Earthquake Engineering
Research Institute

learning from earthquakes

1977
PLANNING and FIELD GUIDES

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

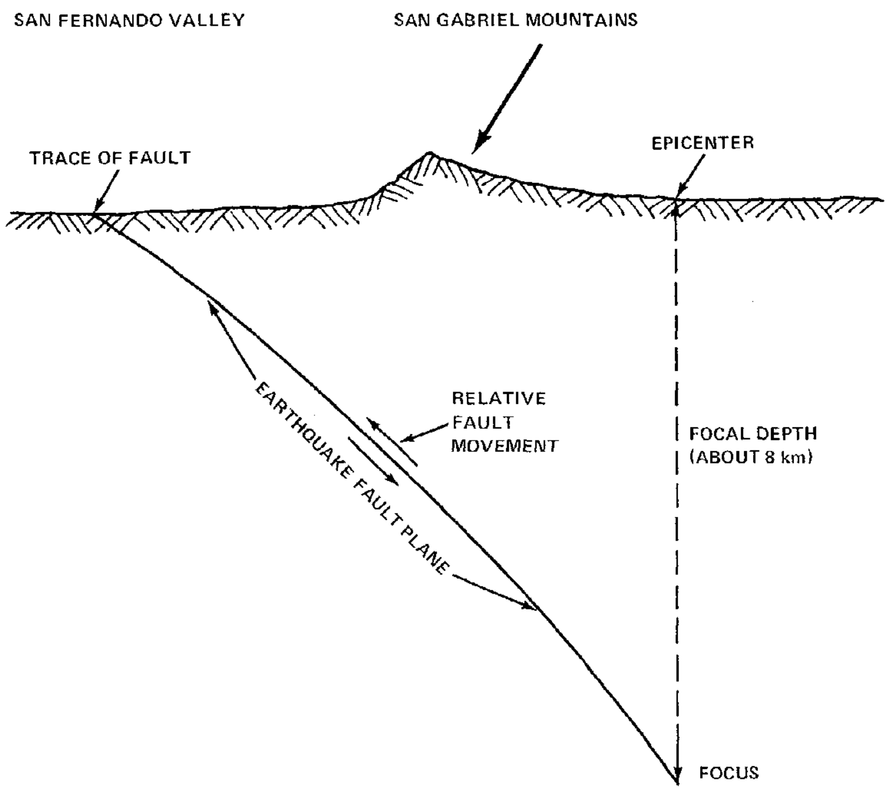

Figure I-1: Idealized Cross-Section of Earth's Upper Crust, 1971 San Fernando Earthquake

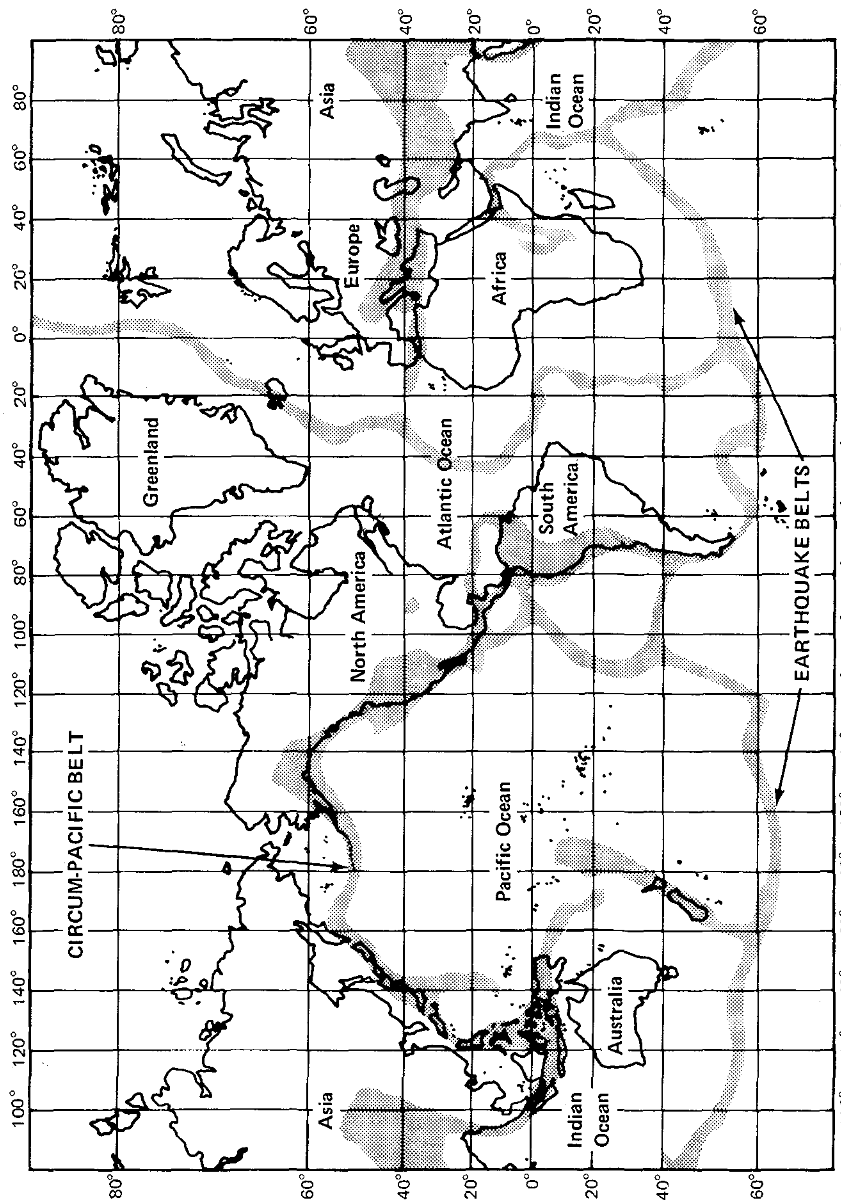

Figure I-2: General Trends of the Earthquake Belts of the World (from Coast and Geodetic Survey Special Publication 282; U.S. Department of Commerce)

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

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

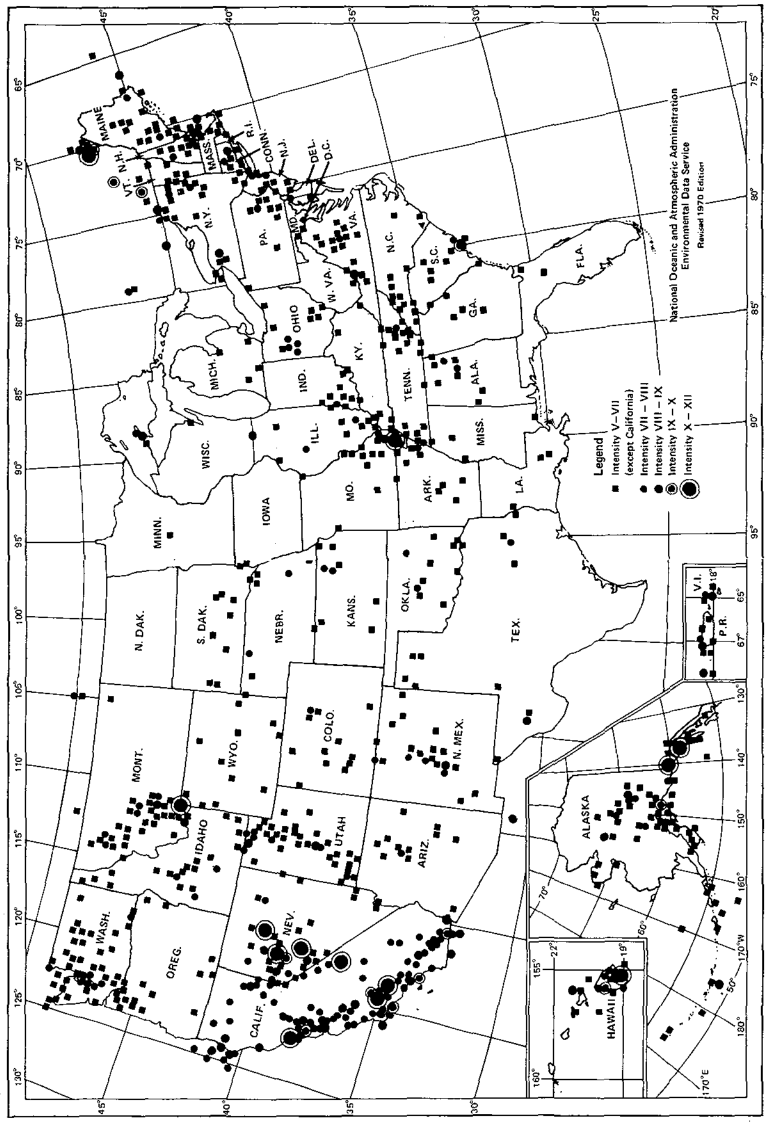

Figure I-3: Earthquakes of Intensity V and Above in the United States through 1970 (from Earthquake History of the United States, Publication 41-1, U.S. Department of Commerce)

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	
Helena, Montana	Oct. 31, 1935 (11:38 AM, MST)	VIII	6.0	None	2 plus "score" injured	$4 million	
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 reference materials since the basis for the estimates varies.

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

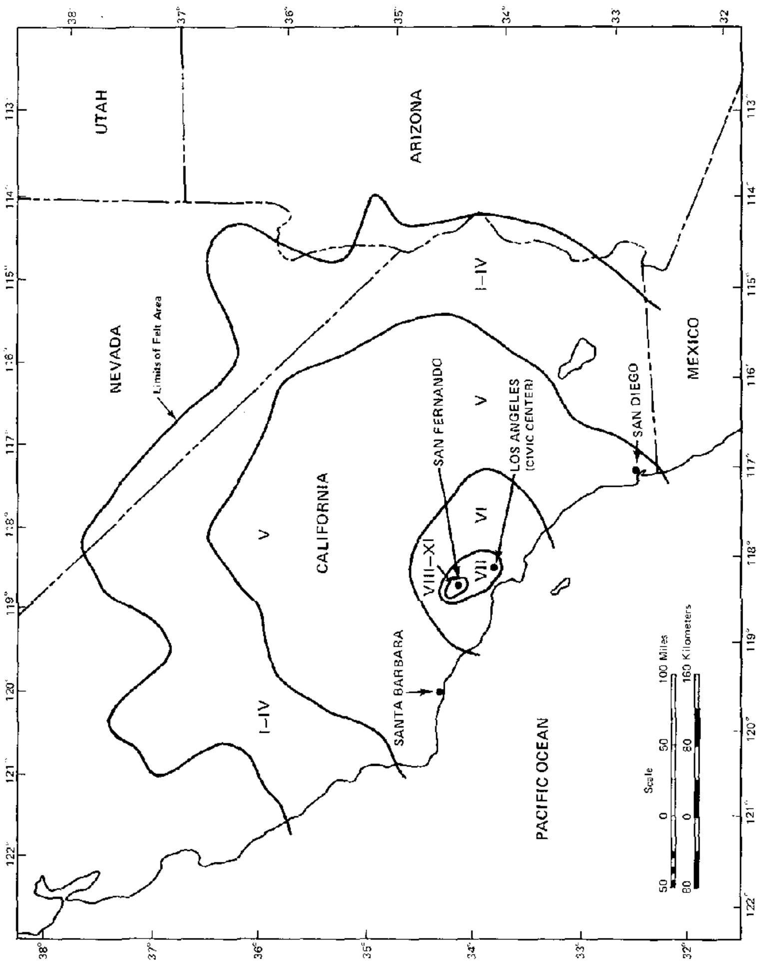

Figure I-4: Intensity and Area Affected by the San Fernando, California, Earthquake of February 9, 1971, 06:00:45 PST (from U.S. Department of Commerce)

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

[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 observations and judgment. Such a guide, carefully prepared, can be helpful even to experienced professionals when in the field. Since many investigators probably will be new at field investigations, though proficient in one of the relevant disciplines, the Guides can also serve a training function.

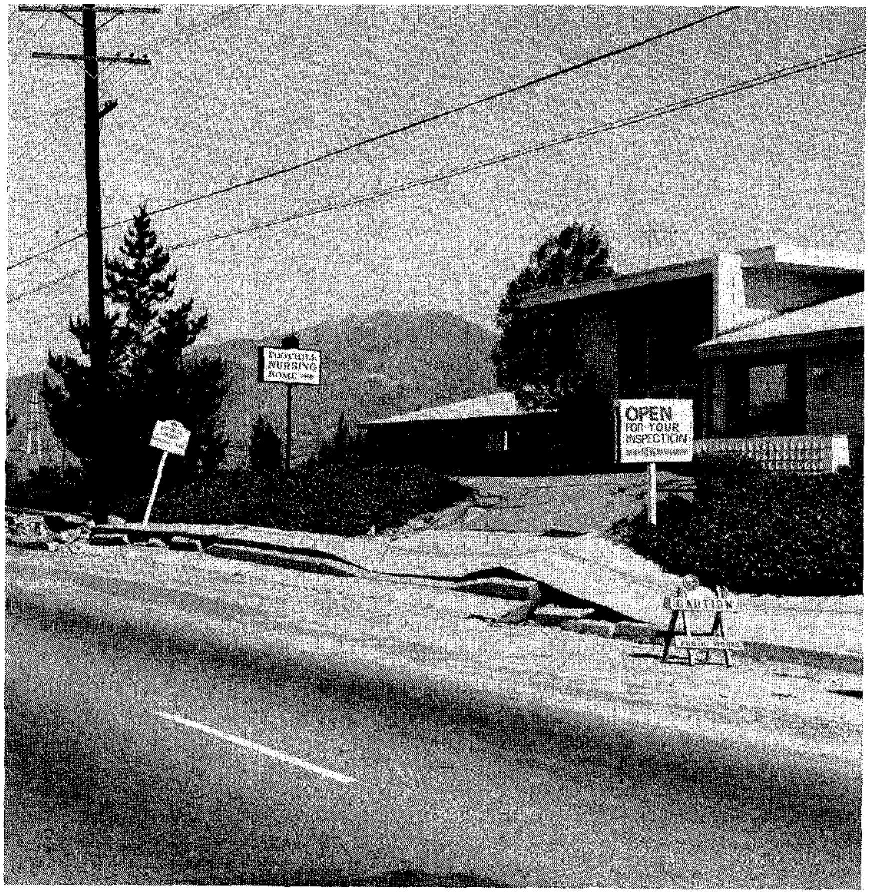

Figure I-5: **Surface Fault Break. Area beyond curb was raised about 3 feet relative to the street. Unoccupied nursing home was damaged but did not collapse. (Los Angeles City Department of Building and Safety photo)**

Figure I-6: Buckling of Freeway Pavement Due to Ground Surface Displacements. (C.M. Duke photo)

Figure I-7: Olive View Hospital. Note stair tower at left which fell away from main building. Roof in right foreground collapsed on parked ambulances. Eight hundred occupants were successfully evacuated from the main building. One person was killed due to a partial building collapse. (Los Angeles City Fire Department photo)

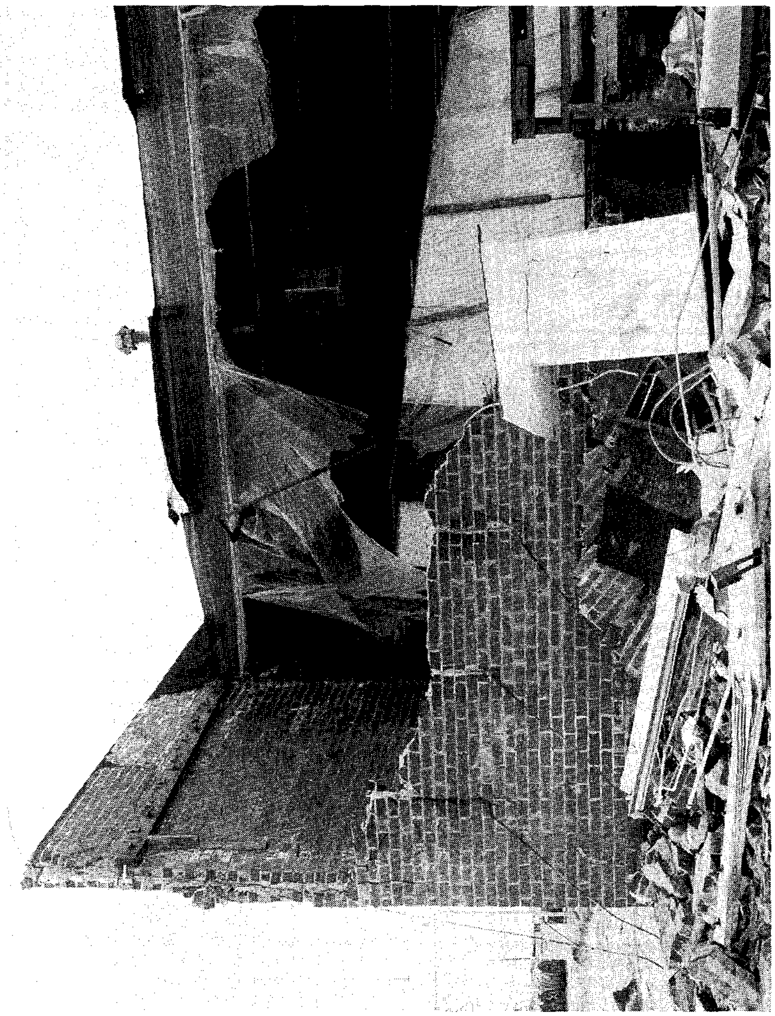

Figure I-8: Typical Industrial Building Damage in City of Sylmar. Average damage to this type of construction in the heavily shaken area was about 17 percent of value. (Los Angeles City Department of Building and Safety photo)

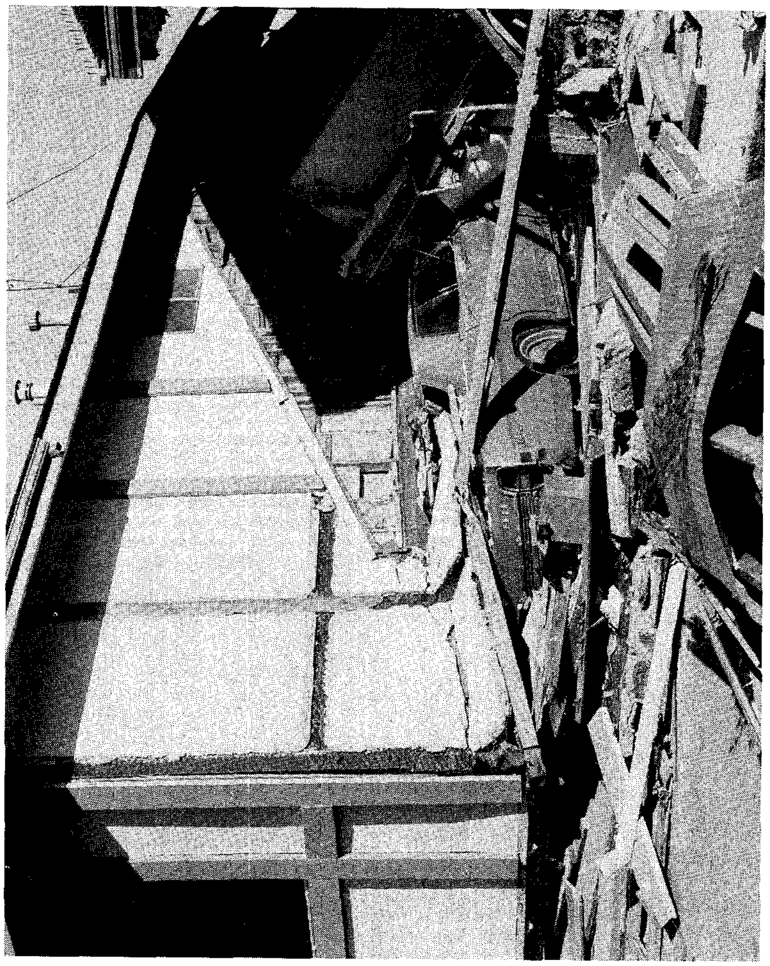

Figure I-9: Collapsed, Split-Level, Single-Family, Wood-Frame Dwelling near Olive View Hospital. Average losses to single-family, wood-frame dwellings in the heavily shaken area were about 7 percent. (Los Angeles City Department of Building and Safety photo)

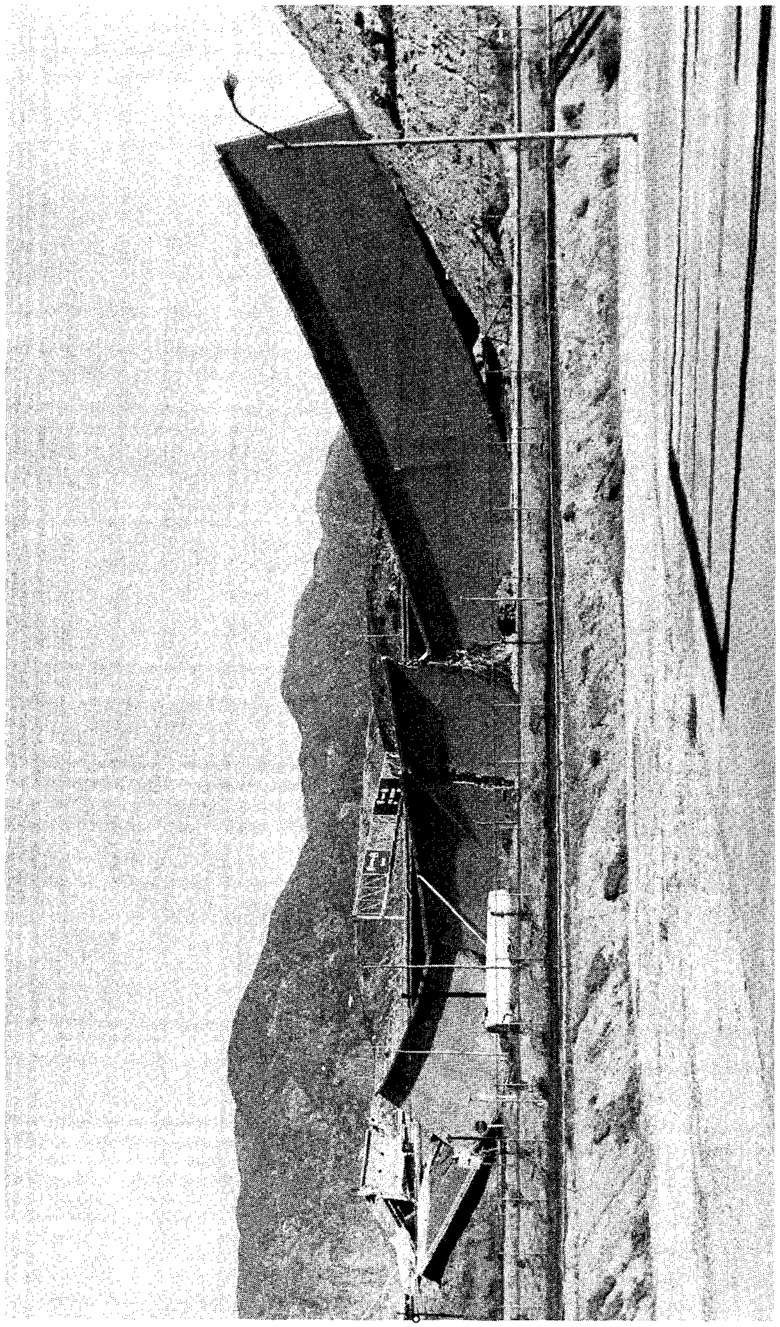

Figure I-10: Collapsed Freeway Overpass. Two motorists were killed by a freeway bridge collapse in this area. (Los Angeles Department of Water and Power photo)

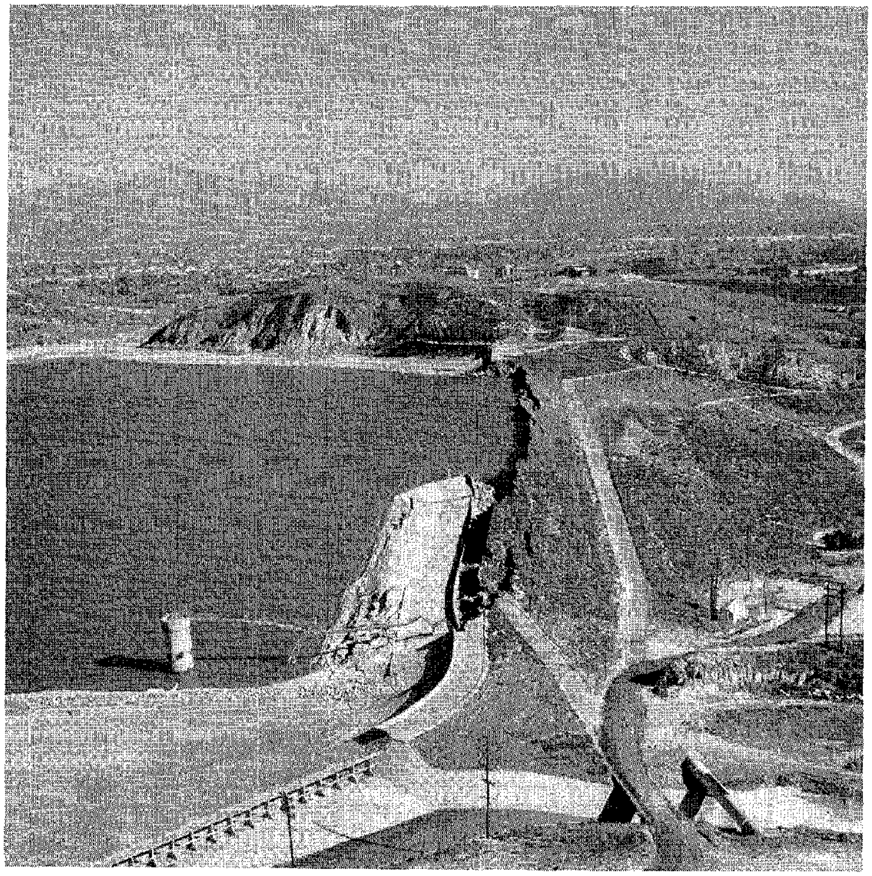

Figure I-11: Partially Collapsed Old (1911) Lower Van Norman Dam. Eighty thousand people were evacuated from the area below the dam; however, the reservoir water was successfully contained by the damaged dam. (Los Angeles City Fire Department photo)

