are there basic techniques which search and rescue personnel should use to ensure their own safety, given the complex nature of the collapsed structure? How should such personnel be trained? (Intradisciplinary.)

The above list is not complete. There are sure to be other areas not specifically addressed which are also of importance to engineers. Other issues are intradisciplinary in different fields. As more experience is gained, and research progresses in the various areas outlined above, more specific research topics are sure to be identified.

Conclusions

Presented above is an overview of the global earthquake problem, couched in a "human effects" context. It is clear from the discussion herein that the current role of engineering for earthquakes is not sufficiently broad to address the entire scope of the earthquake death and injury problem. The infant field of earthquake injury epidemiology needs contributions from many disciplines, especially engineering, to enable it to make an impact in reducing the toll in future events. Structural engineering is necessary to assist in the categorization of collapse and collapse patterns which may be used in the identification of potentially lethal structures; design changes and retrofit priorities and procedures can result. Other engineering disciplines may become involved in the development of location and extrication devices for the collapsed building environment.

Multidisciplinary implies both interdisciplinary and intradisciplinary. New considerations for engineers fall in to both categories. The preceding paper outlines the author's view of some of the important engineering contributions required. Research into the above areas, coupled with that from the other disciplines outlined above, should enhance significantly the development of a field which will reduce significantly the loss of life and hardship produced in future earthquakes.

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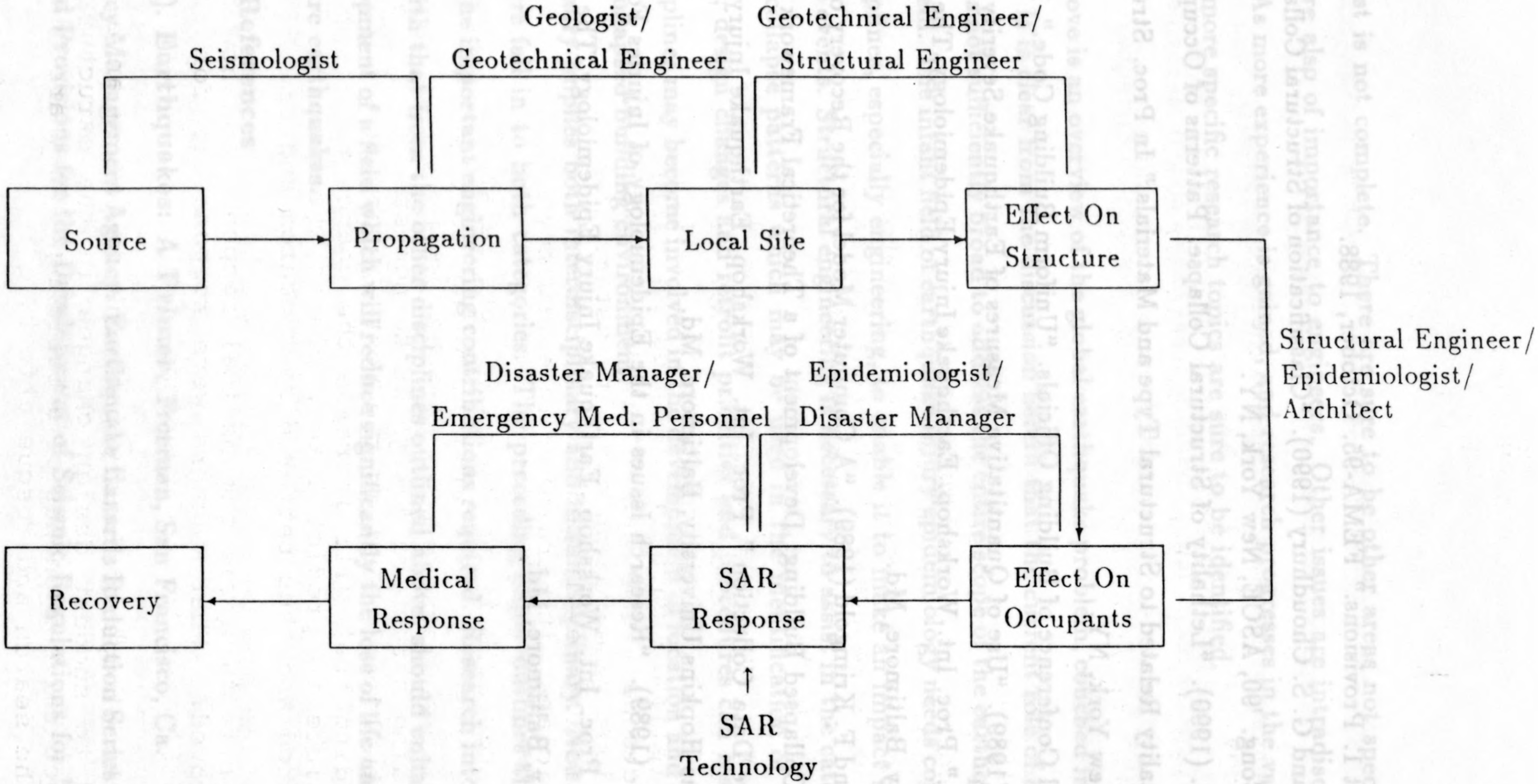

Figure 1: Flowchart of the "Earthquake Process."

NEED FOR A SOUND RESEARCH PROGRAM ON EARTHQUAKE EPIDEMIOLOGY

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There is a need for a sound research program on earthquake epidemiology, particularly with regard to injuries and deaths following building collapse. Multidisciplinary teams should be formed to coordinate research activities from both the engineering, epidemiology, emergency medical, and search and rescue perspective. Some of the important aspects to be addressed by such a research program include:

(1) Development and validation of means to assess the number of fatalities and likely number of injured survivors. A simple field tool for assessing severity of injuries sustained is needed that could be used to predict the immediate health care and search and rescue needs. Analyses should be conducted of previous earthquakes and a study protocol developed to collect data prospectively in the next big earthquake. The protocol should be developed in consultation with existing experts in the field.

(2) Better survey instruments must be developed to assess the health impact of earthquakes. This should include development of the most appropriate sampling techniques in the field. How can reliable data on injuries be collected under difficult field conditions? An extensive review should be conducted of previous research on casualty estimation. The work should be critically evaluated by engineers, epidemiologists, and physicians with training in emergency medicine.

(3) More research is needed on factors related to the survival of those rescued following building collapse. Why did some survive and others were killed? What is the relationship to building structure design or to non-structural components in the building? What is the most appropriate place to be in a building that will increase the chance of survival? Is it possible to predict likely places where survivors could be located and thus better direct search and rescue efforts?

(4) How effective was the medical response and how could it be improved? What factors were responsible for reducing the effectiveness of the response?

(5) Can knowledge of injury patterns following an earthquake be used to suggest design changes in the structural and non-structural components of a building? What are the weak links in the search and rescue effort?

(6) How applicable is data obtained from many different countries to earthquakes and search and rescue efforts in the U.S.? Can we learn from earthquakes in other countries? What differences must be taken into consideration?

(7) What is the relationship between mortality and time from extrication from buildings? What is the most appropriate treatment for the entrapped victim?

(8) Need to be able to collect data on types of lesions and injuries as associated with types of building materials. Can we predict injuries so that we will know what injuries to expect when an earthquake occurs given a knowledge of building design, age of building, population density, etc. For example, if we know that 25% of houses are wooden, 50% unreinforced adobe and 25% reinforced concrete, and an earthquake of a certain magnitude occurring in an area of such and such population density, can we predict the number of casualties.

(9) "Real time response modelling" That is, the development of a casualty estimation system for optimization of rescue activities. Such a real-time casualty estimation system will also serve a major function as an educational tool and as an element in risk communication. A realtime casualty estimation system is principally an effort to bring together research results from a number of different disciplines to develop useful operational directives for disaster response. If it is successfully developed, it will constitute a major step forward for effective research application and implementation.

(10) Building stock characterization: Need to develop a set of global categories to distinguish gross grouping of urban development patterns as related to vulnerability and casualty rates. Need to gather existing building stock data for prototype development. Need to develop criteria for future data acquisition for refinement of algorithms.

(11) Damage estimation models for the global vulnerability classes.

(12) Development of casualty estimation models based on damage estimation for principal building types and principal occupancies. These casualty estimation models will include injury severity discrimination.

(13) Rescue operations management: Models of spatial distribution of casualties identified by building context and injury severity need to be created in order to develop specific management directives. These need to include:
    a. Manpower and equipment demand
    b. Mobilization and logistics

c. Resource allocation over time of rescue operation
d. Medical response and facilities allocation.

(14) Global risk assessment: An assessment of earthquake casualty data in the context of other public health concerns.

(15) Categorization of urban vulnerability: (Units of useful generalization). Building materials, practices vary significantly around the world as do patterns of building use.

Research should attempt to determine the appropriate groupings of urban construction/social patterns for the pooling of data and sharing of algorithms.

(16) Prediction of collapse potential: Research should reevaluate vulnerability functions with a specific focus on the "high-end" damage as it relates to death and injury. So far, most research, particularly in the U.S., has focused on "low-end" damage and on economic issues like repair cost. This will result in a set of vulnerability functions which emphasize aspects of severe damage and collapse in terms relevant to occupant safety.

(17) Use of quantitative injury severity scores to determine injury severity patterns in various forms of building collapse (also prediction), resuscitation potentials (who will die regardless of rapidity of access), salvageability of victims (i.e., determination of those who could be saved by LFSA and ATLS w/in six hours), determination of medical needs (and speed of response required), evaluation of SAR/medical response.

(18) Development of crude indicators (estimators) or predictors of disaster severity (important for rapid assessment of disaster severity- rapid epidemiologic surveillance, "quick and dirty" surveys). Could we develop a rapid sampling frame with which to quickly estimate number of injuries and severity of the injuries?

PRESENT APPLICATIONS OF QUANTITATIVE MEASURES OF INJURY SEVERITY IN EARTHQUAKE RESEARCH:

1. Retrospective Application of Quantitative Measures of Injury Severity to Patients Hospitalized as a Result of the 1988 Earthquake in Soviet Armenia

Currently under way as a collaborative study between the Johns Hopkins Medical Institutions and the Ministry of Health of the Soviet Socialist Republic of Armenia is a longitudinal study of 12,000 patients who sustained injuries severe enough to require hospitalization following the December 1988 earthquake. The objective of this study is to characterize injury severity case-mix for the collapse of buildings in Armenia of a given design and construction using anatomic descriptors of injury such as the AIS and/or ISS. This will require retrospective review of medical records and results of autopsies. Secondly, this study hopes to test the utility of the AIS/ISS in predicting outcome (eg. death, degree of permanent disability) for victims of building collapse. This will allow us to choose those parameters which predict mortality best for earthquake-injured patients. In other words, results from this study should indicate what revisions to the AIS and/or ISS are necessary to render them more applicable to the study of earthquake-related injuries.

The validation phase will be a step-wise process designed to answer important questions about the appropriateness of the proposed changes in the AIS/ISS. The relationship between the modified AIS/ISS severity scoring methodologies and mortality will be explored. Mortality is a widely used measure to test the goodness of a severity scale. It is hypothesized that as severity increases, mortality also increases and several appraisals of the ability of the modified AIS/ISS to predict outcome will be considered. If the changes made have improved the scales' ability to characterize building collapse-related injuries, then mortality predictions derived from these modified scales should also be improved. Perhaps factors postulated to influence injury severity may need to assume a variety of values or weights depending on their importance, as well as uncertainties in the data and/or various interpretations of the data.

Ultimately, we hope to incorporate our analysis of injury severity patterns in the Armenian earthquake into a model of casualty estimation that will allow us to predict the percentage of deaths and range of injury severity sustained for principal building types and occupancies.

2. Development of Simple, Rapidly Applied Physiologic Methods to Assess Severity of Injuries for Victims of Building Collapse

Evaluation of the efficacy of search and rescue and medical care rendered, as well as determination of time trends for morbidity and mortality will require calculation of injury severity at various points in time. This will require the use of physiologic injury scales such as the TS or a modification thereof since physiologic scales are the only ones that reflect changes in the patient's clinical condition over time and which are also easily calculated with information available in the field.

We are currently investigating the utility of an injury assessment tool called "RPV Assessment Method" which is a rapid and simple method to determine the severity of a casualties that can be performed by non-medical personnel under adverse conditions and which also has prognostic value.

The RPV Assessment Method utilizes the three physiologic parameters of Respirations, Pulse, and best Verbal response based on the Glasgow Coma Scale. A person with absolutely no health care background can determine the RPV score of an injured person simply by measuring the respiratory and pulse rates and determining the best verbal response to specified questions, then summing the coded values assigned to those rates and responses.

The underlying assumption is that the human body responds in specific ways to injury, depending on the severity of the trauma. More severe injuries result in physiologic changes from normal which are greater than those associated with less serious trauma. This relationship is reflected in the assignment of coded values to various degrees of physiologic derangement, as seen in Figure 3. There is also indication that RPV has excellent predictive value regarding the ability to estimate the probability of survival after injury. As with all physiologically based severity indexes, the time interval between injury and assessment can affect the score, since the response of body systems to trauma is not instantaneous, but worsens or improves over time. The value of serial assessments and charting of changes over time is obvious for reasons outlined previously.

The RPV Assessment Methodology is a rapid and simple way to determine the severity of a casualty's injury. It can be performed by non-medical personnel, under adverse conditions, with a minimal amount of training. Ultimately, we hope to be able to apply the RPV Methodology at specific points in time (eg. when victim first accessed, when extricated, when first seen by medical care provider, when transportation initiated, upon arrival at hospital), in order to assess the efficacy of search and rescue and medical care rendered.

