Earthquakes and the Urban Environment

Volume I

Author

G. Lennis Berlin

Earthquakes and the Urban Environment

Volume I

Author

G. Lennis Berlin
Associate Professor
Department of Geography
Northern Arizona University
Flagstaff, Arizona

CRC Press, Inc.
Boca Raton, Florida

Library of Congress Cataloging in Publication Data

Berlin, Graydon Lennis, 1943-
Earthquakes and the urban environment.

Bibliography: p.
Includes index.
1. Earthquakes. 2. Earthquakes and building.
I. Title.
QE539.B48 551.2'2 77-16131
ISBN 0-8493-5173-1

Direct all inquiries to CRC Press, Inc., 2000 N.W. 24th Street, Boca Raton, Florida, 33431.

International Standard Book Number 0-8493-5173 (Volume I)
International Standard Book Number 0-8493-5174 (Volume II)
International Standard Book Number 0-8493-5175 (Volume III)

Library of Congress Card Number 77-16131
Printed in the United States

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to the many people who contributed substantially to the creation of this book. The entire manuscript was reviewed by James R. Underwood, Jr., Chairman-Department of Geology, Kansas State University and John Kelleher, Seismologist, U.S. Nuclear Regulatory Commission. Their authoritative criticisms and suggestions are largely responsible for any success of this book. Because it was not possible to make all the changes suggested, the author is solely at fault for any errors or omissions that may remain. The following individuals reviewed portions of the manuscript related to their research specialities: Jack Barrish (Jack Barrish Consulting Engineers), James H. Dieterich (U.S. Geological Survey), Ajit S. Virdee (California State University at Sacramento), James H. Whitcomb (California Institute of Technology), and Peter I. Yanev (URS/John A. Blume & Associates, Engineers). The many individuals who provided photographs vital to the completion of this book are acknowledged in the figure captions.

Two colleagues at Northern Arizona University deserve special thanks. Dominic J. Pitrone provided countless constructive suggestions and invaluable data collection assistance, and Howard G. Salisbury, III, Chairman-Department of Geography and Planning, was untiring in his efforts to accommodate my many special requests. Cartographic assistance was provided by Michael Schramm and Nat Garcia. Carolyn Waller and Virginia Hall typed the entire manuscript.

The talented editors at CRC Press, namely Sandy Pearlman, Jeffrey Eldridge, Terri Weintraub, Beth Frailey, Barbara Perris, and Gayle Tavens, contributed a great deal to the refining of much of the text. These individuals also were most understanding concerning the many delays caused by the author.

My grateful thanks go to my wife Judy for her encouragement and forbearance over the several years that it took to complete this project.

Graydon Lennis Berlin
Flagstaff, Arizona
November 1978

THE AUTHOR

Graydon Lennis Berlin was born in St. Petersburg, Pennsylvania, on May 21, 1943, and educated in the public schools there. He received a B.S. degree in 1965 from Clarion State College (Earth-Space Science), an M.A. degree in 1967 from Arizona State University (Geography), and a Ph.D. degree in 1970 from the University of Tennessee (Geography). He began his educational career in 1968 as an Assistant Professor of Geography and Research Associate at Florida Atlantic University. He joined the faculty at Northern Arizona University in 1969, attaining the rank of Associate Professor of Geography in 1975. Between 1969 and 1978, Dr. Berlin was also a Research Geographer on a part time basis with the U.S. Geological Survey. At the present time he is the Director of the Advanced Training of Foreign Participants in Remote Sensing Program, a joint venture of Northern Arizona University and the U.S. Geological Survey.

Dr. Berlin is a member of several national professional organizations and was elected Chairman of the Geography Division of the Arizona Academy of Science in 1974. He is also a member of Gamma Theta Upsilon, the National Professional Geographic Fraternity and a Full Member of Sigma Xi, the Scientific Research Society of North America. Dr. Berlin is a biographee in American Men and Women of Science, Who's Who in the West, and the Dictionary of International Biography. He is the author of more than 30 journal articles and government reports.