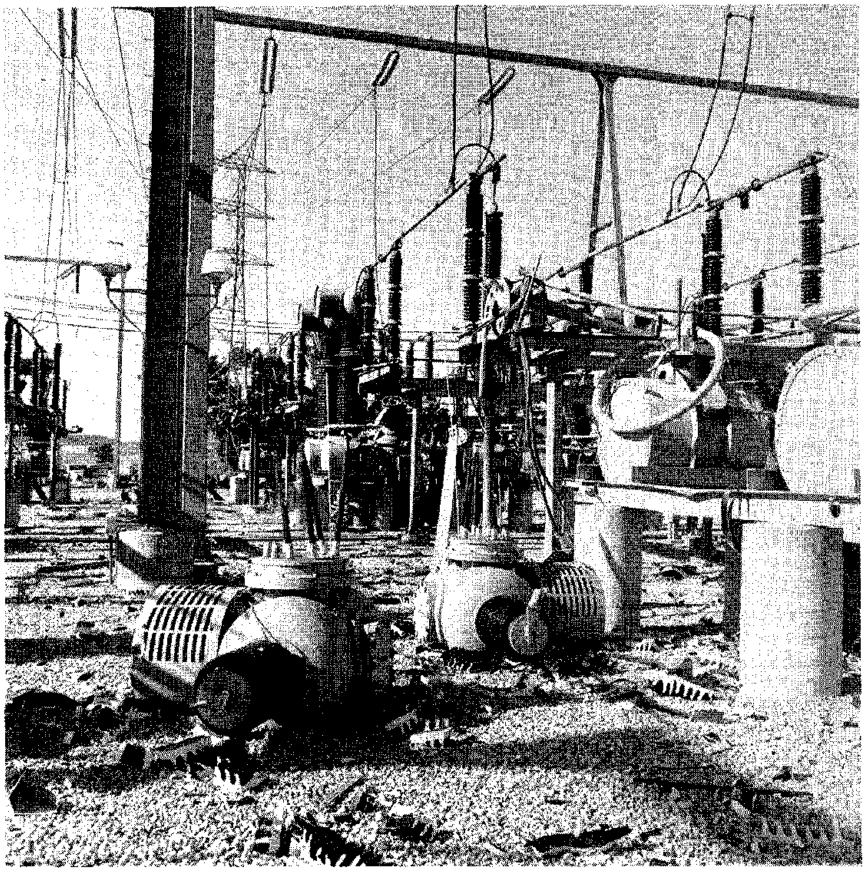

Figure I-12: Damaged Electrical Circuit Breakers at the Sylmar Converter Station. Total damage at this station was about $25 million and required about one year to repair. (Los Angeles Department of Water and Power photo)

While the Field Guides are of international utility, another important set of documents is local in nature. Each city will have particular buildings, dams, pipelines, and emergency service facilities whose response to a strong quake will be of special interest locally or perhaps nationally, e.g., structures designed in accordance with recent code changes, structures selected as typical for the locality, and prevailing hazardous landslide conditions. Information on local geological and soil characteristics will also be of extreme interest. *Data banks* containing maps, plans, and other basic information should be maintained for all participating localities for prompt access by field investigators. The basic responsibility for maintaining these data banks should reside with local government.

These procedures and tools will be to no avail without the rapid post-earthquake promulgation of findings, following professional study and analysis. The new findings need to be assimilated rapidly into the state-of-the-art. Report publication, symposia, and short courses should be planned as integral steps in post-quake research in order to maximize the learning.

Finally, there is a clear need for coordination among the organizations that stand to gain the most from and to contribute the most to earthquake research. Investigations of damaging earthquakes in the United States have varied from routine qualitative inspections to detailed studies involving numerous individuals and government and private agencies. When large numbers of people and agencies have been involved, their effectiveness has suffered from a lack of overall coordination. For example, following the 1971 San Fernando, California, earthquake, there was excessive duplication of effort on survey reports. Also, energy and money were expended on work whose chief product was the relearning of old lessons. On the other hand, a number of critical investigational areas either were overlooked or were not covered in sufficient detail. EERI served a coordinative role following the San Fernando, Managua, and Guatemala earthquakes and is set up to do so in the future, using the philosophy of "Learning from Earthquakes."

The Concerned Professions

In the *building engineering* field, the first investigations which involved detailed analyses of the structural behavior of earthquake-resistive construction followed the two 1952 Kern County, California, earthquakes. This was the first time that significant numbers of earthquake-resistive buildings were tested, because California building regulations requiring earthquake-resistive design were not widely adopted until after the Long Beach earthquake of 1933. The 1952 Kern County, 1964 Alaska, and 1971 San Fernando shocks have been the sites of field testing of modern U.S. earthquake-resistive design methodology.

Essentially, earthquake-resistive design is a procedure wherein changes in criteria and methodology are made based on analyses of building behavior in actual earthquakes and on the results of research done between earthquakes. In several areas of the country, some older buildings have been modified and strengthened to resist earthquake forces, and the behavior of these older buildings in future earthquakes is of interest. However, the greatest opportunities to advance the state-of-the-art of building earthquake engineering have come from real earthquake tests of those structures in which the latest concepts of lateral-force design have been incorporated.

Due to the emphasis on structural behavior in past investigations, the state-of-the-art of the *structural* aspects of building earthquake engineering is far ahead of that of other aspects such as mechanical, electrical, and architectural. However, following the 1964 Alaska and the 1971 San Fernando earthquakes, data on the behavior of some of these nonstructural building systems were gathered and analyzed. There is a need for a much greater investigative effort on these aspects, as the overall behavior of these nonstructural systems has been poor and the associated hazards great.

In the *lifeline earthquake engineering* field, which includes research on the earthquake behavior of public utilities, transportation, waste disposal, flood control, and communication systems, relatively little earthquake investigative effort was made in the United States prior to the 1971 San Fernando earthquake. The state-of-the-art in earthquake engineering for lifelines is therefore generally less advanced than that for buildings. However, there are exceptions to this statement in the larger California utilities. Significant progress was made following the 1971 San Fernando earthquake and a Technical Council on Lifeline Earthquake Engineering has been formed by the American Society of Civil Engineers (ASCE) to encourage further research and progress in this area.

Geoscience investigations are concerned with obtaining new insights and new data on the nature of the earth and on the character of earthquakes by means of geologic, seismologic, and geodetic investigations. The geologist is interested in the earth's near surface as it both influences and is influenced by earthquakes; the seismologist is concerned primarily with quantification and understanding of the earth's geophysical processes; the geodesist is concerned with the changes in position of points on the earth's surface.

Interfaces of geosciences with engineering investigations occur in studies of strong-motion records, permanent ground deformations, estimation of shaking intensities, and aftershocks. Unfortunately, there often has been a considerable time lag of several months between the occurrence of an earthquake and the availability of some of the scientific information needed by the engineers; there is a need for speeding up this process.

Earthquake investigations in the *social science* fields have developed slowly, often on an ad hoc basis as resources have permitted. Such efforts have been largely unsystematic and inadequately integrated into other field investigations. There has been a growing interest in the social impact of earthquakes due to extensions of general research on natural hazards, mounting losses, and the perceived consequences of damaging earthquakes in large urban areas.

Early investigations in the social sciences consisted mainly of reports on the operations of emergency services. Later efforts, particularly those made in response to the 1964 Alaska earthquake, attempted to deal with more fundamental factors. Further research on the 1971 San Fernando and 1972 Managua quakes has produced new information of relevance to the social and managerial sciences. General areas of concern include the following:

1. Emergency responses by individuals, groups, and organizations
2. Secondary economic effects, such as unemployment, disruption of financial and marketing systems, insurance problems, and changes in property values
3. Problems of social control, such as evacuation, looting, relocation, and related measures
4. Analyses of casualties to help determine under what conditions deaths and injuries occurred
5. Assessments of impacts on the social structure, such as population mobility, psychological problems, and the various economic losses

Planning

Both pre- and post-earthquake planning actions are necessary for *all* organizations interested in earthquake investigations. The main planning steps are listed below and are covered in detail in the Summary of EERI Earthquake Response Procedures in Appendix I-B. The complete procedures may be obtained from the EERI Secretary.

Pre-Earthquake Planning Actions:

1. Develop and adopt response and coordination procedures
2. Establish locations for field headquarters (Clearinghouse) or communications centers and provide necessary equipment and supplies
3. Train staffs and investigators
4. Fix responsibilities for investigations (Coordination Plan)
5. Establish and maintain data banks of the following information:
   a. Geological and surface soils data maps
   b. Locations of seismographic stations and sources of data
   c. Lists and location maps of instrumented structures
   d. Lists and location maps of structures (such as buildings, dams, nuclear plants, bridges) deserving of detailed analysis. For each of these structures, assemble or note location of construction drawings, specifications, design calculations, foundation and geological reports, and names of architects and engineers
   e. Maps and brief descriptions of the major lifeline systems and names of chief engineers and their telephone numbers
   f. Street maps and U.S. Geological Survey (USGS) topographic quadrangles

   All of the above material should be assembled and stored at the locations pre-designated as Clearinghouses or Field Headquarters. Periodic checking and updating of this information are needed.

Post-Earthquake Planning Actions:

1. Activate response and coordination procedures
2. Establish Field Headquarters (Clearinghouse)
3. Conduct preliminary reconnaissance surveys to determine overall scope of damage and to identify subjects and areas deserving additional investigation
4. Provide on-the-spot training for local investigators
5. Hold preliminary coordination meetings to (a) discuss the results of the reconnaissance and other preliminary surveys, (b) decide on additional investigations which should be made, and (c) fix responsibilities for these investigations
6. Conduct investigations with research teams representing the organizations accepting responsibilities in advance and at the coordination meeting
7. Analyze research data and prepare reports
8. Rapidly disseminate to the concerned professions critically needed information, including the results of the reconnaissance survey
9. Hold national or international conferences, if justified, to present the results of the research studies

APPENDIX I-A: STAFF AND ADVISORS FOR "LEARNING FROM EARTHQUAKES"

The work leading to the publication of the Field Guides was done by a small staff and a large group of advisors serving on three advisory panels. Together, these people supplied varied technical backgrounds and extensive field investigation experience. The individuals are listed below. Locations are in California, except as otherwise noted.

Staff

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Assistant Project Manager, Engineering:	Jack R. Benjamin Professor Emeritus Stanford University Stanford
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H. J. Degenkolb and Associates
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Systems Development Corp.
Santa Monica

Richard S. Olson
Professor of Government
University of Redlands
Redlands

National Science Foundation Representatives

Charles C. Thiel

John Scalzi

Charles G. Culver (with National Bureau of Standards)

APPENDIX I-B: SUMMARY OF EERI EARTHQUAKE RESPONSE PROCEDURES

INTRODUCTION

The EERI Earthquake Response Procedures have been developed as part of the "Learning from Earthquakes" project. These procedures are based on experiences in past investigations, and they provide checklists and frameworks for an effective response. However, each earthquake will have unique features, and mature judgments by experienced professionals will be required to adapt the procedures to actual events. Modifications of these procedures will be made based on experience and further progress in the "Learning from Earthquakes" project.

The general EERI Earthquake Response Procedures apply to earthquakes occurring anywhere in the world, and include *all* aspects of investigations. The *special plans for California* earthquakes are in cooperation with the California Division of Mines and Geology (CDMG). EERI has engineering responsibilities and CDMG has geoscience responsibilities in these procedures.

Modifications and expansion of these special California procedures for earthquakes in other states and countries will be accomplished during the implementation phase of the "Learning from Earthquakes" project.

GENERAL EERI EARTHQUAKE RESPONSE PROCEDURES

The general EERI Earthquake Response Procedures apply to destructive earthquakes which occur anywhere in the world. EERI responsibilities under these procedures include scientific, engineering, and socioeconomic aspects. Significant aspects of the general plan are as follows:

1. Various points where decisions must be made by EERI officers regarding the scope of the responses and investigations.
2. Designation of the Earthquake Investigation Coordinator (EIC) and the Reconnaissance Team (RT).
3. Establishment of a field investigation headquarters by the EIC (or the Clearinghouse, in the case of a California earthquake).
4. While the primary mission of EERI is the investigation of the effects of the earthquake, it is recognized that there is sometimes an urgent need to determine the safety of buildings. In the past, when requested by local authorities, EERI has suggested procedures to assist the local building officials in determining the safety of buildings. The liability of those making safety inspections is recognized. It has been the practice of local communities to deputize inspectors.
5. Early holding of a preliminary coordination meeting to exchange information, discuss important aspects of the earthquake, and make tentative commitments regarding areas of responsibility for subsequent investigations (Engineering Coordination Plan for California earthquakes).

Table I-3 summarizes these procedures and provides a checklist of actions to be taken. It also lists those responsible for taking the actions indicated.

Table I-3: EERI Actions and Responsibilities Following a Destructive Earthquake

Action	*Responsibility (of)*
A. Destructive earthquake occurs anywhere in the world	
B. Obtain preliminary information from: 1. USGS National Earthquake Information Center (303) 234-3994 2. California Institute of Technology, Seismological Laboratory (213) 795-8806, x. 2295 3. University of California, Berkeley, Seismological Laboratory (415) 642-2160 4. Television and radio	1. Chairman of EERI Committee on Planning Earthquake Investigations: D. F. Moran (805) 642-7461 2. Alternate #1: F. E. McClure Office: (415) 642-1253 Home: (415) 254-8231 3. Alternate #2: J. F. Meehan Office: (916) 445-8730 Home: (916) 487-6235
C-1. Advise EERI officers 1. President: H.J. Degenkolb Office: (415) 392-6952 Home: (415) 564-7592 2. Alternate #1, Vice President, Anestis Veletsos Office: (713) 528-4141, x. 718 Home: (713) 729-4348 3. Alternate #2, Secretary, F. E. McClure Office: (415) 642-1253 Home: (415) 254-8231	Same as above
C-2. For California earthquake, staff Clearinghouse for engineering information in appropriate office of California Division of Mines and Geology (CDMG) or in alternate location	EERI Clearinghouse regional coordinators; response and staffing to be automatic according to procedure following
D. Make decisions on level of EERI initial response	1. President (Degenkolb) 2. Alternate #1, Vice President (Veletsos) 3. Alternate #2, Secretary (McClure) (with necessary Board concurrence)
E. Appoint EERI Earthquake Investigation Coordinator (EIC) and Reconnaissance Team (RT)	Same as above
F. Establish EERI Field Headquarters (for non-California earthquake); coordinate activities of the RT and other investigators, through the Clearinghouse	EIC
G. Suggest procedures to aid local building officials in determining building safety as requested and required	EIC

Table I-3 (continued)

Action	*Responsibility (of)*
H. Investigation by RT	EIC
I. Training and briefing of local investigators	EIC
J. Preliminary coordination meeting:	
1. For California earthquakes, to be held on first or second evening with CDMG meeting; Clearinghouse will advise on meeting time and place	CDMG representatives for California earthquakes
2. For non-California earthquakes, EIC will call the meeting at earliest time depending on progress of reconnaissance investigators; Field Headquarters to advise regarding time and place	EIC
K. Oral reports by RT	EIC and RT
L. Field investigations	Coordination by EIC; individuals, agencies, and organizations accepting responsibility
M. Prepare preliminary reports	Same as above
N. Prepare and publish reconnaissance report	EIC and RT
O. Additional coordination meetings (as required)	EIC
P. Additional investigations (if required)	Coordination by EIC; individuals, agencies, and organizations accepting responsibility
Q. Prepare additional reports (as required)	Same as above
R. Conference (national or international) on earthquake	Conference committee to be established by EERI President

SPECIAL PROCEDURES OF ENGINEERING CLEARINGHOUSE FOR CALIFORNIA EARTHQUAKES

Introduction

The concept of establishing an information Clearinghouse following damaging earthquakes in California was contained in recommendations in the First Report of the California Governor's Earthquake Council dated November 21, 1972. The principal functions of the Clearinghouse are to serve as a center for receiving information regarding damage reports and ongoing field investigations, and for releasing such information to those concerned. The Clearinghouse operation is intended to handle damage information in broad terms of damage to various buildings and utility types, and in various geographic areas. It is not intended to handle the individual building information necessary in order to determine structural safety, which is a function of the local regulatory agency. Clearinghouse responsibilities are divided between the California Division of Mines and Geology (CDMG) and

EERI. The CDMG is responsible for the seismological and geological aspects, and the EERI is responsible for the engineering aspects of the effort, including structures, utilities, transportation, communications, and soils. EERI has accepted the offer of CDMG to share their facilities for the Clearinghouse operations.

EERI response to Clearinghouse operations is planned to be automatic.

For *earthquakes outside of California*, a *Field Headquarters* will be established by the EIC. This Field Headquarters will serve essentially the same function as the California Clearinghouse, except that the CDMG will not be involved, and EERI's responsibilities will include all involved disciplines.

SPECIAL PLAN FOR THE COORDINATION OF ENGINEERING INVESTIGATIONS OF CALIFORNIA EARTHQUAKES

The need for coordination of early post-earthquake engineering inspections and studies for California earthquakes has been advocated by EERI and was contained in the First Report of the Governor's Earthquake Council. EERI was offered and has accepted the responsibility of the leading role in the implementation of the engineering aspects of this recommendation.

The CDMG has responsibility in California for the coordination of early post-earthquake geologic and seismologic investigations.

The purpose of the coordination plan is to maximize the learning from destructive California earthquakes by coordinating the efforts of the many individuals and organizations who will be making engineering investigations. This coordination plan is not intended to be restrictive but rather to avoid needless overlapping as well as the possibility of some areas not being properly investigated.

This coordination plan applies to investigations of the effects of destructive California earthquakes. However, a similar plan will apply for earthquakes in other states.

No attempt has been made to identify all of the numerous specific local jurisdictions such as building, fire, and police departments; sanitation districts; and water and power departments that will become involved. It is anticipated that these agencies will be identified and contacted immediately following the earthquake. The investigation responsibility assignments provide a prearranged framework for the coordination of early preliminary surveys and subsequent detailed investigations. Organizations which are listed first are considered to have the prime responsibility. Additional organizations in California and other states will be contacted as part of the implementation phase of the "Learning from Earthquakes" project. The EERI California Clearinghouse will serve as a message and information center for ongoing preliminary engineering investigations. All investigators should maintain contact with the EERI Clearinghouse representative and keep him informed as to the type and scope of the investigations being made. In turn, the EERI Clearinghouse representative can advise those in the field and other interested parties regarding ongoing investigations, including preliminary results.

A preliminary coordination of subsequent detailed investigations will be accomplished at the preliminary *coordination meeting.* This meeting will be the first formal meeting of those involved or interested in the earthquake investigation and will be held on the first or second evening following the earthquake. Time and location of the meeting may be obtained from the Clearinghouse. Those who should attend the coordination meeting include the EERI Earthquake Investigation Coordinator (EIC), members of the EERI Reconnaissance Team (RT), persons staffing the EERI Clearinghouse, individuals and representatives of organizations which have made preliminary surveys, and those interested in further investigations. This meeting will be used to discuss the results of the preliminary investigations and to reach agreement on subjects deserving further detailed investigation. Responsibilities for further investigations will be discussed and agreed upon. This preliminary coordination meeting will be held in conjunction with the CDMG and will be chaired by their representative.

For earthquakes outside of California, the preliminary coordination meeting will be called and chaired by the EIC. Details of the meeting may be obtained from the EERI Field Headquarters.

Tables I-4 and I-5 are lists of participating organizations and investigation responsibility assignments primarily for California earthquakes. Similar lists for other states will be developed as part of the implementation phase of the "Learning from Earthquakes" project.

Table I-4: List of Organizations Participating In Engineering Investigations of California Earthquakes

Professional
- American Institute of Architects (California Council) (CAIA)
- American Society of Civil Engineers (ASCE)
  - ASCE Technical Council on Lifeline Earthquake Engineering (TCLEE)
- Association of Engineering Geologists (AEG)
- Consulting Engineers Association of California (CEAC)
- Structural Engineers Association of California (SEAOC)

Academic
- Earthquake Engineering Research Laboratory (EERL)—California Institute of Technology
- Massachusetts Institute of Technology (MIT)
- Stanford University (SU)
- Universities Council for Earthquake Engineering Research (UCEER)
- University of California, Berkeley (UCB)
- University of California, Los Angeles (UCLA)
- University of California, San Diego (UCSD)
- University of Illinois (UI)

Government and Military
- *Federal*
  - Federal Disaster Assistance Administration (FDAA)
  - Federal Highway Administration (FHA)
  - National Bureau of Standards (NBS)
  - National Oceanic and Atmospheric Administration (NOAA)
  - Nuclear Regulatory Commission (NRC)
  - U.S. Army Corps of Engineers (COE)
  - U.S. Geological Survey (USGS)

Table I-4 (continued)

California
- Department of Aeronautics (DA)
- Department of Housing and Community Development (CHCD)
- Department of Transportation (CT)
- Department of Water Resources (CDWR)
- Division of Mines and Geology (CDMG)
- Division of Oil and Gas (CDOG)
- Energy Resources Conservation and Development Commission (ERCDC)
- Office of Architecture and Construction (OAC)
- Office of Emergency Services (OES)
- Public Utilities Commission (PUC)
- Seismic Safety Commission (SSC)

Utilities
- East Bay Municipal Utility District (EBMUD)
- General Telephone (GTE)
- Los Angeles Department of Water and Power (LADWP)
- Metropolitan Water District (MWD)
- Pacific Gas & Electric (PG&E)
- Pacific Telephone & Telegraph (PTT)
- San Diego Gas & Electric (SDGE)
- Southern California Edison (SCE)
- Southern California Gas (SCG)

Associations and Institutes
- American Iron and Steel Institute (AISI)
- Insurance Services Office (ISO)
- International Conference of Building Officials (ICBO)
- Masonry Institute of America (MIA)
- Portland Cement Association (PCA)
- Western Oil and Gas Association (WOGA)

Table I-5: Investigation Responsibility Assignments for California Earthquakes

Area of Investigation	*Responsibility of*
Buildings—General	
Structural—General	SEAOC, NBS, IOC, OAC, EERI, ICBO
Masonry	MIA and above
Concrete	PCA and above
Steel	AISI and above
Non-Structural	SEAOC, NBS, ISO, OAC, EERI, ICBO, CAIA
Equipment	CEAC, SEAOC
Statistical loss data	ISO, SEAOC, NBS, MIT
Fire	ISO, ICBO
Buildings—Occupancy	
Dwellings and apartments	SEAOC, NBS, ISO, HUD, CHCD
Mobile homes	ISO
Hospitals	SEAOC, OAC, NBS, VA
Schools	SEAOC, OAC
Military	COE, Navy and Air Force
Nuclear	NRC, Owners
Special Structures	
Tanks (water, sewage, and petroleum)	TCLEE, EERI, ISO, Owners
Towers (radio, television, transmission)	SEAOC, Owners
Soils and Foundations	
Dams and reservoirs	CDWR, USGS, COE, Owners
Ground movements	CDMG, USGS, FHA, COE, CDWR, CT
Foundation soils	USGS, SEAOC, NBS, EERI, COE, ASCE
Soils-structure interaction	USGS, UCLA, EERI, SEAOC
Site amplification	USGS, CDMG, UCLA, EERI
Energy Systems	
Electric power	TCLEE, Utilities
Natural gas	TCLEE, Utilities
Oil	TCLEE, WOGA, Owners

Table I-5 (continued)

Area of Investigation	*Responsibility of*
Water Systems	
Potable water (including dams)	CDWR, TCLEE, USGS, COE, Utilities
Water for firefighting	ISO, Utilities
Storm drainage (including dams)	TCLEE, CDWR, USGS, COE, Local Districts
Sewage	TCLEE, Local Districts
Transportation Systems	
Railroads (including bridges)	TCLEE, Owners
Highways and roads (including bridges)	TCLEE, CDH, FHA, Local Districts
Mass public transportation	TCLEE, Owners
Airports	TCLEE, DA, Owners
Harbors	TCLEE, COE, Owners
Communication Systems	
Telephone	TCLEE, Utilities
Radio and television	Owners
Newspapers and magazines	Owners

The following sections, beyond the EERI California engineering coordination, may be useful for investigations in other areas.

Geoscience	
Geology	USGS, CDMG, Universities, Private Sector
Seismology	USGS, CIT, UCB, Other Universities
Geodesy	NOAA

APPENDIX I-C: REFERENCES TO REPORTS ON EARTHQUAKE INVESTIGATIONS

1. Agadir, Morocco, earthquake, 1960:
   The Agadir, Morocco, earthquake, February 29, 1960: American Iron and Steel Institute, New York, 1962.
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II. PREFACE TO FIELD GUIDES

It is important that users of the Field Guides become familiar with the general philosophy and response procedures presented in Section I, the Planning Guide. The field work will be an interdisciplinary, selective, and coordinated effort based on the philosophy and procedures mentioned therein.