3. **Development of rapid assessment methods for establishing the cause and approximate time of death of a body removed from a collapsed structure.**

These techniques are already used by medical examiners and pathologists in post-mortem examinations to determine cause and time of death. We hope to analyze autopsy results to estimate time of death for victims of earthquake-induced building collapse. This estimate should then be correlated with length of entrapment. In addition to the above, the location of the body in the particular structure will be ascertained. Calculation of the AIS may also require autopsy results on those killed by building collapse to determine precise description of anatomic/tissue damage.

The aim of the above three data collection strategies is to ascertain the nature and severity of injuries throughout a structure as a function of time. It is noted that existing earthquake epidemiology studies probably make some attempt to at least pinpoint the location of each survivor or body found. The above study attempts to add the time dimension and information on injury severity to this data base.

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Figure 1.

Objectives in Using Quantitative Measures of Injury Severity in Analyzing Injury Patterns in Earthquakes

1. Characterization of injury severity case-mix for the collapse of a building of a given design, construction
2. Rapid prediction of emergency health care needs given knowledge of types and numbers of buildings in a given geographic area.
3. Development of triage guidelines
4. Development of casualty estimation models based on damage estimation for principal building types and principal occupancies. These casualty estimation models will include injury severity discrimination.
5. Evaluation of efficacy of search and rescue, and medical care delivered.

Figure 2.

Questions about the quality and timeliness of care for victims of building collapse that will require the application of quantitative measures of injury severity:

1. Are patients being triaged correctly?
2. Is search and rescue effective?
3. Is medical care effective?
4. Which on-site and hospital treatment are more effective?
5. Does efficient search and rescue and emergency medical care influence mortality and morbidity rates?
6. How can new techniques of search and rescue and medical care be tested?
7. Are there a number of late deaths following earthquakes or do most deaths occur within a very short space of time? Could many of the deaths have been prevented by more effective search and rescue, better emergency services, or better long-term definitive care.
8. What happens to survivors after rescue? To they get better before dying, or vice versa? Did the victim survive for a significant time, and if not, why not?

Figure 3.

Coding of Physiologic Variables Used in RPV

Respiratory Rate	Coded Value
0	0
1-9	1
10-24	4
25-34	3
35 and greater	2

Pulse	Coded Value
0	0
1-40	1
41-60	2
61-120	4
120 and greater	3

Best Verbal Response	Coded Value
None	0
Incomprehensible Sounds	1
Inappropriate Words	2
Confused	3
Oriented	4

Figure 4.

Probability of Survival as Function of RPV Score *

R	1	0.089
P	2	0.157
V	3	0.265
	4	0.409
S	5	0.571
C	6	0.719
O	7	0.832
R	8	0.905
E	9	0.948
	10	0.972
	11	0.985
	12	0.992

THE APPLICATION OF EPIDEMIOLOGY TO THE REDUCTION OF EARTHQUAKE RELATED CASUALTIES: RESEARCH NEEDS

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Introduction

To date most research on earthquakes has focused on engineering aspects of structures and their resistance to damage. This research has conducted extensive analyses of previous earthquakes and has led to major advances in our ability to design safer buildings to withstand earthquakes. However, many buildings have not been built to such exact standards and will continue to present a considerable risk to human life. More recent work is looking at ways to make such existing buildings more resistant to damage. However, comparably little research has been conducted that actually looks at the injuries and deaths that occur. In fact, the estimates of the number and extent of injuries and deaths following earthquakes is very crude compared to the estimates of building damage. Extensive predictive models have been created to predict damage for earthquakes of different magnitude or intensity as a result of analyses of previous disasters. Similar models for predicting human damage are extremely crude at best and has been subject to little study.

This paper seeks to outline how the science of epidemiology can contribute to the development of better models to predict earthquake related casualties. It cannot provide many answers since much basic research needs to be done. However, it will outline a framework for the systematic examination of the issues involved in understanding the epidemiology of injuries following disasters, and develop an agenda for future research. Such research cannot be conducted in isolation but requires collaboration with the many different disciplines involved in the study of earthquakes and building collapse.

Epidemiology is that branch of medical science that studies disease in a population rather than in individual patients (Last, 1983; Lilienfeld, 1980). It seeks to study in a systematic way patterns of disease that can be used to develop risk factors or predict disease outcomes and provides the scientific basis for prevention. Epidemiologic principles have made significant contributions to our understanding of diseases and disease transmission, even when the causative agent is not known. For example, long before the AIDS virus was actually discovered, epidemiological studies had identified high risk groups, risk factors for the development of the disease, the means of transmission, and had suggested ways to prevent its further spread. Similarly, studies of the epidemiology of chronic diseases identified factors such as the contribution of saturated fats to the development of heart disease. Central to the science of epidemiology is the belief that adverse effects do not occur at random, but have predictable patterns that can be studied and then be used to form the basis of developing prevention strategies.

Application of Epidemiology to Disasters

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. Studies of attendance at clinics following the 1976 earthquake in Guatemala showed that by the time international medical disaster assistance arrived, new trauma admissions had fallen off dramatically (Seaman, et al., 1984; de Ville de Goye, 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).

A more complete review of the use of epidemiology is available in several reviews of the subject (Logue, et al., 1981; Seaman, 1984; Lechat MF, 1975, 1976, and 1979; Western, 1976). The development of important preventive strategies has also followed epidemiologic studies of disasters. For example, a study of injury patterns following a large tornado in Texas found the lowest risk of injury to be among those who remained inside permanent housing (Glass, et al., 1980). Those who tried to flee in cars were at greatly increased risk of death or serious injury. Those who remained in mobile homes had the highest risk of being killed. These findings led to important recommendations with regard to decreasing the risk of injury during a tornado.

Injury Epidemiology

It is increasingly being realized that injuries occur in predictable patterns and are not simply accidents or acts of God (National Research Council, 1984). While some events such as natural disasters can be predicted by geologists and seismologists, they are difficult to prevent. However, the injuries that follow them can be prevented or at least reduced. Thus, the public health approach to disasters emphasizes injury prevention rather than disaster prevention. A building may still fail in an earthquake, but injuries may be prevented or reduced if those parts of the building likely to be occupied by large numbers of people can be designed in such a way that there is less risk of injury to the occupants. This approach to injury prevention has been very successful at reducing deaths and injuries from automobile crashes. It has not been possible to prevent all automobile crashes, but by improving vehicle design and the use of safety belts and airbags, the risk of injury to the occupants of the vehicle can be reduced considerably. Applying some of the same principles of occupant protection to building occupants may provide important new information for reduction of injuries and deaths from earthquakes.

Injury epidemiology and prevention has developed a framework for analyzing injury-producing events based on dividing the event into phases, each of which may suggest very different strategies for prevention. First developed by Haddon (1980), these phases are labelled pre-event, event or impact, and post-event (Haddon, 1980; Noji and Sivertson, 1987). Each phase represents a different segment of time in which injuries can be prevented (Table 1). In the pre-event phase, we can either prevent the earthquake from occurring or ensure people do not experience it. However, methods to predict an earthquake are generally unreliable, and needless to say, there is no way to prevent its occurrence. The event phase relies on preventing or reducing injuries during the earthquake. This phase is the focus of much attention and much can be done through better engineering of structures to prevent buildings from collapsing. The post-event phase deals with reducing the consequences of the injuries through better search and rescue methods and more effective emergency care. Some researchers have subdivided the post-event phase into the relief phase and the rehabilitation phase, to better separate the acute disaster relief from the more long-term recovery phase.

Table 1. Phases of earthquake where injuries can be prevented.

Phase	Strategy
Pre-event	Prevent earthquake from occurring or ensure people do not experience it.
Event	Reduce injuries during earthquake (antiseismic buildings).
Post-Event	Reduce consequences of injury following building collapse (rapid search and rescue)

Glass (1976) was one of the first to apply epidemiology to the study of building collapse. He identified the type of housing construction as a major risk factor for injuries. Those living in the newer style adobe houses were at highest risk of injury or death, while those living in the traditional mud and stick construction houses had little or no injuries. This study however, was written only by epidemiologists, and made little use of engineering and architectural principles. If such disciplines were included in the study design, more useful relationships between building design and injury patterns may have been able to be developed (Jones N & Krimgold F, personal communication, 1989). More useful information for understanding injury patterns and developing prevention strategies can be obtained through an interdisciplinary research program that draws on the strength of different disciplines.

Epidemiology can play an important role in identifying risk factors relating to the building design and construction. However, careful attention must be given to the integration with other disciplines. The remainder of this paper outlines some of the potential research questions raised from a review of existing studies of earthquake injury epidemiology and how we can use these to develop the field of earthquake injury epidemiology, utilizing the input of other disciplines. Central to basic epidemiology is the description of diseases in time and place and the basic questions of how, where, when, and why these conditions occur. These questions provide a useful framework for determining the needs for further research on injuries following earthquakes.

Time and Place

Unlike most other health conditions, injuries and deaths from earthquakes are concentrated both in time and place. Earthquakes are massive catastrophic events that occur suddenly with long periods between events. They often cause little or no damage. In fact, over 70% of the approximately 1.3 million earthquake-related deaths since 1900 have occurred in 12 single events (Table 2). One single earthquake, the 1976 Tangshang earthquake in China was responsible for 19% of all fatalities in this century.

Earthquakes also occur in very predictable places based on the underlying geological structure of the earth's crust. In the United States, the most lethal earthquake was the 1906 San Francisco earthquake and fire that killed 452 people (Table 3) and was caused by a shift in the San Andreas Fault. The estimated 1.3 million people killed in earthquakes in this century represent about 14,770 deaths each year over an 88 year period. While this number may seem large, when considered in terms of rates per 100,000 population, it corresponds to a rate of only 0.34 per 100,000 population. Even China has reported only about 500,000 deaths since 1900, just double the overall rate (0.60 per 100,000 population using the 1980 population for calculations). More detailed studies which look at mortality rates for smaller geographic areas have not been done. The 1980 all cause world mortality rate is 1,000 per 100,000 population; the motor vehicle mortality rate in the U.S. is 19.4 per 100,000 population. Thus while the mortality rate from earthquakes overall is relatively low, the potential for massive overwhelming number of casualties and injuries within a very concentrated time and place has made them part of the focus of the forthcoming International Decade for Natural Hazard Reduction.

Table 2. Major casualty earthquakes 1900-1988

No. Killed*	Place	Date
242,500	Tangshang, China	1976
200,000	Kansu, China	1920
142,800	Kanto, Japan	1923
66,800	Ankash, Peru	1970
58,000	Mossina, 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 (29%)	Others	
1,300,000 (Total)		

* Rounded to nearest hundred.

RESEARCH NEEDS

Some of the important questions to be raised in the development of a research agenda can be answered by the basic epidemiological questions: how, where, when, and why?

1) How are people killed or injured in a building collapse?

Understanding of the mechanism by which people are killed is essential to developing prevention strategies. Injuries are caused by the transfer of energy to the body in amounts or at rates that exceed the bodies threshold or ability to withstand the energy transfer (Haddon, 1973). Thus, the etiologic agents of injury are forms of energy which may be mechanical, thermal, electrical, chemical, ionizing radiation, or the restriction of energy transfer which occurs during suffocation or drowning, by preventing oxygenation of the blood. In most earthquakes, people are killed by mechanical energy as a direct result of falling building materials. However, surprisingly little is known about the exact mechanisms. For example, anecdotal evidence from Armenia suggests that suffocation from dust inhalation may be a significant factor in many people who die without apparent injury (Noji E, personal communication, 1989). There is a need for detailed autopsy data on a sample of cases to determine the exact cause of death, especially for those with little evidence of external trauma. It may be that developing methods to reduce dust release in building collapse could prevent many deaths.

In some earthquakes few people may be killed by the building collapse but die due to post-earthquake fires. In the big 1923 earthquake in Kanto, Japan over 143,000 people were killed, most of whom died not by the earthquake directly, but by the post-earthquake fire that swept rapidly through the

Table 3. Five most fatal earthquakes in the United States since 1900

No. Killed		Date
452	San Francisco earthquake and fire	1906
173	Alaskan earthquake/tsunami hitting Hawaii and California	1946
120	Long Beach, California earthquake	1933
117	Alaskan earthquake/tsunami	1964
64	San Fernando Valley, Los Angeles, California earthquake	1971

Source: National Oceanic and Atmospheric Administration

damaged area immediately after the earthquake (Seaman, et al., 1984). Similarly the large fire that occurred after the 1906 San Francisco earthquake was responsible for much of the death toll following that event. Some earthquakes produce massive waves or tsunami and have caused a proportion of the deaths in the five largest U.S. fatal earthquakes (Table 3). Another factor that may affect the number of people killed is exposure to cold. In Armenia, for example, it is believed that some of the people who could otherwise have been rescued may have perished due to the intense cold (Noji E, personal communication, 1989).

A clear understanding of the exact causes of death can provide valuable information for understanding how people actually are killed following earthquakes. Autopsy information has provided invaluable data for analyzing automobile crashes and making appropriate modifications to automobile interiors. Such information could also provide useful information upon which to suggest modifications to buildings to prevent death.

2) Where are victims located?

Is there a difference in the locations in a building between the survivors and those who are fatally injured? Determining where people are located when they are injured or killed can provide valuable information to both assist in locating potential survivors, and in making recommendations to building occupants as to what to do during an earthquake. An analysis of successful rescue efforts could provide valuable data on where the survivors were located and what factors contributed to their survival. For example, one women was rescued 13 days and 8 hours following the Tangshang earthquake (Sheng, 1987). She was trapped underneath an iron bed in a collapsed hospital building. The bed created a void space in the collapsed building and prevented her from being killed by falling material. Other anecdotal stories from search and rescue personnel describe situations where survivors are located many days after the earthquake trapped in small spaces such as bathrooms. The walls hold up collapsing material and water can be trapped for drinking. Individual rescues such as these raise a number of epidemiologic questions. Can we learn from the collapse of buildings where potential void spaces are created? Is it possible to design buildings not only to stand up, but also if they sustain a sufficient force that the building "fails," can they be designed to collapse in such a manner that they create the maximum potential for rescue of the building occupants?