TABLE OF CONTENTS

Chapter 1
Introduction and Overview 1
I. Nature of the Book 1
II. Severity of the Problem 1

Chapter 2
Earthquake Parameters 13
I. Cause of Earthquakes 13
II. Elastic Rebound Theory 14
III. Measurement of Crustal Strain 17
IV. Fault Parameters 18
V. Fault Creep 28
VI. Seismic Waves 31
VII. Seismic Instrumentation 42
VIII. Seismic Networks 49
IX. Earthquake Descriptors 54
A. Magnitude 54
1. Magnitude Misunderstandings 61
2. Magnitude and Energy 62
3. Magnitude and Faulting 64
4. Foreshocks, Aftershocks, and Swarms 66
5. Earthquake Frequency 67
B. Intensity 70
1. Intensity Scales 70
2. Data Gathering and Compilation 75
3. Isoseismal Maps 80
4. Empirical Relationships 81
5. Proposed Terminology 82
C. Seismic Data Collection, Analysis, and Dissemination 83
X. Plate Tectonics 86
A. A Mobile View of the Earth 89
B. Future Plate Positions 116
C. Driving Mechanism(s) 116
D. Earthquake Geography 116
E. Intraplate Earthquakes 136

Chapter 3
Earthquake Hazards 141
I. Introduction 141
II. Direct Hazards 141
A. Fault Displacements 141
B. Tectonic Uplift and Subsidence 153
C. Ground Shaking 156
III. Induced Hazards 167
A. Ground Failure 167
1. Slope Failures 167
2. Compaction 181
3. Quick Condition Failures 183

B. Tsunamis 184
1. Tsunami Characteristics 185
2. Tsunami Geography and Historical Tsunamis 187
3. Tsunami Warning Systems 191
C. Seiches 193
D. Fire 195

IV. Multiple Earthquake Hazards 200

Index 203

Chapter 1

INTRODUCTION AND OVERVIEW

I. NATURE OF THE BOOK

Earthquakes have been an integral component of the geologic evolution of planet earth. Since the dawn of history, mankind has been continually reminded of their ruinous power, usually without warning. Although the first attempt to fully document a seismic event and its effects probably occurred in 1755 following the great earthquake in Lisbon, Portugal, scientific earthquake research is mainly a product of the 20th century. Because of the complex nature of earthquake effects, current investigations encompass many disciplines, including those of both the physical and social sciences. Research activities center on such diversified topics as earthquake mechanics, earthquake prediction and control, the prompt and accurate detection of tsunamis (seismic sea waves), earthquake-resistant construction, seismic building code improvements, land use zoning, earthquake risk and hazard perception, disaster preparedness, plus the study of the concerns and fears of people who have experienced the effects of an earthquake.

Data from these investigations help to form an integrated picture of a most complex field of study that Berlin[1] termed *urban seismology.** This monograph attempts to amalgamate recent research input comprising the vivifying components or urban seismology at a level useful to those having an interest in the earthquake and its effects upon an urban environment. However, because some of those interested in the earthquake-urban problem may not have a strong background in the physical sciences, Chapter 2 is devoted to an examination of major earthquake parameters.

II. SEVERITY OF THE PROBLEM

> One of the greatest geotectonic events of our time occurred in southern Alaska late in the afternoon of March 27, 1964. Beneath a leaden sky, the chill of evening was just settling over the Alaskan countryside. Light snow was falling on some communities. It was Good Friday, schools were closed, and the business day was just ending. Suddenly without warning half of Alaska was rocked and jarred by the most violent earthquake to occur in North America this century.
>
> This earthquake has become renowned for its savage destructiveness, for its long duration, and for the great breadth of its damage zone. Its magnitude has been computed by the U.S. Coast and Geodetic Survey as 8.3—8.4 on the Richter scale. Few earthquakes in history have been as large. In minutes, thousands of people were made homeless; 114 lives were lost; and the economy of the entire State was disrupted. Seismic sea waves swept the Pacific Ocean from the Gulf of Alaska to Antarctica; they caused extensive damage in British Columbia and California and took 12 lives in Crescent City, California and 4 in Oregon. Unusually large waves, probably seiches, were recorded in the Gulf of Mexico. The entire earth vibrated like a tuning fork.[2]

This quotation describes, in general terms, several of the dreaded characteristics of an earthquake. Unlike other rapidly occurring natural hazards, earthquakes usually strike without warning or regard to time of day or season of the year and are characterized by numerous direct effects (e.g., ground shaking and permanent crustal movements) and induced effects (e.g., landslides, avalanches, ground subsidence, liquefaction, ground fissuring, tsunamis, seiches, and fire). Earthquakes can kill, injure, and cause property damage thousands of kilometers from their point of origin. Earthquakes are often perceived, although incorrectly, as a force capable of destroying the

* From the Greek *seismos* for earthquake and *logos* for science.

very foundation of the planet, which helps to explain the feeling of fear and helplessness that transgresses all elements of society.

The 1964 Alaska earthquake is atypical in the respect that it did not result in the unusually high death count that can result from seismic events. Hansen and Eckel[2] explain why Alaska was so fortunate.