Each Field Guide is the result of deliberations by an advisory panel of professionals with extensive experience in earthquake investigations. The panels have attempted to define knowledge voids in their respective fields and to translate these into the Field Guides covering what to look for, how to recognize it, and what to record. The comprehensiveness of the Field Guides indicates that there is still very much that we do not know. A partial exception to this is the Buildings subsection of the Engineering Field Guide, whose contents reflect the strong emphasis on this subject in past earthquake investigations.

USERS OF THE FIELD GUIDES

The Field Guides are to be used by professionals, many of whom lack experience in the field investigation of the effects of destructive earthquakes. Those professionals with extensive field experience will have less dependence on the Field Guides, but the guides may be useful in refreshing memories and as aids for training less-experienced professionals.

During the reconnaissance investigation, the Field Guides should be used to help identify important items which should be covered in more detail in followup research investigations. The commentaries and checklists are intended to be used for this purpose. Recording the field information on the forms provided at the back of the Field Guides will help to ensure that adequate detailed information is gathered in a standard format that can be easily reproduced for the information of followup teams.

The Field Guides are *not* textbooks on the engineering, geoscience, or social science aspects of earthquake engineering, nor do they cover the requirements for detailed investigations and reports which may be required in the case of a major earthquake.

RECONNAISSANCE TEAMS, COORDINATION, AND COMMUNICATION

Referring to the Summary of the EERI Earthquake Response Procedures in Section I, Appendix I-B, a destructive earthquake affecting a large metropolitan area in the United States will likely require a large Reconnaissance Team composed of experienced professional investigators representing the major fields covered by the Field Guides. The Reconnaissance Team will identify opportunities and make recommendations for additional investigations. It is not necessary, nor even desirable, that the Reconnaissance Team operate as a single group; however, coordination of the various individual or subgroup efforts is essential. Many other investigators, besides those on the Reconnaissance Team, will be in the field. The *EERI Field Headquarters* (Engineering Clearinghouse in the case of California earthquakes) will serve as the field coordination center. All investigators are urged to maintain contact with the Field Headquarters to report their findings and progress and also to obtain information regarding other investigations being performed.

Communication, following a destructive shock, is usually difficult. Long-distance telephone systems may be operable even when the local system is out of service. The use of amateur radio networks has proven to be useful, particularly in foreign countries. Locations of amateur radio contacts can usually be obtained from local Red Cross units.

COORDINATION MEETING

Those field investigators interested in participating in followup investigations are invited to a Coordination Meeting to discuss their findings and to fix responsibilities for subsequent studies. This meeting will likely be held on the first or second evening following the earthquake. Information regarding the time and place of this meeting may be obtained from the EERI Field Headquarters. The critical problem, in terms of time, is to collect the fragile damage data before they are altered, removed, or covered up, and to get the principal findings into the hands of earthquake engineers and scientists.

IDENTIFICATION AND PASSES

A damaging earthquake in an urban area generally results in the damaged areas and buildings being closed to the public until buildings can be checked for safety. This usually means that some type of pass is required for entry into the area. This creates a problem for earthquake investigators since each community has its own police and its own pass and identification requirements. Letters of introduction from EERI officers and Federal and state officials have been useful for identification in past investigations. However, entry into damaged areas has not been a serious problem, even in foreign earthquake areas.

BUILDING SAFETY INSPECTIONS

The primary mission of EERI is the investigation of the effects of the earthquake; however, it is recognized that a parallel need is the determination of the safety of buildings. EERI has and will cooperate with local authorities to assist in meeting this need. In most cases, outside inspectors have been deputized by local jurisdictions to reduce their liability exposure.

The data gathered as a result of any safety inspections must be made available to the investigating teams.

CLOTHING AND EQUIPMENT

Investigators who enter a damaged area shortly after a destructive earthquake expose themselves to danger from further collapses caused by aftershocks. It has been found that a hard hat, heavy boots to walk on broken glass, and suitable outdoor clothing, depending on the weather, are essential. In addition, in some cases, potable water, food, and shelter may have to be carried into the area. Flashlights with extra batteries and bulbs are indispensable. Most experienced engineering investigators carry cameras, flash units, film, and portable surveying equipment. Earth and social scientists bring the tools of their trades. Travel outside the United States generally requires passports, visas, and immunization records.

Each destructive earthquake will probably present opportunities to relearn old lessons and, hopefully, to learn some new ones. It is essential to make the most of each opportunity. *Investigators must always be on the lookout for new lessons not covered by the Field Guides.* Investigators are cautioned to avoid making *public* statements regarding the adequacy of planning, design, or construction of specific facilities or the effectiveness of emergency responses until all of the available information has been examined and analyzed. It is preferable that such conclusions be reserved for inclusion in a published report.

The Field Guides are in a continual state of revision to keep current with research needs and the state-of-the-art. Suggestions for changes should be sent to the EERI Office.

III. ENGINEERING FIELD GUIDE

INTRODUCTION

This Engineering Field Guide is intended for use by professional engineers, architects, and planners investigating and reporting the earthquake performance of buildings, community lifelines, and soils; it also contains information on how to gather and compile statistical data. For quick field reference it presents a number of commentaries and checklists.

The objective of these engineering investigations is to learn as much as possible from the earthquake performance of engineered works; it is important to report good as well as poor performances. The earthquake itself, its location, and the engineered works affected by it will determine the available lessons to be learned.

No priorities are assigned to the items in the checklists, but if full investigation is not practical, the study of items which reflect on the evaluation and efficiency of the latest and most current theories and practices should be given preference over the documentation of previously substantiated knowledge. Buildings or other structures containing strong-motion accelerographs or comparable instrumentation should receive priority attention in almost any earthquake investigation. It is of preemptive interest to document in detail the behavior of such structures.

Community lifelines (transportation, communications, energy, water, and sewage systems) require comprehensive and detailed investigations, reflecting the need for developing more general behavior data in this area.

The behavior of soils underlying or adjacent to a structure has a profound effect on structural behavior. Permanent surface soil movement such as settlements, landslides, liquefaction, and surface fault rupture generally results in serious structural damage. It is essential that the soil effects be identified so that a meaningful evaluation of the building damage can be made. Precise geodetic measurements before and after an earthquake are necessary in order to determine the amounts and directions of surface movements.

Soils aspects more related to geology are presented in Section IV, the Geoscience Field Guide.

The Statistical Data section of the Engineering Field Guide summarizes the traditional and introduces the probabilistic approaches to the gathering and analysis of earthquake damage data. Recommendations of some specific types of data to be collected are presented. Appendix III-A, Statistical Sampling and Analysis in Earthquake Investigations, provides a realistic evaluation of the possible uses of probability and statistical techniques in future earthquake investigations.

The organization of the Engineering Field Guide consists of short *commentaries* under most specific subjects followed by *checklists.* To minimize repetitious wording, the following statement precedes, by implication, most checklist statements (therefore they may appear as incomplete sentences):

> "Observe, record, and evaluate the behavior or significance of . . ."

The commentaries are intended to summarize lessons learned from past earthquakes, to present briefly current design philosophy, and to bring up subjects for which there is an urgent need to gather more performance data. It was not possible to achieve all three of these objectives in every case. In the buildings field, the abundance and variability of available earthquake performance experiences precluded reasonably short summaries and some were therefore omitted. Similarly, the design philosophies for some items are subject to individual interpretation, and lack of space precluded presentations of the complete subjects. Frequently, critical needs for performance data could not be identified except in a very general way for focusing attention on the performance of those particular facilities which indicate the success or failure of current procedures or theories in the art of earthquake-resistive design.

Investigators should be aware of the possible damage to relatively large or long buildings and lifeline facilities caused by ground surface waves. However, evidence of such damage is difficult to observe in the field without the help of instrumental records.

Appendix III-B contains sample forms for gathering field data on buildings and lifelines, and a form to be used by building departments. Full-size versions of these forms to be used for reproduction and field use are located at the back of this book. Completed forms should be sent to the EERI Field Headquarters for reproduction and dissemination.

BUILDINGS

INTRODUCTION

Buildings with earthquake-resistive features generally have performed better than have those without such features. Each destructive shock has exposed some deficiencies in design criteria and construction practices. Investigations and subsequent in-depth studies following past destructive earthquakes have often resulted in changes in the design and construction of earthquake-resistive buildings. While the features of the earthquake and the structures it affects will determine the lessons to be learned, the investigator should be on the alert to review all *effects* that may have a bearing on current design and construction practices. Effects which may assist the analyst in determining the influences of permanent surface ground displacements, site amplification, soil-structure interaction, and cumulative unrepaired damage from past earthquakes must be considered. Behavioral comparisons of different systems under like intensities of ground motion are important, as are behavioral comparisons of like systems under different ground motion intensities. Modern earthquake-resistive buildings containing strong-motion accelerographs or comparable instrumentation should receive priority attention in almost any investigation.

In a region (such as California) that customarily incorporates earthquake-resistive design requirements into its building codes, most of the design lessons are learned from the damage and lack of damage to buildings designed under the codes. Few new design lessons may be learned from the relatively good behavior of older buildings built prior to the imposition of these codes. If the earthquake occurs in an area where structures are not habitually designed for earthquake resistivity, the opportunities for learning new design lessons diminish, but it may still be important to review damage in order to identify vulnerable construction features.

Notwithstanding the past experiences and the directions given in the various commentaries and checklists which follow, *the investigator must be on the lookout for unanticipated new lessons.*

The earthquake performance of buildings housing critical functions (such as hospitals, fire stations, and emergency communication centers) deserves special attention. The effects of the building's behavior on the ability of the facility to fulfill its primary function should be examined.

Immediately following a damaging shock, the local building department is usually overworked because of the necessity of inspecting buildings to determine if they can be occupied safely. Very few building departments are staffed sufficiently to handle the numerous inspections needed after a major earthquake in their area, and they will probably need help from private engineers and building departments of other cities. (A recommended form for building departments to record building damage data is included at the end of the Engineering Field Guide, page 100.) This means that there will probably be a considerable demand for such inspections by local structural engineers, and the gathering of fragile earthquake damage data may have to be done by engineers from outside of the area.

DEFINITIONS

The following definitions are from "Recommended Lateral Force Requirements and Commentary," published in the *Structural Engineers Association of California* (SEAOC) *Code* (1973).

SPACE FRAME is a three dimensional structural system composed of interconnected members, other than bearing walls, laterally supported so as to function as a complete self-contained unit with or without the aid of horizontal diaphragms or floor bracing systems. This definition is intended to be general enough to permit members to be sloped or battered as well as horizontal and vertical, so as not to exclude special space structures. Usually, space frames are composed of horizontal beams or girders and vertical columns. There may or may not be diagonal members associated with the space frame, such as knee-braces, rod-bracing, X-bracing, etc.

SPACE FRAME — VERTICAL LOAD-CARRYING is a space frame designed to carry all vertical loads. The frame may or may not be moment-resisting. The words 'complete' (as related to space frame) and 'all vertical loads' (as related to space frame — vertical load-carrying) are not to be construed in an absolute sense. Accordingly, where these words appear in this commentary, they will be modified, or be understood to be modified, with the word 'substantially.' The reasoning here is that the action of a multistoried building is not significantly influenced by the presence of a minor portion of bearing walls — around a stairwell, for example. Also, in a tall building with setbacks, the completeness of the frame for the tower, when carried through to the foundation, is not adversely affected by bearing walls in the base structure adjacent to the tower. Neither does it seem reasonable to require that basement walls be frame-supported; nor walls of not more than one story that are supported directly on foundation walls.

SPACE FRAME — MOMENT-RESISTING is a vertical load-carrying space frame in which the members and joints of that part of the space frame selected to be 'moment-resisting' are capable of resisting design lateral forces by bending moments. This frame has members and joints designed to resist the bending moments corresponding to a set of stipulated or assumed proportions of the prescribed lateral forces. This system may or may not be enclosed by or adjoined by more rigid elements which would tend to prevent the space frame from resisting lateral forces. The design and construction of the frame to resist bending moments may or may not have any relation to its ability to receive the design load because of more rigid elements which are in the structure or which may encase the frame. However, in the case of both Moment-Resisting Space Frames and Ductile Moment-Resisting Space Frames, defined below, it is essential that it be shown that neither the elastic nor inelastic action, including failure of the more rigid elements, will impair the vertical- or lateral-load-resisting ability of the space frame.

SPACE FRAME — DUCTILE MOMENT-RESISTING is a moment-resisting space frame of structural steel or of special reinforced concrete conforming to the SEAOC Code.

BOX SYSTEM is a structural system without a substantially complete vertical-load-carrying space frame. In this system, the required lateral forces are resisted principally by shear walls as hereinafter defined. It is a composite system of vertical-load-carrying framing, bearing walls, and perhaps other lateral stiffening shear walls. The structure may have some columns, but generally columns in conjunction with bearing walls. Shear walls may also be bearing walls. Horizontal elements which distribute the lateral forces between the masses accelerated by the earthquake and the vertical resisting elements (shear walls) may be diaphragms of any of several materials, or horizontal bracing trusses. In summary, a box system is characterized by all of the following: (1) incomplete vertical-load-carrying space frame; (2) bearing walls carrying part or all of the vertical loads; (3) lateral forces resisted by shear walls; and (4) horizontal distributing system consisting of diaphragms or bracing trusses.

SHEAR WALL is a wall designed to resist lateral forces parallel to the wall. Braced frames subjected primarily to axial stresses shall be considered as shear walls for the purpose of this definition. A shear wall is normally vertical, although not necessarily so.

LATERAL-FORCE-RESISTING SYSTEM is that part of the structural system to which the lateral forces are assigned by the structural engineer. The entire space frame need not be part of the lateral-force-resisting system, but the latter must be completely stable in all directions, independent of other space frame elements or shear walls that may be attached thereto. Generally, this will mean not less than two frames in each direction, corresponding to the two principal axes of the building or structure, and spaced far enough apart to assure stability.

DIAPHRAGM is essentially a horizontal girder composed of a web (such as a floor or roof slab) with adequate flanges, which distributes lateral forces to the vertical resisting elements. For the purposes of this Code, horizontal bracing trusses or systems must conform to the provisions applicable to diaphragms. A diaphragm may be inclined or curved, like a sloping or curved roof.

DYNAMIC APPROACH is a simplified analysis which provides a rational basis for establishing equivalent static forces to simulate the conditions and stresses that will occur under complex earthquake ground motion. Rigorous dynamic analyses can be made for the effect of recorded ground motions on simplified structures and these are to be encouraged toward further improvements in practical design criteria for aseismic design. But the design criteria to be used in the day-to-day design of structures must not be so complex as to be impractical, nor so involved as to require a disproportionate part of the total design effort. At this stage of knowledge, the best that can be accomplished reasonably is to have the design criteria fairly consistent with the dynamic nature of the problem; hence, the term 'dynamic approach.'

STATIC FORCE EQUIVALENTS are a set of design static forces established to simulate the effects, in shears, moments, and direct stresses, of the erratic earthquake ground motion. It is to be noted that during an earthquake there are, in fact, no externally applied forces on a structure other than the base shear, base moment, and a base vertical force. The last is not specifically covered in the SEAOC Code, but is provided for by the requirement for the combination of stresses resulting from the full vertical design loads with those resulting from the prescribed seismic forces. Also special provisions are set forth where reductions in vertical load caused by vertical ground motion are important. In the SEAOC Code the design base shear is defined and is resolved into static force equivalents.

BASE SHEAR is the total lateral earthquake design force on the structure in a particular direction being considered, which is generally normal to a principal axis (in plan) of the structure. The base shear is the horizontal force transmitted from the ground into the structure. The base shear, or the shear at any level, is the summation of the individual lateral forces from the top down to the base or to the level in question.

TRIANGULAR DISTRIBUTION is a method for resolving the base shear into static force equivalents applied laterally to the structure. Fundamentally, as the structure vibrates each mass is subjected to inertia forces. By Newton's Law, these inertia forces are proportional to mass times acceleration. When deflection is proportional to force as in the elastic range of action, for which design criteria are established, the acceleration is proportional to the deflection of the mass. Hence, the inertia forces are proportional to mass times acceleration, and also to mass times deflection. Since the masses and their distribution are known, it is only necessary to know the shape of the deflection curve in order to have a means to distribute the base shear. It has been demonstrated that for an idealized uniform building vibrating in the fundamental mode, the shape of the deflection curve is essentially a straight line, zero at the bottom and maximum deflection at the top of the structure. If the mass is uniformly distributed over the height, the multiple of the equal masses times the linear deflection results in a triangular distribution of the base shear, zero at the bottom and maximum at the top.

RESPONSE is the effect produced on a structure by earthquake ground motion. The spectral response is the maximum response during an earthquake. When a recorded ground motion is applied to a series of simple spring-mass structures, varying only by the natural period, the plots of the spectral responses constitute the earthquake spectra. These earthquake spectra may be determined without damping or with damping, usually of the viscous type. The spectra may be expressed as velocity spectra, acceleration spectra, displacement spectra, or other variables related to these units. In any event, they all express a response characteristic of the particular earthquake. Their development has been an outstanding accomplishment in engineering seismology and very useful in the application of a dynamic approach to code earthquake-resistant design criteria.

DAMPING is a rate at which a natural vibration decays. If a simple spring mass system were set in motion and had no damping, it would continue to vibrate infinitum. To some degree energy is lost and this energy loss results in a decreasing amplitude of vibration. In a forced vibration, such as that which might be induced by an earthquake, the effect of damping is to decrease significantly the magnitude of the response of the structure to ground motion. For mathematical purposes, considering response in the elastic range only, it is usual to assume so-called 'viscous damping' or damping proportional to velocity. In actual structures the nature of the damping is not so simple, as inelastic action takes place, especially in destructive earthquakes. Suffice it to say here that it is the combination of damping in the elastic range, inelastic action, and other factors that accounts for the good behavior of structures designed for modest lateral forces in rather severe earthquakes.

MODES: Simplified spring-mass systems have only one mode in which they can vibrate. Most real structures are capable of vibrating in several configurations, or modes, each with its own natural period. The elastic response of a structure capable of vibrating in several modes is the sum of the concurrent responses of each of these modes. It has been shown that each mode can be represented by a spring-mass system of period equal to that of the mode represented, and of a certain proportion of the total mass of the actual structure. Hence, the dynamic approach used in justifying the period criterion for base shear encompasses the analysis of the response of the modal spring-mass systems in somewhat idealized configurations.

TORSION: Structures vibrate in complex ways, involving translational vibrations and also torsional vibrations. Torsional vibrations, like translational vibrations, can occur in multiple modes. Torsional effects are most severe in unsymmetrical structures, but even symmetrical structures are subject to torsional vibration, and the SEAOC Code stipulates that provision be made for 'accidental torsion' as well as torsion due to calculated eccentricities.

DRIFT (as used in lateral force design for wind or earthquake) has two connotations:

1. The lateral deflection, due to design forces of wind or earthquake, of any point in the structure relative to the ground, or the absolute deflection;
2. The incremental lateral deflection in any story due to the design forces of wind or earthquake. This concept is more properly the story drift, or the relative motion of the upper floor to the lower floor of any story.

OVERTURNING MOMENT is the moment on the structure as a whole at any given level, due either to wind or to earthquake lateral forces. The SEAOC Code restricts itself to criteria for determining the overturning moment due to earthquake.

BUILDING SEPARATIONS are separations between two adjoining buildings, or parts of the same building, with or without frangible closures, for the purpose of permitting the adjoining buildings or parts to respond to earthquake ground motion independently.

SETBACKS are any offset horizontally in the plane of an exterior wall of a structure. Usually these require the transfer of shear from the upper wall across the setback to the wall below. Provision for overturning moment also requires special attention at setbacks. The SEAOC Code considers the more usual case of concurrent physical and dynamic setbacks. It can occur that a physical setback will not create a dynamic irregularity. Conversely a dynamic irregularity can be created without a physical setback. These special conditions should be carefully considered by the structural engineer to produce proper aseismic design.

STRUCTURAL CONCEPTS

Lateral-Force-Resisting Systems

Commentary: The type of lateral-force-resisting system used in construction has a significant influence on building performance. Some basic systems commonly used are moment-resisting space frame, shear wall, braced frame, box, and various combinations of these. The architectural design concept may often limit the choices of structural systems.

The objective of this subsection is to identify buildings whose basic architectural concepts and types of lateral-force-resisting systems have influenced performance, both good and poor. The systematic effects of siting and space distribution and their use should be considered. General factors to be considered are the relationship and compatibility between architectural and structural concepts and the behavior of the different systems used.

Redundancy is a general factor of importance in system performance. Although in many modern multistory buildings redundancy virtually has been eliminated by the use of metal curtain walls and moveable partitions, it still is found in, for example, a design providing multiple systems, such as combined rigid-frame and shear-wall systems within the same structure.

Checklist:
1. Architectural and structural concepts and their relationship
2. Redundancy, whether logical system or otherwise
3. Relative behavior of different systems in the same general area
4. Relative behavior of similar systems in different intensity zones

Irregular Systems

Commentary: Reentrant corners, insets, setbacks, and similar breaks in the continuity of the lateral-force-resisting system tend to result in areas of localized damage. These irregularities may be due to discontinuous and inadequate force paths, unrecognized force components, and/or construction variabilities.

Torsional responses are expected in buildings having marked asymmetry in geometrics, stiffnesses, and masses. Torsion can also arise from other sources, such as the presence (and participation in the building response) of stairs, partitions, and masonry infill walls. Structural failures and shifting in the structural response characteristics due to damage can contribute to a torsional response. Restricted deformation as evidenced by pounding against adjacent structures can induce torsion.

It is possible to overcome partially the problems of irregular systems, but this requires careful and thorough design and execution in the field. Measures which are effective or ineffective in controlling or reducing damage in irregular systems should be noted.

Checklist:
1. Irregular plans and setbacks in elevation
2. Changes in the lateral-load-resisting system, in materials, masses, or stiffnesses
3. Evidences of torsional response
4. Relative behavior of regular and irregular systems in the same general area
5. Good and poor design details and construction procedures

Overturning

Commentary: The tendency of a building structure to overturn is characterized by the vertical cantilever bending response to ground motion which results in compressive and tensile forces in columns, bending in shear walls, and vertical loads to foundations. The magnitude of overturning forces is not well known, but contributing factors include intensity and frequency of ground motion, soil-structure interaction, and dynamic characteristics of the building.

For buildings supported by spread footings, the resistance to overturning is limited to the stabilizing moment due to the weight of the building, including foundations and surcharge. Even so, there have been no known cases where buildings have overturned as a whole (including foundations) except where foundation soil failures were involved. Those overturned or collapsed buildings that were supported by space frames generally failed as a result of columns failing in shear, compression, or bending. More basic data are required and they can best be obtained from observing the behavior of instrumented buildings close to *instruments located on the ground.* If instrumented buildings are not available for observation, then analysis of relatively simple tall structures should be made, preferably those close to instruments located on the ground outside of the structure. (See commentaries under Soils and Soil-Structure Interaction in other subsections of this Field Guide, pages 75 and 64, respectively.)

Checklist:
1. Tension cracks in concrete columns
2. Damage at splices of steel columns
3. Are columns offset at splices, indicating the possibility of lift-off and coming down in a different place
4. Damage to beams, girders, or shear wall elements which indicates uplift of columns
5. Evidence of uplift or compression failures between columns and footings or between footings and the ground
6. Tension or compression failures of piles; damage to pile caps

STRUCTURAL COMPONENTS

Moment-Resisting Space Frames — General

Commentary: Damage and failures generally can be attributed to lack of adequate design, detailing, and/or construction. Lack of sufficient ductility in beams and columns, particularly in reinforced concrete, has resulted in collapses. Large lateral deflections or drift have resulted in structural damage, failures, and damage to nonstructural items such as partitions, windows, ceilings, and filler walls.

More earthquake performance data are needed on the behavior of moment-resisting frames, preferably in structures which contain accelerographs. More data will permit better verification of design procedures by allowing the correlation of actual versus computed response and response versus distribution of damage. Data on actual lateral deflections of frames are needed. The influences of noncalculated walls, stairs, and other stiff elements need more clarification, as do the performances of details and connections.

Checklist:

1. Observe behavior of frame as a whole, with particular attention to failure modes, signs of distress, loading variations, types of connections, and inelastic behavior
2. Structural damage caused by deformation affecting adjacent elements
3. Damage to nonstructural elements such as infill walls, stairs, and partitions, as well as their influence on structural damage

Moment-Resisting Space Frames — Reinforced Concrete

Commentary: The overall earthquake performance of reinforced concrete space frames has been poor. The principal causes of damage and collapse have been inadequate lateral strength, poor reinforcement details, and lack of ductility. Contributing to the damage have been some code changes which have liberalized the determination of the strength of members without commensurate load effect increases.[*] Spirally reinforced columns generally have performed better than have tied columns. Thin floor slabs acting as frame-beam systems have performed poorly.

Present practice recognizes the need for more ductility in concrete frames, and some codes require special design and reinforcement details for reinforced concrete moment-resisting frames in seismic regions. There is a need to obtain considerable performance data on the behavior of these concrete ductile moment-resisting frames, particularly when they are subjected to ground motions which force them into the plastic range.