The study of injury patterns from previous earthquakes also may help predict those characteristics that are related to survivability of building collapse. It may not be cost-effective or possible to strengthen older buildings to prevent collapse, but relatively simple modifications may increase the probability that collapse will cause fewer injuries; for example, strengthening stair wells, bathrooms, or creating "safe" corridors. Research efforts such as these will require the cooperation of engineers, architects, search and rescue personnel, medical staff, and epidemiologists.

An important issue for search and rescue personnel is locating trapped survivors. Little scientific research has been done to predict where trapped survivors are likely to be located in a collapsed building. Can we approach the rescue of people in a damaged building in a scientific manner? As part of search and rescue efforts, data should be collected on the successful rescue efforts, particularly relating to the parts of the building where survivors were at the time of collapse. Another research question is whether or not studies of the epidemiology of injured survivors can lead to advice as to the best way to dismantle a collapsed building. What approach will provide the highest likelihood of a successful rescue without doing more damage to those trapped?

The behavior of building occupants during an earthquake is another area for research. No good guidelines exist for what is the best plan of action once a building begins to shake. Foreshocks may provide valuable warnings that can affect behavior. For example, the Montenegro earthquake of 1979 came in two shocks with enough time between them for people to get outside their houses (Tiedemann, 1989). Studies from the 1980 Italian earthquake suggest that those who immediately ran outside were less likely to be injured or killed (de Bruycker, et al., 1985). However, while running outside may be good advice in rural areas, it may not necessarily be the best thing in densely populated urban areas. Narrow streets provide no protection and can rapidly fill with debris falling from collapsing side walls or roofs of buildings; whereas inside the building major parts of the building may be left standing and provide protection. Reports from the Chilean earthquake suggest that a number of people were killed from falling building overhangs as they tried to escape (Aroni S, personal communication, 1989). The anecdotal stories of people surviving under desks or beds suggest that such behavior may prevent injuries. However, only by developing accurate studies of the location of injured and non-injured persons can we develop sound advice as to the best behavior to reduce the likelihood of injury. The advice is likely to be specific for certain types of buildings and may be different for densely populated urban areas versus rural areas.

3) <u>When do people die following building collapse?</u>

Understanding when people die following building collapse can provide important information for planning rescue efforts. However, little is known concerning the effectiveness and appropriateness of the different levels of search and rescue, because no formal evaluations of these efforts have been carried out. Evidence from the few studies that exist suggest that most people who are successfully rescued are excavated by local survivors immediately after the quake occurs.

Studies of acute blunt trauma as represented by motor vehicle trauma have shown that rapid extraction, resuscitation, and transportation to hospital can dramatically affect survivability following injury (Sacco, et al., 1984). In fact, much is made of the "Golden Hour." This concept suggests that the probability of survival is greatly increased if persons can be transported to definitive care within one hour of injury. Such rescue times are unachievable in most earthquake situations. Even if they could be achieved for limited numbers of people, the patients would rapidly overcome available medical resources, which themselves are probably heavily affected by the earthquake. However, the limited earthquake rescue literature to date suggests that rapid rescue is essential to increase survivability.

Olson (1987) has defined the "Golden 24 Hours" as the period of time during which the victim in a collapsed building has the greatest chances of surviving if rescued. However, little data are available to support this concept. A study of the 1976 Tangshang earthquake in China (Sheng, 1987) however, found that 99.3% of those extracted by rescue squads within one-half hour survived, whereas only 81% of those extracted between one-half hour and one day survived. Only 7.4% of those who were extracted on the fifth day survived (Table 4). Similar findings of rapidly declining probability of being alive at extraction were found in the 1980 Southern Italian earthquake (de Bruycker, et al., 1985). However, these rather crude calculations do not taken into account that the less severely injured may be rescued earlier or that those people showing signs of life are easier to locate, and thus will be extracted earlier. Future studies need to consider factors such as the severity of injury (Noji, et al., 1989).

Table 4. Survival rates vs. Rescue time
Tangshang Earthquake, 1976

Time of Extraction Surviving	Number of Persons	(%)	Number Surviving	% Surviving	Cumulative %
1/2 hour	2,277	(21.3)	2,261	99.3	29.9
1 day	5,572	(52.1)	4,513	81.0	89.6
2 days	1,638	(15.3)	552	33.7	96.9
3 days	348	(3.3)	128	36.7	98.6
4 days	395	(3.7)	75	19.0	99.6
5 days	459	(4.3)	34	7.4	100.0
0-5 days	10,689	(100)	7,653	70.8	

Adapted from: Sheng ZY, 1987.

Information needs to be collected on those that die so that the time of death can be predicted. This may help predict the potential for rescue. The predictive models for survival time are based largely on blunt trauma such as that due to motor vehicles. Anecdotal stories are told of large numbers of victims surviving for days after an earthquake. Some people may be trapped in voids in the building, but are relatively uninjured. Thus, the severity score and other models used for classical blunt trauma injuries may not be appropriate for use in disaster situations. There is a need for more research to develop more appropriate tools for assessing severity of injuries related to earthquakes.

In planning research on the efficacy of search and rescue, the distinction must be made between light search and rescue conducted immediately following an earthquake, and heavy urban search and rescue. Most people are rescued with light rescue methods using untrained, uninjured survivors who use simple tools such as shovels and axes. In the 1980 Italian earthquake it was estimated that about 97% of the trapped survivors taken to one medical center were extracted using primitive tools such as shovels or bare hands, and only 3% were rescued using tractors or cranes (de Bruycker, et al., 1983). More research is needed to determine the needs for expert outside assistance with search and rescue. Often such help can only be of assistance for heavy urban rescue where there is a likelihood of survivors trapped in voids within buildings.

4) Why do people die following earthquakes?

Earthquakes themselves do not kill people, but rather the majority of injuries are caused by the building or its components. Seaman, et al. (1984) found a direct linear relationship between mortality and the number of houses destroyed for 19 earthquakes in Turkey during the period 1912-1976 (approximately 8.5 people killed per 100 houses destroyed or badly damaged). Few studies, however, have looked at exactly what components of a building cause the injuries, particularly in those situations where some people are killed and others only injured or escape without injury. To date most antiseismic building designs have been engineered to preserve the integrity of the building with variable attention to the effects of non-structural components on injury risk. Falling light fixtures, other equipment such as wall-mounted x-ray machines or even overhanging verandas, may become lethal weapons even when the integrity of the building remains intact. Analysis of previous building failures may lead to the development of simple effective retrofit prevention strategies. Engineers generally tended just to look at degree of structural collapse in analyses of collapsed buildings. However, some collapses may be more "friendly" to its occupants than others. Analysis of previous earthquakes may provide useful information to the retrofitting of existing buildings and the design of buildings with an eye toward massive earthquakes that exceed the ability of the building to remain intact. Other factors to be considered include the likelihood of the building to burn or catch fire -- which was a problem following earlier Japanese earthquakes.

5) Predictive models

There is a need to develop better methods to predict the number of people killed and injured following an earthquake. This information is essential for both rapidly assessing the magnitude of the problem and for planning rescue and other relief efforts. In the absence of such data the relief effort may not be appropriate for the needs (de Ville de Goyet, et al., 1976; Zeballos, 1985). In one earlier model, Lechat (1979) proposed using a ratio of injuries to deaths as a useful guide to predict the number of injuries. This information could then be used to assess medical needs after earthquakes, and predict the amount of supplies and personnel needed in a disaster relief effort. However, the ratio of 3:1 injuries to deaths only applies to the sample of 3 earthquakes used in the initial analysis, and a limited number of other earthquakes (de Bruycker, et al., 1985). A more comprehensive analysis by Alexander (1985) found it was not a useful predictor when studying other earthquakes. Even if such models could be refined, taking into account various other factors such as building type, intensity of earthquake, etc., accurate estimates of fatalities are often not available. It may take days or weeks before reasonable estimates of the number of fatalities become available. There are often large discrepancies in the number of fatalities reported by different sources for the same earthquake. For example, three different estimates are available for the number of people killed in the Nicaraguan earthquake in 1972 (Coultrip, 1974; OFOA, 1988; Whittaker, et al., 1974).

Another possible approach is to develop a predictive model based on earthquake risk. While geologic maps that outline the earthquake prone areas are available, they do not relate to risk of death or injury. A predictive model could possibly be developed based on a combination of factors such as risk of earthquake of defined magnitude, the particular building construction of the area at risk, and the population likely to be affected. To be able to develop such a model, there is a need to develop simple measures of the lethality of the injury producing potential of different types of buildings, particularly as they relate to different severities of earthquake. A simple classification system for building types should be based on their potential to both cause injury, and also with regard to their potential for creating void spaces upon collapse.

6) <u>Definition of variables for research studies</u>

It is impossible to compare injury patterns for different disasters without establishing common definitions. Even if broad definitions are available it is essential to have more exact measures of severity in order to enable more detailed comparisons to be made (Noji, et al., 1989). It is essential to develop simple scoring systems to quantify the extent of trauma. These are usually based on prediction of survivability. However, detailed medical information is often not available in the acute disaster situation.

As discussed earlier there may be problems counting the number of people killed. However, the problems of measurement are even more acute when trying to measure the number of injured. There is no standardized definition of injury in use. Most studies to date have only classified injuries as fatalities and non-fatalities (persons injured). Others have used uninformative terms such as minor, serious, or critical. There is a need to develop standardized definitions since there is a huge difference between minor contusions and life-threatening injuries requiring hospitalization. Future developments of earthquake injury severity scores will greatly assist in this but may be difficult to use in all situations (Noji, et al., 1989). The practicality of a simple definition which separates injuries into those that would require inpatient hospitalization (if available) and those that can be managed safely as outpatients needs to be determined. This definition would at least allow separation of minor from serious injuries. The low ratio of people injured to killed in Tangshang is probably due to their only recording cases of "severe injury" (Tiedemann, 1989).

The data needed for comparative studies is often lacking even for such basic information as the magnitude of the earthquake (Mercalli or Richter scales), the number of deaths, number injured (using standard definitions) or the size of the affected population. In most areas of the world where major earthquakes have occurred official census records are poor. Other problems include uncounted urban migrants, or other groups such as the refugees from other republics, who were living with relatives in Armenia.

Even when good census data are available, as in California, other factors such as the proportion of people commuting to and from the affected area may greatly affect the population present at the actual time of the earthquake. Thus, even to estimate the population at risk may be difficult. The risk of injury may vary greatly by the type of building a person is occupying, which changes depending on the time of day that an earthquake occurs. For example, the 1933 earthquake in Long Beach, California caused significant damage to school buildings, but no deaths because it occurred at a time when school was not in session (Jones, 1989). Wooden, single family homes, such as suburban houses in California, are reasonably earthquake resistant. Even if they did collapse their potential to cause injury is much less than that of an unresistant old stone building, like those often used for businesses, offices, or schools.

Time of day can also affect the ability to escape. In Guatemala, the 1976 quake occurred at 3:05 in the morning while everyone was asleep. If the same quake had occurred later in the day many more people would have been outside and thus uninjured. The 1988 Armenia earthquake occurred at 11:41 in the morning, and thus many people were trapped in office buildings or factories. If it had occurred at another time of day, very different patterns of injury and places of injury would have occurred.

Conclusion

Despite the inherent difficulties in conducting studies of injuries following earthquakes a number of studies have already shown that it is possible to collect valuable information that can be used for prevention. However, more refined methodologies will need to be developed (Armenian, 1989). These will include the development of appropriate sampling frames, the use of case-control studies, and the use of multivariate techniques for analysis. The integration of epidemiologic studies with those of other disciplines such as engineering, architecture, the social and other medical sciences is essential to the provision of suitable variables for analysis. Interdisciplinary studies are necessary if we are to develop improved understanding of injuries following earthquakes and the development of effective strategies for reducing injuries from earthquakes.

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EARTHQUAKE RELATED CASUALTIES AND EMERGENCY RESPONSE

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The occurrence of large magnitude earthquakes in urban areas poses many complex planning and operational problems for the various disciplines involved in emergency response. The difficulties are particularly severe for those activities directly related to immediate life saving -- search and rescue, medical care, fire fighting, toxic control-- because of the need for a rapid, massive response to occur in an environment of reduced communications and imperfect systems for determining where and how to apply resources efficiently.

The 1985 Mexico City and 1988 Armenian earthquakes provide important insights for officials responsible for planning for future seismic disasters and those professionals who will have the operational responsibilities for locating and treating earthquake victims. The Johns Hopkins workshop provided an important forum for sharing information among some of the groups and individuals who have expertise and experience to share. The workshop underscored the need for on-going exchanges between emergency planners, search and rescue professionals, structural engineers and the medical profession.

From the perspective of operational requirements for search and rescue, there are a number of important issues that need further elaboration either through additional review of data from past earthquakes or research by knowledgeable professionals:

1. **Development of a methodology for assessing the likelihood of finding surviving victims in collapsed structures.** Recent experience suggests that one of the major problems relating to search and rescue is the uncertainty regarding how to decide which sites are most likely to contain trapped victims. As a consequence, it is difficult to decide how to assign what is almost inevitably limited search and rescue resources in an efficient manner.