> Less violent earthquakes have killed many more people. The reasons are many: The damage zone of the Alaskan quake has a very low population density; much of it is uninhabitated. In Anchorage, the one really populous area in the damage zone, many modern buildings had been designed and constructed with the danger of earthquakes in mind.
>
> The generative area of the earthquake was also sparsely inhabited . . . destructive short-period vibrations presumably were attenuated to feeble amplitudes not far from their points of origin. Most residential buildings, more-over, were cross-braced wood-frame construction, and such buildings usually fare well in earthquakes.
>
> The timing of the earthquake undoubtedly contributed to the low casualty rate. It was a holiday; many people who would otherwise have been at work or returning from work were at home. Schools were closed for the holiday. In coastal areas the tide was low; had tides been high, inundation and destruction by sea waves would have been much more severe.

Other areas have not been as fortunate as Alaska. Recorded history has repeatedly been witness to the devastation of cities (Figures 1 and 2) and the killing of millions. As a conservative estimate, the death count for all seismic events most probably exceeds 5,000,000, and injuries would be in the tens of millions. China has lost more than 2,100,000 of its citizens; Japan more than 500,000; Italy more than 370,000; and India more than 350,000.

Table 1 lists major earthquakes and death counts from 856 through 1977. The largest loss of life was associated with the Shensi, China (now People's Republic of China) earthquake of 1556, in which approximately 830,000 lives were lost. This count compares to some 600,000 American deaths incurred in all wars and ranks as the third worst natural disaster in the history of humanity. It is preceded only by the 1931 Yellow River, China flood (3,700,000 deaths) and the 1970 Ganges Delta and Bangladesh cyclonic storm (more than 1,000,000 deaths). The second most disastrous earthquake also occurred in the People's Republic of China. The July 28, 1976 Hopei Province event reportedly killed approximately 655,000 people and injured more than 700,000. The third most catastrophic seismic event was the 1737 Calcutta, India earthquake which killed more than 300,000 people. Seven earthquakes have been responsible for 100,000 or more deaths.

The U.S. has been very fortunate in terms of lives lost as compared to other countries with an earthquake hazard (Table 2). Our worst seismic disaster was the 1906 San Francisco earthquake through which at least 700 lives were lost. The death count for all destructive U.S. earthquakes is less than 1700 (Table 2), with property damage totaling about 1.9 billion dollars (Table 3). It is probable, however, that our worst seismic disasters are ahead of us. Details for selected damaging earthquakes in the U.S. are described in Appendix A.

In certain years, the greatest loss of life from natural hazards is attributable to the earthquake. However, on the average, approximately 10,000 lives are lost each year to this hazard. For the period from 1947 to 1967, Saarien[3] ranked earthquake casualties third behind flood and hurricane deaths. Approximately 56,000 people were killed by earthquakes during this 20-year period. However, earthquake-attributable deaths for 1976 surpassed 690,000 (Table 1).

The urban development of the U.S. is a very recent phenomenon when compared to other countries which have seismic risks; this helps explain why so many countries have a long history of great loss of life caused by devastating earthquakes. Countless cities in these countries have occupied unsafe sites for centuries, and periodically they

FIGURE 1. Aerial photograph of downtown Managua, Nicaragua following the December 23, 1972 earthquakes, depicting complete destruction for many city blocks and smoldering rubble in the area of heaviest damage. Approximately 75% of the city was leveled to rubble. (From Lander, J. F. and von Hake, C. A., *Earthquake Inf. Bull.*, 5, 9, 1973.)

