INTRODUCTION TO THE EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

The Earthquake Engineering Research Institute (EERI) is a professional society devoted to finding better ways to protect people and property from the effects of earthquakes. The Institute was founded as a nonprofit corporation in California in 1949 as an outgrowth of the Advisory Committee on Engineering Seismology of the United States Coast and Geodetic Survey. The membership of approximately 600 (as of 1976) is national in scope. The members have special competence or interest in one or more facets of earthquake engineering and include engineers, earth scientists, architects, and social scientists, as well as people from a number of other disciplines.

The work of the Institute consists of investigating destructive earthquakes, holding conferences, publishing earthquake engineering reports, advising government agencies, and otherwise contributing to the advancement of the field. Presidents of EERI have been L.S. Jacobsen of Stanford University; Paul E. Jeffers, Consulting Structural Engineer, Los Angeles; George W. Housner of the California Institute of Technology; John E. Rinne, Structural Engineer with Earl and Wright, San Francisco; Karl V. Steinbrugge, Insurance Services Office, San Francisco; C. Martin Duke of the University of California, Los Angeles; and currently Henry J. Degenkolb, Consulting Structural Engineer, San Francisco.

EERI is probably best known for its field investigations and reporting of the effects of destructive earthquakes, including recently its coordination of the investigative efforts of other organizations. Included in the membership are most of the leading U.S. earthquake investigators from all of the relevant fields. Included in the Institute's investigations have been the earthquakes in Chile, 1960; Peru, 1970; San Fernando, California, 1971; Nicaragua, 1972; Peru, 1974; and Guatemala, Italy, and the Philippines, 1976.

Presently, EERI is supported by the National Science Foundation with a 3-year grant to implement a plan for earthquake investigations.

I. PLANNING GUIDE

JOINT EFFORT NEEDED ON EARTHQUAKE INVESTIGATIONS

Studies of past earthquakes have provided the principal basis for modern concepts of seismic safety, but EERI is chiefly concerned with learning from future earthquakes. We have missed some learning opportunities due to lack of planning, and recent experience, notably at San Fernando, California, in 1971, provides a better basis for planning of investigations.

Such investigations cannot be restricted only to earthquakes in California and Alaska, because many other states are also subject to destructive earthquakes. Some 282 earthquakes were felt in 22 states in 1972. Of course, emphasis should be placed on the more highly seismic states.

The investigation of destructive earthquakes involves the engineering effects, the scientific effects, and the socioeconomic effects. A successful investigation requires a high degree of cooperation among local governments in the afflicted area and national, university, and other research organizations. The cooperation of other kinds of agencies, namely professional societies and construction and financial organizations, is also needed. Moreover there must be an effective coordinating body. EERI, with the aid of its National Science Foundation grant, offers to play this coordinating role.

Some of the main topics to be studied in future earthquakes include:

1. How well will the new earthquake-resistive design standards, introduced as a result of recent earthquakes, stand up under the next test?
2. To what extent will the construction outside of California and Alaska stand up to earthquakes?
3. In what ways can we improve the seismic performance of public utility and transportation systems?
4. What will be the effectiveness of planned emergency procedures and emergency buildings and facilities?
5. What will be the distribution of statistical data on dollar losses for various types of construction and occupancy?
6. What will the next earthquake tell us about how earthquakes are generated, and about how people react to earthquake effects?
7. Where are the unmapped active faults and potential landslides in each locality?
8. Under what local geological conditions will the hardest shaking and greatest fault breakage occur?
9. How confidently can earthquakes be predicted?

The aim of the Planning and Field Guides is to help maximize the learning to be gained, on the above and other subjects, from investigations following future destructive earthquakes. The Guides are meant for use in the planning and field execution of such investigations. Through their use, both the afflicted communities and the investigators can understand how to participate in the investigation and what information is of greatest value.

Details and background are provided on subsequent pages. The Planning Guide, pages 1 through 41, is intended for executives and planners, while the Field Guides, pages 42 through 200, are for field investigators.

SEISMIC RISK TO CITIES

EARTHQUAKES

Strong earthquakes usually are caused by movement on a fracture of the earth's crustal rocks. This generally takes the form of sliding along a rupture plane called a *fault*, in response to a relief of strain.

Figure I-1 shows an idealized cross-section through the upper part of the earth's crust, illustrating some aspects of the faulting which caused the 1971 San Fernando, California, earthquake. Some common earthquake engineering terms are illustrated in Figure I-1.

It is common for earthquakes to occur repeatedly along the same fault over a long period of years. Major faults like the San Andreas in California are generally thought to be the boundaries between two differentially moving crustal plates. In the case of the San Andreas Fault, the oceanic (West) plate is moving north with respect to the continental (East) plate. Where these two plates impinge at the fault, movements tend to be "jerky" as the plate edges alternately stick and slip. The ultimate cause of the movement of the crustal plates is related to tectonic processes in the earth's mantle beneath the crust.