2. **Elaboration of our understanding about the probable patterns of collapse, particularly in U.S. building types considered to have significant potential for failure during earthquakes**, e.g. non-ductile reinforced concrete midrise buildings, tilt-ups built prior to 1974, unreinforced masonry.

3. Related to #2 above, is the **need to develop cadres of engineers knowledgeable about collapse patterns and skilled**

in making assessments about the likelihood of void spaces having been created as well as the capability to work alongside search and rescue teams.

3. **More knowledge about the period of time during which trapped victims might be expected to survive.**

4. **Enhanced knowledge about techniques for medical treatment of victims trapped in structures, including appropriate treatment for victims immediately following their rescue.**

EARTHQUAKE RELATED CASUALTIES

DONALD H. CHEU, M.D., F.A.C.S.

Earthquake preparedness has generally come in spurts, usually after a major earthquake. The fire fighting water supply of San Francisco was not improved until after the 1906 earthquake. The Fields Act to improve the earthquake stability of school buildings in California occurred after the 1933 Long Beach temblor. The Hospital Act requiring that California hospitals remain functional after a major earthquake came after the 1971 San Fernando quake in which two hospitals had actual building collapse and several other hospitals in Southern California had to be evacuated. The actual medical response to a major earthquake has lagged even farther behind. While some efforts were generated toward the management of earthquake victims in the mid 1970's with the development of the concepts of CCP's (Casualty Collection Points) and the DSA (Disaster Support Area), the next step in actually attempting to deal with the injured earthquake victim did not occur until the formation of the California Earthquake Task Force in 1981. This was also the result of a major event, the Mount St. Helens volcanic eruption.

Even though at just about every earthquake preparedness program, the major theme includes the idea that the first priority after a major earthquake is to "**SAVE LIVES**", this has tended to take a back seat to the engineering investigations. That is not to say that since 1981 a significant amount of time and effort has not been spent on the medical response program. The problem has been that the development of the response plans are based on a very limited quantity of casualty data. Some of the reasons for this paucity of data include:

1) Up to the present time, there has not been a significant effort to collect the type of data required,
2) There is no standardized method of documenting the types and severity of

the injuries,

3) Medical teams responding to an earthquake with significant numbers of casualties are there to treat the injured and the collection of data is a secondary mission,

4) During the hectic early days after a catastrophic earthquake, those not providing direct care to the victims are not welcomed because they are viewed as just another group that needs to be fed, housed and provided with sanitary needs,

5) Governments and governmental agencies are frequently unwilling to release the exact victim data or they may not themselves have collected this information.

What data are we attempting to gather that will assist us in the care of those injured as a result of a major earthquake ? The data we need should include 1) the types and severity of the injuries, 2) how the injuries were incurred, 3) the correlation of building types to those injured or killed, 4) the correlation of the medical care provided at the scene, during transportation, in holding areas, and at definitive care centers with the survival and morbidity of the injured victim, and finally 5) how hospitals were able to cope with the number of victims presented to them from the emergent early days to the period of recovery.

The first step in the study of Earthquake Related Casualties will have to be the standardization of a method of describing the injured. We can not adequately base our studies on such vague terms as major, minor, critical, immediate, or delayed unless they are assigned some value. The method described in the paper by Dr.'s Noji, Jones, Smith, and Krimgold from the Johns Hopkins University Working Group[1], in which values are given to the physiological variables of Respiratory Rate, Pulse Rate, and Best Verbal Response, may be the avenue to take (Figure 1). If this is the route of the future, then it must be accepted by all those interested in the research of earthquake related casualties. In California and other regions which have accepted the START (Simple triage and rapid treatment) triage methodology, the RPV scoring system could be adapted to retain the Immediate, Delayed and Minor categories. Instead of reprinting the Triage Tags already in use in those California counties utilizing the California Fire Chiefs Triage tags, the physiological variables and their coded value could be printed on stick-on labels to be attached to the present tags in the area already allotted to "vital signs" (figure 2).

CODING OF PHYSIOLOGIC VARIABLES USED IN RPV[1]

Respiratory Rate	Coded Value
0	0
1-9	1
10-24	4
25-34	3
35 and greater	2

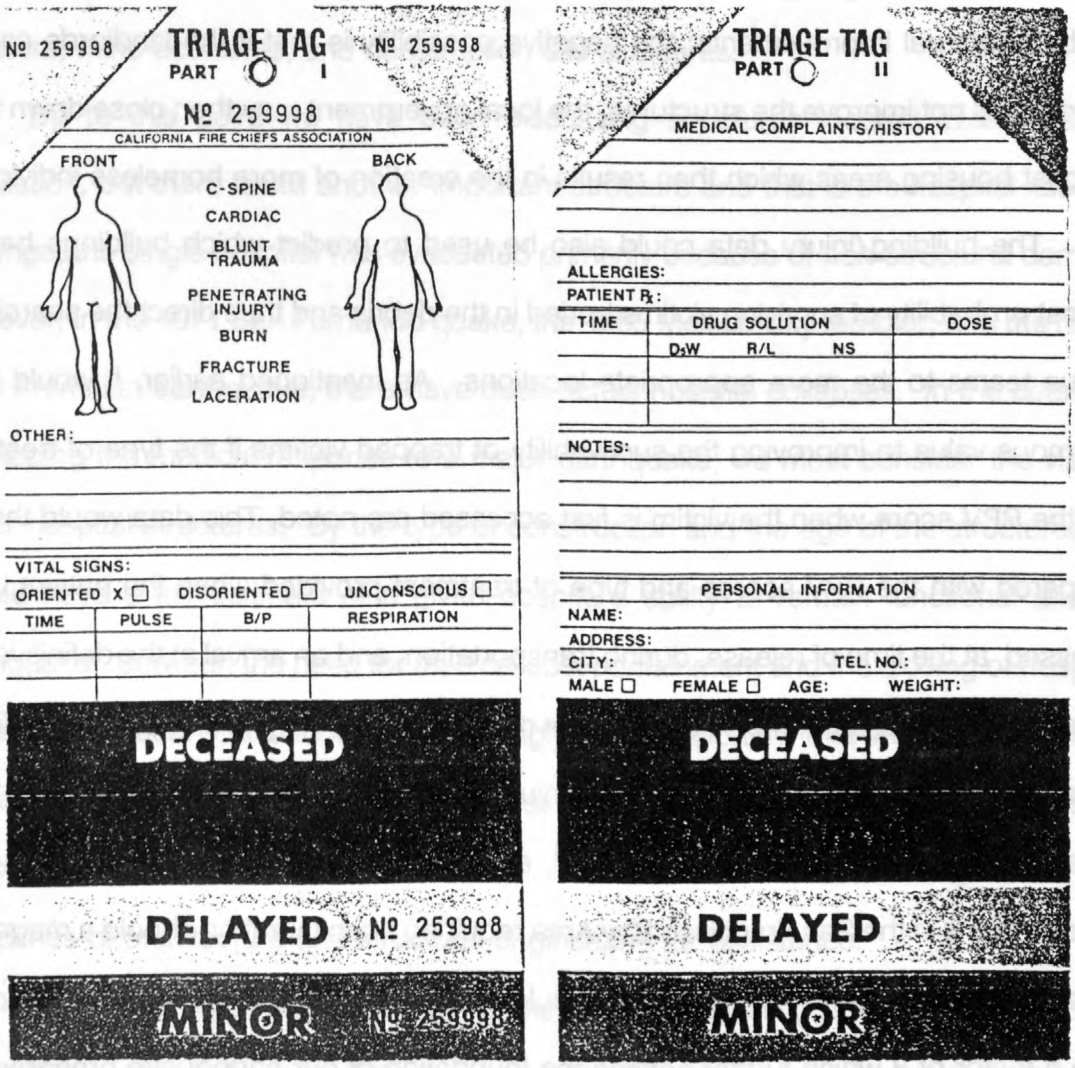
Pulse	Coded Value
0	0
1-40	1
41-60	2
61-120	4
120 and greater	3

Best Verbal Response	Coded Value
None	0
Incomprehensible Sounds	1
Inappropriate Words	2
Confused	3
Oriented	4

RPV Score	Probability of Survival
1	0.089
2	0.157
3	0.265
4	0.409
5	0.571
6	0.719
7	0.832
8	0.905
9	0.948
10	0.972
11	0.985
12	0.992

Figure 1

It is also vital for planning purposes to see if we can correlate the type of structures with the types of injuries and the percentage of overall injuries which occur in a given type of structure. The unreinforced brick-bearing wall structures are often noted as the most dangerous type buildings, but if they enclose a wood construction, the danger may be outside with the rain of falling bricks. In more recent earthquakes in Mexico City and in Armenia, the killer structures appear to be the ones of less ductile concrete floors and columns. Armed with structure/injury correlated data, we could plan somewhat more accurately the medical manpower and supply needs for different segments of a given population based on the existing structures. From the experience of past major earthquakes, the early intelligence on casualties is frequently lacking for many hours to days after the temblor has struck, but by knowing the types of structures located in a given area, an educated guess could be made as to where the early medical response should be directed and thus could be built into the response plan. An automatic response


№ 259998 TRIAGE TAG № 259998
PART I
№ 259998
CALIFORNIA FIRE CHIEFS ASSOCIATION
FRONT BACK
C-SPINE
CARDIAC
BLUNT TRAUMA
PENETRATING INJURY
BURN
FRACTURE
LACERATION
OTHER:
VITAL SIGNS:
ORIENTED X ☐ DISORIENTED ☐ UNCONSCIOUS ☐

TIME	PULSE	B/P	RESPIRATION

DECEASED
DELAYED № 259998
MINOR № 259998

TRIAGE TAG
PART II
MEDICAL COMPLAINTS/HISTORY
ALLERGIES:
PATIENT ℞:

TIME	DRUG SOLUTION	DOSE
	D5W R/L NS	

NOTES:
PERSONAL INFORMATION
NAME:
ADDRESS:
CITY: TEL. NO.:
MALE ☐ FEMALE ☐ AGE: WEIGHT:
DECEASED
DELAYED
MINOR

Figure 2

pattern could reduce the response time which is critical in the saving of lives. Other studies[2] have shown that the majority of individuals are rescued and treated in the first 24 hours by their neighbors. Once again, with the appropriate risk data, training and organizing the population to respond to their neighbors needs after a major earthquake could be concentrated in the high risk areas. This is not without its difficult side of the equation, for this will make known which buildings are at greatest risk and the media and affirmative action groups could cause undue pressure on the landlords and the local political scene. The positive aspect would be if the landlords were able to decrease the risk by structural improvements; the negative possibility is that if the landlords can not afford or will not improve the structures, the local government may then close down these low cost housing areas which then results in the creation of more homeless individuals.

The building/injury data could also be used to predict which buildings had the highest probability of surviving victims buried in the debris and thus direct the search and rescue teams to the more appropriate locations. As mentioned earlier, it would be of enormous value to improving the survivability of trapped victims if the type of treatment and the RPV score when the victim is first accessed are noted. This data would then be compared with the RPV scores and type of treatment provided when the patient is first accessed, at the time of release, during transportation, and on arrival at the definitive care center with the final outcome. However, the method of collecting this data may be difficult in that there were at least 6000 seriously injured victims in Mexico City[3], 15,000 in the Armenian earthquake of December 1988[4], and it is predicted that there will be 44,000 injured victims in the San Francisco Bay Area requiring hospitalization should a magnitude 8.3 earthquake strike at 4:30 pm[5]. It should also be noted that the NOAA predictions have a factor of 3 which further softens the foundation of our earthquake preparedness planning.

From the data concerning the Armenian earthquake of 1988, many cases of Crush

Syndrome were recorded. What was the percentage of Crush Syndrome in Armenia ? What was the reason for the low rate of 2-5% Crush Syndrome victims in the 1976 Tangshan earthquake when there were many crush injuries[6] ? As noted in the previous paragraph, it would appear paramount that we relate the time of entrapment, the degree of crush injury, the physiological parameters previously described, and the treatment protocols to see if we can reduce morbidity and mortality for these victims. For this type of research to proceed, we do not need to wait for an earthquake to occur, for we find entrapped victims secondarily to buildings damaged by on-going wars, other natural disasters, mine accidents, and construction site accidents.

Up to this point we have been discussing structures located in the general population, but there is still another important structure and that is the hospital itself. In Coalinga, the single hospital was evacuated primarily because of non-structural damage. However, in the 1971 San Fernando quake, the 1985 Mexico City temblor, and the recent 1988 Aremnian earthquake, there have been actual hospital collapses. In the course of developing the medical response to a major earthquake, we must consider the viability of our hospital structures. By the type of construction and the age of the structures, we should have a fair estimate of a given hospital's ability to remain functional after an earthquake. Between the need for medical cost containment and the closing of hospitals for financial reasons, it becomes increasingly more important that we find methods of perhaps reinforcing our old hospitals at rates lower than rebuilding if we are to preserve this vital segment of our medical resources. Thus we looked to our colleagues from the disciplines of architecture and structural engineering for assistance.

Some agency should be assigned the task of publishing periodically a list of the many different journals and publications which deal with earthquake related data so that those interested in a variety of data can be made aware of the data's existence. Many of us confine our literature search within the narrow scope of our own specialties and may not be aware of material available in another specialty entirely foreign to our usual sources of information.

Finally, we must convince local, state and national government officials that research on earthquake related casualties is crucial to the better understanding of the needs of those injured by earthquakes and how this information will help mitigate the pain, suffering, morbidity, and deaths. They and others must be made to understand that while we are attempting to develop techniques which will help solve the problems of caring for mass casualties, the goal of this research is not politically driven.

CONCLUSIONS

1. We must develop a standard means of categorizing the injured if we are to produce any comparable earthquake related casualty data. I would suggest that we test the RPV system suggested by Dr. Noji and his group to see if the statistics from the Washington Hospital Center Patients can be reproduced.