Checklist:

1. Concrete frames in general
2. Concrete frames designed to ductile concrete specifications
3. General pattern of concrete cracking and evidence of brittle or ductile behavior
4. What is failure mode
5. Where they can be determined, reinforcing details such as ties, stirrups, and splices of longitudinal steel (if plans are available or bars are visible)
6. Axial load cracking (tensile or compressive)
7. Shear or diagonal tension cracks
8. Efficiency or deterioration of joints

Moment-Resisting Space Frames — Structural Steel

Commentary: Under ordinary conditions, structural steel is ductile, and attention has been directed toward developing better moment connection details and the avoidance of buckling.

Checklist:

1. Any tendency to develop a general plastic mode as indicated by permanent story drift
2. Signs of failure in welds, including cracks, lamellar tearing, or laminations
3. Plastic hinge development in the columns and/or beams
4. Moment connections considering type, flexibility, stiffeners, and ductility; compare behavior of different types of connectors in similar intensity zones
5. Column bases including anchor bolts, local column buckling, connection material, and grout
6. Column splices
7. Stairs including movement at connections and interaction with frame

Other Frames

Commentary: This designation applies to frames and/or members not designed as part of the lateral-force-resisting system. These elements have been found to be damaged as a result of the building deformations or as a result of their independent response to earthquake motions. More data are needed to aid in providing improved design criteria.

Checklist:

Members which are not part of the lateral-force-resisting system, such as beams coplanar with and connected to shear walls

Shear Walls

Commentary: Damage to shear walls has occurred due to deficient shear and moment capacities, deficient reinforcing around openings, deficient development and splicing of reinforcing, offsets in wall locations from floor to floor, and torsional behavior of the building as a whole. Inadequate design and construction errors have resulted in damage at construction joints in concrete and in unit masonry walls. Inappropriate post-construction modifications, such as cutting of openings in walls, have resulted in increased damage.

Precast concrete shear (tilt-up) walls have performed satisfactorily in one-story buildings when interconnections of panels to each other and to floors and roofs have been adequate and where no failures of the roof diaphragms have occurred.

Combined action of shear walls and enclosing space frames has been good where the shear walls have been adequate. Relatively tall and thin shear walls have responded like vertical cantilever beams, but spandrel beams between these walls have suffered damage.

More data are needed on the performance of shear walls. The behavior of structures with combined moment-resisting space frames and shear walls should yield valuable data, if they have been subjected to strong ground motion.

Checklist:

1. General
   a. Post-construction modifications (such as cutting holes for doorways

and mechanical access) without adequate strengthening
   b. Damage to other elements due to shear wall deformation
2. Poured-in-place concrete
   a. Layout and vertical continuity of shear walls in each story and the pattern of damage
   b. Pattern of concrete cracks and crushing in damaged areas
   c. Movement at construction joints, cracks, and implied condition of keys and dowels if they cannot be directly observed
   d. Material discontinuity at construction joints
   e. Joinery between shear walls, diaphragms, framing members, floors, and foundations
   f. Presence, continuity, and extent of opening reinforcement; types and locations of splicing (if plans are available or bars are visible)
   g. Quality of concrete
   h. Connections of infill shear walls to the frame
3. Precast concrete (in addition to the items mentioned above for poured concrete)
   a. Type and condition of inserts or other fasteners to the frame, between units, and to the diaphragms
   b. The system of load transfer among units, between units and the structural frame, and between units and the foundation
   c. Development of diaphragm chords (edge members resisting tension and compression)
4. Masonry (in addition to the items noted for concrete)
   a. The condition of mortar and grout, quality of construction, and type of bond
   b. Were concrete columns poured before or after masonry walls were constructed; generally, columns poured after have exhibited better bond to masonry
   c. Location of cracking (through mortar or units)
   d. Connections of foundations
5. Wood
   a. Type of sheathing (blocked or unblocked plywood, straight or diagonal boards, and metal straps)
   b. Type, pattern, spacing, and condition of sheathing fasteners
   c. Buckling, splitting, or delamination of sheathing
   d. Anchorage and development of ties, struts, chords, or other members transferring concentrated loads among elements of the structure
   e. Connections to foundations
6. Steel
   a. Type of wall (corrugated or stiffened sheet)
   b. Out-of-plane buckling or tension failures
   c. Shear transfer elements to frame and foundation
   d. Shear transfer elements between units

Braced Frames

Commentary: There have been several cases where steel "X" bracing has deformed and ruptured and has resulted in damage to other elements due to excessive deformation and/or torsion. Such failures generally could be traced to inadequate strength, lack of ductility, and/or poor connection details. More data are needed on the behavior of various types of bracing and connection details.

Checklist:

1. Behavior of braced frames as the lateral-force-resisting system (or part of it)
2. Joint efficiency, considering type of joint, eccentricity, and ductility
3. Buckling or stretching of members
4. Effects on other elements
5. Deformation or fracture of connectors or connection parts

Precast and/or Prestressed Concrete

Commentary: While the quality of individual precast concrete elements usually is high, the performances of the connections between elements and between elements and other parts of the structure have generally been poor because the connections were inadequate and/or lacked ductility. The failure of connections has resulted in an excessive number of lateral deflections and collapses.

Relatively few prestressed, lift-slab buildings have been subjected to strong earthquake motions. The failure of the Four Seasons apartment building in the 1964 Alaska earthquake is a classic example.

There is a need to gather more general data on the behavior of systems using precast and/or prestressed concrete. (See Nonstructural Components, page 57, for information on architectural panels.)

Checklist:

1. Overall system behavior
2. Evidences of progressive failure
3. Connections between elements, between elements and frame, and between element and foundations
4. Type of prestress system; were tendons grouted; effectiveness of anchorages
5. Cracks due to vertical motions or reversals

Diaphragms

Commentary: Diaphragms are critical elements in the overall lateral-force-resisting system of a building. Present design criteria are based mostly on results of testing of relatively small and simple assemblies, plus experience in earthquakes. Some serious deficiencies in plywood diaphragms with weak wall anchorages were found following the 1971 San Fernando earthquake. Some failures in concrete diaphragms have been observed. Little data have been collected on the performance of metal deck diaphragms with and without concrete fill or on those employing poured gypsum, fiberboard, or pressed paper panels, cellular concrete, or panels of precast concrete.

Checklist:

1. Determine overall system, including influences of torsion, discontinuities, reentrant corners, openings, and flexibility
2. Methods of transferring loads between diaphragms and other parts of resisting systems
3. Chords, drag struts, and continuity ties; diaphragm webs at points of concentrated loading

4. Did diaphragm provide lateral support to walls; check condition of attachments; did lateral diaphragm deformations contribute to wall damage
5. Relative behavior of plywood diaphragms with and without steel anchors connecting joists to walls
6. Connections in metal deck, fiberboard, pressed paper, cellular concrete, and precast concrete panels
7. Concrete topping slab on precast elements, particularly its bond to the elements, and evidences of slab buckling
8. Gypsum deck, its forms and supporting members
9. Horizontal rod bracing systems with regard to adequacy of connections and rod yielding; were rod ends upset or straight

Foundations

Commentary: Failures of concrete building foundations have been rare in recent earthquakes except where permanent ground movements, such as surface fault rupture, settlements, liquefaction, and landslides, were involved.

Present design criteria appear to be adequate, possibly even over-conservative. Investigators should continue to check for evidences of concrete foundation failure. However, it is more important to determine if the building was adversely affected by permanent movements of soils beneath or adjacent to the structure.

Failure of a basement wall was noted in the 1971 San Fernando shock, and more data are required on possible dynamic action of backfill soils on retaining walls. Soils and soil-structure interaction are covered in later sections of this Field Guide (see Soils subsection, page 75).

Checklist:

1. Evidence of excessive foundation movement or failure such as
   a. Vertical movement: punching or rotating of columns relative to footing or slab on grade, gaps under footings, rocking of footings, damage to grade beams, settlements of foundations, and tension cracks in piles
   b. Horizontal movement: open cracks in basement slab, cracks and/or offsets in basement walls, open cracks between backfill and foundation walls, rotation of footings, and cracking or rupture of pile foundations
2. Condition of backfilling around structure: soil type, water presence, cracks, subsidence, slumping; movement of attachments (stairs, walks, etc.); and breaking of utility lines
3. Surface ground ruptures in soils around building, especially those involving vertical or horizontal offset
4. Subsoil liquefaction (sand boils, etc.)
5. Basement walls, horizontal cracks indicating high dynamic soil pressure (see Fills and Walls subsection, page 78)
6. Influence of batter piles on behavior (see also Harbors, page 67)
7. Depth to water table

NONSTRUCTURAL COMPONENTS

Architectural Treatment and Elements

Commentary: The damage to architectural treatment and elements can result in significant dollar losses and hazard to occupants. Stairways have been blocked by collapses of surrounding partitions or wall cladding. There have been widespread collapses of suspended ceilings with light "T" bar metal runners and splined or lay-in acoustical tiles. In some cases, lighting elements are incorporated into the ceiling system.

In many cases, little attention has been given to the earthquake-resistive design of these elements. Performance has been relatively good when the elements and their attachments to the structural system were especially designed to resist lateral forces and to be compatible with deformations.

The important items to note are the performance of the connections of the architectural elements to the building structure and the joints between the component parts of the architectural unit. *It is also important to record the contrasting performance of the architectural elements on different sides of the building and at different floors.* Look for concentrations of damage at particular locations and attempt to determine why the damage occurred.

Building elements without intended structural functions may interact with the structural system. Among these items are infill walls, partitions, curtain walls, suspended ceilings, and surface finishes. The purpose here is to determine how the design of these elements can be improved to mitigate earthquake hazards and to determine whether structural interactions (either beneficial or detrimental) occurred which should receive attention in design. Particular attention should be paid to building elements which fail by unexpected mechanisms, progressive or sequential failure patterns, unusual lack of damage or severity of damage, and good and poor interactions between the architectural and the structural systems.

Checklist:

1. Interaction with structural system
   a. Nature of interaction
   b. Effect on interaction resulting from the type of architectural elements used and their connections to the structural system; were clearances, if any, adequate
   c. Effect of interaction on structural system
2. Exterior treatment and elements
   a. Glass, glazing details, and mullions, including provisions for distortion of openings
   b. Cladding and veneer on walls, including attachments
   c. Canopies and marquees overhanging critical exits or pedestrian areas
   d. Decorative screens: metal, masonry, wood, and plastic
   e. Sunshades over windows and openings
   f. Precast panels, including attachment to structure
   g. Decorative sculpture or ornamentation tied to the building
   h. Large-scale graphics or illuminated signs
3. Interior treatment and elements
   a. Veneers and finish materials on walls, including methods and attachments
   b. Suspended ceilings: ceiling materials, grid system, hangers, and bracing
   c. Movable and fixed partitions with respect to provisions for clearances, bracing (in and out of plane), and anchorage
   d. Furniture and equipment: wall-hung objects, dishes, files, etc.
   e. Decorative sculpture or ornamentation including anchorages

Elevators and Exitways

Commentary: Damage to building facilities concerned with the entrance and egress of personnel has been common. Exterior walls frequently collapse over exits and public ways. The problems posed are particularly serious in high-rise construction where stairways are blocked by the collapse of surrounding partitions, and elevators are rendered inoperable due to the lack of electrical power and/or damage to the equipment. Elevator counterweights frequently are thrown out of their guide systems due to inadequate strength in the guides or to the nature of their attachment to the structural frame.

Checklist:
1. Elevators
   a. Elevator guide systems and equipment, especially those which may have been reinforced to resist increased lateral forces; are counterweights in guides
   b. Elevator shafts and cabs
   c. Location and number of elevator cabs; record type, year installed, and type of controls
   d. Elevator penthouses
   e. Shifting of motors, machinery mounts, and misalignment; type of anchorage
   f. Emergency power system
   g. Emergency "intercom" system
   h. Emergency earthquake "cut-off" provisions
2. Exitways
   a. Debris on stairs, landings, and passageways; type of enclosing walls
   b. Emergency lighting system
   c. Stairways: types, locations, widths, and attachments to structure
   d. Circulation pattern and distance to exterior spaces, alleys, streets, or courtyards
   e. Debris in streets and exterior spaces that impedes pedestrian circulation, particularly at exits
   f. Handrails and other safety devices
   g. Exit doors and operational impairments due to warping, jamming, or other damage

Mechanical, Electrical, and Plumbing

Commentary: Damage to building mechanical, electrical, and plumbing equipment received particular attention following the Alaska, San Fernando, and Managua earthquakes. In view of the large economic losses, this is a particularly important area for additional investigations.

Insufficient attention has been given to the lateral force design of the equipment itself or to its anchorage and bracing. Machinery is often placed on vibration isolators which are inadequate to resist strong earthquake motions. Equipment adequately bolted to concrete floors and foundations has often performed satisfactorily except for damage to the equipment itself.

Suspended electrical light fixtures have proved to be vulnerable to earthquake motion except for those incorporating specially developed features.

Large tanks on roofs and in penthouses have performed poorly when not adequately braced and anchored. Tank movements have ruptured connecting piping, and the building below has flooded. Some tanks have overturned and fallen through the roofs. There have been several cases of leakage from damaged sprinkler and other piping.

Performance data are needed on equipment and piping which have been especially designed and installed to resist strong earthquake motions in order to evaluate their effectiveness.

Checklist:

1. General

   Note what performed well and what did not; what systems were operational; general evaluation of anchorage or bracing of equipment; specific data on principal equipment critical to operational use of building

2. Mechanical
   a. Equipment in general: was equipment bolted down, anchored, or specially braced
   b. Vibration isolators: what part failed; were snubbers provided; list number and type of isolators used and estimate equipment weight
   c. Was equipment itself damaged even when adequately anchored and braced
   d. Heating and ventilating ducts, including automatic dampers, hangers, straps, and ties
   e. Ducts passing through walls at chases or sleeves
   f. Damage related to objects falling on equipment
   g. Interaction with structural and architectural elements
   h. Did equipment continue to perform function even though damaged
3. Electrical
   a. Electrical light fixtures (suspended and flush), conduits, transformers, switch gear, panel boards, and noninterruptible equipment
   b. Damage related to overturning, sliding, or to other objects falling on equipment
   c. Electrical central control stations in tall buildings
   d. Were auxiliary or alternate power supplies available; did they function
   e. Damage at building construction or expansion joints
4. Plumbing
   a. Was piping braced to resist earthquake forces; effectiveness of bracing; were flexible joints used — if so, how did they perform
   b. Locations of breaks and apparent causes, including influence of materials
   c. Pumps, drains, and controls
   d. Automatic sprinkler system with respect to operability
   e. Damage at building construction or expansion joints

MISCELLANEOUS

Quality of Construction and Materials

Commentary: Serious deficiencies in the quality of materials and construction practices reduce the opportunities for learning *design* lessons. However, important lessons may be learned regarding how to improve quality and assurance controls of materials and systems. In some cases, testing of materials may be necessary to determine the effectiveness of their quality assurance controls.

Checklist:

1. Quality of construction and materials in concrete as indicated by movements at construction joints, rock pockets, and lack of bond or cover of reinforcing; obvious omissions are, if plans are available, deviations from design in placement or reinforcement
2. Grouting procedures, placement of reinforcing, or omissions, and quality of mortar and grout in masonry construction
3. Quality of welded, bolted, and riveted connections
4. Timber construction practices such as nailing, bolting, connection eccentricities, edge distances, bearing areas, and split or checked material

Repaired and Strengthened Structures

Commentary: Several buildings which have been repaired and/or strengthened to resist earthquake forces have been subjected to moderate earthquake motions. The performance of these buildings has been variable depending on the extent and adequacy of the repairs and strengthening. Strengthened public schools in Southern California performed well in the 1971 San Fernando shock. A school in Managua which had its first story strengthened following the 1931 shock suffered damage in the second story in 1972.

The cumulative effect of unrepaired or inadequately repaired damage can seriously affect the earthquake performance of structures. Frequently, badly cracked walls and partitions are merely plastered over and repainted.

Dangerous parapets and appendages over public ways have been removed or anchored in several California communities. Some of these modified buildings suffered damage to their brick walls below the roof lines in the 1971 San Fernando earthquake.

Various earthquake damage repair techniques have been used. These range from merely restoring structures to their condition before the shock to extensive strengthening procedures. Injection of epoxy compounds into cracked concrete members has been used recently. Patching of cracked and spalled concrete has been done with cement grout and epoxy. Plywood roof connections to walls were modified and strengthened on a few buildings in Southern California following the San Fernando earthquake.

Performance data are needed on repaired and strengthened buildings in order to evaluate the effectiveness of the methodologies and techniques.

Checklist:

1. Existence and types of repair and/or strengthening details
2. In mortar and/or plastic adhesive repairs, did failures occur in original materials, in repair materials, or in the bond between the two
3. Evidences of parapet removal and/or anchoring
4. Effectiveness of school-building strengthening programs
5. Evidences of unrepaired or inadequately repaired damage

Consequential Damage

Commentary: In this category are damages due to fire and external water such as tsunami, seiche, rain, flood, dam breaks, and fire suppression.

With the exception of San Francisco in 1906, fire following U.S. earthquakes has not been a serious problem. However, given the proper set of conditions, serious conflagrations are still a possibility. Fire destroyed a petroleum cycling plant in the 1952 Kern County earthquake, oil tanks in the 1964 Alaska shock, and several structures in the 1971 San Fernando earthquake.

High-rise structures pose special problems in fire control, especially if elevators are inoperative and stairways are filled with debris. Water to fight fires is frequently not available from supply mains due to pipe or other damage. More general performance data are needed on fire following earthquakes, especially regarding building design and construction practices which are effective in the prevention and control of fires. Specific information should be collected to separate fire damage from earthquake damage. Refer to the subsection on Elevators and Exitways (page 59) for additional information.

Water from rain and fire-suppression activities has caused extensive damage to ceilings, finish materials, furnishings, and contents. Tsunamis have caused severe damage to structures.

Checklist:

1. Fire
   a. Preliminary data
      (1) Initial cause of fire and its place of origin
      (2) Combustible materials in building which fed fire and allowed it to spread; conditions of wood panelling, plastic accessories, fabric, furniture, and equipment; toxic combustion gases, if existent
      (3) Streets adjacent to the buildings: did debris or surface ruptures affect accessibility to fire and rescue team operations
      (4) Were elevators, stairways, and corridors operable
      (5) Weather conditions which intensified or mitigated effects of fire, such as dry or rainy season, high winds and humid or dry conditions
      (6) The extent to which firespread affected other floors and areas
      (7) Availability of firefighting supplies and equipment
   b. Internal utilities
      (1) Water supply system: was it operational for firefighting; emergency water supply system
      (2) Electrical power system: were emergency electrical power systems or emergency generators available and functional
      (3) Natural gas supply system: was there an automatic shutoff valve and did it operate
      (4) Telephone and communication systems
   c. Fire-resisting elements
      (1) Firewalls and separations between floors: was their integrity maintained or did they shatter and permit firespread
      (2) Firedoors: were there any operational impairments
      (3) Structural fireproofing
2. External water
   a. Preliminary data
      (1) Source and details of cause
      (2) Direction and magnitude of water force
      (3) Natural environmental conditions and topography in areas adjacent to building
   b. Damage
      (1) Foundations: building substructure and soils

(2) Building superstructure
(3) Mud and silt
(4) Building contents, ceilings, carpets, and finishes

Contents

Commentary: Extensive damage has occurred to certain types of contents such as those involving glassware, small parts on shelves, and those in unbraced storage racks. Storage batteries for emergency lighting systems have sometimes shifted on their shelves, either falling off or breaking their electrical connections. Generally, there has been little attention given to methods of preventing these losses. Adequate bracing and anchorage of storage systems can prevent their overturning, but stored materials may still slide off the shelves. Storage systems are now being built in which the storage racks themselves provide the structural support for the building.

More data are needed on the performance of storage systems so that losses to contents may be mitigated. Data should be collected on a selective basis. Statistical sampling and analysis techniques should be employed, if possible (see Appendix III-A).

Checklist:
1. Are storage racks anchored and/or braced; was system effective; did racks collapse; did stored materials fall from braced racks
2. Methods which were effective in reducing losses; relative behavior of plastic and glass containers
3. Biological, radiological, corrosive, noxious materials, and bacteria or isotope storage
4. Are storage racks independent of the building, supported by the building, or do they provide support for the building
5. In hospital laboratories, did loss of contents cause operational problems

Dwellings

Commentary: The general behavior of wood-frame dwellings has been good except for those that were not adequately anchored to their foundations, had excessive wall openings, had poor interconnection of elements, or were affected by permanent surface-ground displacements. Unreinforced masonry chimneys have performed poorly, as have reinforced but inadequately anchored types. Some modern split-level dwellings suffered severe damage in the 1971 San Fernando shock. The behavior of gypsum board and let-in wood bracing has been poor in many instances. More data are needed on the behavior of modern wood-frame dwellings when subjected to various intensities of ground motion. Comparative data are needed for those located on various types of soils and foundations.

Dwellings constructed of unreinforced masonry, including brick, concrete block, and stone have poor performance records.

Due to the relatively large number of dwellings as compared to commercial buildings, the procedures discussed in the subsection on Statistical Data (page 78) and Appendix III-A, entitled "Statistical Sampling and Analysis in Earthquake Investigations," may be applicable for the collection and analysis of dwelling data.

Checklist:
1. Was primary cause of damage ground shaking or ground displacement
2. Types of construction: size, stories, framing, and foundations
3. Chimneys: details of footing, reinforcing, and anchorages to framing
4. Walls: openings, bracing, and materials; are foundations on natural soils or man-made fills; is site level or sloping
5. Approximate dwelling valuation and extent of damage and repair costs

Soil-Structure Interaction

Commentary: The phenomenon of soil-structure interaction is an element in the response of structures to earthquakes. It is exhibited as a difference in the vibratory motions between the base of the structure and nearby free-field ground surface, the latter normally being the more violent motion. Definitive measurements of this effect require the instrumental recording of strong earthquakes in the basement and nearby free field. However, properly conducted aftershock measurements have yielded useful soil-structure interaction results in past earthquakes. Certain qualitative phenomena may indicate the presence of interaction (or of other effects as well): for example, ground cracks around the foundation. Refer to the foregoing subsection on Overturning (page 52) and the following subsection on Soils (page 75).

Checklist:
1. Cracks in the soil around the base of the structure, which could also result from settlement
2. Extent of movement of basement contents
3. Foundation or subsoil evidences of rocking of the building
4. The combination of stiff massive structure resting on flexible soil gives the greatest interaction, suggesting special attention to such cases
5. Examine the compatibility of main shock accelerograph records of basement and free-field motions
6. Aftershock measurements, if adopted, should be quickly implemented in order to catch some of the larger aftershocks; triaxial sensors should cover free-field, deepest basement, ground floor level, and roof, as a basic minimum

LIFELINES

INTRODUCTION

The term "lifelines" is considered to include the transportation, communications, energy, water, and sewage systems vital to the support of any community.

Relatively little attention was focused on the antiseismic design of lifelines in U.S. earthquake investigations before the Kern County shock in 1952. Significant lifeline performance data were also gathered after the 1964 Alaska and especially after the 1971 San Fernando shocks, as well as from some foreign earthquakes.

In contrast to those for buildings, the amount of useful data collected in the past on the earthquake performance of lifelines is small, except perhaps for bridges. For this reason the commentaries for lifelines are less specific than are those for buildings, and the checklists are more detailed.

Since the 1971 San Fernando shock, design changes have been and are being incorporated into many new and old parts of California lifeline systems, such as dams, electrical power systems, freeway structures, and communication systems. The performances of these new designs are of particular interest. Comparative performance data are needed to determine the effectiveness of changes. It is essential that good as well as poor performances be reported. *The ability to continue to function is of first-order importance as are estimates of time and magnitude of efforts needed to restore service.* ■

The subsection on Buildings (page 46) presents commentaries and checklists for conventional buildings in lifeline systems. The subsection on Soils (page 75) contains more information regarding permanent soil movements.

TRANSPORTATION SYSTEMS

Transportation systems include highways, railroads, harbors, airports, and mass transit.

Highways — Including Bridges, Overpasses, Roadbeds, and Tunnels

Commentary: The 1971 San Fernando earthquake was the first real test of *California* freeway overpass structures, and the failures revealed deficiencies: principally the inadequate tying together of spans and structural elements. Design criteria and details for these structures have since been modified considerably for new construction. Some existing structures have been retrofitted to increase their lateral-load-carrying capability. The 1976 Guatemala earthquake provided an indication that structures which incorporate new seismic design techniques can survive major earthquakes.

Damage to roadbeds has been associated with permanent ground displacements, such as settlements, landslides, cracking, and surface fault ruptures. To date, highway tunnels have not been severely tested.

Checklist:

1. Bridges and overpasses
   a. Extent of damage to and degree of usability of bridges in California which have been designed and constructed or strengthened under the specifications modified since February 9, 1971; compare, if possible, pre- and post-1971 bridges in various intensity zones; note the orientation of the longitudinal axis of the bridge and compare damage of other structures having similar orientation
   b. Extent of damage to and degree of usability of highway bridges other than those noted in (a) above
   c. Relative influences on bridge damage of differential earth movements or foundation failure and ground shaking
   d. Connections or restraints between bridge elements; note bearing details (in particular, "rocker-type" bearings are extremely vulnerable)
   e. Dynamic action of backfills on retaining wall and bridge abutments

2. Roadbeds
   a. Fill settlement as influenced by fill soil type, depth, and types of underlying soils
   b. Landslides related to soil types, cuts or fills, moisture content, and slope designs
   c. Pavement devices intended to bridge-over settlements of approach fills
   d. Damage due to surface fault rupture
3. Tunnels
   Tunnels including landslides, fault rupture, and settlements

Railroads — Including Bridges, Roadbeds, and Tunnels

Commentary: Damage to roadbeds and rails has been noted in numerous past shocks, and was generally a consequence of landslides, subsidence, and other permanent ground displacements. Tunnel damage was severe in the 1952 Kern County shock where the fault plane cut through tunnels. In other cases, tunnel damage has been largely confined to landslides at entrances.