When the locations of all of the large world earthquakes are plotted on a map (Figure I-2), it is readily apparent that the majority occur in zones or "belts." Among these, the circum-Pacific belt is responsible for 90 percent of

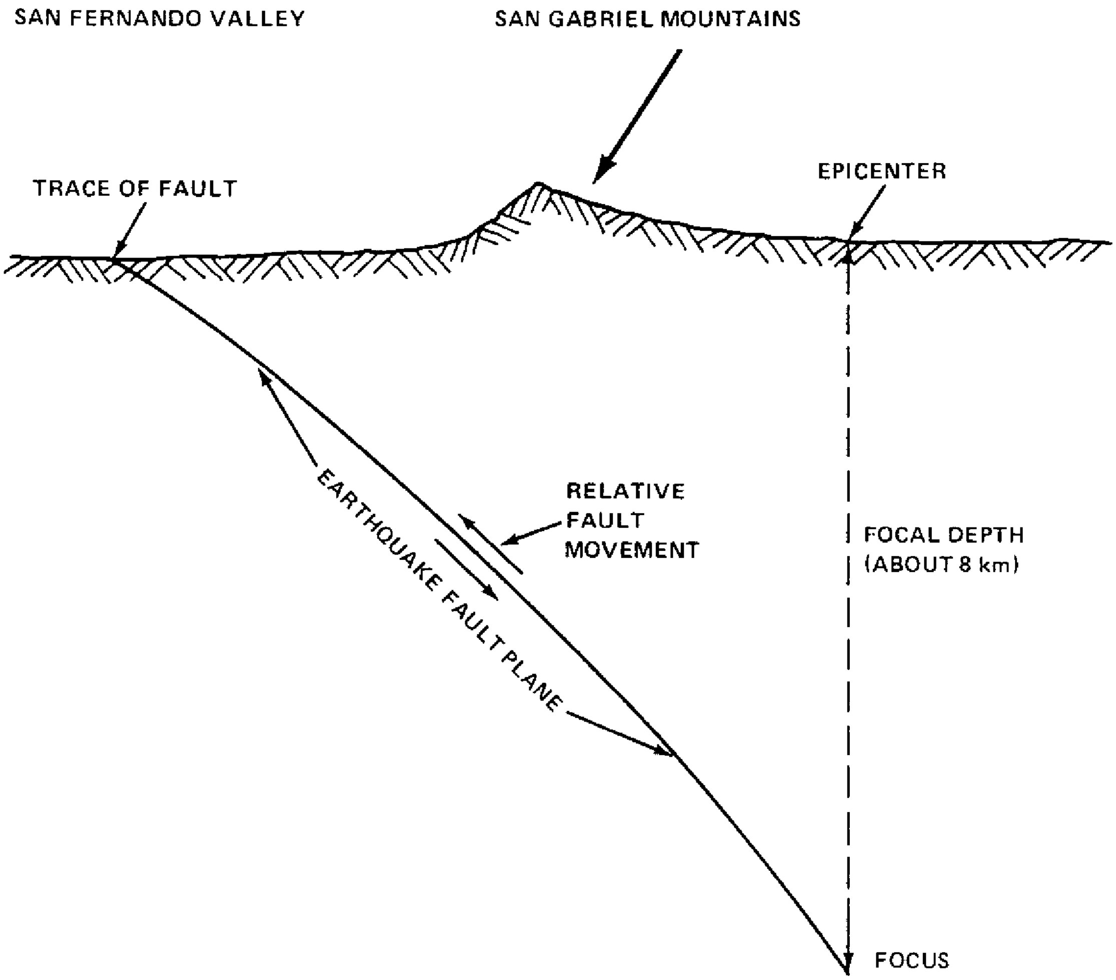

Figure I-1: Idealized Cross-Section of Earth's Upper Crust, 1971 San Fernando Earthquake