2. We need to develop reliable data correlating numbers and types of injuries to building structure types. Without this type of data, we will continue to produce medical response plans to earthquakes on soft foundations. By categorizing the building types, we may then utilize data from around the world and at the same time share our data with other countries.

3. We need to determine if we can improve the salvage rate of those trapped in collapsed buildings. This type of information will apply to building or mine shaft collapse from any cause.

4. With the appropriate data, we could concentrate the initial medical/search and rescue response to the areas of greatest risk and thus decrease the response times. We could also concentrate the local neighborhood self-help activities to those with the greatest risks. Because of the normal population movements, the risk areas could change depending on the given time period.

5. Structural studies could also suggest which hospitals are at greatest risk. A medical response plan should be built around the probability that these at-risk hospitals will not only be unavailable as a resource but may add to the overall casualty problem (that is, their patients may need to be evacuated as well as the staff and patients becoming injury victims of the earthquake).

6. We need to convince local, state, Federal, and foreign government officials that the post earthquake data collection is for humanitarian needs and not political causes.

7. To collect this data, which includes injury types and severity, location where the victim was injured, physiological parameters, treatment protocols, and building types, appropriate data collection forms must be developed which will allow us to collect the data without being too complex.

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Workers Compensation and Life/Health Insurance: Potential Exposure from a Major Earthquake

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The impact on the insurance industry from its exposure under workers compensation insurance and life/health insurance is unknown and practically unstudied. Given the potential for billions of dollars in claims, it is rather amazing the extent of the lack of knowledge. There are at least several reasons for this. First, the insurance industry generally views insuring natural hazards as a property insurance problem. Secondly, no simple methodology seems to exist for estimating the bodily injury exposure. And thirdly, perhaps most people think that the exposure is probably not that great anyway, because buildings in the United States are better designed than most other countries. The California Insurance Department's annual questionnaire is directed only to property insurers.

After the Whittier earthquake on October 1, 1987, the Department requested property/casualty insurers to report their losses. The responses showed 72 claims and $345,287 in workers compensation losses. A similar questionnaire sent out by the Department in 1971 after the San Fernando earthquake didn't include a question on workers compensation. Neither questionnaire asked life and health insurers for their losses.

In October, 1988, AIRAC released a study which may be the first published attempt at estimating workers compensation losses from a major earthquake. The methodology is simple, but reasonable. A cost estimate is made for deaths, major injuries, and minor injuries. Then estimates of the frequency relativities between these three groups are made. This reduces the problem to estimating only the number of deaths of workers by area. Assuming 10,000 deaths of workers in Los Angeles leads to an estimate of $4 billion in workers compensation losses.

No analysis has been attempted for non-worker life and health, yet the number of students, dependents, and retired persons covered by life and health insurance greatly exceeds the number of workers covered by workers compensation insurance.

The following premiums were earned in California in 1988:

workers compensation	$ 7,219,000,000
life insurance	$10,736,000,000
accident and health	$ 8,156,000,000
property/casualty	$23,713,000,000
state total	$49,824,000,000

Even though no serious estimate of the cost of deaths and injuries to insurers has been attempted, the general outline of a viable methodology can be envisioned, with analogy to workers compensation:

(1) the possible types of injuries can be identified and scored as to difficulty and cost. Such scoring systems are in common use in medical insurance and medicare.

(2) ratios can be estimated in terms of frequencies of types of injuries versus deaths.

(3) this can lead to a total cost per death, including injuries.

(4) estimates would have to be made of deaths per type of residential building (homes, apartments, etc.), stores, schools, etc., or wherever people not covered by workers compensation might be located during an earthquake.

(5) an aggregate expected loss could be made for each level of earthquake for a given portfolio of home and buildings.

An additional factor to be considered would be an estimate of the damage to hospitals and therefore the availability of medical aid. This is anologous to the availability of fire protection in the estimating of losses for fire following an arthquake.

Insurers price and underwrite risks according to the perception of risks. Currently, no life and health insurer considers the earthquake hazard in the pricing or underwriting of life and health insurance. In theory, this could be done, but it would be a new concept for life and health insurers.

Whether the insurance coverage is structural damage, general liability, workers compensation, fire following, automobile, or life and health, the indicated methodology for estimating insurance losses always seems to be based on the inventory of buildings and dwellings in a given earthquake zone. Therefore, whichever insurance coverage is being considered, an analysis must first be made of the expected structural damage to a specific type of building, in a specific location, for a given size earthquake. From the analysis of structural damage, a second analysis can then be made of the losses under each type of insurance coverage.

The future work should therefore move along a parallel set of tracks. The first track of activity must be to continue to expand the analysis of structural damage to include types of faults, proximity to faults, soil conditions, urban hazard mapping, and types of structures and contents. Some of this work is now being done in California (for dwellings only) as part of the AB 1885 study by the California Department of Insurance and the Department of Conservation (Division of Mines and Geology).

The second track of activity would be to estimate the insurance losses given a certain level of destruction to buildings and dwellings. The All-Industry Research Advisory Council (AIRAC) is the only organization actively promoting research in this area.

While much of the present work is based on research originally done by the U.S. Geological Survey, a directed research effort by federal agencies toward estimating the social and economic consequencies of a major earthquake is much needed.

NEEDED RESEARCH ON SOCIAL AND ORGANIZATIONAL FACTORS AFFECTING MEDICAL OUTCOMES FOLLOWING EARTHQUAKES

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INTRODUCTION

A number of different factors can influence the rates and severity of earthquake-related fatalities and injuries, including earthquake magnitude and ground shaking intensity; time of day the earthquake occurs; population density in the areas that are affected; characteristics of the built environment, such as age age and type of building stock; and the presence or absence of secondary earthquake hazards, such as fire.

Such factors are generally recognized as important by researchers, policymakers, and emergency planners. However, it is less frequently acknowledged that medical outcomes such as deaths, complications arising from earthquake-generated conditions, length of hospitalization, and short- and long-term disability are also likely to be affected by a range of social and organizational factors. Among the most important of these factors are the capacity of emergency medical service systems to respond to earthquake-related medical needs; the availability of trained personnel, medical-care facilities, and other important resources; and the overall ability of affected jurisdictions to respond effectively to victims' needs following a major earthquake.

Societies clearly differ on these dimensions. Societies that cannot provide basic health care for members of the population on an everyday basis are highly unlikely to be able to launch an adequate emergency medical response in the event of a major earthquake. For example, at present, earthquake victims with severe injuries stand a better chance of surviving and avoiding long-term disability if they life in developed countries, as opposed to developing societies. Important differences are also likely to exist among communities in the same society, as the discussion which follows on emergency medical service (EMS) systems in the U.S. will attempt to illustrate.

VARIABILITY IN EMS SYSTEMS IN THE U.S.: IMPLICATIONS FOR MEDICAL OUTCOMES IN EARTHQUAKES

EMS systems were originally established in the U. S. by Federal initiative in the mid-1960s to respond to the need for better care for accident and trauma victims. The National Academy of Sciences, in an influential report (1966), termed accidental death and injury the "neglected disease of modern society," because so many accident victims were dying due to the inability of medical care systems to respond rapidly with life-saving measures. Efforts to stimulate the development of EMS have resulted in better training for emergency responders, improved emergency response times, and other changes that have enhanced the effectiveness of emergency care, and as a consequence health-care systems today do a much better job than they did in the past of preventing death and long-term disability due to accidents and other emergencies. However, improvements have not been uniform, and EMS systems still vary considerably in their ability to provide treatment in medical emergencies. Thus, medical outcomes are affected to some extent by community differences.

EMS Organization and Funding. A recent survey of state EMS departments (Dawson, 1985) shows that states have taken different approaches to EMS implementation. Among the findings cited in the survey report are that: (1) states differ in the amounts of money they allocate to EMS, as well as in how that money is spent; (2) there is "great variation between the number of emergency vehicles and services available to U. S. residents depending on the geographic area in which they reside" (p. 6); (3) EMS communications systems vary in sophistication across states; and (4) states differ in the disaster-related roles and responsibilities assigned to EMS officials.

In addition to differences across states, variation is also considerable at the local level. A range of community and system characteristics are likely to affect EMS operations, including rural/urban differences; whether services are provided by paid personnel or volunteers; whether EMS systems involve primarily public agencies (e.g., fire and police departments) or contractual agreements with private providers; and levels of training and qualification of EMS providers such as physicians and emergency medical technicians.

Financing has a major impact on the provision of EMS, just as it has on the quality of other medical services; poorly-financed systems that cannot meet ongoing daily demands are likely to have few resources left over to earmark for disaster-related tasks.

In an earlier paper (Tierney, 1985), I discussed other aspects of the social and organizational context that also have an impact on EMS system operations: the status concerns of physicians, who typically want to retain control over the care of patients and are reluctant to yield control to other EMS providers; differences in hospital prestige and resources; the geographic complexity of the planning area encompassed by the EMS system; and the confusion that frequently develops over disaster-related roles and responsibilities.

Factors that affect EMS operations on an everyday basis cannot help but carry over into the disaster situation. Although high-quality everyday EMS delivery does not necessarily lead automatically to excellent EMS delivery in disasters, EMS systems that do not function well on an everyday basis are unlikely to be able to respond to disaster-related demands. Deficiencies in EMS delivery can be expected to translate into disadvantageous medical outcomes for earthquake victims.

Health-Care Resources. Highway accidents, major explosions and fires, and other life-threatening events typically call for specialized medical personnel and equipment. The availability or absence of such resources in a community can affect victims' chances of survival in an emergency. Communities differ in the extent to which resources such as heavy extrication equipment, inhalation therapy devices, and special burn and trauma treatment facilities are available. Similarly, earthquake-prone communities are quite likely to differ in the extent to which they are able to mobilize heavy rescue equipment, skilled search and rescue personnel, and other resources that are critical to the emergency treatment of earthquake victims. In an actual earthquake situation, such differences may translate into differences in mortality and morbidity.

The fact that hospitals are such critical health-care resources and so vulnerable to earthquake damage is the reason California has established strict code requirements for hospital buildings and enacted legislation such as the Hospital Seismic Act. Residents of California can be reasonably confident about the ability of most hospitals to survive a major earthquake. An awareness of the tragic consequences of failure to mitigate earthquake hazards in hospitals, which were made so clear in the 1971 San Fernando event, led the U.S. Veterans Administration to establish rigorous earthquake standards for its hospitals; such facilities are likely to perform quite well in future earthquakes. However, in many other jurisdictions, hospital seismic safety leaves a great deal to be desired. In future earthquakes, we can expect to see variation in the ability of these critically important resources to withstand earthquake shaking and deliver emergency care following an earthquake. These differences will almost certainly affect patient outcomes.

Additionally, communities differ in the degree to which they have experience with disasters in general and earthquakes in particular, as well as in the commitment they make to emergency preparedness. Prior experience and learning as well as pre-event planning are thus likely to constitute another set of variables that affect how communities respond to meet the medical needs of earthquake victims.

CONCLUSIONS

In its recent report on the 1988 Armenia earthquake, the Earthquake Engineering Research Institute suggested 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 ability of local emergency health care systems to respond to victims' needs. Members of the reconnaissance team who studied the care of victims in the Armenian event, and who were aware of the situation in other recent major earthquakes worldwide, observed that in many cases emergency care providers were apparently unable to administer basic forms of treatment that could have kept victims' conditions from deteriorating. They also noted that providing such basic life-saving assistance is fundamentally a local community responsibility, since the time-frame during which such assistance can be effectively administered is so short as to preclude involvement by outside providers (Wyllie and Filson, 1989). These observations have several implications: (1) ultimate health outcomes in earthquakes depend critically on the manner in which emergency medical care systems respond to earthquake injuries; (2) while there are some response-related tasks that may prudently be left to extra-community organizations, the provision of emergency medical care is not among them; and (3) local variation may make a great difference in earthquake-related mortality and morbidity. It is clearly important to have more information on the capabilities of local health-care systems as a factor in medical outcomes.

Little research of this type has been attempted to date. The most complete work on intercommunity differences in disaster-related EMS delivery (Quarantelli, 1983) is based on data that are more than ten years old, and enough has happened in the emergency health care field since the time of that study that its conclusions may be dated. Moreover, that study focused on the characteristics of the organized EMS response in various types of disasters and on sources of variations in response, but did not then attempt to relate these emergency response variables to ultimate medical outcomes, except in the most general way. Additionally, no earthquakes were included in the disaster EMS project (since no damaging earthquakes occurred in the U.S. during the data-collection period) making it impossible to know what special problems earthquakes might present for patient treatment. In short, very little is known about how the social and organizational environment affects mortality and morbidity in earthquakes, and many hypotheses might be advanced.

Activities that would contribute to improving our understanding of this topic include the following:

1) reviewing the medical and health-care literature to identify social and organizational factors that determine medical outcomes in other life-threatening situations, such as accidental trauma and injury in general, and generalizing to the earthquake case on the basis of this information;

2) developing indicators of medical system performance that are applicable to earthquake casualty studies, using literature reviews, panels of experts, and related approaches;

3) combining sets of indicators into testable models;

4) applying models retrospectively, to assess their adequacy with respect to mortality and morbidity data collected in past earthquakes; and

5) collecting data on medical outcomes and on key health-care service system indicators in future earthquakes.

This work should ideally be undertaken by interdisciplinary teams comprised of medical and health-care researchers; persons specializing in earthquake damage and effects on the built environment; and specialists in health care service system organization and processes.