Generally, railroad bridges perform better in earthquakes than do highway bridges, probably because the structures are tied together by rails.

Checklist:
1. Checklist items are essentially the same as for Highways (page 65), except that there have been no recent code changes in lateral force design criteria for railroad bridges
2. Obtain the following information and check for damage
   a. Foundation type
      (1) Piles
      (2) Spread footings
   b. Column type
   c. Orientation of bridge axes
   d. Column connection detail
      (1) At foundation
      (2) At deck or cap
   e. Foundation condition
      (1) At abutment
      (2) At columns
   f. Column condition
      (1) Shear cracking
      (2) Moment cracking
      (3) Tilting
   g. Deck bearing detail condition
   h. Abutment condition
      (1) Deck impacting
      (2) Dynamic action of backfill
      (3) Throwing of stones from deep holes
   i. Wing wall condition
      (1) Cracking
      (2) Dynamic action of backfill
   j. Apron condition — slippage
   k. Expansion joint condition
      (1) Observed from roadway
      (2) Observed from underneath (if accessible)

l. Approach road to deck
   (1) Compressive failure
   (2) Buckling
   (3) Settlement
m. Superstructure condition
   (1) Lateral offset at joints
   (2) Vertical displacement
   (3) Girder
   (4) Floor beams
   (5) Stringers
   (6) Bracing
n. Plans, if available; otherwise, approximate dimensions

Harbors

Commentary: Severe damage to harbor facilities has occurred in numerous past earthquakes. Damages have been due to ground shaking, tsunamis, liquefaction, consolidation of soils, and landslides. Material-handling equipment, such as traveling cranes, has been damaged.

Checklist:
1. Compare behavior of harbor, dock, and pier structures relative to construction type (e.g., pile-supported piers, quay walls, or sheet pile bulkheads); determine cause of damage (e.g., ground shaking, permanent ground movement, or tsunami)
2. Liquefaction, sand boils, settlements, or landslides
3. Influence of batter piles on damage; compare similar facilities with and without batter piles
4. Material-handling equipment such as moving cranes and conveyor systems; did moving equipment jump off rails

Airports

Commentary: Aside from damage to buildings and control towers, the damage to airports has been to pavements and underground utilities. Interruption of electrical power for communications and other services has crippled operations.

Checklist:
1. Control towers, including equipment and their anchorages, with emphasis on their ability to remain in operation
2. Runways and taxiways with emphasis on ability to remain usable; consider effects of differential soil movements
3. Runway lighting systems, control lights
4. Underground utilities, fuel systems, and emergency electrical power
5. Temporary emergency runways, control towers, and staging areas

Mass Transit

Commentary: Topics for investigations will depend on the type of system, but will be similar to those listed under Highways, Railroads, and Communication Systems. Performance of automated equipment and facilities — particularly anchorages and unique construction — should be noted. Preservation of alignment and grades of trackage, stations, tunnels, and performances of unique support structures are important. Communication systems are critical in an emergency and should be evaluated (see Communications subsection, below).

Checklist:
Checklist items will be similar to those under Highways, Railroads, and Communications, depending on the type of system.

COMMUNICATION SYSTEMS

General

Commentary: Communication systems are assumed to include telephone and telegraph, radio, television, mail, newspapers, and magazines. In addition to the effects of damaged buildings, failures of communication systems have been due to (1) broken lines, (2) damage suffered by equipment, which was not properly anchored or braced, (3) lack of commercial electrical power, and (4) system failures due to overloading. Emergency electrical power sources have failed in many cases due to lack of adequate bracing and anchorage of equipment, fuel systems, batteries, and switch gear.

Telephone and Telegraph

Commentary: Damage to telephone switching station equipment was particularly severe at one location in the 1971 San Fernando shock. Most of the damage was the consequence of inadequate equipment anchorage and bracing. Some telephone equipment bracing systems have been improved as a result of experience in San Fernando, and some existing bracing has been modified. Breakdown of systems due to overloading has been common in emergencies, although companies are taking steps to prevent this.

Checklist:
1. Equipment anchorages and bracing, especially those conforming to the latest lateral-force design criteria
2. Underground services with emphasis on those systems specifically designed to allow for differential earth movements
3. Microwave towers and disks
4. Emergency power supplies
5. Pole and line breakage

Radio and Television

Commentary: The performances of radio and television systems depend, to some extent, on the damage suffered by buildings housing studios and transmitters. Many stations have mobile ground and air units. Some stations have remote transmitting stations and antenna towers. Failure of emergency power supplies has curtailed transmissions. Generally, one or two stations in each area are designed as part of the Emergency Broadcasting System, and these are intended to remain on the air and be operable after a disaster.

Checklist:
1. Radio and television equipment including anchorages and bracing with emphasis on ability to remain operational; did building damage affect operability
2. Antenna towers, considering heights, foundations, type (guyed or free-standing), and materials
3. Emergency power supply system

Newspapers and Magazines

Commentary: In addition to building damage, misalignment of sophisticated printing equipment and lack of electrical power have affected the operation of newspaper and magazine plants.

Checklist:
1. Alignment of printing equipment as it affects operability
2. Damage to stock of printing materials
3. Interruption or delay of service caused by building damage
4. Equipment damage due to building collapse
5. Electrical power supply
6. Storage rack damage

ELECTRICAL POWER SYSTEMS

General

Commentary: Damage to electrical power generating plants and transmission and distribution systems has received special attention following recent destructive earthquakes in the United States

Since about 1933, most California electrical utilities have used earthquake design criteria which are in excess of those required by local building codes for their critical facilities. This practice has resulted in the relatively good behavior of these facilities in earthquakes. Weaknesses in large pieces of electrical equipment were apparent in the 1971 San Fernando shock. Some changes in lateral force criteria for electrical equipment have been made since 1971, and considerable research is presently underway. Some existing equipment has been modified to conform to these new criteria.

It is generally most important to review the earthquake behavior of electrical facilities which have been especially designed to resist earthquake motions and particularly equipment which has been designed, braced, and anchored in accordance with recent criteria. The ability of these plants to continue to operate after a destructive earthquake is essential.

Fossil-Fueled and Hydroelectric Generating Plants

Commentary: Building damage has occurred to plants without specific lateral force design resistance. Outages have also been caused by misalignment of turbines and damage to smokestacks and fuel tanks. Plants designed to be earthquake resistant have generally performed well.

Checklist:

1. Boiler and supporting frame
   a. Boiler tubes, lining, equipment, and controls
   b. Buckstays or lateral force stops
   c. Piping and duct work which is connected to the boiler and to the ground or the support structure
   d. Main support structure for distortion, cracked welds; broken bolts or rivets
   e. Footings for new cracks, spalled concrete, or exposed reinforcing
   f. Auxiliary tanks and chemical feed systems
   g. Fuel storage and transportation systems
2. Circulating water system
   a. Pumps, gates, or other equipment
   b. Cracks, spalled concrete, and exposed reinforcing
   c. Change in flow characteristics which might be indicative of damage
   d. Wet spots along the ground in vicinity of inlet piping which could indicate leaks
   e. Muddy water indicating possible cracks in the discharge lines
3. Hydroelectric water supply
   a. Change in seepage
   b. Distortions or cracks in cradles or footings
   c. Decrease in flow capability of the conduit
4. Turbine and generator
   a. Were turbines or auxiliary equipment shut down; if so, ascertain from operating personnel the cause of shutdown and amount of shaft misalignment, if any
   b. Inspect turbine pedestal for evidence of cracking, spalled concrete, or exposed reinforcing
   c. Distortion and possible untracking of main crane beam or trolley; distress of seismic uplift inhibitors, if present
5. Control room
   a. Did failure of control-room equipment cause plant malfunction; if so, determine nature of the failure and the type of mountings used
   b. Did failure of auxiliary support systems, such as lighting, heating, or ventilation, cause control building to be inoperative
   c. Battery and equipment racks
6. Other structures and appurtenances
   a. Fuel oil and gas pipelines and operability of valves
   b. Attachments between structures, or between pipelines and tanks or structures
   c. Smokestacks, including operability, overall condition, base connection, and conditions at about two-thirds of height and at breeching; tilting
   d. Operability of doors and windows, cracked windows, buckled siding, and plumbing damage
   e. Ground distortion or subsidence in yard areas

Geothermal, Gas Turbine, and Nuclear Powerplants

Commentary: See applicable items under Fossil-Fueled and Hydroelectric Generating Plants (page 70). Nuclear powerplants represent a very special case, and it is doubtful that any investigators other than experts employed or commissioned by the Nuclear Regulatory Commission (NRC) would be allowed entrance into these facilities.

Checklist:
1. Possible changes in geothermal source
2. Incipient landsliding adjacent to facilities
3. Waste disposal facilities

Transmission Lines

Commentary: The earthquake behavior of electrical transmission lines has been good. Some damage has occurred due to landslides and has affected towers and poles. Outages have been caused by conductors swinging together and short-circuiting.

Checklist:
1. Surface fault movements or landsliding which affected towers, poles, and sag in conductors
2. Tower or pole damage; condition of tower members and base connections; how far were poles embedded
3. Short-circuiting of conductors and damaged insulators

Switchyards and Substations

Commentary: Transformers and other heavy electrical equipment have shifted and overturned when they were not adequately anchored. Electrical switching and converting equipment has suffered damage due to shaking. Some improvements in the earthquake-resistive design of circuit breakers and other large pieces of electrical equipment have been made since 1971, and research is continuing in this area. The behavior of equipment incorporating the latest design criteria is of special interest.

Switch racks, conductors, and ceramic insulators have been damaged by differential soil movements and ground shaking.

Checklist:
1. Control buildings
    a. Electrical equipment including panelboards
    b. Did failure of auxiliary support equipment (such as lighting, heating, or ventilation) cause station to be inoperative
2. Yard equipment
    a. Movement of equipment on rails and base pads; condition of anchorages
    b. Electrical equipment
    c. Settlement or misalignment of footings
    d. Ceramic materials
3. Yard structure
    a. Broken connections and distortion in structure and cracked footings

b. Soil movements or cracking between footings

Distribution Systems

Commentary: Damage to overhead electrical distribution systems is usually severe in areas with older, non-earthquake-resistive buildings, due to falling parts of buildings and to fire. Underground systems generally have performed satisfactorily except when affected by differential soil movements. Lack of damage should be reported, as should damage by degree and impact on service. Unbraced transformers on pole-supported platforms have proved to be especially vulnerable to earthquake motions.

Checklist:
1. Underground vaults
2. Connections between vaults and underground conduit or duct banks
3. Overhead pole and platform-mounted transformers

LIQUID AND GAS CONVEYANCES AND ASSOCIATED FACILITIES

This subsection discusses water, oil, gas, drainage, and sewer pipelines, conduits, and tunnels, as well as liquid and gas storage, pumping, treatment, and control facilities.

Pipelines and Conduits

Commentary: Underground damage has been associated with permanent ground displacements, although damage to old lines due to pressure variations and intrusion of foreign objects has been noted. Surveys of underground damage to sewerlines were made via television following the 1964 Alaska and 1971 San Fernando quakes.

Checklist:
1. Pipelines and conduits, considering kinds of materials and types of joints which
   a. Crossed fault displacements
   b. Experienced ground shaking
   c. Experienced ground settlement
   d. Experienced landslides or liquefaction
2. Joints, valves, fittings, check valves, meters, services, and miscellaneous fittings
3. Changes in leakage rates
4. Interties; isolator valves

Canals and Flumes

Checklist:
1. Changes in leakage rates
2. Cracked cradles, footings, or distortion in support structures

3. Settlement or misalignment
4. Lining of canal walls or flumes
5. Change in flow capacity
6. Damage to supporting or adjacent soils

Tunnels

Commentary: Water tunnel damage occurred in the 1971 San Fernando earthquake, generally in the fault rupture areas.

Checklist:
1. Change in flow capacity
2. Ground surface leakage changes
3. If tunnel is drained, look for rock falls, or new cracks in lining
4. Racking of walls

Tanks

Commentary: Tanks may contain gases or liquids and may be constructed of earth, concrete, steel, wood, or plastic. They may be buried, resting on the ground surface, or elevated.

Damage to surface-mounted and elevated tanks has occurred in many destructive earthquakes. Tanks resting on the ground surface have suffered buckled and ruptured walls as well as damaged and collapsed roofs. Tank movements have resulted in ruptured connecting piping, with resultant loss of contents. Elevated tanks without earthquake-resistant design features have performed poorly; there have been numerous collapses. Those with specified lateral-force-resistive features have performed much better.

Checklist:
1. Type of foundation and soils
2. Buckling and other damage to tank shells; compare full and partially full tanks; how full was tank at time of earthquake
3. Tank shell contact with the footing; consider tank bottom and shell construction; evidence of vertical movement
4. Piping connected to the tank; consider flexibility of the connections
5. Type of roof construction and supporting structure
6. Changes in leakage rates
7. Elevated tanks, including bracing, columns, and foundations
8. Ability to function

Pressure-Boosting and Pressure-Reducing Stations, Wells, and Pressure Pumps

Commentary: None

Checklist:
1. Reliability of power and fuel supply
2. Type of foundation and soils
3. Mechanical and electrical equipment, including anchorage and bracing, if any

4. Types of well casings
5. Contamination of potable well water from adjacent waste-water disposal facilities
6. Ability to function

Potable Water and Wastewater Treatment Facilities

Commentary: Ground shaking, differential earth movements, landslides, and losses of power have caused damage and have rendered facilities inoperable. Damage to a major water treatment plant in the 1971 San Fernando shock was the result of landslides and ground shaking.

Checklist:
1. Site topography and soil conditions; relative damage due to permanent differential earth movements or earth shaking
2. Piping and containers storing dangerous chemicals
3. Reliability of power and fuel supplies
4. Mechanical and electrical equipment, including anchorage and bracing, if any
5. Ability to continue to function

Dams and Reservoirs

Commentary: Earth and rock dams constructed by the hydraulic-fill method have suffered serious damage in earthquakes, and some have failed. Minimum damage has occurred to modern compacted earth-fill dams. Some concrete dams have been damaged in earthquakes while others have survived without damage. The importance of dams requires that they be closely inspected after every earthquake regardless of apparent damage. Downstream population and critical facilities must be considered in evaluating the safety of dams.

Checklist:
1. Earth and rock (fill)
   a. Cracks parallel to the axis, indicating either sliding of part or all of the upstream or downstream faces or earthquake-induced settlements in rockfill shells
   b. Cracks perpendicular to the axis indicating settlement or distortion of the dam; changes in preexisting cracks
   c. Settlement and/or lateral movements of crest; resurvey crest lines
   d. Increase or decrease in seepage, or seepage now occurring where it apparently did not previously
   e. Change in color of seepage water indicating solids in water
   f. Surface slumps or sand boils
   g. Cracking offsets in rock or concrete parapet walls or training walls
   h. Increase or decrease in leakage past gates
   i. Bulging of the ground at the toe of the dam
   j. Changes in water level or pressure, where foundation or embankment piezometers are available
2. Concrete
   a. New cracks
   b. Increase or decrease in leakage past gates

c. Abutment rockfalls
d. Changes in seepage and seepage into galleries and shafts; condition of water seals
e. Changes in water level or pressure where foundation drains or piezometers are available
f. Settlement or horizontal movement of crest; resurvey crest

3. Spillway, inlet, and outlet structures
   a. Damage to spillways and inlet and outlet structures
   b. Auxiliary structures such as gate hoists, gates, and valves; operability subsequent to earthquake affected by binding that might indicate distortion
   c. Joint displacements
   d. Ability to function

SOILS

GENERAL

Commentary: The organization of these Field Guides calls for attention to soils in both this section and Section IV, the Geoscience Field Guide. The division of soil topics places in Section III those aspects which are essentially structural: that is, soil as a foundation of structures; structures made of earth (including landslides); and earth retained by structures. In Section IV have been placed those aspects related essentially to soil as formed and placed by nature: that is, identification of representative soils of the region and their formation; properties and distribution; occurrence of ground water; moisture conditions of soils at the time of the earthquake; and broadly distributed phenomena such as a real settlement and damage distribution (isoseismal mapping). Soils engineers and engineering geologists participating in post-earthquake investigations will need to make use of both Sections III and IV.

Investigators looking specifically at the performance of buildings and lifelines will have identified many of the important instances of soil and foundation failure. The following list indicates other subsections of Section III where the attention of the investigator is specifically directed to the effects of soil:

INTRODUCTION, page 45
BUILDINGS — *Overturning,* page 52
BUILDINGS — *Foundations,* page 57
BUILDINGS — *Soil-Structure Interaction,* page 64
LIFELINES — *Introduction,* page 64

The soils engineer must maintain close liaison with investigators in these other fields to ensure that the case records contain the benefit of his own particular expertise. All such case records should include all available evidence concerning the nature of the soil and its general condition (wet, dry, etc.). In some regions, the water table fluctuates considerably during the year, and it is important that the water conditions at the time of the earthquake be documented as well as possible.

The investigators must obtain data describing the properties of the soils being reported, and should be as accurate as possible in stating the color and classification of the observed soil types. The Unified Soil Classification system should be used for identifying soils.

It is important that isoseismal mapping teams include engineers professionally qualified to evaluate damage to structures.

Checklist:

1. Work jointly with structural and geoscience investigators
2. Use the soil-relevant checklists in Sections III and IV
3. Carefully describe the properties of soils of interest
4. Learn the Modified Mercalli Scale (see Section I, Planning Guide, page 10)

GROUND CRACKING AND SURFACE FAULT RUPTURE

Commentary: In most large earthquakes, permanent deformations of the ground occur, and evidence concerning these deformations is vital to the proper interpretation of the damage to buildings and lifelines and of the nature of the earthquake mechanism. Two examples from the 1971 San Fernando earthquake illustrate the importance of good observations. On the one hand, because ground cracks with vertical offsets were observed near the Juvenile Hall, it was initially thought that the damage to the Hall was caused by fault rupture. However, careful documentation of the permanent ground movement proved that a large shallow slide had occurred on a very flat slope. On the other hand, a detailed search for ground cracks in the vicinity of the Olive View Hospital showed that permanent ground deformation contributed little if at all to the overall damage.

Fault ruptures and ground surface cracking generally become obliterated very shortly after an earthquake. They should be located on suitable base maps immediately after an event. The record should include magnitude and direction of vertical and horizontal movements. Effects on overlying structures, paving, utilities, etc., should be noted. These studies should be made in cooperation with geoscience field observations in Section IV.

Checklist:

1. Join with geoscientists to find and map the cracks and fault breaks
2. Pay special attention to cracks and breaks affecting structures

LIQUEFACTION

Commentary: Future progress in analysis and prediction of liquefaction is very heavily dependent upon observations following earthquakes. Situations where liquefaction has occurred during an earthquake must be carefully documented. Equally important is documentation of cases where saturated granular soils have *not* liquefied.

Hence, one of the primary concerns in evaluating soil behavior is the early identification of any liquefaction problems before the evidence is obliterated. Investigators trained in the fields of soil mechanics and geology should note evidence of sand boils (identifying the location and character on suitable maps) and should dig down a few feet to ascertain depth of the liquefied material. The location and magnitude of any subsidence effects attributed to liquefaction should be determined, including effects on structures, utilities, dams, highways, etc.

Landsliding or lateral earth movements possibly due to liquefaction should also be identified and located for possible future detailed subsurface investigation.

Although the cause of liquefaction is relatively well understood, *much more information is needed before soils engineers can predict with confidence the probability of liquefaction occurring in a given situation.* If detailed subsurface information on a particular location is not available at the time of the post-earthquake investigation, an accurate description and location of instances of liquefaction will permit further definitive data to be obtained at a later date. In this way, the state-of-the-art can be advanced with the ultimate possibility of reliable predictions of the liquefaction phenomenon.

Checklist:
1. Join with geologists to map the occurrences and nonoccurrences of liquefaction
2. Explore sand boils below the surface; preserve selected boils for later detailed study
3. Emphasize study of structures and landslides affected by liquefaction
4. Information on ground-water table

LANDSLIDES

Commentary: A major soils problem in earthquake engineering is assessment of the likelihood of the occurrence of earthquake-induced landslides in natural soils. Hence it is essential to compile more information concerning the geological settings in which such landslides can occur. Especially when landslides interrupt transportation routes, the evidence contained in the slide will be obliterated quickly. Conversely, the cuts made by bulldozers or shovels to move away landslide debris offer an unusual opportunity to examine the nature and distribution of the different soils and rocks with the debris.

Checklist:
1. Bedding planes, joints, and other weaknesses exposed in the landslide scar should be noted, as should any evidence of the presence of ground water
2. Absence or presence of sand boils or other flow phenomena
3. Effects on any foundations and building superstructure
4. Damage to structural components as contrasted to nonstructural damage; blocking of exits or routes of accessibility; direct effects on structures due to slumping and lateral pressure
5. Differential movements between cut-and-filled ground, particularly in the vicinity of the "daylight line"
6. Landslides (generally on very flat slopes) which may be due to liquefaction

DISTRIBUTION OF SHAKING DAMAGE

Commentary: At present, there still is considerable controversy regarding the effect of local soil and geological conditions upon the damage to buildings caused by ground shaking. More information is needed on this subject to permit compatible building code provisions to be formulated.

Hence, early in a post-earthquake investigation, it is essential to identify any possible correlation between building damage and soil conditions. Local geologic and soil maps should be consulted, if available. The nature and depth of the surface soil is important, especially in connection with damage to short buildings. The nature of the construction and number of stories of damaged and undamaged buildings should be noted. Buildings that are still standing should be checked to see if foundation settlement or horizontal movement has contributed to the damage. To the extent possible, it should be determined whether significant pre-earthquake settlements and cracking have occurred.

An isoseismal map will be of aid in such a study, as will multiple accelerograph records. Borings and field measurement of shear wave velocity will be of value in analysis. Aftershock ground motion measurements can be quite useful if properly planned and conducted.

Checklist:
1. Determine soil properties down to the 100-foot or greater depth
2. Compare performances of similar structures, such as dwellings, on different soils
3. Conduct aftershock ground motion measurements if a reconnaissance study suggests that a soil-versus-damage relation exists

FILLS AND WALLS

Commentary: There is a major need for quantitative data concerning the settlement of compacted embankments and other compacted fills, especially when there is no foundation failure. Behavior of walls retaining backfills is important. Behavior of buried structures and walls which retain earth is important.

Checklist:
1. Record any information that indicates the importance of volume decreases, lateral spreading, and settlement of underlying soils; estimate the magnitude of the total settlement
2. Where walls which retain backfills are deformed or moved, sketch if possible the pattern of permanent deformations in the backfill; note any gaps between backfill and wall; basement damage and racking of walls in tunnels and conduits
3. More data are needed on possible dynamic action of backfills

STATISTICAL DATA

GENERAL

The purpose of this subsection is to discuss how the gathering of quantitative monetary and damage loss data may be maximized.

Damage information, intended for use in *evaluating design methods,* has been gathered following most destructive U.S. earthquakes since about 1900. Damage to engineered facilities has been the primary concern, and recent efforts have been focused on those facilities whose designs represent the latest state-of-the-art. This focus on problem areas had led to in-depth studies. Technical publications have been produced, and changes in codes and standards have resulted. Another objective of design-oriented studies is making engineers and other responsible individuals aware of the hazards resulting from and lessons taught by earthquakes.

Monetary and other quantitative damage data have been gathered following many earthquakes, and these data have been used to predict losses from future earthquakes. However, the available loss data are quite variable and do not include the full range of behavior of all types of buildings in various intensities of ground motion. This is particularly true for earthquake-resistive construction. The availability of funds, competent investigators, and time has determined the scope of past surveys of this type. It is not anticipated that this situation will change appreciably after future earthquakes. A plan of action is needed which will make the best use of the available resources and time. The elements of such a plan are to (1) recognize the existence, availability, and quality of data, and (2) evaluate its importance. These are primary functions of the Reconnaissance Team. However, in a major earthquake these determinations will likely require followup teams which will have the manpower and time to investigate the matter thoroughly.

Coordination of the engineering with other surveys such as those discussed in Section V, the Social Science Field Guide, is essential. Casualty and organizational impairment studies must be correlated with engineering studies of the buildings where the casualties or impairments occurred.

Wherever possible, the full range of behavior (ranging from total loss to no damage) should be included. It is not essential that accurate quantitative data be acquired immediately following the earthquake. It is important that reasonable quantitative estimates of the extent of damage be documented quickly before such information becomes difficult to obtain. Remember, documentation of an absence of damage is as important as documentation of damage.

There may be situations where the application of probabilistic principles will be indicated. Examples of this are the behavior of a large number of dwellings and similar buildings in different intensity zones. See Appendix III-A, entitled "Statistical Sampling and Analysis in Earthquake Investigations."

DAMAGE PROBABILITY FOR ENGINEERED BUILDINGS

General

This discussion applies to engineered buildings, such as large one-story and multistory structures.