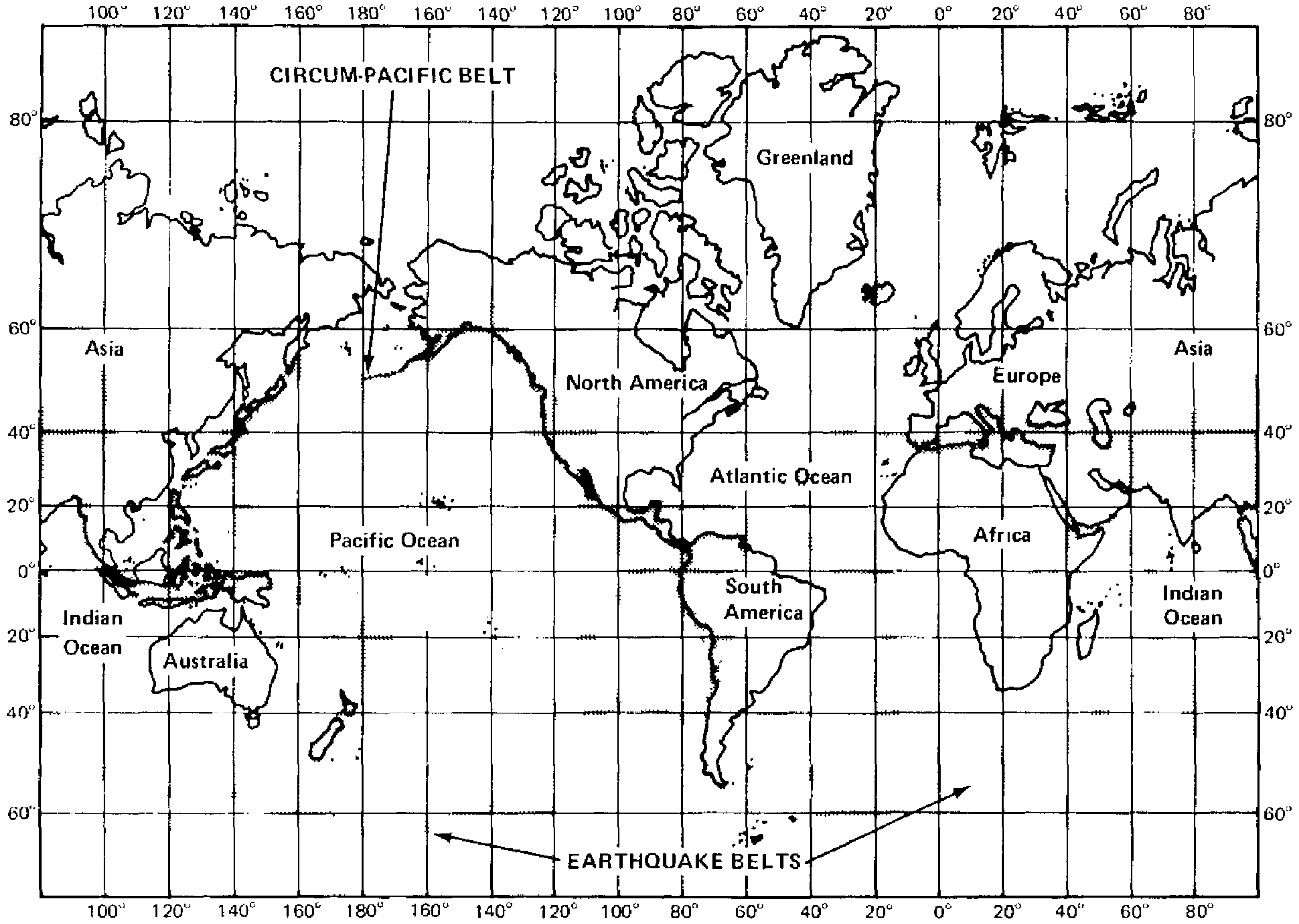

Figure I-2: General Trends of the Earthquake Belts of the World (from Coast and Geodetic Survey Special Publication 282; U.S. Department of Commerce) the world's earthquakes. Figure I-3 shows the locations of damaging earthquakes in the United States from earliest history through 1970.

The main features of selected U.S. earthquakes which occurred from 1663 through 1971 are shown in Table I-1. Included are data on the location, maximum intensity, magnitude, length of surface faulting, and life and dollar losses. The life and estimated dollar losses are affected by the locations of the shocks with respect to population centers and by the quality of building construction in the affected areas.

The *intensity* of an earthquake is a measure of its seismic effects of all types. The Modified Mercalli Intensity Scale (1956 version) is summarized in Table I-2. The lower intensities on the scale are based primarily on human and structural responses to shaking, whereas the higher intensities, such as XI and XII, involve permanent distortions of the ground. Damage to structures usually does not occur in intensity V or less.

Isoseismal maps, such as Figure I-4, are useful in providing an overall picture of the geographical patterns of earthquake damage, including the influence of soils and local geology. The isoseismal lines (lines of equal intensity) on such a map serve to separate areas experiencing different intensities.

The approximate *magnitude* of an earthquake can be obtained quickly from seismic instrument records. Quoting Dr. Charles F. Richter, inventor of the Richter Magnitude Scale, the magnitude of an earthquake is obtained as "the logarithm of the maximum amplitude on a seismogram written by an instrument of a specific standard type at a distance of 100 kilometers (62 miles) from the epicenter. . .The largest known earthquake magnitudes are near 8¾; this is a result of observation, not an arbitrary ceiling like that of the intensity scales."[1] Magnitude can also be related to the earthquake's vibratory energy. A one-unit increase on the magnitude scale corresponds roughly to a 32-fold increase in energy released.

Each earthquake has only one magnitude but many intensities. Confusion is often created by news reporters who fail to recognize the distinction between the two scales.

A tsunami, or seismic ocean wave, may be generated by quake-accompanying changes in the elevation of the sea bottom, or by submarine landslides. Such a wave may be tens of feet high when it approaches certain types of shorelines. The generated waves reach velocities of 500 to 600 miles per hour in the deep ocean, where they are only a few feet in height. Tsunamis can affect areas several thousands of miles from their origin, and warning systems have been developed to predict their impending approach so that vulnerable areas can be evacuated. However, the existence of such warning systems does not preclude lives from being lost. Despite 6 hours of warning given, 61 lives were lost in Hilo, Hawaii, in 1960 due to the tsunami that originated off the coast of Chile after a major earthquake there in May of that year.

Differential ground movements, such as landslides, settlements, and surface fault breaks, have resulted in severe damage to property but relatively few casualties in U.S. earthquakes. Extensive damage resulted from huge landslides in the 1964 Anchorage, Alaska, quake.

Fires following earthquakes have not been a serious problem in U.S. earthquakes, with the notable exception of those after the 1906 San Francisco, California, shock. However, conditions still exist in many urban

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[1] Richter, C F , Elementary Seismology, W. H Freeman and Company, 1958, page 17.