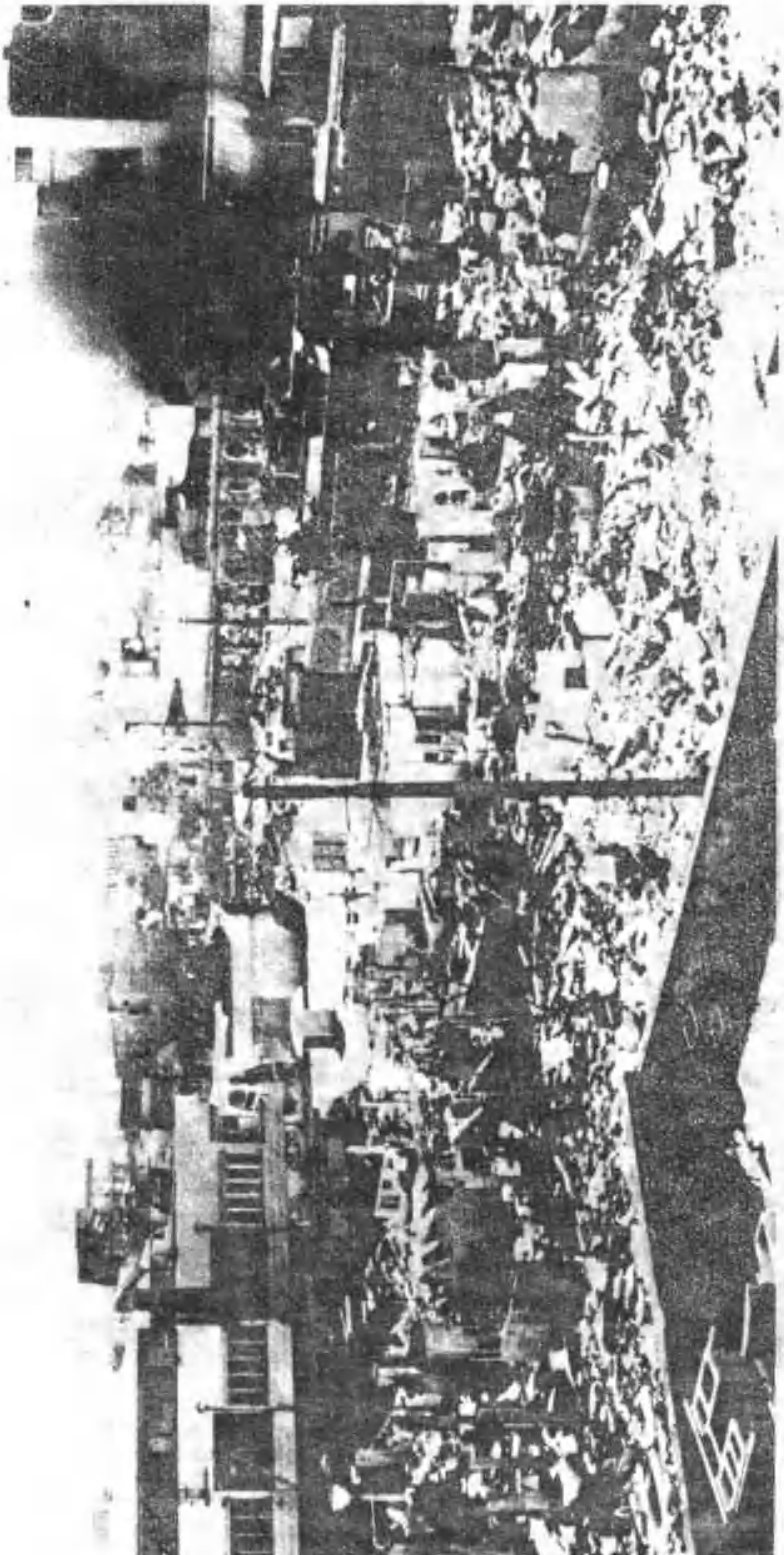

FIGURE 2. Ground view showing devastation of a downtown area of Managua, Nicaragua following the December 23, 1972 earthquakes. (Courtesy of James L. Ruhle and Associates, Fullerton, Calif.)