In order to prepare forecasts of damage expected to occur in future earthquakes, it is necessary to know how various types of structures have behaved during various intensities of ground shaking. This same knowledge is also essential for cost-benefit studies to determine the relative effectiveness of various possible steps to mitigate the earthquake hazard.

At any intensity of shaking, not all buildings of a similar type and size will respond in the same way. These differences arise even though all of the buildings meet the same building code requirements. The reasons for this are discussed in the Buildings subsection of this Field Guide (page 46). Damage must be documented for enough similar buildings in the same intensity of shaking so that both an average level of damage and the variance of the damage can be determined.

For the foreseeable future, each major earthquake will still be a unique experience from the standpoint of statistical investigation, involving a different city with different types of construction. Hence it is not possible to give an exact list of the data that should be collected. In general, the basic idea is to document the general level of damage for samples of similar buildings as a function of the intensity of ground shaking. Investigators must be alert as to how this general aim can best be applied, using the following guidelines. *These guidelines apply to engineered structures, such as very large one- or two-story and multistory buildings.* Other guidelines would apply to small dwellings.

Categories of Damage

The following categories can be applied to most buildings (investigators may need to modify these categories for some applications):

None:	No damage
Slight:	Isolated nonstructural damage; repair costs less than 5 percent of market value
Moderate:	Considerable nonstructural and slight structural damage; repair costs less than 25 percent of market value
Severe:	Considerable structural and extensive nonstructural damage; repair costs less than 50 percent of market value
Total:	More economical to demolish than to repair
Collapse:	Structural collapse

Types of Buildings

Three ways in which buildings and other structures may be categorized are according to (1) the structural system, (2) the degree of seismic resistance incorporated in the design, and (3) function or occupancy.

Some useful categories with regard to the structural system include ordinary and ductile steel and concrete moment-resisting space frames, concrete shear walls, mixed concrete and/or masonry shear walls and moment-resisting frames, reinforced concrete or masonry-bearing walls, and precast concrete walls.

Some useful categories regarding design seismic resistance include no specific seismic design requirements; Uniform Building Code (UBC) Zones 1, 2, and 3, or SEAOC prior to 1970; UBC or SEAOC after 1970; California Field Act and California Hospital Act. The greatest needs are for data concerning (1) the relative effectiveness of UBC Zone 1 and Zone 2 requirements, and (2) the relative effectiveness of the various types of provisions that have been in effect in California at various times. While more data concerning damage to buildings without specific seismic resistance are always useful, lesser priority should be assigned to obtaining such data.

A sample involving ten or more buildings, with similar types of structural system and levels of seismic resistance in each intensity zone, will give useful results.

Intensity of Ground Shaking

Locations of all buildings should be marked on a map for later comparison with official maps for the geographical variation of intensity. Usually it will be necessary to rate intensity on the basis of the Modified Mercalli Intensity Scale which fortunately utilizes damage to nonengineered structures and which thus can be used to rate intensity independently of the damage to engineered structures. Investigators should note damage to nearby non-engineered buildings, and should be especially alert to document damage to samples of buildings located near strong-motion instruments.

Instrumented Buildings

Commentary: Increasingly, dynamic analysis is being used as a design tool for multistory buildings. Hence, it is important to learn how the motions of a building, as predicted by dynamic analysis, relate to potential damage. This type of information comes best from the study of the damage (or nondamage) experienced by buildings in which strong-motion records are obtained at several elevations as well as at the foundation level. Such records may be used to validate a mathematical model of the building and to compute the inter-story distortions and floor accelerations experienced during the earthquake.

The calculated motions and distortions may then be correlated to damage if the damage information has been documented after the earthquake. Therefore, high priority should be given to documenting the type and extent of damage experienced by instrumented buildings, on a *floor-by-floor* basis.

Checklist:

1. Nature of structural damage: in just one or two members, or in many members
2. Exterior cladding and glazing: fraction of windows that fell out from each floor; fraction that cracked or were distorted in frames and must be replaced
3. Interior partitions: nature of damage (cracks, spalling); fraction of partition area requiring touch-up, and fraction requiring replacement
4. Overhead ceilings and lighting fixtures: fraction that fell, and fraction requiring major repairs
5. Contents: was movement of contents moderate (requiring only a few hours to restore to normalcy), major (requiring several days to restore to normalcy), or enough to cause injuries
6. Any damage to mechanical and electrical equipment
7. Any partial or complete blockage of emergency exits
8. Did elevators still function after the earthquake; were they out of service for more than a day
9. Did electricity remain available after the earthquake; if not, was the problem inside the building itself
10. Was water available throughout the building immediately following the earthquake; if not, was the problem inside the building itself
11. Did emergency systems function

APPENDIX III-A: STATISTICAL SAMPLING AND ANALYSIS IN EARTHQUAKE INVESTIGATIONS

STATISTICAL SAMPLING

The purpose of this appendix is to provide a realistic evaluation of the possible uses of probabilistic and statistical techniques in future earthquake investigations.

Conventional statistical sampling procedures are based on the laws of probability and include the key assumptions that the purpose of sampling is known with certainty and that effective sampling can be accomplished. Statistical sampling procedures have had their major application in the manufacture of nominally identical items in which there is little question about what to measure or how to measure it. The major effect has been focused on efficiency and reliability of sampling. Building construction, however, deals with unique products. The facility has been tested by the earthquake and the question is, what data should be obtained and how should they be recorded.

The concern of this discussion is with presenting reasonably simple concepts of statistical sampling and their limitations that should be considered at the next opportunity to conduct an earthquake performance survey of engineered facilities. The reasons for making such an effort are twofold: efficiency in the data gathering effort, and the expansion of knowledge in interpreting the data.

BASIC ASSUMPTIONS

First, probabilistic and statistical procedures deal with idealized mathematical models, and this is true with the suggested sampling techniques of interest. For example, real dice are never considered in assessing the probabilities associated with a dice game. The dice are mathematically perfect as are the table and the players. The translation from mathematics to reality requires the use of human belief or human acceptance that the difference between reality and mathematics can be neglected.

Second, the population from which the sample is taken is assumed either to be known, as with a deck of cards, or to be nearly infinite in size, as with all concrete cores that can be taken from all concrete buildings in California. The size of the population is assumed not to influence the sampling in the latter case. In contrast, if we select the ace of spades from a single deck of ordinary playing cards, we can assume that the second draw will not produce another ace of spades. At the other extreme, if we take one card from an infinite number of decks of cards, the receipt of one ace of spades will not change the probability (one in fifty-two) that the next card is also an ace of spades.

Third, all items in the population to be sampled are identical insofar as the question to be answered by sampling is concerned. For example, if the purpose of sampling the performance of single-family dwellings after the 1971 San Fernando earthquake is to estimate the proportion in the valley that suffered more than 10-percent loss, the population consists of all single-family dwellings in the valley. The degrees of ground shaking and ground displacement vary throughout the valley, so it is better to limit the population to a single level of ground shaking for engineering analysis.

Statistical procedures cannot define this boundary and thereby the population to be sampled. That is, the population cannot be defined by the mathematics of probability.

A part of this assumption that is often not appreciated is the conflict between the need for a uniform population and the population size itself. The more the required uniformity in defining the population of single-family dwellings by ground shaking, construction, age, etc., the smaller the available population becomes until, in the limit, the sample results may well be almost meaningless since the entire population is confined to a single building.

As the population size increases, however, another factor enters the problem. The reliability of the sample result decreases with increase in lack of homogeneity in the population. Variabilities are almost always additive so that the reliability of an estimate decreases as more and more influences are combined in order to obtain a larger population.

Fourth, and finally, there is the obvious assumption that random-sampling techniques can be employed. It is not possible to random sample many processes of interest including the earthquake phenomena themselves.

EFFICIENCY

The first and most obvious reason to employ random-sampling techniques is efficiency in the obtaining of useful and reliable data. A proper sample of size 10 to 20 can yield as reliable an estimate of a mean loss ratio as one of size 1,000 or 10,000. If both mean and variability are of concern, a proper sample size of 20 to 50 is adequate.

An associated problem is that of bias. For example, mean damage level estimates for the San Fernando Valley based on a tour of the spectacular damaged areas are highly biased, and there is no way to remove this bias. In contrast, a proper survey yields sufficient information to adequately describe all levels.

Efficiency can be attained through statistical sampling techniques, but there is a price that must be paid. We must be willing to accept the concept that a probability model describes the variability we record in the data. With loss levels in buildings, the probability model can be complex and some of its properties may be obscure while other properties can be complex, and some model properties may not even fit reality. Here again, the decision is a human one. The key does not lie in precision in choice of model but in an understanding of the questions to be answered by analysis of the data. If model inconsistencies influence the answers to key questions, there is no choice but to refine the model.

The objective of sampling is to define the sufficient statistic of the model. Note that the quest for efficiency has led us to acceptance of a model for variability and now we use the model properties to attain efficiency in sampling. For example, there is reason to expect that loss levels in dwellings are more or less exponentially distributed. That is, if we plotted the familiar bar chart or histogram of data for all levels of damage, it would appear as in Figure III-1. A very convenient mathematical equation has a shape near enough to this shape to make this relationship a first trial model. This curve is also plotted in Figure III-1 and it is seen that the data are scattered around this curve. Now, efficiency in sampling is found by observing that this particular curve has a single parameter or unknown constant to be evaluated. A random sample of size 10 to 20 will adequately define this parameter, and

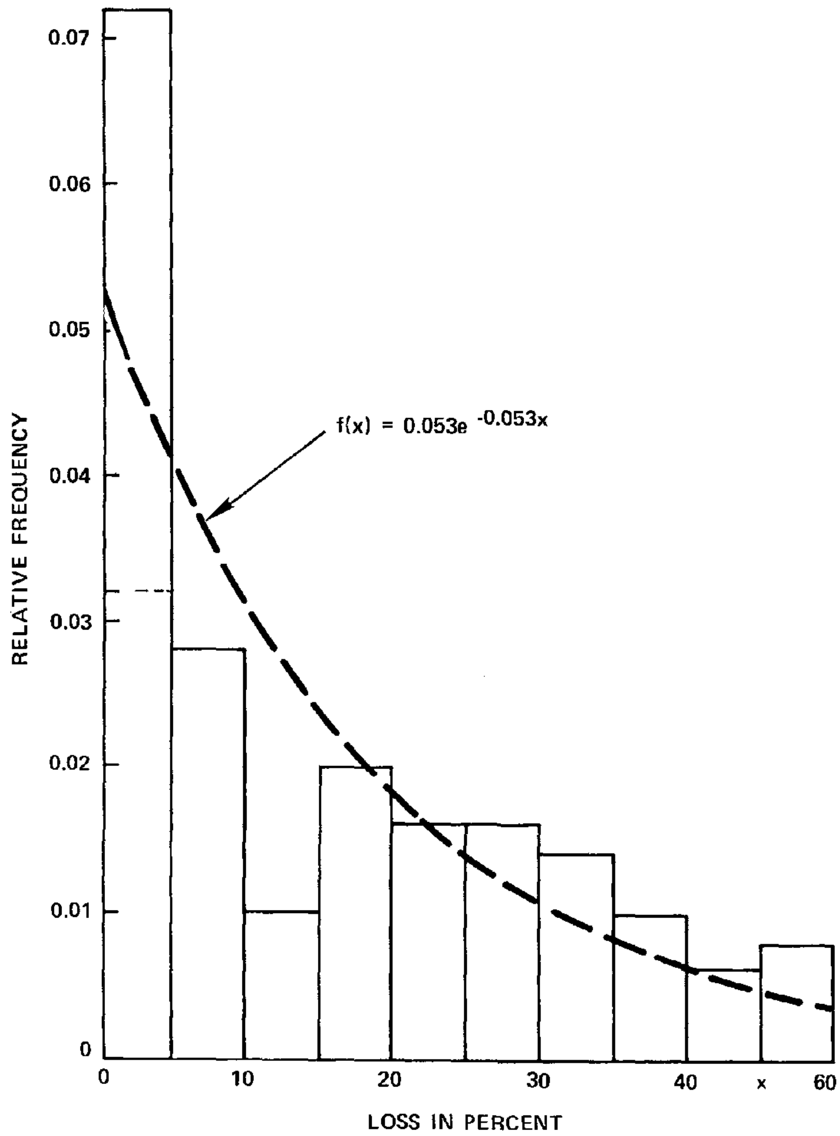

Figure III-1: Histogram and Fitted Model

all the data are then summarized by the model chosen, the estimate of this parameter, and the sample size. If, however, there is some confusion as to which probability model to employ, the mean, variance or standard deviation, and sample size summarize the data for a vast array of models. A sample size 20 to as much as 100 may be desirable to adequately define these parameters.

Fortunately, although there are a wide variety of probability models, the relationships between models are known and experience has shown that almost all natural phenomena can be satisfactorily modeled using no more than 6 to 10 models and that 2 or 3 of these dominate almost all studies.

The difficult problem is not the attainment of efficiency but rather the fundamental definition of the questions being investigated by the damage survey.

EXPANSION OF KNOWLEDGE

Most of the studies of damage after an earthquake have been lesson-oriented by observance of successes and failures. This is a valid and productive technique. Each observation constitutes a Bernoulli trial. The estimation of the proportion of successes or failures defines the binomial probability law. Unfortunately, the informational content of the model is limited to successes and failures.

An expansion of knowledge beyond observance of lessons is possible providing the optimum questions can be asked and data can be obtained to define the answers to these questions. For example, little attention has been paid to the damage phenomena themselves. That is, the focus has been on damage prevention rather than on a basic understanding of the phenomena. If damage is the sum of random events, none of which dominate, the damage should be normally distributed, the common bell-shaped curve. In contrast, if damage is interactive, one failure leading to another, damage should be more or less lognormally distributed. Damage to underground facilities and water and sewerlines appears to be lognormally distributed. The implications are important. If underground damage occurs at random, normally distributed, mitigation measures cannot be focused but should be spread more or less uniformly over the entire system. In contrast, with interactive damage, mitigation should focus on limiting the interaction. With this as a hypothesis, the survey of damage to buildings should be focused on the development of the initial damage and thus on those structures which received little or no attention after the 1971 San Fernando earthquake. For example, the mobile homes that fell off their supports are then of little interest and attention should be focused on the process that initiates this damage phenomenon.

Thus, the growth of knowledge about earthquake damage not only can proceed in the traditional pattern, but there is a further level of study that arises as a consequence of the characteristics of probabilistic laws and their occurrence in natural phenomena.

RANDOM SAMPLING: CONCEPTS AND EXAMPLES

The basic technique in statistical random sampling is to control every factor that must be controlled, and to randomize all other influences. For example, a complex series of experiments with concrete beams required that 110 identical specimens be constructed. After 60 beams were carefully fabricated and cast, the plant went on strike for several months before the next 50 beams could be poured and cured. In the interim, there had been a noticeable change in the product so that the experimenter had two distinct sets of beams with different properties. Everything that could be controlled had been carefully programmed, but it was obviously not possible to proceed by testing the beams in order of manufacture. To do so would hopelessly bias the results by building in a transition point from one set of beams to the other.

The answer was to randomize the selection of the beams. Each of the beams was given a number 000 to 109 in the order in which they were stacked, one set and then the other set. Then, the order of selection for testing and use in the program was determined using a table of random numbers. Each number in such a table is as likely to be found as another. Thus, if the first number observed in the table was 089, that beam was used in the first experiment and, if the second number was 014, that beam was used in the second test. In that manner, the influence of variation in manufacturing was randomized.

After the 1971 San Fernando earthquake, let us assume that the performance of average one-story, light commercial buildings was desired. The population to be sampled consists of all such buildings in the area where the earthquake was felt. Note that if the overall performance is desired, the population must be defined in such a manner.

It is also unlikely that the number of such structures in the felt area is known so that the sampling program must plan for this contingency also. The basic technique is exactly the same as used in the beam example only not all identified structures will be examined. If a map existed which showed the location of every one-story, light commercial building in the felt area, it would be a simple matter to number these structures from 0000 to perhaps 9999. Then, a sample of size 100 could be identified using a table of random numbers. These 100 identified structures would be thoroughly examined and the loss level estimated. If the survey were to include only those buildings with masonry walls, the sample would involve only such structures and their performance. If a sample of 100 masonry-walled buildings were desired, the basic sample might identify in order 300 light commercial buildings. The survey would then proceed as before, only recorded data on loss would be confined to those of the proper type until 100 investigations were completed.

The obvious criticism of such a procedure is that it is possible that none of the worst damaged structures would be included. Is this important? If the purpose of the study is to obtain the mean loss, the mean loss will be adequately defined even if none of the worst wrecks is examined. The reasoning is that each loss level is represented by a proportionate number of buildings and this proportioning is present in the interpretation of the results. In effect, a mean of 5 can be obtained by averaging 0 and 10, 2 and 8, etc., so that if one extreme is not recorded, this is balanced probabilistically at the other end of the scale. There is also a bit of "slight of hand" here, for statistical sampling only yields an estimate of the mean loss level, one with high reliability but not perfect reliability. To obtain the "exact" loss level, the entire population must be examined.

As an alternate approach, assume that no data exist as to what the felt area is and the damage levels have not been estimated. We can establish a rectangular grid 100 miles by 100 miles and number each square-mile area consecutively, 0000 to 9999. A sample of size 1000 would identify a sufficient number of such areas containing one-story, light commercial buildings. Many areas would contain none of these structures while a few would contain many.

If the number is not too large, each might be examined. If the survey remains unmanageable, each identified square-mile area can now be subdivided into 100 identical square elements, all of them numbered, and a sample of 100 identified using the table of random numbers. Examination of these selected areas will yield a random sample of the loss level.

There are a wide variety of sampling techniques so designed as to represent optimum plans under particular problem and population constraints. Thus far, few of them have been applied to earthquake damage surveys so that there is a considerable amount that needs to be learned in this area.

STATISTICAL ANALYSIS EXAMPLES

It is instructive to examine a few sets of damage data from the 1971 San Fernando shock to illustrate concepts and some of the basic techniques, and to point out both advantages and problem areas with these methods.

DWELLINGS

Steinbrugge et al. (1971) is the source of all the data used in the examples. Figure 24 of that report is repeated here as Figure III-2. The indicated data were then replotted on semi-log paper, Figure III-3. Note that the ordinate is unity minus the abscissa values of Figure III-2. If the data in each set lie sensibly along a straight line, a reasonable fit to the exponential probability model is indicated. This model is sketched in Figure III-1 for a different set of data. In all cases, a reasonable fit to the trial model is found. The scatter of the data about the line should be random for a satisfactory fit.

If the chosen model provides a reasonable fit and does not violate important physical conditions, some useful information can be obtained from the probability plot that is not evident in the basic data. First, the fitted straight lines intersect the zero axis for loss as follows:

Dwelling Type	Intersection (percent)	100 Minus Intersection
1 & 2 story	90	10
2 story	82	18
Pre-1940	43	57
All	31	69

The right column of figures gives an estimate of the percentage of undamaged (zero-loss) dwellings.

The ordinate in Figure III-3 is logarithmic and the abscissa is linear so that the probability of a loss equal to or greater than any given value, G(x), varies exponentially (Benjamin and Cornell, 1970) according to

$$G(x) = c \exp(-\lambda x)$$

x = loss level
λ = a constant
c = unity minus the probability of zero loss

Thus, if the probability model is satisfactory, only two constants need to be defined, and a sample of size 20 is likely adequate for most purposes to evaluate these constants.

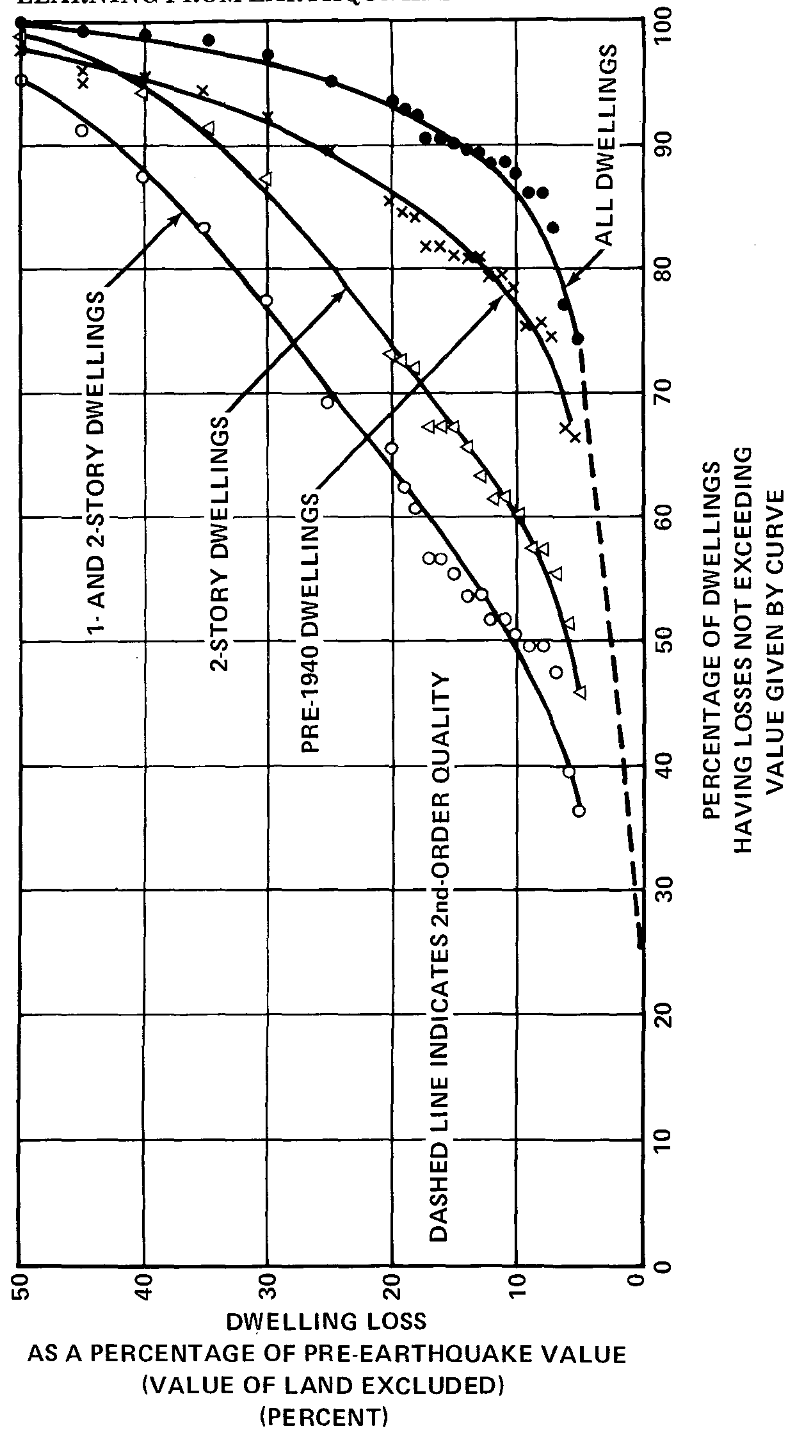

Figure III-2: Wood-Frame Dwelling Loss (From Steinbrugge et al., 1971, p. 23)

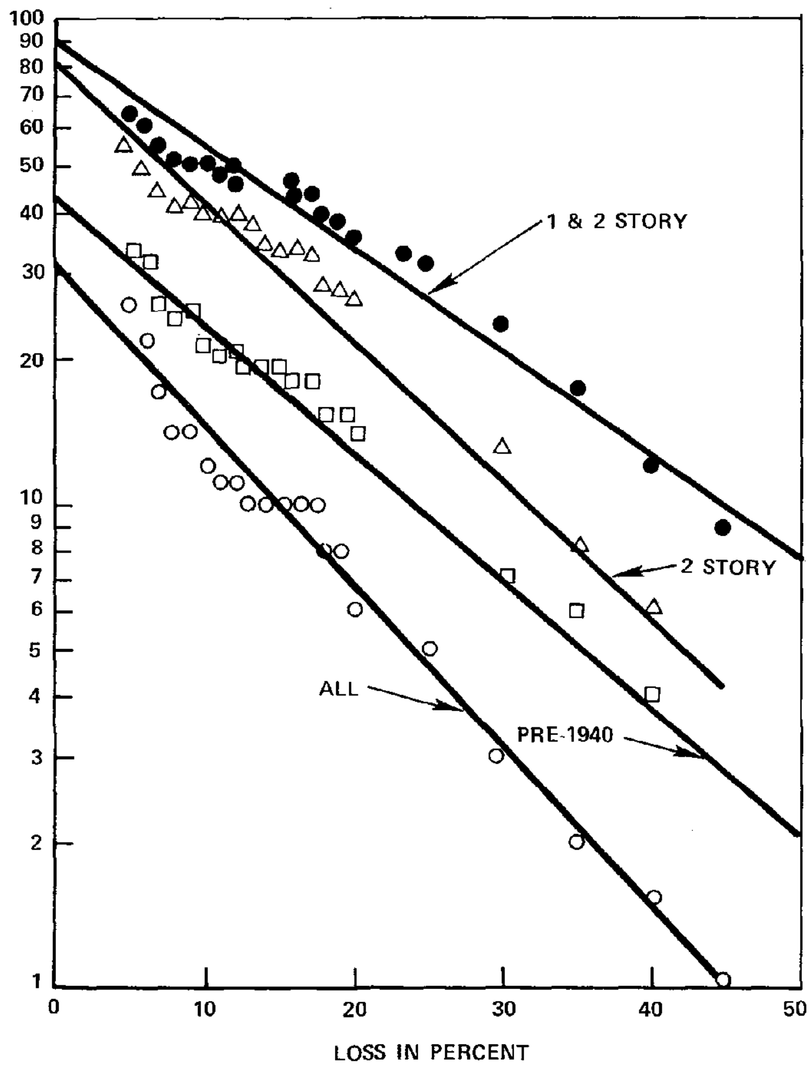

Figure III-3: Data of Figure III-2 Plotted for Fit to Exponential Distributions

One of the interesting observations from Figure III-3 is concerned with the relatively small variation in slope between the fitted lines and the zero-loss intercepts which indicate the proportion of undamaged structures. If a dwelling is damaged, not in the zero-loss class, probabilities of attainment of loss levels are relatively independent of construction.