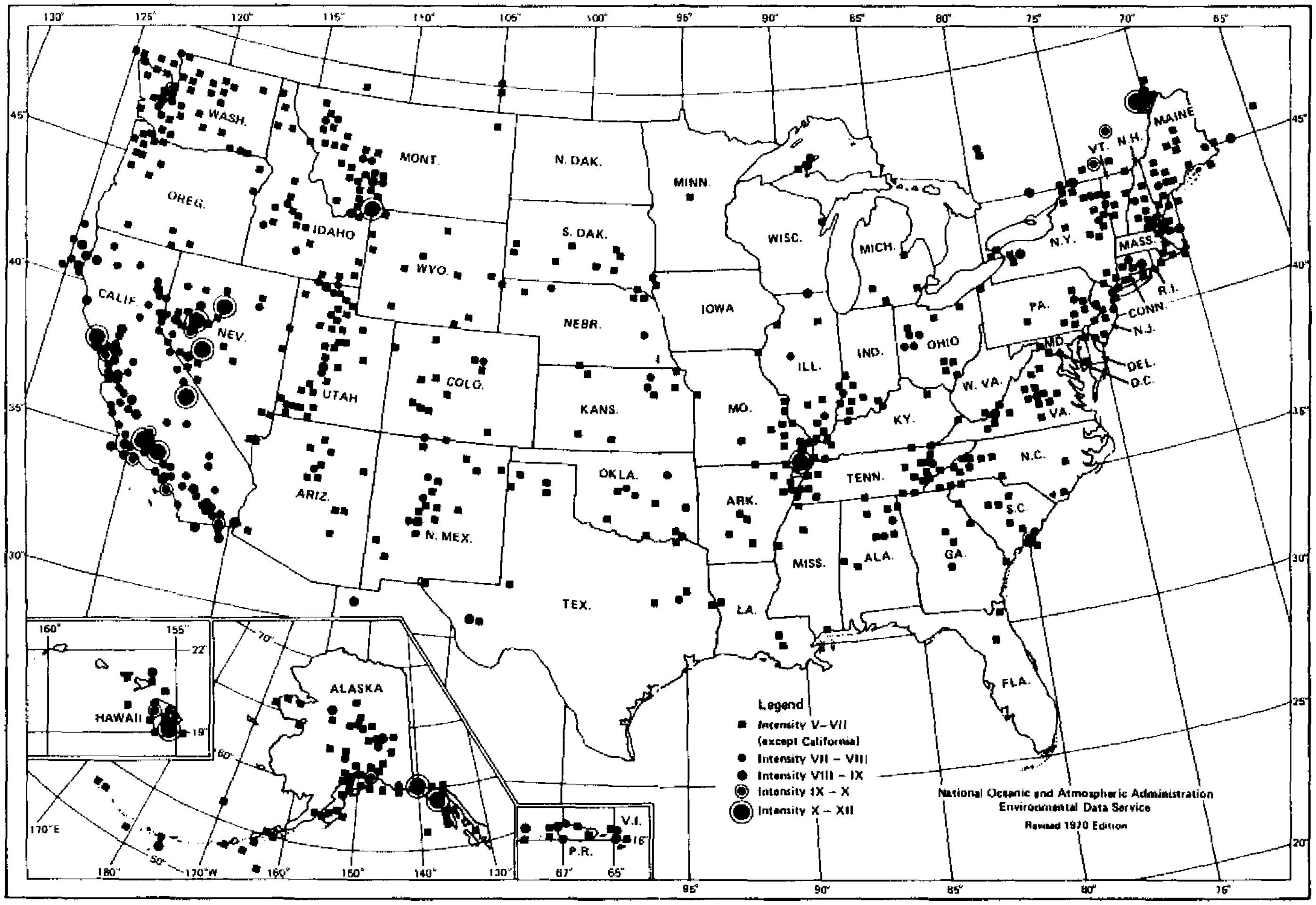

Figure I-3: Earthquakes of Intensity V and Above in the United States through 1970 (from Earthquake History of the United States, Publication 41-1, U.S. Department of Commerce)

Table I-1: Selected U.S. Earthquakes, from 1663 through 1971[1]

Name of Earthquake	Date and (local) Time	[2]Maximum Modified Mercalli Intensity	[3]Richter Magnitude	Approximate Length of Surface Faulting (miles)	[4]Lives Lost	[5]Dollar Loss	Remarks
St Lawrence River Region	Feb 5, 1663	X					
Cape Ann, Massachusetts	Nov 18, 1755	About VIII					
New Madrid, Missouri	Dec. 16, 1811 (about 2:15 AM) Jan. 23, 1812 (about 8:50 AM) Feb. 7, 1812 (about 10:10 AM)	XII XII XII	Over 7	See Remarks column	1		Richter assigned a magnitude of greater than 8 based on observed effects; surface faulting possibly occurred; Nuttli (1973) assigned body-wave magnitudes of 7.2, 7.1, and 7.4
Ft. Tejon, California	Jan. 9, 1857 (about 8:00 AM)	XI	Over 8	Over 200			Possible 30-foot right-lateral displacement
Owens Valley, California	Mar. 26, 1872 (about 2:30 AM)	XI	Over 8	100	27		Approximate magnitude 8.3 (Greensfelder, 1972)
Charleston, South Carolina	Aug. 31, 1886 (9:51 PM)	X		None	27 killed outright; plus 83 or more from related causes	$5 million to $6 million	
San Francisco, California	Apr 18, 1906 (5:12 AM, PST)	XI	8.3	190 minimum; 270 possible	700 to 800	$400 million incl fire; $80 million earthquake only.	Portions of the San Andreas fault are under the Pacific Ocean
St Lawrence River Region	Feb 28, 1952 (9:19 PM)	VIII	7.0				
Santa Barbara, California	June 29, 1925 (6:42 AM)	VIII-IX	6.3	None	12 to 14	$6.5 million	The dollar loss is for the City of Santa Barbara, losses elsewhere were slight
Long Beach, California	Mar. 10, 1933 (5:54 PM, PST)	IX	6.3		Coroner reported 86, 102 is more probable	$40 million to $50 million	Epicenter in ocean off Newport Beach; associated with Inglewood Fault
Helena, Montana	Oct. 12, 1935 (12:51 AM, MST)	VII		None		$50,000	First of three destructive shocks; other two occurred Oct. 18 and 31