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DATA ACQUISITION FOR EARTHQUAKE HAZARD MITIGATION

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ABSTRACT

Immediately after the December 7, 1988, Spitak (SSR) earthquake), data were collected for five basic categories of studies: geologic, seismological, engineering seismology, engineering, and societal studies. These data and the results of the studies are now being used to:

1. Guide the reconstruction process.
2. Call for change in professional practices of siting, design, and construction.
3. Expand the capability for hazard and risk assessment.
4. Increase public awareness.

Such applications will over time will make any nation less vulnerable to future earthquake occurrences. Multidisciplinary post-earthqauke data acquisition like this should be an integral part of every nation's mitigation strategy.

INTRODUCTION

On May 23-27, 1989, representatives of the United States team who went to Armenia after the December 7, 1988, Spitak earthquake met with other specialists in Yerevan to share their insights on the earthquake. This paper contains some of these insights which were offered to Soviet authorities and practitioners as recommendations to aid the reconstruction and recovery process and as proposals for cooperative endeavors which should reduce the chances of a disaster like this one from happening again in the Soviet Union and other parts of the world. A basic premise of the paper is that knowledge alone makes no contribution to earthquake hazard mitigation if it is unknown, misunderstood, inappropriate, unintelligible, misdirected, or ignored by government officials and practitioners (Hays, 1988).

GEOLOGIC SETTING OF ARMENIA

Armenia is located in a compressional tectonic environment where, over time, the collision of the Eurasian and Arabian tectonic plates has produced a broad zone of faulting and crustal deformation that extends southward from the Caucasus Mountains in Armenia to northern Turkey and Iran. The December 7, 1988, Spitak earthquake is the latest in a long series of earthquakes in the region reflecting the ongoing collision.

SCIENTIFIC AND TECHNICAL FACTS ABOUT THE EARTHQUAKE

The magnitude 6.8 earthquake, which struck Spitak at 11:41 a.m. local time, leaving an estimated 25,000 dead, 18,000 injured, 510,000 homeless, and reconstruction costs of $16 billion, was one of the worst disasters of the 20th century. It reminded the world what a damaging earthquake can do to a nation, its urban centers, gross national product, and the societal fabric.

The impacts of the Spitak earthquake have been extensively reported; therefore, only the basic scientific and technical information used for earthquake hazard mitigation will be described here. These facts, based on information in the reconnaissance report of the Armenia earthquake published in 1989 by Earthquake Engineering Research Institute, are as follows:

1. In the 400 square kilometer epicentral region affected most severely by the Spitak earthquake, the damage statistics for the four principal types of buildings: stone bearing wall, composite frame and stone wall, precast concrete frame, and precast concrete-panel are:

   a) 314 buildings collapsed,

   b) 641 needed to be demolished,

   c) 1,264 needed repairs or strengthening, and

   d) only 712 (24%) remained habitable after the earthquake.

2. Damage to stone-bearing-wall buildings, which were the predominant construction type in Spitak, occurred in a variety of ways:

   a) The onset of damage typically occurred at building corners with almost every surviving building showing visible cracks.

   b) In some buildings, the walls tilted away from the hollow-core concrete plank floors, resulting in the collapse of the planks.

   c) The end walls collapsed in some building; whereas, in others, the end walls remained upright and the middle collapsed as a consequence of the failure of the precast hollow-core concrete planks to act as an effective floor diaphragm, causing the transfer of forces to the masonry walls.

3. Precast concrete frame buildings, a major type of construction in Leninakan and throughout Armenia, were typically constructed in long rectangular configurations with columns and beams providing the

vertical load carrying system. The floor and roof systems were hollow-core precast concrete plans, without topping slabs or positive connections to the building frame. Perimeter walls and selected interior walls of unreinforced masonry infill, precast fascia panels, and precast-concrete-shear panels were designed to provide lateral stability in the longitudinal direction; whereas, the frames were designed to provide the lateral-load resisting path in the transverse direction. The most common failure patterns included:

a) Separation at wall, floor, and corner connections.

b) Loss of longitudinal stability due to infill masonry (typically volcanic tuff) falling out of the frames.

c) Damage at corner splices, which consisted of lap welds of reinforcing steel bars extending from the upper and lower column sections. Due to poor quality control in the field, these splices were often eccentric.

d) Loss of containment due to minimal hoop reinforcement.

e) Buckling of columns at reinforcing splices.

f) Failure of frames due to the rigid, heavy, precast infill panels.

4. The Spitak earthquake produced evidence of two important physical effects:

a) the "direct hit" which Spitak took because of its location in the near field on the up-thrown block of the causative thrust fault.

b) the amplifying effects of the 200-300 m thick clay lake-bed deposits underlying Leninakan. These deposits, which have a shear wave velocity of 300-350 m/sec, amplified the foundation ground motion in the 0.5 - 2.5 second range by a factor of ten or more, relative to rock. In buildings whose periods of vibration had been lengthened by the onset of damage, these effects caused further damage and collapse.

5. Armenian engineers rated the epicentral intensity as IX to X (MSK-64 intensity scale). They estimated that levels of horizontal peak ground acceleration may have reached 0.50 to 1.0 g in Spitak, with possibly a large vertical component as well because of the thrust fault.

The estimated level of horizontal acceleration in Leninakan was about 0.40 g, based on seismoscope records.

Recorded peak ground acceleration values are 0.21 g at Ghoukasian (located 33 km from the epicenter) and 0.06 g at Yerevan (located 100 km from the epicenter).

6. The U.S. Geological Survey collected data from 1,750 aftershocks on conventional and broad band seismometers. These data are being analyzed by US and USSR scientists to delineate the rupture zone and define the rupture mechanisms and soil amplification effects.

AN OPPORTUNITY TO ADVANCE EARTHQUAKE HAZARD MITIGATION

Multidisciplinary post-earthquake investigations should be an integral part of every nation's mitigation strategy. In the aftermath of a damaging earthquake, the reconstruction and recovery processes receive highest priority. Many communities seek an immediate investment of capital to rebuild their community just as it was before the earthquake struck. However, a tragedy also provides a window of opportunity for adopting mitigation measures that will prevent a repitition of the disaster and for acquiring data for earthquake hazard mitigation. The communities that utilize the opportunity of the damaging event to acquire basic data are the ones that are most likely to incorporate mitigation measures in the reconstruction process.

After the Spitak earthquake, several types of post-earthquake investigations were undertaken to advance fundamental knowledge and to foster mitigation. They were:

- Geological Studies - field investigations to determine the cause, nature, degree, and spatial distribution of faulting, regional tectonic deformation, landslides, liquefaction, and wave inundation from seiches, tsunamis, and dam failures.

- Seismological Studies - measurement programs using arrays of permanent and mobile seismographs to locate the main shock and individual earthquakes of the aftershock sequence, to define the spatial extent of the rupture zone of the causative fault, and to determine the focal mechanism of the main shock.

- Engineering Seismology Studies - measurement programs using arrays of permanent and portable strong motion accelerographs to measure the amplitude, spectral composition, and duration of strong ground motion for a wide range of magnitudes, epicentral distances, and soil profiles.

- Engineering Studies - investigations of individual buildings to determine the failure mechanisms, nature, degree, and spatial distribution of damage to the entire range of structures, exposed to the physical effects of the earthquake, including: single family dwellings, low-to-high rise buildings, schools, industrial facilities, lifeline systems, and critical facilities.

- Societal Studies - interviews and on-site observations to determine how the populace reacted before, during, and after the earthquake, focusing especially on behavior during the response and recovery periods.

These investigations provided the data needed to guide reconstruction and foster the the enactment of earthquake hazard mitigation measures in Armenia.

IMPORTANT LESSONS FROM THE SPITAK EARTHQUAKE

Several important lessons were gained from the post-earthquake studies of the Spitak earthquake. They reinforced lessons reported by Earthquake Engineering Research Institute (1986) and included:

1. Active faults cannot be ignored in the development of urban centers--Parameters of the fault located near Spitak shaped the characteristics of the ground shaking. The Spitak fault which released the December 7, 1988, earthquake is a reverse or thrust fault that is tectonically related to the much more prominent North Savan fault. Both faults were mapped prior to the earthquake and have late Quaternary displacement. The Spitak fault broke the surface over a distance of 15 km and had nearly 2 m vertical displacement.

2. A community that does nothing to prepare for a damaging earthquake sows the seed of disaster, especially if damaging earthquakes have occurred there in the past--Armenia was unprepared for an earthquake disaster, even though damaging earthquakes had occurred there in the past. In 1967 a magnitude 5.1 earthquake centered near Spitak caused minor damage. The most significant recent event in the area, a magnitude 6.5 earthquake that occurred on May 28, 1926, caused severe damage in Leninakan (formerly known as Alexanderkan).

3. The destructiveness of an earthquake depends on its size, proximity to an urban center, the soil underlying the buildings, facilities, and lifelines in the urban center, and the state-of-preparedness--Villages like Spitak and Stephankan took a "direct hit" in the epicentral region. Leninakan, although 32 km from the epicenter, sustained heavy damage partly because the soil underlying the city amplified the ground motion. This phenomenon was similar in some ways to that experienced in Mexico City in the September 19, 1985, Mexico earthquake (Earthquake Engineering Research Institute, 1988, 1989a).

4. A community is always working against time--The critical time frames are:

   a) seconds for the duration of ground shaking (Spitak probably experienced less than 10 seconds of ground shaking),

   b) minutes for the first occurrence of the aftershock sequence (a magnitude 5.8 aftershock occurred 5 minutes after the main shock, causing collapse of damaged buildings, schools, hospitals, and factories),

   c) hours to a few days for emergency response and search and rescue activities (90 percent of the people rescued from the collapsed buildings were saved in the first 48 hours, mainly by nonprofessionals),

   d) years to decades for development of personal and community preparedness, recovery programs, and an integrated earthquake prediction system (community preparedness was inadequate for the disaster caused by the Spitak earthquake and the societal component of the earthquake prediction sytem was not well developed), and

e) decades to centuries for the seismic cycles of active faults to be completed with recurrent fault rupture and release of moderate-magnitude earthquakes (Armenia has many active faults which have been mapped; determination of their seismic cycle for a range of magnitudes should be accelerated through paleoseismicity studies).

5. Earthquake prediction and warning are of limited value when the societal component is not as well developed as the scientific component--Soviet authorities were advised 3 years earlier by theirscientists of the increased probability of a damaging earthquake in Armenia, but the capability to respond to this warning was lacking when needed.

6. A primary cause of damage to buildings is underestimation of the amplitude, frequency composition, and duration of the ground shaking--The earthquake had an epicentral intensity of MSK IX-X; whereas, the design was for intensity VII, i.e., about one-eighth the actual force level. Neglect of soil amplification led to underestimation of these three parameters of ground shaking in Leninakan. Seismic microzonation mpas for Leninakan should be reevaluated and revised to reflect this experience, incorporating probabilistic mapping techniques.

7. Good quality of construction provides a margin of safty to compensate for uncertainties scientists and engineers face in siting and design--Quality of construction and detailing were poor in Armenia. Modern reinforced concreted frame buildings designed and constructed in the 1970's failed and became death traps primarily because the hollow-core concrete floor plank systems were not constructed and anchored in a way that allowed them to participate with the strucutre in the absorption of energy.

8. Almost all earthquakes produce "surprises" because knowledge about the nature and effects of earthquakes is either lacking or not applied--A damaging earthquake exposes the flaws in:

a) siting and design of structures and lifeline systems,

b) construction practices,

c) emergency response, and

d) personal and community preparedness.

Although the Spitak earthquake was not a surprise in terms of the seismotectonic framework of the region, the disaster showed for the first time: a) the harsh realities of the first 48 hours of search and rescue in a winter environment and the difficulties faced by international search and rescue teams to arrive in the "golden 48-hour period," b) the vulnerability of precast reinforced concrete frame buildings--for which a large inventory still exists in Yerevan (the capital) and in other parts of the Soviet Union, and c) the injury to death ratio, which is typically 3 or 4 to 1, was reversed in the earthquake--creating a major public health problem.

CRITICAL QUESTIONS GUIDING DATA ACQUISITION AFTER FUTURE DAMAGING EARTHQUAKES

The goal of earthquake hazard mitigation is to reduce the destructiveness, morbidity (injuries), and mortality (deaths) associated with future earthquakes, using one or more of the available technical and social strategies. Destructiveness is primarily related to three factors:

- o The magnitude or energy release of the earthquake,
- o the proximity of the earthquake focus to an urban center, and
- o the extent to which mitigation measures have been adopted and implemented through siting, design, and construction practices in the urban center when the earthquake strikes.

Data acquisition should be planned to build a database that quantifies the nature and extent of the earthquake hazards and facilitates the assessment of the risk. To quantify the hazards and risk, data must be collected to answer questions in the following categories (see Figure 1):

1. Deaths, Injuries, and Destructiveness - How did morbidity (injuries), mortality (deaths), and economic losses correlate with the distribution of buildings and facilities in the affected area? What was the state-of-preparedness in the urban area?

2. Failure Mechanisms - For each type of building or facility in the affected urban area, what were the primary and secondary failure mechanisms? Why did some buildings of a specific type not fail?

3. Design and Construction - To what standard (code) was each damaged building designed? When? What was the actual demand on the building? What was the design capacity? During design and construction, what practices were followed to ensure strength, ductility, and redundancy? How was quality controlled?

4. Siting - What physical characteristics controlled the critical design parameters: magnitude, wave attenuation, local soil response for the damaged building or facility?

5. Affected Area - What were the spatial dimensions of the geographic area affected by the earthquake? What geologic, geophysical, and geotechnical paramters controlled them?

6. Severity - How severe were the primary and secondary physical effects in the near- and far-source regions of the earthquake? What geologic, geophysical, and geotechnical parameters controlled them?