LIGHT INDUSTRIAL BUILDINGS

The loss distribution by wall type for light industrial buildings without major soil disturbance is shown in Figure III-4 (Figure 43, Steinbrugge et al., 1971) in the form of a histogram or bar chart.

Is there an important difference between the mean loss with tilt-up concrete walls and the mean loss with unit masonry walls? The numerical summaries of the two sets of data are

	Tilt-Up (percent)	**Masonry (percent)**
Mean Loss, $\bar{x}$	15.08	11.75
Standard Deviation, s	10.14	6.03
n	30.00	20.00

Is the difference in the means significant or is it the consequence of the randomness of the loss phenomena? A standard hypothesis test approach yields the conclusion that the difference in the means is not significant at the 5-percent level of significance.

If the concern is with the difference in loss levels themselves rather than the means, it is a simple matter to compute the probability of relative loss levels. To do this, we assume that loss level is a random variable. The difference between the mean losses with tilt-up and masonry has a mean of

$$m = 15.08 - 11.75 = 3.33$$

The variance is the sum of the variances (assuming the data are uncorrelated) (Benjamin and Cornell, 1970),

$$\sigma^2 = (10.14)^2 = (6.03)^2$$
$$\sigma^2 = 11.80$$

Figure III-5 shows the distribution of the difference in loss levels. If the difference can be assumed to be normally distributed, the probability that the difference is positive can be found from tables to be 0.61 and that it is negative is 1 - 0.61 = 0.39. Thus, the probability that tilt-up losses exceed masonry losses is approximately 1.5 times that of the inverse condition.

HIGH-RISE BUILDINGS

The data on the loss in high-rise earthquake-resistive construction of reinforced concrete and steel are shown in Steinbrugge et al. (1971) (Figures 47 and 48), Figures III-6a and b, and are summarized in Tables 13 and 14 of Steinbrugge et al. (1971). A statistical analysis of the data was made with results given in Table III-1. A correlative analysis was made to determine if there was a correlation between

Table III-1: Statistical Analysis of Loss Data for High Rise Buildings

	Stories Above Ground	Distance (miles)	Loss[1] (c/sf)	Stories Above Ground	Distance (miles)	Loss[1] (c/sf)	Stories Above Ground	Distance (miles)	Loss (c/sf)
$\bar{x}$	11.2	20.96	9.38	16.78	21.43	7.204	14.10	21.20	8.25
s^2	6.08	4.78	140.85	76.62	2.097	78.76	50.40	3.61	109.80
s	2.47	2.18	11.87	8.75	1.45	8.87	7.10	1.90	10.48
V	0.22	0.10	1.27	0.52	0.08	1.23			1.27
sSD	2.35			8.905			6.41		
rSD	0.436			0.702			0.475		
sSL	-6.54			29.86			9.32		
rSL	-0.223			0.385			0.125		
sDL	-6.96			4.503			1.41		
rDL	-0.269			0.350			0.071		
	Reinforced Concrete, n=25			Steel, n=27			Composite, n=52		

[1] c/sf = cents per square foot

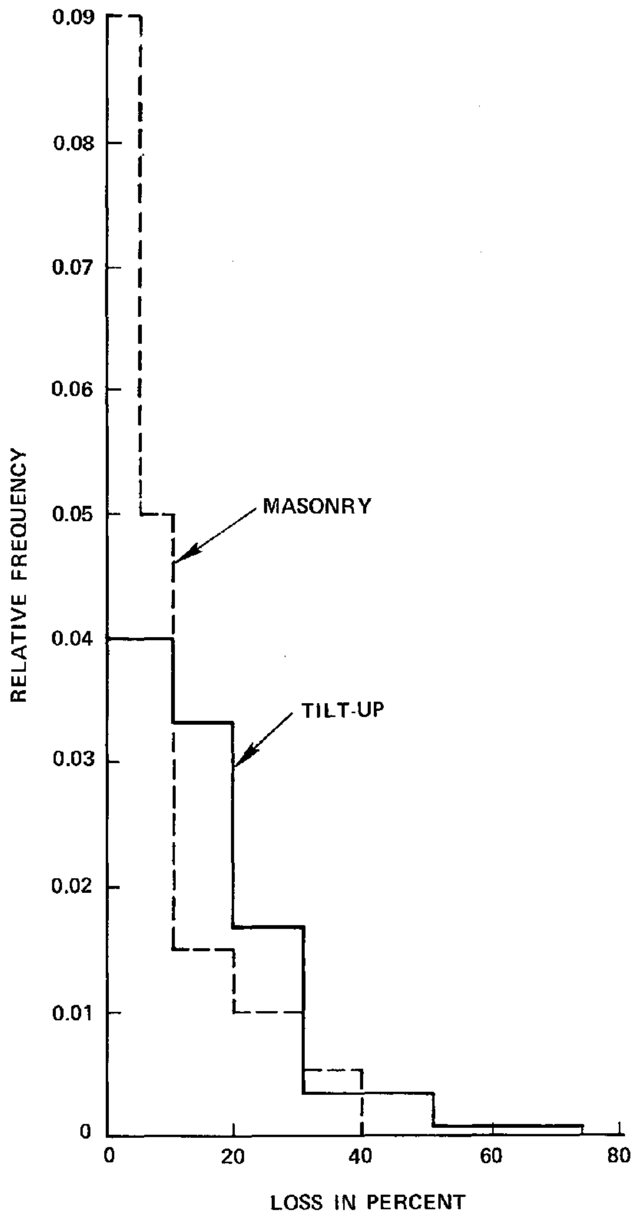

Figure III-4: Histogram of Loss to Light Industrial Buildings without Major Soil Disturbance (after Steinbrugge et al., 1971, Figure 43)

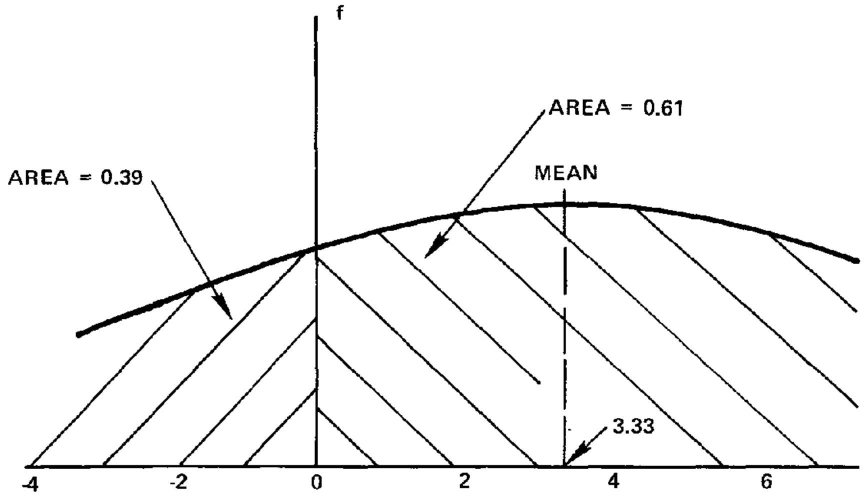

Figure III-5: Probability Density Function of Difference in Loss Level

a. Stories and epicentral distance
b. Stories and loss in cents per square foot
c. Epicentral distance and loss in cents per square foot

The only significant correlation was between stories and distance for high-rise steel structures. Both sets of data were combined to servè as a standard of comparison. There were no significant differences between the mean losses in steel and concrete buildings using standard statistical techniques.

The Steinbrugge et al. (1971) analysis shows that the highest loss was sustained by reinforced concrete buildings:

Dollar Loss in Cents per Square Foot	Material
680	Concrete
192	Concrete
65.5	Concrete
41.7	Concrete
35.5	Concrete
35.0	Steel
33.3	Concrete
29.5	Concrete
28.3	Steel
28.0	Steel

If the loss random variable, Figure III-7, is examined, all the loss levels except the two largest follow the lognormal probability model satisfactorily. The two largest loss values, 680 and 192 cents per square foot, appear inconsistent with the probability model, so that the damage to these two structures possibly arises from somewhat different phenomena than with the balance of the buildings.

The loss data are plotted as Figure III-7 on lognormal probability paper. The data fit the lognormal probability model satisfactorily. Loss values of 1 percent and less could not be separated from the data plot of Steinbrugge et al. The logarithmic loss scale would spread these low-loss-level points out if values could have been estimated. The median loss levels of 5.6 and 3.6 cents per square foot are found at the 50-percent cumulative probability point on the abscissa for concrete and steel respectively. The different slopes of the fitted lines give a strong subjective indication that, for the San Fernando event, loss levels tend to be consistently lower with steel than with concrete. This statement could not be made from the estimates of the mean values alone. A more interesting point is the indication that damage is interactive from fit to the lognormal model.

Another useful type of study employs linear models (Brownlee, 1960) in which loss, for example, is hypothesized to be a function of various parameters plus a random variation usually assumed independent of these same parameters. Figure III-8 shows a comparison of three different linear models using the data of Figure 28 (Steinbrugge et al., 1971). In Figure III-8a, percent loss is shown as a linear function of distance; in Figure III-8b, the logarithm of percent loss is plotted against distance as a linear function; in Figure III-8c, both loss distance scales are logarithmic. In each case, a regression line has been fitted to the data. The best fitted line is defined as that having the least sum of squares of deviations of loss between data points and the line. Subjectively, the log-log plot provides the best fit. The one-

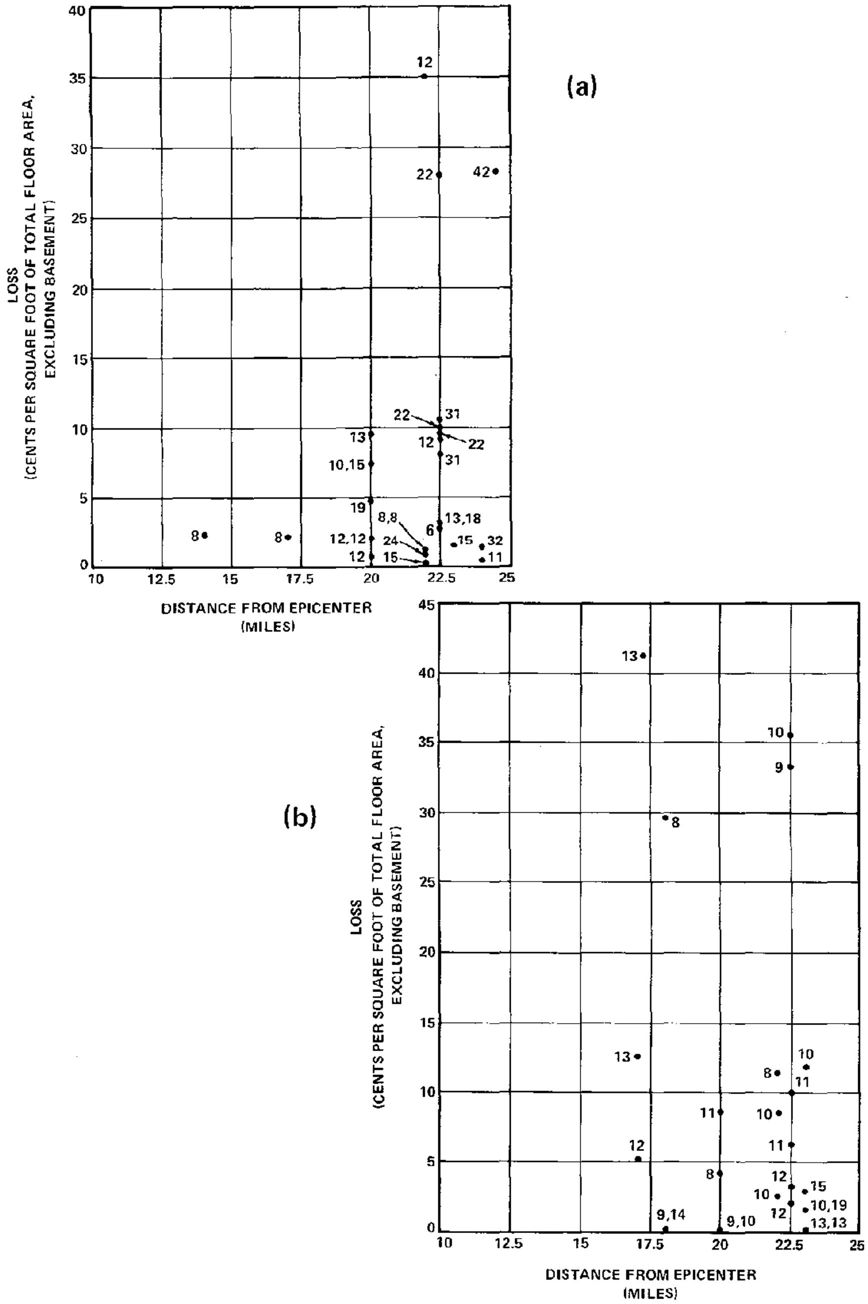

Figure III-6: Earthquake-Resistive High-Rise Building Loss Data (a = Reinforced Concrete; b = Steel Frame) (from Steinbrugge et al., 1971, Figures 47 and 48) (Number by dot indicates story height above ground; two numbers by dot indicate two buildings)

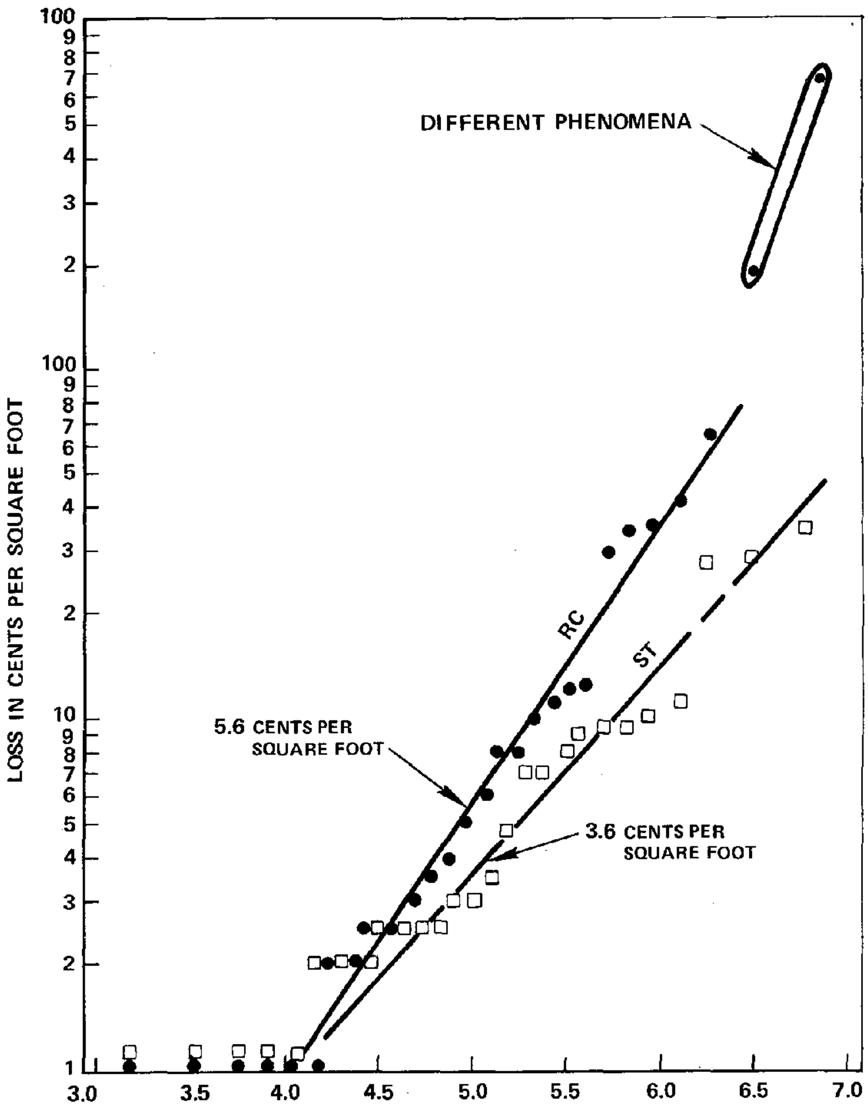

Figure III-7: Loss to Earthquake-Resistant High-Rise Construction (RC = Reinforced Concrete; ST = Steel Frame)

standard-deviation dashed lines on each side of the fitted line should contain about two-thirds of the data. The exponent of 2.85 with the log-log model is interesting. If damage is an interactive process, this exponent should be larger than 2.0. That is, if damage was a pure function of energy, the exponent should be close to 2.0, but if interaction also decreases with energy, the exponent should be larger than 2.0, as it proves to be.

CONCLUSION

The purpose of this discussion has been to present a realistic viewpoint of the possibilities and problems associated with employing statistical sampling and analysis procedures in earthquake investigations. Examples of simple applications are also included. It appears reasonable to conclude that the techniques show promise of being of value in future investigations following a damaging earthquake.

Interested investigators are encouraged to apply some of the techniques to make a beginning in the assembly of a body of experience in the use of probabilistic procedures in earthquake investigations.

REFERENCES TO APPENDIX III-A

Benjamin, J. R., and C. H. Cornell, Probability, Statistics, and Decision for Civil Engineers, McGraw-Hill Book Co., 1970.

Brownlee, K. A., Statistical Theory and Methodology in Science and Engineering, John Wiley and Sons, 1960.

Steinbrugge, K. V., E. E. Schader, H. C. Bigglestone and C. A. Weers, San Fernando Earthquake: February 9, 1971, Pacific Fire Rating Bureau, San Francisco, 1971, 93 p.

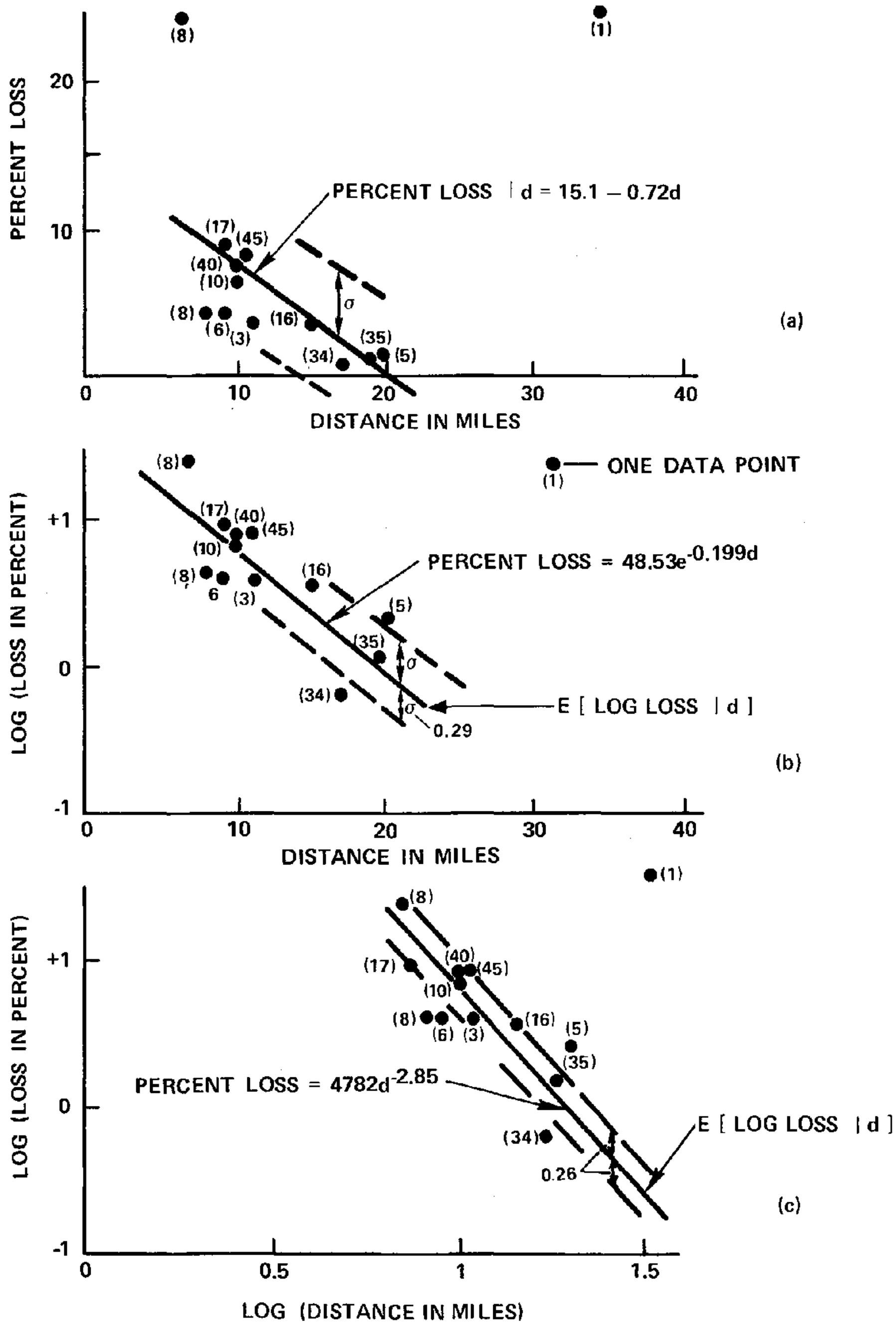

Figure III-8: Mobile Home Damage Data (a = Linear Plot; b = Linear Log Plot; c = Log-Log Plot) (Numbers in Parentheses = Number of Mobile Homes)

APPENDIX III-B: RECONNAISSANCE INSPECTION FORM—BUILDING

Investigator: ______________________ Date: ________

Building or Facility Data

Name: ______________________ When Built: ________

Address (or location): ______________________

____

Stories: ____________ Basement(s): ____________

Vertical load system: ______________________

Lateral load system: ______________________

Walls: ______________________

Foundations: ______________________

Soils: ______________________

Site: Sloping ________% Level ________

Strong-motion recording instruments? Yes ____ No ____

Earthquake Damage

General: ______________________

____

____

Estimated total losses: Less than 10% ____ 10-50% ____

Over 50% ____

Is building functional? Yes ____ No ____ Why not? ____________

Status of utilities: ______________________

Does building warrant further investigation? Yes ____ No ____

Why? ______________________

Estimated Modified Mercalli Intensity ______________________

Casualties: Deaths ________ Injuries ________ Unknown ________

Miscellaneous Data

Architect: ____________ Engineer: ____________

Are plans available? Yes ____ No ____ Where? ____________

Photos ________ Roll ________ Frame ________

(Use back for sketches and additional notes)

RECONNAISSANCE INSPECTION FORM—LIFELINES[1]

Investigator: ______________________ Date: ________

Facility Data

Name of facility: ______________________

Location: ______________________

Lifeline function: ______________________

Owner: ____________ Contact: ____________

Are drawings available? Yes ____ No ____ Where? ____________

Date constructed: ____________ Strong-motion recording instruments? Yes ____ No ____

Is lifeline contained in a building? Yes ____ No ____ If yes, use building form, in connection with this lifeline form.

Description (capacity and features): ______________________

____

Foundation material: ____________ Sloping ________% Level ________

Earthquake Damage

Lifeline: ________ Building: ________ Foundation: ________

Principal cause of damage: Shaking: ____________ Differential Ground-surface movement: ____________

Description of damage: ______________________

____

Estimated total loss: Less than 10% ____ 10-50% ____ Over 50% ____

Is lifeline functional? Yes ____ No ____ Why not? ____________

Estimated time to repair: 1 day ____ 1 week ____ 1 month ____ Complete reconstruction required ____

Casualties: Deaths ________ Injuries ________ Unknown ________

Causes of casualties: ______________________

Does lifeline warrant further investigation? Yes ____ No ____

Why: ______________________

____

Miscellaneous Data

Photos: ________ Roll ________ Frame ________

Sketch reference: No. ________ Location ________

Building form reference: Name of facility ____________ Date ________

(Use back for sketches and additional notes)

[1] Water, energy, communication, and transportation.