Table I-1 (continued)

Name of Earthquake	Date and (local) Time	[2]Maximum Modified Mercalli Intensity	[3]Richter Magnitude	Approximate Length of Surface Faulting (miles)	[4]Lives Lost	[5]Dollar Loss	Remarks
Helena, Montana	Oct. 18, 1935 (9:48 PM, MST)	VIII	6.25	None	2 plus "score" injured	$3 million to over $4 million	
Helena, Montana	Oct. 31, 1935 (11:38 AM, MST)	VIII	6.0	None	2 plus "score" injured		
Imperial Valley, California	May 18, 1940 (8:37 PM, PST)	X	7.1	40 minimum	8 killed outright; 1 died later of injuries	$5 million to $6 million	M.M. IX for building damage and M.M. X for faulting; 19-foot offset of All American Canal
Santa Barbara, California	June 30, 1941 (11:51 PM, PST)	VIII	5.9		None; 1 hospitalized	$250,000	Epicenter in ocean
Olympia, Washington	Apr. 13, 1949 (11:56 PM, PST)	VIII	7.1	None	8	$15 million to $25 million	
Kern County, California	July 21, 1952 (4:52 AM, PDT)	XI	7.7	24	10 or 12 in Tehachapi	$37,650,000 to buildings; $48,650,000 total (incl. Aug. 22 aftershock)	M.M. XI assigned to tunnel damage from faulting; vibration intensity to structure generally VIII, rarely IX; faulting probably longer, but covered by deep alluvium
Bakersfield, California	Aug. 22, 1952 (3:41 PM, PDT)	VIII	5.8	None	2; 15 injured in Bakersfield	See above	
Fallon-Stillwater, Nevada	July 6, 1954 (4:13 AM, PDT)	IX	6.6	11	None; several injuries	$500,000 to $700,000, incl. $300,000 to irrigation system	M.M. IX assigned along fault trace; vibration intensity VIII; first of two shocks on same fault
Fallon-Stillwater, Nevada	Aug. 23, 1954 (10:52 PM, PDT)	IX	6.8	19	None		M.M. IX assigned along fault trace; vibration intensity VIII; second of two shocks on same fault
Fairview Peak, Nevada	Dec. 16, 1954 (3:07 AM, PST)	X	7.1	35	None		M.M. X assigned along fault trace; vibration intensity VII; two shocks considered as a single event from the engineering standpoint
Dixie Valley, Nevada	Dec. 16, 1954 (3:11 AM, PST)	X	6.8	30	None		
Eureka, California	Dec. 21, 1954 (11:56 AM, PST)	VII	6.6	None	1	$1 million	

Table I-1 (continued)

Name of Earthquake	Date and (local) Time	[2]Maximum Modified Mercalli Intensity	[3]Richter Magnitude	Approximate Length of Surface Faulting (miles)	[4]Lives Lost	[5]Dollar Loss	Remarks
Port Hueneme, California	Mar. 18, 1957 (10:56 AM, PST)	VI	4.7	None	None		Epicenter in ocean
San Francisco, California	Mar. 22, 1957 (11:44 AM, PST)	VII	5.3	None	None; about 40 minor injuries	$1 million	Epicenter near Mussel Rock
Hebgen Lake, Montana	Aug. 17, 1959 (11:37 PM, MST)	X	7.1	14	19 presumed buried by landslide, plus probably 9 others killed, mostly by landslide	$2,334,000 (roads and bridges); $150,000 (Hebgen Dam); $1,715,000 (landslide correction)	M.M. X assigned along fault trace; vibrational intensity was VIII maximum; faulting complex, and regional warping occurred; dollar loss to buildings relatively small
Prince William Sound, Alaska	Mar. 27, 1964 (5:36 PM, AST)		8.4	400 to 500	110 killed by tsunami; 15 killed from all other causes	$311,192,000 (inc. tsunami)	Also known as the "Good Friday Earthquake"; fault length derived from seismic data
Puget Sound, Washington	Apr. 29, 1965 (8:29 AM, PDT)	VIII	6.5	None	3 killed outright; 3 died from heart attack	$12.5 million	M.M. VII general; M.M. VIII rare
Parkfield, California	June 27, 1966 (9:26 PM, PDT)	VII	5.5	23½ and 5½	None	Less than $50,000	Damaging earthquakes in same area in 1901, 1922, and 1934; the 1966 shock had peak measured acceleration of 50 percent gravity
Santa Rosa, California	Oct. 1, 1969 (9:57 PM, PDT)	VII-VIII	5.6	None	No deaths; 15 injuries; 1 heart attack	$6 million to buildings; $1,250,000 to contents	Two shocks considered as a single event from the engineering standpoint
Santa Rosa, California	Oct. 1, 1969 (11:20 PM, PDT)	VII-VIII	5.7	None			
San Fernando, California	Feb. 9, 1971 (6:01 AM, PST)	VIII-IX	6.6	12	58 deaths; 5,000 reported injuries	$478,519,635	Many reported injuries were minor, but public or charitable services requested