TABLE 1

Earthquakes Resulting in Major Loss of Life

Year	Locality	Deaths
856	Corinth, Greece	45,000
1038	Shensi, China	23,000
1057	Chikli, China	25,000
1170	Sicily	15,000
1268	Silicia, Asia Minor	60,000
1290	Chikli, China	100,000
1293	Kamakura, Japan	30,000
1456	Naples, Italy	60,000
1531	Lisbon, Portugal	30,000
1556	Shensi, China	830,000
1667	Shemaka, Caucasia	80,000
1693	Catania, Italy	60,000
1693	Naples, Italy	93,000
1731	Peking, China	100,000
1737	Calcutta, India	300,000
1755	Northern Persia	40,000
1755	Lisbon, Portugal	60,000
1759	Baalbek, Lebanon	30,000
1783	Calabria, Italy	50,000
1797	Quito, Ecuador	41,000
1819	Cutch, India	1,543
1822	Aleppo, Asia Minor	22,000
1828	Echigo (Honshu), Japan	30,000
1847	Zenkoji, Japan	34,000
1868	Peru and Ecuador	25,000
1875	Venezuela and Colombia	16,000
1896	Sea Wave, Sanriku Coast, Japan	22,000
1897	Assam, India	1,500
1898	Sea Wave, Japan	22,000
1905	Kangra, India	20,000
1906	Valparaiso, Chile	1,500
1906	San Francisco, California	700
1907	Kingston, Jamaica	1,400
1908	Messina, Italy	75,000
1915	Avezzano, Italy	29,970
1920	Kansu, China	180,000
1923	Tokyo-Yokohama, Japan	143,000
1930	Apennine Mountains, Italy	1,500
1932	Kansu, China	70,000
1935	Quetta, Pakistan	60,000
1939	Chillan, Chile	30,000
1939	Erzincan, Turkey	23,000
1946	Eastern Turkey	1,300
1946	Alaska-Hawaii Sea Wave, Honshu, Japan	2,150
1948	Fukui, Japan	5,131
1949	Pelileo, Ecuador	6,000
1950	Assam, India	1,500
1953	Northwestern Turkey	1,200
1954	Orleansville, Algeria	1,657
1956	Northern Afghanistan	2,000
1957	Northern Iran	2,500
1957	Outer Mongolia	1,200
1957	Western Iran	2,000
1960	Agadir, Morocco	12,000
1960	Southern Chile	5,700
1962	Northwestern Iran	10,000
1963	Barce, Libya	300
1963	Skopje, Yugoslavia	1,100
1964	Southern Alaska	131
1965	El Cobre, Chile	400
1966	Eastern Turkey	2,529
1966	Tashkent, Soviet Union	1,800
1967	Caracas, Venezuela	236
1968	Northeastern Iran	11,588
1970	Western Turkey	1,086
1970	Northern Peru	38,000
1971	Bingol, Turkey	812
1972	Managua, Nicaragua	12,000
1973	Veracruz, Mexico	527
1974	Northern Pakistan	5,300
1975	Eastern Turkey	2,386
1976	Guatemala	23,000
1976	Northern Italy	1,000
1976	West Irian, Indonesia	4,450
1976	Bali, Indonesia	563
1976	Hopei, China	655,000
1976	Philippine Islands	5,000
1976	New Guinea	133
1976	Turkish-Iranian border	5,000
1977	Bucharest area, Romania	1,500
1977	Southern Iran	167
1977	Shahr Kord area, Iran	348
1977	Sumbawa, Indonesia	180

Adapted from Office of Emergency Preparedness, Disaster Preparedness, Vol 3, U.S. Government Printing Office, Washington, D.C., 1972, 80; Hill, M. R., Earth hazards — an editorial, *Miner. Inf. Ser.*, 18, 58, 1965; data were obtained from the National Earthquake Information Service-U.S. Geological Survey and Associated Press reports for the years 1971 through 1977.

TABLE 2

Lives Lost in Major U.S. Earthquakes

Year	Locality	Lives lost
1811	New Madrid, Missouri	Several
1812	New Madrid, Missouri	Several
1812	San Juan Capistrano, California	40
1868	Hayward, California	30
1872	Owens Valley, California	27
1886	Charleston, South Carolina	60
1899	San Jacinto, California	6
1906	San Francisco, California	700
1915	Imperial Valley, California	6
1918	Puerto Rico (tsumani from earthquake in Mona Passage)	116
1925	Santa Barbara, California	13
1926	Santa Barbara, California	1
1932	Humboldt County, California	1
1933	Long Beach, California	115
1934	Kosmo, Utah	2
1935	Helena, Montana	4
1940	Imperial Valley, California	9
1946	Hawaii (tsunami from earthquake in Aleutians)	173
1949	Puget Sound, Washington	8
1952	Kern County, California	14
1954	Eureka-Arcata, California	1
1955	Oakland, California	1
1958	Khantaak Island and Lituya Bay, Alaska	5
1959	Hebgen Lake, Montana	28
1960	Hilo, Hawaii (tsunami from earthquake off Chile coast)	61
1964	Prince William Sound, Alaska	131
1965	Puget Sound, Washington	7
1971	San Fernando, California	65
1975	Halape, Hawaii (tsunami from local earthquake)	2

From National Science Foundation and U.S. Geological Survey, Earthquake Prediction and Hazard Mitigation Options for USGS and NSF Programs, U.S. Government Printing Office, Washington, D.C., 1976, 4.

TABLE 3

Property Damage in Major U.S. Earthquakes

Year	Locality	Damage ($ million)
1865	San Francisco, California	0.5
1868	San Francisco, California	0.4
1872	Owens Valley, California	0.3
1886	Charleston, South Carolina	23.0
1892	Vacaville, California	0.2
1898	Mare Island, California	1.4
1906	San Francisco, California	24.0
	Fire loss	500.0

TABLE 3 (continued)