7. Impact Time and Duration - How much time was there between the first precursors of the earthquake and its maximum physical effects. How long did the physical effects last?

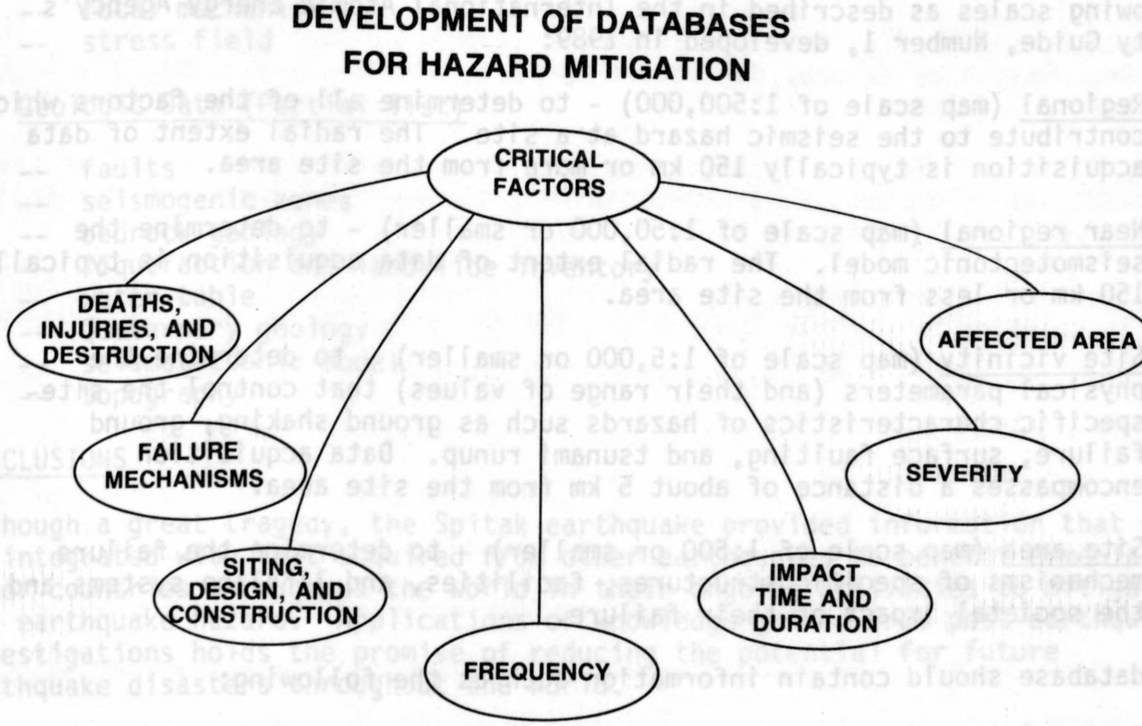

Figure 1. Categories of information that should be collected in worldwide post-earthquake investigations to foster earthquake hazard mitigation.

8. Frequency - How often on the average is an earthquake of this severity expected to occur in this region?

After each damaging earthquake, these data are entered into a database which provides a technical basis for studies to extrapolate the lessons to other locations and other events.

DATABASE

The quantity and quality of the technical data in the database are the two most important factors that facilitate its use in studies to foster earthquake hazard mitigation. If the database is complete and the studies are integrated, mitigation strategies can be implemented rapidly with minimalcontroversy. The technical database should be developed on the following scales as described in the International Atomic Energy Agency's Safety Guide, Number 1, developed in 1989:

Regional (map scale of 1:500,000) - to determine all of the factors which contribute to the seismic hazard at a site. The radial extent of data acquisition is typically 150 km or more from the site area.

Near regional (map scale of 1:50,000 or smaller) - to determine the seismotectonic model. The radial extent of data acquisition is typically 150 km or less from the site area.

Site vicinity (map scale of 1:5,000 or smaller) - to determine the physical parameters (and their range of values) that control the site-specific characteristics of hazards such as ground shaking, ground failure, surface faulting, and tsunami runup. Data acquisition encompasses a distance of about 5 km from the site area.

Site area (map scale of 1:500 or smaller) - to determine the failure mechanisms of specific structures, facilities, and lifeline systems and the societal impact of their failure.

The database should contain information such as the following:

o Societal Data (partial list)

- deaths and injuries
- homeless
- economic losses
- loss of function
- political and legal considerations
- cultural (museum, art, architectural losses)

o Engineering Data (partial list)

- construction data
- damage distribution for each class of buildings
- building plans
- building codes

- o Engineering Seismology data (partial list)
  - -- building and free field strong ground motion records
  - -- geologic properties of the building foundation
  - -- isoseismal map
  - -- microzonation maps
- o Seismological Data (partial list)
  - -- seismicity
  - -- seismic wave propagation
  - -- soil response
  - -- seismicity
  - -- focal mechanism
  - -- stress field
- o Geologic Data (Partial list)
  - -- faults
  - -- seismogenic zones
  - -- bedrock geology
  - -- liquefaction and landslide inventory
  - -- water table
  - -- Quaternary geology
  - -- seismotectonic model
  - -- topography

CONCLUSIONS

Although a great tragedy, the Spitak earthquake provided information that can be integrated with that acquired from other earthquakes to benefit Armenia and other countries throughout the world in their ongoing activities to mitigate the earthquake hazard. Applications of knowledge gained from post-earthquake investigations holds the promise of reducing the potential for future earthquake disasters throughout the world.

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EARTHQUAKE CASUALTIES: A CONCEPTUAL FRAMEWORK AND INTERDISCIPLINARY APPROACH

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INTRODUCTION

The subject of earthquake casualties is both important and urgent. Although earthquake studies are of recent historic origin, much progress has been made on the scientific and physical aspects. The emphasis on death and injury, their prediction, field study, economic impacts, and planning for direct mitigation and prevention have visibly lagged behind. Thousands of human lives are at stake as well as billions of dollars. Progress in this area will take time, and time is both lives and money.

Probably more than in most other earthquake related areas of study we are dealing here with a subject that requires an effective interdisciplinary approach. Not only are a great number of separate disciplines involved, with quite distinct and varied paradigms, but the need is for integrated cooperation and emphasis rather than just input from the various fields. The problem of "earthquake casualties", beyond considerations of physical injury and death and their medical consequences, involves questions of seismology, the engineering of the built environment, the nature of both the physical and the sociological environments, aspects of personal and group psychology and behavior, economic short and long term issues, as well as many planning and preparedness aspects. Injuries are both physical and psychological and by virtue of their numbers have a significant impact on the particular community and society. The interdisciplinary team must not only contain representatives from the various disciplines but must be trained and capable of working together effectively and with a common base of agreement on objectives and methods.

This paper will discuss examples of interdisciplinary activities involved in dealing with earthquake casualties, the key players involved in these activities, and a conceptual framework for this complex problem.

THE INTERDISCIPLINARY ACTIVITIES

The interdisciplinary nature of this problem is reflected in the details of its many activities. Examples include the following:

(1) Vulnerability studies, estimates of predicted risks before the event, require the cooperation of many specialists and suffer significantly from the lack of hard and reliable data on some aspects in the chain of events. As these become available, vulnerability studies will need to be iterated and upgraded.

(2) Collection of earthquake injury data and its analysis and interpretation need the collective efforts of researchers from a number of disciplines. A conceptual model is required reflecting the many concerns and a systems approach. Data collection from many earthquakes is needed in order to understand the influence of changes in physical location, cultural and societal variables, and the characteristics of earthquakes including the time and season of their occurrence.

(3) The planning and execution of injury mitigation efforts are again activities requiring interdisciplinary cooperation. Their effectiveness will depend to a great extend on the quality of such cooperation.

(4) Since behavior during an earthquake, irrespective of the environment in which one

finds oneself, can be a decisive factor in either causing or preventing injury, education and training can play a significant role. These should be based on an interdisciplinary input reflecting an understanding of likely behavior under different circumstances, their likely consequences and the means of achieving desired behavior modification.

(5) Planning for adequate disaster response with respect to injuries requires close collaboration between the providers of medical care after the event and those disciplines engaged in studying the likely characteristics of the earthquake and its various consequences.

(6) In order for search and rescue operations to be most effective they should be both planned and executed in a comprehensive manner and with full interdisciplinary input. For example, knowledge of the prior training and the likely behavior of people in a particular earthquake and physical environment may enhance the likely success of a rescue operation.

(7) A variety of earthquake policy issues related to injuries, which require governmental actions, need the involvement and cooperation of the full spectrum of relevant disciplines.

THE KEY PLAYERS

Many disciplines need to be involved in this problem. It requires both specific specialty and the desire and ability of cooperating as members of a large team with many overlapping smaller groups. Some of the key players include the following:

(1) Seismologists and earth scientists deal with their own basic research and at the same time may be called upon to respond to some special questions raised by others.

(2) Epidemiologists and medical practitioners play an obvious role. So do people in emergency medicine who need to apply their expertise to the special problems related to earthquakes.

(3) The design professionals, engineers, architects and interior designers, create the built environment which may contribute to injury and death. Beyond the obvious role of structural engineers in designing seismically safe structures, the work of other engineering specialties, mechanical, electrical, etc., influences potential earthquake injuries. All designing professionals can contribute to a built environment which decreases the probability of injury and maximizes the chances of survival and rescue if a failure should occur. This can be best achieved by suitable interdisciplinary endeavors.

(4) Economists and financial experts dealing with the general economic impact of injuries, as well as with the specific impact on medical facilities, services, and insurance institutions can play a significant role in both planning for an earthquake disaster and in influencing appropriate public policy.

(5) Behavioral scientists, sociologists, psychologists and educators, have a lot to contribute in predicting, explaining, and possibly modifying undesirable behavior which may lead to death and injury.

(6) Planners, experienced in dealing with large physical and societal systems as well as those with more specific interests, are very valuable in providing the glue that brings together various participants in an interdisciplinary endeavor.

The consideration of the interaction between disciplines may also serve as a tool of focussing and identifying issues of importance.

A CONCEPTUAL FRAMEWORK

The need exists for some model, or conceptual framework, which is at the same time comprehensive, simple, and flexible. In dealing with complex problems, conceptual models can be useful and stimulating tools for better understanding and analysis. The proposed conceptual framework is shown in Figure 1, inspired by a similar matrix used in the problem of preventing motor vehicle crash injuries (Haddon, 1980; Kraus, 1981).

Figure 1: Conceptual Framework for Earthquake Casualties

PHASES	FACTORS: Human	Physical	Socio-Economic	Circumstantial
Pre-Event (EQ)				
Earthquake				
Recovery				
Long Range				

The model uses four fundamental phases of general applicability to earthquakes: the pre-earthquake, earthquake, recovery, and long range phases. Within each phase, in focusing on casualties, we can consider four groups of factors which influence death and injury in various ways; namely human, physical, socio-economic, and circumstantial factors. Each of the 16 phase-factor interactions represents an area of specific sets of concerns within the comprehensive picture of the matrix as a whole. The phases also remind us of the "continuing" aspect of earthquake casualties. Beyond the obvious casualties during the event, injuries can and do occur during the recovery period that are earthquake-related, and there is evidence of long range psychological and emotional injury, as well as some physical ones. The long range phase merges into the pre-earthquake phase for the next event, with particular significance when a seismic gap is identified, or another reason arises for an earthquake warning or prediction.

Hopefully, the conceptual framework will serve some useful purpose in that it should facilitate identifying the various roles the interactions play in mitigating and preventing casualties. Let us exemplify some interactions by discussing a number of issues.

The **human factors** include personal characteristics such as age, sex, state of health, etc. At the **pre-earthquake phase** they affect personal preparedness planning and receptivity for training towards greater protection from injury. During the earthquake they influence behavior and the probability of either greater safety or increased likelihood for death and injury. For example the starting and propagation of fires, with subsequent injuries, during both the **earthquake and early recovery phases**, are due to a combination of both human and other factors. **Human factors** during the **recovery phase** would impact the medical problems of the homeless, another aspect of earthquake related injuries. Also, **human factors**, including curiosity and lack of discipline, contribute to tsunami losses, sometimes at great distances from the epicenter. One example is the 11 deaths at Crescent City, California, in 1964, due to the tsunami generated by the Alaskan earthquake hours earlier. **Long range - human factors** interactions influenced by physical and circumstantial histories are, for example, the prevailing attitudes that exist about specific earthquake dangers. While fires have occurred during U.S. earthquakes (Aroni, 1971; Aroni, 1987), with 1906 San Francisco being the major example, the predominant fear is of building and other collapses. This is in contrast to Japan, where the fear of earthquakes is dominated by the fear of fire. An obvious explanation for the Japanese reaction is their past repeated experience, for example the Kanto earthquake of 1923, when the majority of the 90,000 deaths were caused by fire (Arnold, 1982).

Physical factors include all the characteristics and variability of the built environment, as well as those of local and regional seismicity. These factors obviously have a major impact on casualties and are important for the considerations appropriate for each of the four phases. Included in the **physical factors** are non-structural elements, as well as building contents.

The **socio-economic factors** are a large group including institutional factors, cultural aspects, and the variability of circumstances of families, communities and regions, all of which affect issues of injury at the different phases. During the **pre-earthquake phase** they are relevant for considerations of planning, preparedness and education. The performance of social organizations, for example hospitals and the various industrial and work environments during all earthquake phases can have a major impact on casualties. Social roles and relations as well as human characteristics among those in the same location during the **earthquake phase** may account for one person being injured and another not. For instance, in the Coalinga earthquake, a husband who left his living room to exit the house directly through the front door was uninjured while his wife who left the same living room to exit circuitously through the kitchen was injured by broken glass. The wife was seeing to her children who were in the backyard playing (Aroni and Durkin, 1985). In the **recovery phase socio-economic factors** are also important in providing the needed organization and resources, including those for the homeless, and in making a difference to the health of individuals.