ABBREVIATIONS:

M.M. = Modified Mercalli Intensity
PST = Pacific Standard Time
PDT = Pacific Daylight Time (Subtract 1 hour for Pacific Standard Time)
MST = Mountain Standard Time
AST = Alaska Standard Time
G = Gravity

FOOTNOTES:

[1] Partially from: "A Study of Earthquake Losses in the Los Angeles, California Area," Federal Disaster Assistance Administration and Housing and Urban Development, 1973.

[2] M.M. intensities are those assigned by the U.S. Coast & Geodetic Survey (now USGS) when available.

[3] Slight variations will be found in various publications.

[4] Original sources do not always clearly indicate if deaths include those attributable to exposure, unattended injury, heart attacks, and other nonimmediate deaths.

[5] Value of dollar at time of earthquake; use of these figures requires a critical examination of ref-

areas which could result in a conflagration following a destructive earthquake.

Table I-2: Modified Mercalli Scale, 1956 Version[1]

I.	Not felt. Marginal and long-period effects of large earthquakes.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV.	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.
V.	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI.	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken, knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D[2] cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
VII.	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII.	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in

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[1] From *Elementary Seismology* by C. F. Richter, W. H. Freeman and Co., Inc., 1958.

[2] Masonry A, B, C, D: To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering (which has no connection with the conventional Class A, B, C construction):

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Table I-2 (continued)

	flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX.	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.
X.	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI.	Rails bent greatly. Underground pipelines completely out of service.
XII.	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

HAZARDS AND RISKS TO THE POPULATION

The *hazards* associated with earthquakes are violent shaking, surface fault breaks, tsunamis, and great landslides. Of these, the most prevalent is the violent shaking hazard.

The number of people who may be killed or injured by an earthquake varies with several factors including (1) the location of the shock with respect to population centers; (2) the types of building construction occupied by or adjacent to people; (3) the time of day; (4) the accompaniment of fires and tsunamis; and (5) the efficiency of rescue operations.

There are no seismic hazards without people. For example, in 1811-1812 only one person was killed as a consequence of the New Madrid, Missouri, earthquake (magnitude 8+; the region affected by shocks was sparsely settled). The same event today in that region would be calamitous. In the 1972 Managua, Nicaragua, earthquake (magnitude 6.25), there were an estimated 10,000 deaths in that city of some 400,000 people. The large number of casualties was due to the collapse of poorly constructed and heavily occupied buildings. The 1971 San Fernando earthquake (magnitude 6.6) illustrates the influence of chance — 80,000 people lived downstream from the Lower San Fernando Dam which was severely damaged but which, by a narrow margin, managed to retain the water in the reservoir. The San Fernando earthquake occurred at 6:01 AM, finding most people at home in relatively safe, one-story, wood-frame, California-type residences rather than out on the freeways or working in congested urban areas of the greater Los Angeles Basin, which contain many old non-earthquake-resistive buildings. Forty-four of the 58 deaths in the San Fernando shock occurred in the collapse of an old non-earthquake-resistive building at the San Fernando Veterans Administration Hospital.

In general, it is feasible to design and construct buildings and public utilities so that casualties and financial losses are reduced to acceptable