Property Damage in Major U.S. Earthquakes

Year	Locality	Damage ($ million)
1915	Imperial Valley, California	0.9
1918	Puerto Rico (tsunami damage from earthquake in Mona Passage)	4.0
1918	San Jacinto and Hemet, California	0.2
1925	Santa Barbara, California	8.0
1933	Long Beach, California	40.0
1935	Helena, Montana	4.0
1940	Imperial Valley, California	6.0
1941	Santa Barbara, California	0.1
1941	Torrance-Gardena, California	1.0
1944	Cornwall, Canada-Massena, New York	2.0
1946	Hawaii (tsunami damage from earthquake in Aleutians)	25.0
1949	Puget Sound, Washington	25.0
1949	Terminal Island, California (oil wells only)	9.0
1951	Terminal Island, California (oil wells only)	3.0
1952	Kern County, California	60.0
1954	Eureka-Arcata, California	2.1
1954	Wilkes-Barre, Pennsylvania	1.0
1955	Terminal Island, California (oil wells only)	3.0
1955	Oakland-Walnut Creek, California	1.0
1957	Hawaii (tsunami damage from earthquake in Aleutians)	3.0
1957	San Francisco, California	1.0
1959	Hebgen Lake, Montana (damage to timber and roads)	11.0
1960	Hawaii and U.S. West Coast (tsunami damage from earthquake off Chile coast)	25.5
1961	Terminal Island, California (oil wells only)	4.5
1964	Alaska and U.S. West Coast (includes tsunami damage from earthquake near Anchorage)	500.0
1965	Puget Sound, Washington	12.5
1966	Dulce, New Mexico	0.2
1969	Santa Rosa, California	6.3
1971	San Fernando, California	553.0
1973	Hawaii	5.6
1975	Aleutian Islands	3.5
1975	Idaho/Utah (Pocatello Valley)	1.0
1975	Hawaii	3.0
1975	Humboldt, California	0.3
1975	Oroville, California	2.5
Total		1878.0

From National Science Foundation and U.S. Geological Survey, Earthquake Prediction and Hazard Mitigation Options for USGS and NSF Programs, U.S. Government Printing Office, Washington, D.C., 1976, 3.

have been partially or totally destroyed (Figures 1 and 2). For example, Managua, Nicaragua was hit by destructive earthquakes in 1844, 1858, 1881, 1898, 1913, 1918, 1928, 1931, 1968, and 1972 (Figures 1 and 2). The site of the city has never been abandoned, and after each quake, a great number of seismically unsafe structures rise from the ruins to await a similar fate sometime in the future.