Finally, the group of **circumstantial factors**, for example the time and season of the earthquake, can have a profound influence. In the United States, so far, we have been very lucky with respect to the timing of damaging earthquakes. The 1933 Long Beach earthquake, which caused extensive damage to pre-Field Act school buildings, occurred at 5:45 in the afternoon when the schools were empty (Millikan, 1933). The 1964 Alaska earthquake, although 8.4 in magnitude, struck a sparsely populated area in the late afternoon of Good Friday when offices and commercial establishments were closed in the heavily damaged downtown Anchorage. The death toll of the 1971 San Fernando earthquake certainly would have been considerably higher if the event had occurred three hours later, when between 100 and 300 staff and patients would have occupied the first story of the Olive View Hospital

Psychiatric building, which was crushed during the earthquake, and in the areas of the main hospital which were destroyed by the collapsed stairway towers (Johnston and Strand, 1973).

As far as the season of the earthquake is concerned, major secondary sources of casualties and damage associated with California earthquakes are landslides and dam failures, primarily in winter and spring, and uncontrolled fires, primarily in summer and fall (U.S. Geological Survey, 1981).

In conclusion, it seems that much work needs to be done, in many earthquake prone countries, to provide the understanding and the empirical data required to answer the many questions raised by the conceptual framework. The important challenge of saving lives and decreasing injury in earthquakes requires significant interdisciplinary work and makes the contribution of each particular single profession essential but otherwise unimportant.

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STATUS OF MEDICAL INPUTS IN VULNERABILITY STUDIES CONDUCTED BY U.S. FEDERAL AND STATE AGENCIES

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INTRODUCTION

In the U.S., earthquake vulnerability studies sponsored by Federal and State Agencies for metropolitan centers located in areas of high seismic risk are a relatively recent development. These studies typically determine the estimation of: (1) Damage/functional impairment to critical emergency services and lifelines, (2) Dollar loss, (3) Homeless, and (4) Deaths and injuries, following a major seismic event. In the U.S., the first attempt to develop a comprehensive vulnerability study, "A Study of Earthquake Losses in the San Francisco Bay Area", was initiated in 1971 by the National Oceanic and Atmospheric Administration (NOAA) for the Office of Emergency Preparedness (OEP), and published in 1972. Since then, at least 19 additional vulnerability studies have been sponsored by Federal and State agencies for other selected regions throughout the U.S., while two others sponsored by FEMA are in preparation for the areas of Boston and St. Louis. (See Bibliography Index attached.)

GENERAL CHARACTERISTICS OF VULNERABILITY STUDIES

Typically, an earthquake vulnerability study represents a technical product developed as an interdisciplinary team effort by experienced professionals in a pre-earthquake estimation of damage and casualties anticipated on a regional basis. It's primary objective is to realistically determine for planning purposes the anticipated impact that a major damaging earthquake will have on a specific urbanized region identified as the "study area". The study area selected for analysis may vary in size depending on the cohesiveness of a specific region, its seismic exposure, and relationship to an active fault zone or zones. For example, the MATCOG/MDDD study completed in 1974 in the New Madrid seismic belt area as referenced in Table 1 covered an area which spanned parts of three states: Mississippi, Arkansas, and Tennessee. Other studies are smaller in size, some with study areas limited to one or two counties within a state.

The fundamental purpose of vulnerability studies is to produce a document which can be used for planning purposes, either as a tool for preparedness planning prior to the earthquake event and/or emergency response planning for recovery after the event. As such, most studies present a planning scenario which as closely as possible mirrors what losses and casualties could be anticipated in building facilities, lifelines, medical services, and populations when impacted by a major earthquake within the study area. Seismic intensity distribution maps are normally included for a particular scenario earthquake. Accordingly, vulnerability studies may typically carry a statement that the earthquake impacts reported, including damage assessments and scenario maps, are intended "for planning purposes only".

Paramount to the development of the vulnerability study is the formulation of anticipated seismic intensity levels based on geological and seismological data of the region. Equally important is the development of a building inventory as a data base representation of the existing building stock located in the study area. Typical data included in the building inventory contains such characteristics as: building type, class of construction, age (date of construction), size, location, building function and occupancy, all or parts of which influence building performance under forces generated by an earthquake. Since building code standards are not retroactive, the age, or date of construction of the building, is particularly important as it could result in the classification of the building as an older, existing hazardous structure with a high casualty and life loss exposure.

TIME VARIABLES IN ESTIMATION OF EARTHQUAKE CASUALTIES

It is important in conducting vulnerability studies to recognize that life loss and injuries sustained during an earthquake vary according to the time of day and season of the year that the event takes place. Historic records clearly indicate that casualty patterns change according to where persons are located at the time of the seismic event, in either an indoor or outdoor environment. For example, at 2:30 a.m. it is expected that the general population would be at home, while at 2:00 p.m. most people would be at work or school. Each of the two time periods indicated would have the general population occupying a different building type with a different structural system subject to a different performance expectation.

On the other hand, another critical time would be at 4:30 p.m. which represents the start of the "rush hour" when many would be travelling in their cars or outside as a pedestrian during a peak travel period of the day. To make it even more complex, it is noted that patterns of earthquake casualties also change according to the time of year, for example, a dry, warm summer period versus a cold, wet rainy/snowy winter. In estimating earthquake casualties, it is imperative that such variables be taken into account. Several of the vulnerability studies reviewed used the three time periods indicated above as the basis for the estimation of three sets of figures representing anticipated deaths and injuries at these critical hours.

REVIEW AND ASSESSMENTS

Early studies were developed to determine the extent of the demands to be placed on medical resources and facilities, including major acute hospitals, blood banks, clinical laboratories, nursing homes, medical supplies, ambulance services and medical personnel, and their response in a severe earthquake. Earthquake effects on immediate and vital public needs were also analyzed as a means of determining how response efforts could be unexpectedly modified.

While damage estimates for buildings and lifelines are at an acceptable level, it is generally agreed that in all vulnerability studies issued to date, estimated figures for deaths and injuries are of less credibility, primarily because of the lack of medical input. In some cases, hospitalized injuries are simply established at a 4 to 1 ratio of deaths based on historic records, and non-hospitalized injuries calculated at an 8 to 1 ratio. Some of the studies developed more recently do not even attempt to include estimations of casualties, principally due to lack of medical back-up, sufficient performance data, and accurate building inventories. Table 1 presents a compilation of casualty data, or lack of, reported in 20 vulnerability studies conducted by U.S. Federal and State agencies and lists the sources for such data.

CONCLUSIONS AND RECOMMENDATIONS

Based on these findings, it is recommended as a major step forward in the development of future vulnerability studies that medical professionals be included in the multidisciplinary team involved in the study and derivation of casualty data. Compared to other countries, 1976 Tangshan earthquake with 250,000 deaths, 1985 Mexico earthquake in Mexico City with 20,000 deaths, and 1988 Armenia earthquake with 25,000 deaths, historic data in the U.S. are inadequate and require the sharing and transferability of world-wide intelligence on the development of an earthquake casualty data-base for input into future vulnerability studies.

To carry-out the advancement of vulnerability studies in the estimation of life loss and injuries at the international level, it is further recommended that suitable efforts be implemented to:

(1) Assess compatible methods on an international level to include input from the medical profession in the estimation of life loss and injuries due to earthquake.

(2) Propose appropriate international guidelines for the development of earthquake vulnerability studies.

(3) Establish a comprehensive international data-base record of all earthquake casualties reported for use in future studies.

(4) Encourage each country to conduct a comprehensive earthquake vulnerability study at an appropriate government level for one of its regions located in a high risk seismic area as a cooperative earthquake hazards mitigation goal and for response planning purposes during the International Decade.

Table 1

ESTIMATES AND DATA SOURCES OF EARTHQUAKE DEATHS AND INJURIES REPORTED IN U.S. VULNERABILITY STUDIES BY U.S. FEDERAL AND STATE AGENCIES

Source	Year	Study Area	Fault Zone	Casualties* Deaths	Injuries
NOAA	1972	SFO Bay Area, CA	San Andreas	10,360	40,360
			Hayward	6,650	24,900
NOAA	1973	LAX Co. Area, CA	San Andreas	11,190	44,760
			Newport-Inglewood	18,858	75,432
		Orange Co, CA	San Andreas	1,195	4,780
			Newport-Inglewood	1,870	7,480
MATCOG/MDDD	1974	3 State Area, MW(1)	New Madrid Belt, etc.	1,100	4,400
USGS	1975	Puget Sound, WA(2)	Seattle Epicenter	2,170	8,680
			Olympia/Tacoma Epic.	2,030	8,120
USGS	1976	Salt Lake City(3)	Wasatch	1,930	7,720
			Magna	1,872	7,488
SSAC	1979	State of Utah(4)	Wasatch/Cache Valley	19	289
NSF	1979	Midwest Res. Inst.	New Madrid	646	64,567
FEMA	1979	State of Hawaii	All Islands	86	345
ADES	1980	Anchorage, AK(5)	Knik, Castle Mt.	35	265
FEMA	1980	Anchorage, AK(6)	Knik, Castle Mt.	144	176
FEMA	1980	State of Calif.	North San Andreas	11,000	44,000
			Hayward	8,000	30,000
			South San Andreas	14,000	55,000
			Newport-Inglewood	23,000	91,000
USGS	1981	SFO/LAX/Orange, CA	North San Andreas	11,370	44,340
			Hayward	3,380	10,550
			South San Andreas	12,495	49,980
			Newport-Inglewood	20,755	83,020
DMG	1982	LAX Area, CA	San Andreas	(Not Reported)	
FEMA	1982	Oahu/Honolulu, HI	In Zone 2 Area	375	775
DMG	1982	SFO Bay Area, CA	San Andreas	(Not Reported)	

Table 1 (continued)

FEMA	1985	Central U.S.(7)	New Madrid	4,907	19,590
USGS	1985	LAX Region, CA	(All Potential)	(Not Reported)	
DMG	1987	SFO Bay Area, CA	Hayward	4,400	13,200
FEMA	1988	Charleston, SC(8)	Woodstock/Ashley, etc.	2,143	8,574
DMG	1988	LAX Area, CA	Newport-Inglewood	(Not Reported)	

NOTES:

* Exclusive of dam failure, casualty figures based on: (1) maximum estimated casualties, (2) maximum credible postulated earthquake for the study area, and (3) most critical time of day and/or night. Injury data indicate hospitalized (major) injuries only.

(1) 3 State Midwest Study Area: Mississippi (DeCoto Co.), Arkansas (Crittenden Co.), (Shelby Co.) Tennessee.

(2) 6 County Area, Washington: Snohomish, King, Pierce, Thurston, Mason, Kitsap.

(3) 4 County Area, Utah: Weber, Davis, Salt Lake, Utah.

(4) 100-year death and injury figures limited to hospital and nursing home populations only.

(5) Casualty figures limited to local medical facility populations, and include potential activity on Aleutian Megathrust Fault Zone.

(6) Casualty figures represent all injuries, and include any potential of acivity on Aleutian Magathrust Fault Zone.

(7) Six cities: Carbondale, Evansville, Little Rock, Memphis, Paducah, and Poplar Bluff.

(8) Tri-County Area, S. Carolina: Charleston, Berkeley, Dorchester

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BY U.S. FEDERAL AND STATE AGENCIES
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WALTER W. HAYS is Deputy Chief for Research Applications in the U.S. Geological Survey's Office of Earthquakes, Volcanoes, and Engineering. Since 1977, and after 16 years as an educator and a research engineering seismologist, he has been responsible for fostering research applications and loss reduction throughout the United States. On behalf of UNESCO, he participated in earthquake engineering programs in Algeria and Jordan. Through USGS's international activities, he contributed to scientific programs in Spain, Italy, Japan, China, Argentina, Switzerland, Austria, and the Soviet Union. He participated in the formative phases of the International Decade for Natural Disaster Reduction. A former Director of the Earthquake Engineering Research Institutes, Dr. Hays chairs its Committee on Continuing Education, which has worldwide activities. He has published more than 100 papers, books, and reports.

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KARL V. STEINBRUGGE is a Structural Engineer and Consultant on Earthquake Loss Estimation. He has served as past chairman of the California Seismic Safety Commission, past president of the Earthquake Engineering Research Institute, and past president of the Seismological Society of America. He has been a consultant to Federal and State government on earthquake loss estimations for over 30 years and has authored and co-authored over 100 papers and studies on earthquakes, earthquake damage and losses, and earthquake loss estimation (monetary and casualties).

KATHLEEN J. TIERNEY has been involved in social science research on disasters since 1974. She held an appointment at Adjunct Assistant Professor the Institute of Safety and Systems Management, University of Southern California before she began her tenure at the Disaster Research Center at the University of Delaware. She has served as a consultant to the California Seismic Safety Commission, the Southern California Earthquake Preparedness Project, and the California Specialized Training Institute and has participated in the development of a training course on earthquake hazards for the Federal Emergency Management Agency's National Emergency Training Center. Her publications on earthquake and emergency management issues include Report on the Coalinga Earthquake of May 2, 1983 (California Seismic Safety Commission , 1985), "Emergency Medical Preparedness and Response in Disasters: The Need for Interorganizational Coordination" (Public Administration Review, 1985), and Physical Disability and Earthquake Hazard Mitigation (University of Colorado). Ms. Tierney earned a Ph.D. in Sociology from Ohio State University, where she spent 5 years as a Research Associate at the Disaster Research Center. She is a member of the American Sociological Association, the International Sociological Association's Research Committee on Disasters, and the Earthquake Engineering Research Institute.