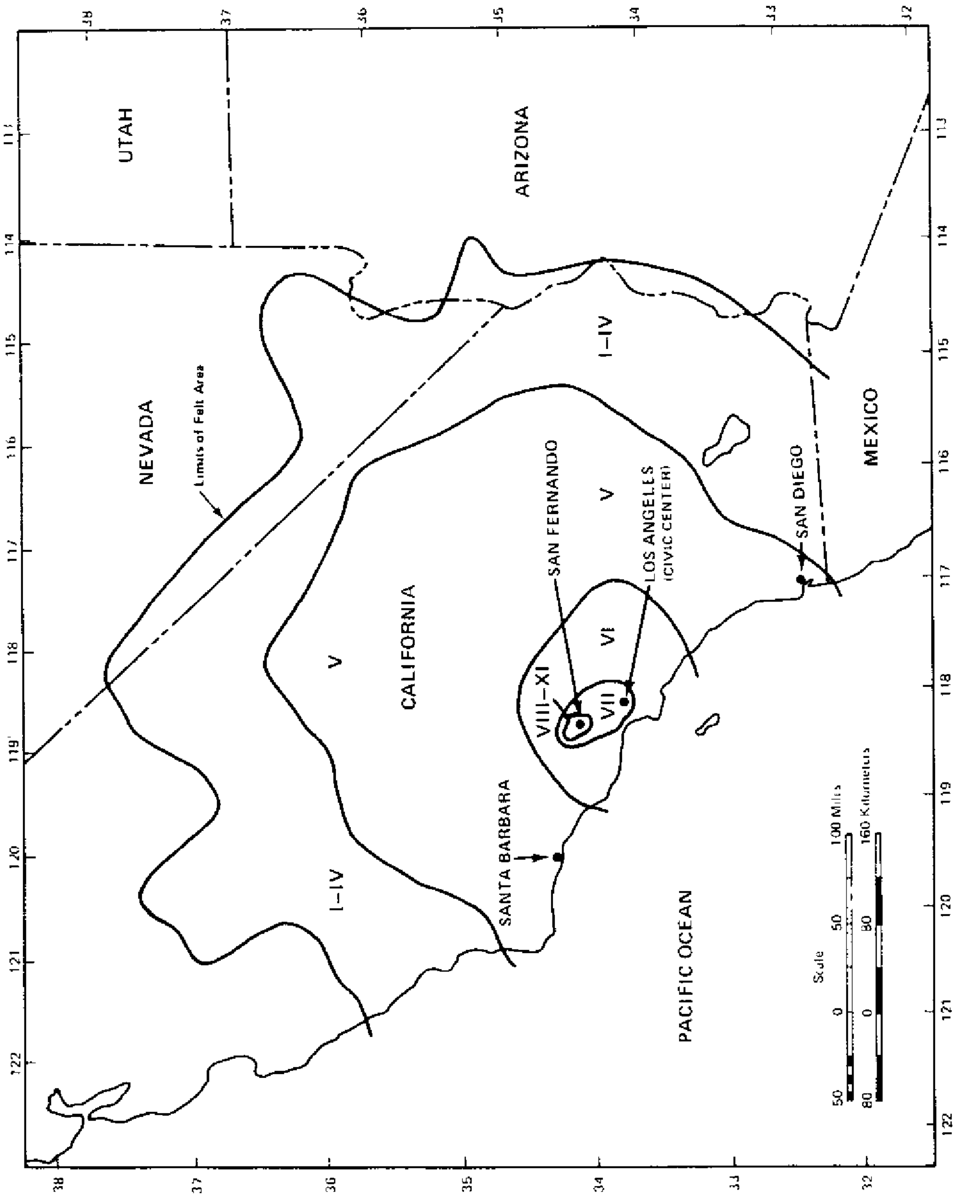

Figure I-4: Intensity and Area Affected by the San Fernando, California, Earthquake of February 9, 1971, 06:00:45 PST (from U.S. Department of Commerce) limits. The question of how much loss is acceptable is for the local public to answer. It is not economically feasible to make structures "earthquake proof." There must be a cost-benefit tradeoff.

The hazards are high from old non-earthquake-resistive construction (e.g., unreinforced masonry bearing-wall buildings). The removal or strengthening of large numbers of these buildings constitutes a major problem in earthquake-prone areas. A few communities in California have programs to attack this problem. Also, several areas in Southern California have completed programs wherein dangerous parapets and building appendages either have been removed or strengthened.

Extensive research is being conducted in order to develop methods for predicting earthquakes. Some of the advance warning signs under study include changes in seismic wave velocity, gradual movement associated with faults, and changes in ground-water levels. These research efforts will result in valuable information being learned about the causes and mechanisms of earthquakes, and the efforts may someday lead to a reliable prediction methodology. However, at the present time (1976) no available procedures are adequately reliable to forecast the time, location, and magnitude of future earthquakes with sufficient accuracy to be of practical value for evacuating areas. Experience with the tsunami warning system in the Pacific Ocean indicates that evacuations of potentially hazardous areas are difficult to accomplish. When and if accurate predictions of earthquakes are possible, predictions apparently will have little effect on the resulting physical damage to man's constructed environment.

It would be useful to know how frequently a specific location will be subjected to high-intensity ground motion, or how often a large-magnitude earthquake will occur on a particular segment of a fault. The quantification of such estimates using past statistical data leads to a statement of *risk.* There have been several statistical studies made to develop such information. However, as Table I-1 illustrates, the historical record is quite brief in terms of geologic time. Also, the geographical distribution throughout the United States is quite irregular, as seen in Figure I-3. The seismic data for risk studies in Japan and China have a much longer historical base, so that statistical forecasts in those countries can have a higher level of confidence.

Some building regulations require special geologic and seismologic studies of specific sites for important structures in order to develop *design* earthquake criteria. Such studies are required for important facilities such as nuclear electric generating plants and California dams and hospitals.

SEISMICITY OF THE UNITED STATES

Following are brief descriptions of the *seismicity* or earthquake activity of the various regions of the United States.[1]

Northeastern Region: The northeastern region of the country contains zones of relatively high seismic activity. New York and Massachusetts have experienced numerous shocks, several quite severe. This region also is affected by large earthquakes originating in adjacent Canada, principally in the St. Lawrence River Valley.

Eastern Region: With the exception of the 1886 Charleston, South Carolina, earthquake, this region has a moderate amount of low-level

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[1] From Earthquake History of the United States, U.S. Department of Commerce, Publication 41-1, Revised Edition, through 1970.

earthquake activity. Earthquakes occur throughout the region and the axis of the principal activity roughly parallels the coast.

The occurrence of earthquakes in the mountainous areas of the eastern region is not surprising, as there seems to be a process of adjustment generally continuing in such regions, but the occurrence of the Charleston shock in a sandy plain is more difficult to explain.