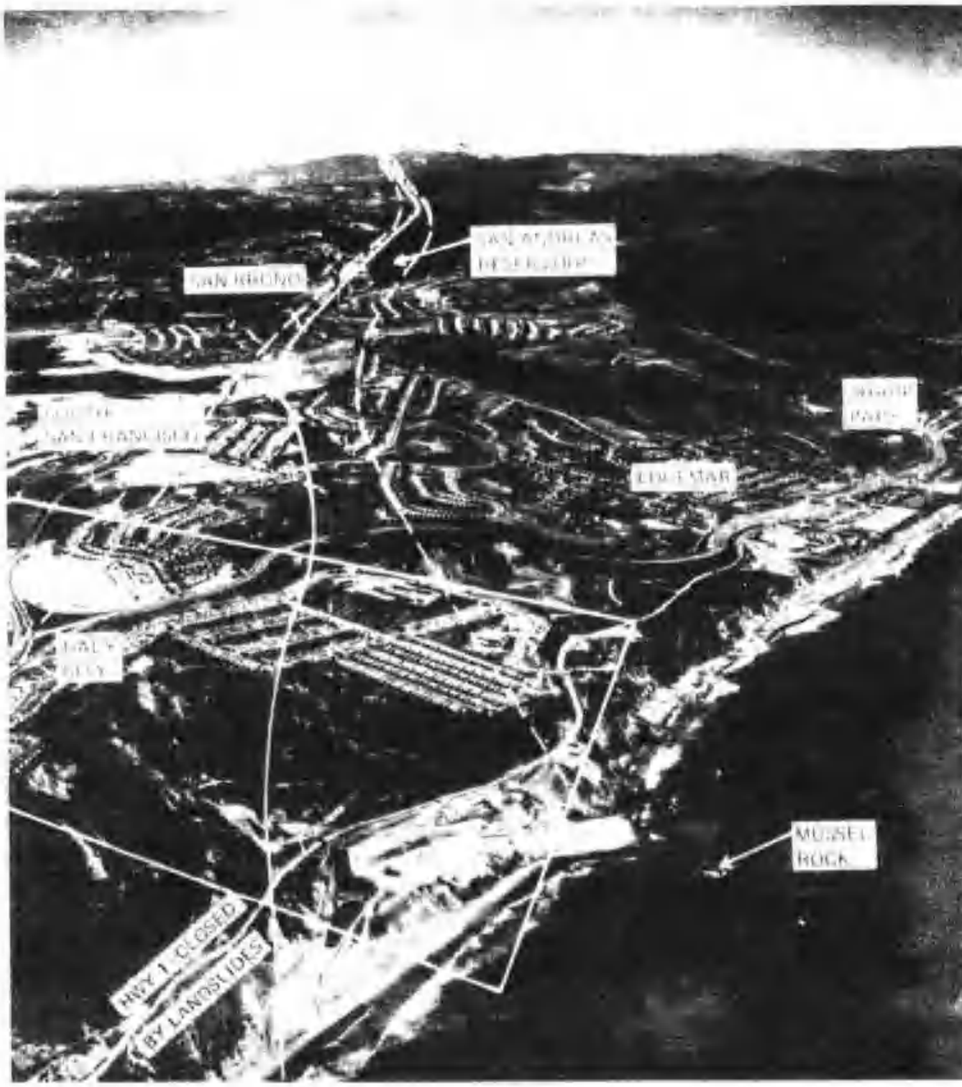

FIGURE 3(A). Aerial view of the San Andreas fault zone just south of San Francisco. (From Committee on Seismology, *Seismology Responsibilities and Requirements of a Growing Science. Part I. Summary and Conclusions*, National Academy of Sciences, Washington, D.C., 1969, 14.)

The situation in the U.S., as well as in other countries, is rapidly changing as the earth becomes an overpopulated and urban planet. As these urban areas rapidly expand, a greater percentage of the world's population encroaches upon active seismic zones, and earthquakes are becoming one of the most awesome geologic hazards to life and property.

Two examples characterize the changes that have occurred in this country. Only a few lives were lost in the New Madrid, Missouri earthquakes of 1811 and 1812 because the area was sparsely populated. These earthquakes were centered in southeastern Missouri, and complex geomorphic alterations occurred, including the formation of Reelfoot Lake in northwestern Tennessee. Because of the extent of geomorphic disruption and the area over which the earthquakes were felt, many seismologists believe that