Central Region: The Upper Mississippi and Ohio Valleys are regions of relatively frequent earthquakes. Three of the great earthquakes of recorded history occurred in the Upper Mississippi region in 1811 and 1812. Grave damage was prevented in this area only because it was sparsely settled. The extent and severity of land-form changes from these shocks have not been equalled by any other earthquake in the contiguous United States.

Western Mountain Region: Montana, Utah, and Nevada have been subjected to earthquakes of considerable severity, and there is a region in Mexico, just south of the U.S.-Mexico border, which has had one major earthquake and many minor ones. A quake-related danger of considerable importance was evidenced in the 1959 Montana earthquake when a great avalanche claimed 28 lives and formed a barrier which blocked the Madison River, creating Hebgen Lake.

Washington and Oregon: From 1841 to 1970, many earthquakes of intensity V or greater centered in Washington and Oregon. Other quakes were felt, but they were centered either offshore in the Pacific, in British Columbia to the north, or in neighboring states. Most of the earthquake activity occurred in the western part of the region, with the stronger shocks in the neighborhood of Puget Sound. The heaviest recent activity occurred in Washington: in 1946 a few miles west of Tacoma; in 1949 near Olympia; and in 1965 near Seattle. A few of the earlier shocks may have equaled or possibly exceeded those of 1946 in intensity, but lack of detailed information prevents satisfactory comparison.

Alaska: Few of the Alaska shocks have caused severe damage because of the absence of large population centers. Seismic activity is separated into two zones. One zone, approximately 200 miles wide, extends from Fairbanks through the Kenai Peninsula to the Near Islands. The second zone begins north of Yakutat Bay and extends southeastward to the west coast of Vancouver Island.

In 1899 the Yakutat Bay area experienced one of the notable earthquakes of the nineteenth century. The shore was raised over a considerable length, and at one point there was a vertical fault slip of 47½ feet — one of the greatest fault movements known. On March 27, 1964, one of the greatest geotectonic events of our time occurred in southern Alaska. In minutes, thousands of people were made homeless, 125 lives were lost, and the economy of the entire state was disrupted. Tsunamis swept the Pacific Ocean from the Gulf of Alaska to Antarctica and caused extensive damage along coastal Alaska, British Columbia, and California.

Hawaii: Seismic activity centers on the island of Hawaii, and much of it is associated with volcanic processes. However, the stronger shocks that are sometimes felt throughout the islands are of tectonic origin. The greatest known earthquake, in 1968, was extremely violent and destructive, considering the sparsely settled nature of the island. Shocks north of Hawaii are often felt strongly on the islands of Maui, Lanai, and Molokai.

California and Western Nevada: Earthquakes in California and western Nevada represent approximately 90 percent of the seismic activity in the contiguous United States. The majority of these shocks occur at relatively shallow focal depths, which partly accounts for the greater violence of earthquakes in this region as compared with those occurring in the central or eastern United States. The principal fault in this area — the San Andreas Fault — extends over 600 miles through California, from near the Salton Sea in Southern California northwest to Shelter Cover in Humbolt County. Movement along this fault was responsible for the great earthquakes in 1857 near Fort Tejon and for the 1906 San Francisco shock, as well as for many shocks of lesser magnitudes.

Puerto Rico Region: Many earthquakes have been felt in Puerto Rico since the settlement of the island by Europeans, and several of the shocks have resulted in severe property damage. There is much geologic and topographic evidence that earthquakes have been of relatively frequent occurrence in this region for thousands of years.

Following are eight selected photographs of damage caused by the San Fernando, California, earthquake of February 9, 1971, which occurred at 6:01 AM local time (Figures I-5 through I-12).

EARTHQUAKE INVESTIGATIONS

PHILOSOPHY

While a great deal can be learned about earthquake hazard mitigation through laboratory and analytical studies, the most effective teacher is the impact of a full-scale earthquake on a full-scale city. No method of design of buildings or dams can be proved fully adequate except by such field tests in the laboratory of nature. No theory of the cause of earthquakes can be accepted unless it correctly explains what happens in nature. No seismic disaster preparedness plan can be confidently implemented unless its principles have been tested through use.

Therefore, it is absolutely essential to increase to the maximum the learning from future destructive earthquakes. This becomes the objective of earthquake investigations.

This contention is stronger today than in previous times because of the recent deployment of hundreds of strong-motion accelerographs in and around major engineering works and along active faults. These instruments are set to record ground and structure motions in strong earthquakes and will provide invaluable quantitative data to augment the damage data, thus leading to greater professional confidence in the research findings obtained from studies of earthquakes. Additionally, in the scientific arena, many new instruments recently have been installed to obtain data on faults, focal mechanisms, and ground motions.

To maximize the post-quake learning opportunity, we must first be as specific as possible about *what we do not know.* In earthquake engineering and the related sciences, this is more easily said than done, but it nevertheless must be attempted. The Field Guides in Sections III, IV, and V in effect contain catalogs of the research needs in the fields of earthquake engineering and of the supporting earth and social sciences.

Practically speaking, what we do not know has to be translated into: What do we look for? How do we find it and recognize it? What evidence do we record? That is, a field methodology is required, and it is the other main element of the Field Guides. The investigator needs a Field Guide in his pocket, covering his own professional specialty, which will help guide his