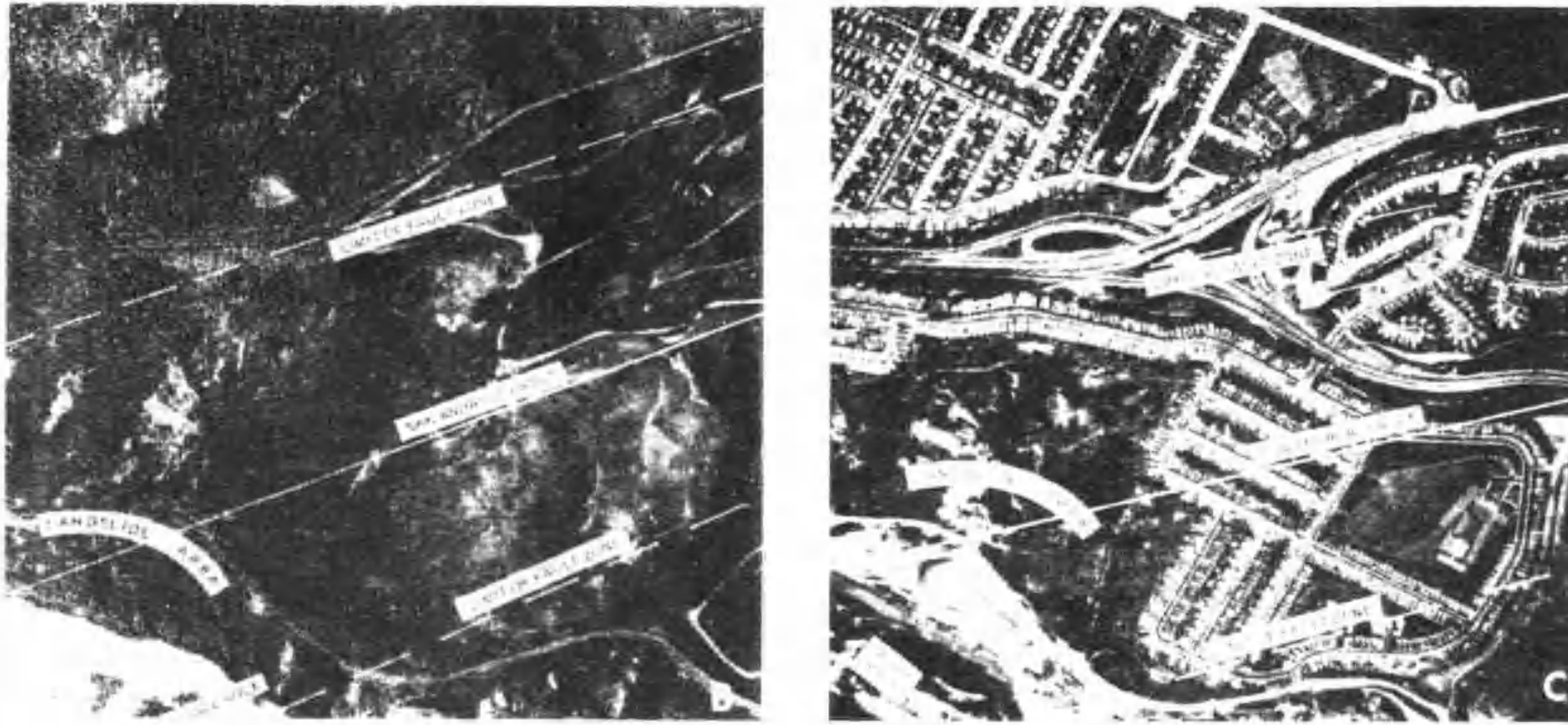

FIGURE 3(B) Low-level view in 1956 of area outlined in Figure 3A. (From Committee on Seismology, *Seismology Responsibilities and Requirements of a Growing Science. Part I. Summary and Conclusions.* National Academy of Sciences, Washington, D.C., 1969, 14.) (C) Outlined area as it appeared in 1966. The dashed lines approximate the fault zone, and the solid line approximates the surface trace formed by the 1906 San Francisco earthquake. The large structure in the lower right-hand corner of C is a public school. (From Committee on Seismology, *Seismology Responsibilities and Requirements of a Growing Science. Part I. Summary and Conclusions.* National Academy of Sciences, Washington, D.C., 1969, 14.)

three of the earthquakes were among the most powerful ever to strike North America. If the same area, now densely populated, were to be struck by quakes of the same size, the results would be gargantuan. The 1906 San Francisco quake affected a population of about 500,000 and was responsible for approximately 700 deaths; a repetition today would affect more than 5,000,000 Californians.[4]

The impact of urban encroachment upon the active San Andreas fault is dramatically depicted in Figures 3A, 3B, and 3C. These aerial views of the same area show the rapid covering of the fault zone in ten short years. Some 50,000 housing units (Daly City area) are now located in this part of the fault zone, just to the south of San Francisco (Figure 4). The large structure in the lower right-hand corner of Figure 3C is a public school.

Many Americans believe that earthquakes are a problem for only those living in Alaska and California. However, the Panel on the Public Policy Implications of Earthquake Prediction-National Academy of Sciences has presented the realistic view.[5]

> Seventy million people throughout the United States live with a significant risk to their lives and property from earthquakes. Another 115 million are exposed to a less significant, but not negligible, seismic risk. Only 8 percent of Americans can safely ignore the earthquake hazard. But most Americans occupy, use, or are served by constructed facilities that were not designed to resist earthquakes and that could collapse in a quake with major losses of life and property.

In Appendix B, "felt earthquakes" are given for the years 1972 through 1977; note that in 1976 earthquakes were felt in 33 states.

Frank Press,[6] formerly of the Massachusetts Institute of Technology and a member of the President's Science Advisory Committee and now the President's Science Adviser, has summarized the apathy and potential dimensions of future earthquakes in the U.S.

> . . . one member questioned the need for a major investment in research, pointing out that in the history of our country only a few hundred lives were lost to earthquakes and that the apparent loss from earthquakes in this century could not have averaged more than about $20 million per year. What was overlooked in this critique was the future loss potential from a reoccurrence of a great earthquake . . . . Tens of billions of dollars and tens of thousands of casualties are the kinds of numbers that have been appearing in sudden-loss estimates. Catastrophic earthquakes have occurred in the past and will occur in the future . . . . The new ingredient is the astronomic growth in population and investment in the earthquake-prone regions of our country . . . . The San Fernando earthquake of 1971 was a sobering experience to geologists and engineers. This relatively small tremor (much less than 1 percent of the energy released in the San Francisco quake) occurred in a densely populated region. The damage bill came to $500 million. Too few people know that one dam was stressed to near the failure point and that a slightly larger shock on another day would have resulted in casualty figures in the tens of thousands [Figure 5].

Several excellent books and articles vividly document the destruction and personal accounts of survivors. A sampling has been included for the following earthquakes: (1) 1556, Shensi, China;[7] (2) 1755, Lisbon, Portugal;[8] (3) 1811 to 1812, New Madrid, Missouri;[9] (4) 1906, San Francisco;[10-12] (5) 1923, Tokyo, Japan;[13] (6) 1959, Hebgen Lake, Montana;[14] (7) 1960, Agadir, Morocco;[15] (8) 1964, Alaska;[16,17] (9) 1970, Peru;[18] and (10) 1976, Guatemala.[19]