APPENDIX III-C: EMERGENCY BUILDING INSPECTION FORM

DEPT. OF BUILDING AND SAFETY CITY OR COUNTY OF

CONDITIONS

A	BUILDING ADDRESS							
B	ZIP CODE		C	DISTRICT OFFICE		DATE		TIME
OWNER, TENANT OR MANAGER						PHONE		
ADDRESS (OWNER, TENANT OR MANAGER)								
D		USE OF BUILDING						
E		CAUSE OF DISASTER	F		SITE DAMAGE	1. YES ☐	2. NO ☐	
G		BLDG. TYPE	H		NO. OF STORIES	I		ROOF COVERING
J		NO. OF LIVING UNITS	K		NO. OF LIVING UNITS DAMAGED	L		EST. YEAR OF CONSTRUCTION
M		EST. % OF DAMAGE <10% 10-50% >50%	N		EST. VALUATION OF DAMAGE			
O		DESCRIBE DAMAGE (CHECK ONE)						

NON-STRUC. DAMAGE ☐ NONE	☐ Architectural	☐ Exterior	☐ Interior	☐ Glass
	☐ Mechanical	☐ Piping	☐ Equipment	☐ Elevators
	☐ Electrical	☐ Equipment	☐ Lights	☐ Controls
STRUCTURAL DAMAGE ☐ NONE	☐ No Collapse	DAMAGE:		
	☐ Partial Collapse	WHAT PORTION:		
	☐ Total Collapse			

ACTIONS

P		BUILDING SAFE FOR OCCUPANCY	1. YES ☐	2. NO ☐	3. PARTIALLY ☐
Q		PERMIT REQUIRED	1. YES ☐	2. NO ☐	PLANS REQ'D.
R		JOB ORDER ISSUED	1. YES ☐	2. NO ☐	JOB ORDER NUMBER
S		BUILDING POSTED AS UNSAFE	1. YES ☐	2. NO ☐	DATE / TIME
T		NEEDS REINSPECTION	1. YES ☐	2. NO ☐	BY
U		DISCONNECT UTILITIES	1. YES ☐	2. NO ☐	TYPE
V		BARRICADES REQUIRED	1. YES ☐	2. NO ☐	DATE REQUIRED
W		CERTIFICATE OF HAZARD ISSUED	1. YES ☐	2. NO ☐	DATE ISSUED

			Vacate (and)			Partially Vacate (and)			Other –	
X		RECOMMENDED ACTION (CHECK ONE)	1. Repair ☐	2. Demolish ☐	3. Only ☐	4. Repair ☐	5. Demol. ☐	6. Only ☐	7. Repair ☐	8. None ☐
Y	Number of Living Units Vacated	NOTES:								
Z		1. YES ☐	2. NO ☐							

INSPECTED BY	TEAM
CODED BY	TEAM CAPTAIN

IV. GEOSCIENCE FIELD GUIDE

PREFACE

The Geoscience Field Guide has been written to serve as an aid to researchers (experienced and inexperienced as earthquake investigators) entering the field in the aftermath of an earthquake, regardless of when or where the earthquake occurs.

The Field Guide suggests answers to the following questions:

1. What is or was the state-of-the-art on ground behavior and the geosciences at the time of the earthquake?
2. What information is needed which can be obtained only by detailed field investigations?
3. How can the quantifiable parameters of ground behavior be recognized in the field?
4. How and what data should be recorded?

In the following Introduction to this Field Guide we discuss what past earthquakes have taught geoscientists and what needs to be learned from future events (questions 1 and 2 above), and we summarize the state-of-the-art and the current problems we face. Summary outlines are included under some of the subjects. The subsection on Planning is a methodology statement of the *duties* of geoscientists *before and immediately following* an earthquake. The subsection on Data Collection is an aid leading to the collection and dissemination of useful data, with a minimum amount of unnecessary duplication and loss of valuable information (question 4 above).

Checklists, or information-gathering forms, are included in the Data Collection subsection and are also reproduced in larger size at the back of this book to facilitate direct reproduction for field use.

The Appendices comprise important information basic to application of the geosciences in data collection and complete investigation of earthquakes in the field. Included also is a special paper on submarine earthquake investigations (Appendix IV-A).

INTRODUCTION

A prime objective of the Geoscience Field Guide is to identify the principal problems in investigating earthquakes relative to the roles of seismology, geophysics, geology, and geodesy.

What *is* being done, and what *needs* to be done to ensure that the necessary data are gathered, that the data are gathered with reasonable efficiency — without too much repetition and overlap — and that they are made available to appropriate persons and agencies.

Successful implementation of a viable plan to investigate earthquakes depends basically on (1) an adequate supply of well-trained, professional personnel, (2) full financial support, and (3) organization and coordination of the activities of agencies and individuals. In terms of field observations, personal experience in the investigation of earthquakes is a great asset, and long-range planning for earthquake-response procedures must — and generally does — provide opportunity for young scientists and engineers to gain such experience.

DEFICIENCIES IN PRE-EARTHQUAKE INFORMATION

What has been conspicuously deficient or lacking in past earthquake investigations?

The first well-organized, thorough, scientific investigation of an earthquake was that conducted by the California State Earthquake Investigation Commission of the 1906 San Francisco earthquake. The Commission should be rated high in the competence of its field investigators and on its report, which was published by the Carnegie Institution. However, its field parties conspicuously lacked background scientific data — including basic topographic, geologic, and geodetic maps and information. There have been great improvements in building up adequate background scientific data and maps in certain areas (San Fernando, 1971, for example), but *this lack or inadequacy remains perhaps the first and greatest problem* today in the field investigation of earthquakes in most parts of the world.

There has been a serious general lack of precise geodetic data available prior to all earthquakes. In no case have there been enough precise coordinates — vertical and horizontal control — to permit a close delineation of land surfaces before and after an earthquake. Detail and frequency of repetition of horizontal and vertical measurements have been insufficient to allow rapid construction of accurate "before and after" maps of the land surface in an earthquake area.

Another obvious deficiency in pre-earthquake data which are needed by the scientific investigator of an earthquake has been in instrumentation. We have lacked — and still lack, seriously — objective data on ground motions in earthquakes. A glaring modern example is the great 1964 Alaskan earthquake, during which not one strong-motion record was obtained. The 1971 San Fernando quake was the first in which pre-earthquake, strong-motion instrumentation even approached adequacy.

In general, there has been a deficiency in *pre-earthquake planning* of scientific investigations which should be conducted immediately after a major earthquake occurs.

DEFICIENCIES IN POST-EARTHQUAKE FIELD INVESTIGATIONS

Two comprehensive terms — coordination and communication — suggest present-day problems of scientific field investigations of earthquakes. Occurring on the fringes of a densely populated metropolitan area, the 1971 San Fernando quake probably had more investigators and investigating agencies than any previous earthquake — with the possible exception of the 1952 Kern County earthquakes which occurred in a region in which there was an abundance of petroleum geologists. Coordination between agencies and their staff scientists is necessary for increased efficiency, avoidance of undue overlap and duplication, and in the interests of reduced overall cost. *Daily* communications between technical workers from different agencies and different disciplines, including engineers and social scientists, during field study of an earthquake increase learning by all and increase effectiveness of the following days' work.

A second shortcoming in recent post-earthquake investigations has been *lack of previous field experience* in such earthquake studies on the part of a great majority of the investigators. Field checklists and guides such as this are a major part of our methodology to improve this situation.

News of an earthquake brings an immediate need by earthquake scientists for certain basic information in answer to questions such as: Where was the epicenter? What was the approximate magnitude? Is there surface faulting? If so, where and how much is it? What is the damage situation? What about access for field investigators? Improved seismographic coverage, aerial reconnaissance, and means of communicating have helped in the prompt dissemination of basic information to those who will use it, but deficiencies remain in these areas.

In California (with its high frequency of damaging earthquakes) the scope of earthquake research and earthquake-protective measures recently has been greatly increased by government. Recent measures enacted into law have notably enhanced efforts to "meet the earthquake challenge." After 5 years of intensive work by the Joint Committee on Seismic Safety of the California Legislature, supported by the Governor's Earthquake Council, a new law has established a California Commission on Seismic Safety ". . . with responsibility and authority to develop seismic safety goals and programs, help evaluate and integrate the work of State and local agencies concerned with earthquake safety, and see that the programs are carried out effectively and the objectives accomplished."

CONTRIBUTIONS OF SEISMOLOGY

Seismologists must record on their seismographs the onset of the seismic waves, and they must calculate the position and other parameters of the earthquake and its aftershocks. It is in the seismological literature that there resides the legacy of knowledge of destructive earthquakes around the world from early historical times. The seismologist brings to the study of destructive earthquakes the theory of their causation and the knowledge of wave effects, propagation paths, and ground motions which is required for a general synthesis.

Experiences gained from large earthquakes in various regions are valuable to the extent that they can lead to the prediction of the behavior of the ground in future earthquakes. In light of this, the requirements of the *engineer,* so far as design is concerned, have a crucial impact on the emphasis a seismologist will give the various aspects of the ground shaking and of the source properties.

CONTRIBUTIONS OF GEOLOGY

What are the principal geologic problems in connection with earthquakes and how can geologists best contribute to earthquake research?

Geology *supplements* seismology in the study of earthquakes. It provides information on rock formations and their characteristics, stratigraphy, structure, and geologic and tectonic histories. Particularly related to earthquake research is geology's concern with faults, fault systems, and ground features and effects.

To maximize learning, the investigation of earthquakes must be interdisciplinary — the geologist must correlate his data with those of the seismologist, geodesist, engineer, and social scientist. Although he can best contribute certain kinds of specialized data, the geologist must be aware of, and must be able to interpret and utilize, a variety of data from other fields. Geology is, first of all, a field science, and it is probably in the *field observations* that the geologist makes his most valuable contribution after an earthquake.

Geoscientists are developing more understanding of and data on the buildup of crustal strain and earthquake precursors, which permit earthquake prediction in a broad sense. But *forecasting the location, time, and extent of important secondary faulting and ancillary or auxiliary faulting* seems presently beyond the capabilities of our scientific disciplines. Yet, secondary faulting and ancillary faulting within a major fault zone can be equally as destructive as offsets along the master, causative fault. How can we make real progress toward solving this problem? On the part of the geologist, an important approach is the detailed, large-scale mapping of *all* faults, along with the best analysis possible of the ages and activity of such faults.

Ground shaking is the predominant ground effect accompanying earthquakes, in terms of structural damage and its direct cause of injuries and loss of life. Of course, by definition, an earthquake *is* ground shaking, and again, by definition, it is a seismological problem. However, here again the closest of team work is indicated between the scientific and engineering disciplines. The geologist is best equipped to map and study the geological phenomena (such as ground cracking, compaction, settling, all manner of landsliding, mud volcanoes, mud, sand, water geysers, and other indicators of liquefaction, shattered ridges, and other local evidences of ground acceleration) which accompany and result, in part, from ground shaking.

The seismologist gathers and studies strong-motion records, and the geologist plays an important role in relating these records to local and regional geology. Questions which concern him are, for example: What is the relationship among differences in local intensities and thicknesses and distribution of alluvium and soils? Between topography and ground acceleration? Between suballuvial geologic structures and ground-acceleration phenomena?

Finally, the geologist is uniquely responsible for information on and maps of the rock formations, stratigraphy, structure, and tectonic setting of the earthquake, both in the epicentral area and in the regional tectonic province. He works with seismologists and other geophysicists on geological interpretation of their data. Knowledge of the fault systems — their characteristics and ages — and the deformational history and crustal strain pattern of the earthquake area is vital to understanding the earthquake history and mechanism. *An earthquake is not an isolated event, but fits into a pattern and history of regional tectonics and strain accumulation.*

The occurrence of an earthquake brings up new, specific needs for geologic data; for example, a *geologic cross-section through the hypocenter* and transverse to the strike of the causative fault.

CONTRIBUTIONS OF SUBMARINE TECHNOLOGY[1]

New tools, new techniques, and new capabilities are extending earthquake investigations below sea level.

All of the duties or activities of the earthquake investigation team that

[1]See Appendix IV-A for a more complete treatment of the special problems of submarine investigations.

should be performed before and after the earthquake for land sites should also be performed, as appropriate, for submarine areas. Geologic and topographic maps of key areas should be collected, and a list of personnel trained and/or experienced in earthquake investigation and in marine investigation should be available and periodically updated. Strong-motion seismographs should be installed wherever possible in seismically active offshore areas, plans of offshore structures in such active areas (e.g., oil well platforms in the Santa Barbara Channel) should be available, and strong-motion seismographs should be installed in such structures. There should be a continuing effort to improve bathymetric mapping and geodetic control of the sea floor, just as there is on land.

There is a great deal of specialized equipment which is required for investigating submarine earthquakes. The type of equipment necessary varies somewhat depending on where the earthquake occurs. The depth of the fault trace below the sea surface is a most important factor, but many other factors such as sea conditions, water temperatures, abundance of hazardous marine animals, water clarity, and nature of the sea floor, influence the type of equipment necessary.

Research in marine geophysics, geology, and geodetics is expensive and complicated by environmental factors, but it cannot be neglected in modern earthquake investigations.

CONTRIBUTIONS OF GEODESY

The application of geodetic techniques to the study of crustal movements has received increasing attention in recent years. These movements may be purely local, such as landslides, local sloughing of top soil in the vicinity of man-made cuts, or subsidence of small areas; or the movements may be large ones correlated with extensive geological fault systems, occurring over long periods of time and exhibiting tectonic uplift or depression.

The results of geodetic studies can provide scientists in the fields of geology and geophysics, or the engineer in the field of public works or mapping, indications of crustal movement which might be quite extensive or perhaps quite trivial.

The key to the study of these movements must always be a framework of geodetic stations on the periphery of, or exterior to, the suspected moving area.

DESIGN EARTHQUAKE

Potential damage to a structure, due to a moderate-to-major earthquake, can be induced by either one or a combination of the following (Hudson, 1972):

1. Dynamic structural loads due to ground shaking (primary effect, see Data Collection subsection, page 124)
2. Ground failure, including surface faulting and landslides (primary or secondary effects)
3. Special earthquake hazards, such as tsunamis (secondary effects)

Of primary importance to engineers is the ability to predict which of the above will be a threat to a particular site.

The prediction is concerned with items (1) and (2) above and is commonly called a *design earthquake.* Ideally it is a time history of ground acceleration as used in a dynamic analysis, or as transformed into a response spectrum (Hudson, 1956; Housner, 1970).

The development of design earthquakes was an outgrowth of strong-motion data collected beginning in 1933 (Jennings et al., 1969; Seed and Idriss, 1970; Schnabel et al., 1971; Trifunac, 1971) and by observation and mathematical interpretation of the damaging effects of earthquakes (Table IV-1).

In recent years, geoscientists have taken a more active role in the collection and use of much of the data needed for the development of design earthquakes. These data should be acquired in such a manner as to meet the needs of scientists and engineers alike.

Additional data are needed first for a greater understanding of *how the earth moved* at a particular location, and second for an understanding of the cause of the movement.

The damage potential to a particular site-structure system is believed to be a function of the earthquake source (size, type, and orientation to the site), travel path (distance from source to site and regional geology) (Duke et al., 1972; Udwadia and Trifunac, 1972), and the local "site" geologic conditions (Duke, 1958; Duke and Leeds, 1963; Lastrico et al., 1972; Richter, 1959, 1972), as well as of the structure itself.

The relative importance of the above parameters will vary considerably from one location to another, sometimes within a relatively short distance (Gutenberg, 1957; Hudson, 1972; Trifunac, 1971). Duke (1960) pointed out that this rapid variation can be very damaging to long structures such as bridges.

Table IV-1: Design Earthquake Parameters

1. Magnitude
2. Seismicity of the area in question (foreshocks,mainshock, and aftershocks)
3. Frequency of occurrence of a given magnitude or ground acceleration
4. Duration of strong motion (>0.05 g) or "bracketed duration"
5. Maximum acceleration — horizontal and vertical
6. General level of repeatable high accelerations
7. Predominant periods of ground motion
8. Proximity of site to energy center (hypocenter) on closest distance to causative fault
9. Soil-structure interaction
10. Available recorded strong-motion data

POTENTIAL GEOLOGIC PHENOMENA

In order to clarify the relative importance of source, travel path, and site geology relative to damage potential, let us divide the region involved in an earthquake, particularly where structures are damaged, into three zones (Table IV-2). Zone A is the nearest to the source; Zone C is the farthest. The assumption made is that the primary factors controlling ground behavior, and therefore damage, will vary from zone to zone. The size, shape, significance, and continuity of the individual zones will be a function of the source, travel path, site geology, and the structures within the zone. Hence there will be a unique relationship between an earthquake and its zones. The essence of geoscience earthquake studies is to determine this relationship. Table IV-2 is a reference to be used to illustrate the relationship of the hypothesized zones (A, B, and C). As an example, Zone A may be defined by such *potential geologic phenomena* as surface faulting, differential settlements, high accelerations, and permanent regional bedrock deformations. The following subsection discusses some of the geologic phenomena associated with earthquakes.

EARTHQUAKE SOURCE

Commentary: Earthquakes are believed to be caused by a sudden, but not always uniform, slippage along a fault, probably usually a "stick-slip" process on a fault surface. This slippage allows the elastic strain energy, stored in the deformed rocks on either side of the fault, to be released, and was first described by Reid (1910) as "elastic rebound."

In some areas, such as California, large earthquakes are generally associated with faults of extensive Quaternary activity (Allen et al., 1965). There is increasing evidence that some of these large earthquakes may be multiple events (Reid, 1910; Trifunac and Brune, 1970) and may have long durations but not necessarily correspondingly high accelerations (Bolt, 1973). Small earthquakes are more random and sometimes more difficult to associate with specific faults (Allen et al., 1965; Bolt and Miller, 1971).

It has become increasingly apparent that the earthquake source has multifaceted effects on earthquakes. For example:

1. Focal depth controls, in a significant way, the area of the earthquake in which the shock is felt, length of surface faulting, and intensity of damage
2. Length of faulting will affect the frequency content, duration of motion, and area in which the shock is felt
3. Different types of faults will affect damage patterns differently (for example, thrust faulting may cause more damage to structures on the upthrown block)
4. Direction of faulting may focus energy (Trifunac and Brune, 1970)
5. Multiple events complicate the effects of source on surface faulting, duration of motion, and ground accelerations — this is especially important for very large earthquakes
6. Dip-slip faults tend to enhance P and SV motions; strike-slip faults may produce greater SH amplitudes (Bolt, 1970)
7. Relatively small earthquakes can cause considerable damage and loss of life in limited areas
8. Nearer the source, an earthquake's effects may dominate local geology (Udwadia and Trifunac, 1972)

Unfortunately, until 1971 there were few strong-motion records obtained within close proximity to the source of a moderate or major earthquake. Therefore, it has been difficult to assess the direct effects of the source in the near field.

Aftershocks are earthquakes which begin shortly after the mainshock. Generally, with the passage of time these aftershocks decrease in size and frequency; however, they have been known to continue for years following the main event. They occur either along the main or subsidiary faults and are

Table IV-2: Near-to-Far Zones and Potential Geologic Phenomena[1]

	Zone A (*Nearest to Source*)	Zone B (*Intermediate*)	Zone C (*Farthest from Source*)
1. Source	Possible surface faulting; main and subsidiary faults, tsunami development		
2. Tectonic Ground Deformations	Local to regional permanent bedrock deformations		
3. Settlement	Differential settlement in granular Holocene (Pleistocene?) deposits and artificial fill; across contact of poorly consolidated/consolidated materials	Possible differential settlement in Holocene deposits	
4. Ground Failures	Major landslides (liquefaction); local wave development; bearing capacity failures due to liquefaction	Landslides and local waves (?); bearing capacity failures due to liquefaction	Rare, rockfalls (?)
5. Aftershocks	Many, on main and subsidiary faults		

[1]Tsunami hazard thousands of miles from source not considered. The region involved in an earthquake has been divided into three zones: Zone A is nearest to the source; Zone C is farthest. Listed (zone by zone) are the geologic phenomena that may occur as the result of an earthquake. As an example, Zone A may experience, and therefore be defined by, such phenomena as surface faulting and regional tectonic ground deformations. There is no attempt to define the size, shape, or continuity of zones.

Table IV-2 (continued)

	Zone A *(Nearest to Source)*	Zone B *(Intermediate)*	Zone C *(Farthest from Source)*
6. Accelerations	High accelerations on bedrock; somewhat lower on regolith (soil)	Regolith (soil) sites greater than bedrock sites	Regolith (thick soil) sites greater than bedrock sites (frequency-dependent)
7. Duration of Motion	Moderate, slight; decrease with distance (?)	Small-to-moderate earthquakes may have decrease in duration; large earthquakes increase in duration	Bedrock = thin regolith (decrease in duration); thick regolith sequence = relative increase in duration
8. Topographic Focusing and Resonance Effects	Topographic effects possible; importance (?); focusing (?) and resonance (?)	Resonance and focusing important; topographic (?)	Topographic (?) (period of waves too long?); focusing and resonance effects possibly greatest cause of damage
9. Predominant Periods of Ground Motion	Short to moderate	Moderate to long; noticeable peaks on very soft sediments only	Long
10. Damage Potential	Ground failure (surface faulting, etc.); ground shaking	Ground shaking; ground failure	Ground shaking only

probably due to time-dependent stress readjustment related perhaps to water movements. The size and distribution of aftershocks are related to the total source area or volume of strained rocks prior to the main shock (Bolt, 1970). The 1971 San Fernando quake (magnitude 6.5) produced an aftershock sequence which covered a relatively small area in and around the San Fernando Valley, whereas the Chilean earthquake of 1960 (magnitude 8.5) had an aftershock distribution equivalent to the size of the State of California (Allen et al., 1965).

From an engineering standpoint, shallow foreshocks[1] and aftershocks (Ambraseys, 1969) of a size similar to the mainshock can cause considerable damage to undamaged and weakened structures (Allen, 1965). A classic example took place in California, when a large aftershock of the 1952 Kern County earthquake occurred on a fault 20 miles from the main fault trace. Considerable damage was experienced in Bakersfield due to this event (Oakeshott, 1955). It is evident, therefore, that aftershocks must not be ignored in engineering and seismic studies (Merz and Gornell, 1973).

Summary Outline:
1. Directional aspects of ground motion and failure as a function of distance from the source
2. Effects of source on damage potential as a function of distance
3. Cumulative effects of multiple events on duration of motion, ground accelerations, and building damage (Trifunac and Brune, 1970)
4. Nature and extent of foreshocks and aftershocks (size, distribution)
5. Relative importance of body and surface waves as a function of distance (Bolt, 1970; Schnabel and Seed, 1973)
6. Cumulative damaging effects of foreshocks, mainshock, and aftershocks
7. Measurement of mainshock and aftershock ground motions at places that will eliminate site effects

PERMANENT GROUND DEFORMATIONS

Commentary: Permanent ground deformations can be classified as follows:
1. Tectonic (uplift, subsidence, folding, and tilting)
2. Settlement (compaction)
3. Ground failures (landslides, lateral spreading, and bearing-capacity failures due to liquefaction and loss of shear strength)

Tectonic deformations are commonly associated with shallow-focus earthquakes. These irregular ground deformations have occurred and have been quantitatively documented by geodetic methods in Japan (Chinnery, 1961), Alaska in 1964 (Bonilla, 1970; Eckel, 1970), Chile in 1960 (Retamal and Kausel, 1969), and San Fernando in 1971 (Yerkes et al., 1973). The importance of such movements is obvious, particularly in coastal zones; however, to date, they have generally not been possible to predict.

Surface faulting, accompanied by extensive ground deformations, may be quite extensive, with traces hundreds of miles long and exhibiting horizontal

[1]Cluff and Carver (1973) noted that a foreshock of the 1972 Managua earthquake saved many lives "as frightened persons left their homes and were sleeping in open fields" when the damaging mainshock occurred.

and/or vertical movements in the tens of feet. Generally, faults where this type of movement occurs are relatively easy to identify.

Problems arise in the recognition of potential subsidiary faulting that may accompany the mainshock. Bonilla (1970) indicated that in exceptional cases the cumulative length of subsidiary faulting may be as much as 95 percent of the length of the main fault. He further stated that displacements on these subsidiary faults may be as much as one to a few feet and at distances as great as 8.5 miles from the main trace. In addition to subsidiary faulting, there is the problem of variability in fault slip as a function of distance below the ground surface and local geology. Field studies of faulting indicate that ruptures can be absorbed or amplified as they pass through rock or soil (Bonilla, 1970), with little relationship between traces and offsets noted at depth (Oakeshott, 1955). These phenomena, although poorly understood, are of great importance to the design and potential repair of structures which cross active faults.

Settlement by compaction is a densification of generally loosely consolidated, very young (Holocene), cohesionless deposits due to vibration. Identification of this type of settlement poses a problem if the problem is associated with tectonic movements. As much as 4½ feet of settlement was documented at Homer, Alaska, in 1964. Two feet of that settlement was tectonic; the remainder was due to compaction. Varying amounts of compaction have been observed during other earthquakes, such as Niigata, Japan, in 1964 (Seed and Schnabel, 1972) and Chile in 1960 (Retamal and Kausel, 1969).

Liquefaction is defined as the transformation of a granular material from a solid state into a liquefied state, as a consequence of increased pore-water pressures (Youd, 1973). This process accounts for major bearing-capacity failures due to a "quick" condition such as occurred in Niigata in 1964; failures by lateral spreading such as occurred in the Juvenile Hall slide in the 1971 San Fernando quake (Youd, 1973); and major landslides on sloping surfaces (Seed, 1968).

Landslides can also occur in moist to dry materials due to loss of shear strength (Gaus and Sherif, 1972) and at large distances from the source, e.g., 50 to 60 miles in the case of the 1952 Kern County earthquake (Oakeshott, 1955).

Ground cracking or rupturing is generally a prominent feature of shallow-focus earthquakes (Hansen, 1965). It may be associated with poorly compacted backfill around structures (Housner, 1965) and buried pipelines, or it may occur in natural earth materials. It may be localized (such as in Managua in 1972) or cover large areas (such as in Alaska in 1964).

Summary Outline:

1. Development of geologic attenuation map(s):
   (a) Extent and nature of nonlinear soil behavior as a function of magnitude, distance, duration of motion, and local geology
   (b) Development of strain maps
   (c) Plotting of seismic data (instrumental and other(s) and contours for possible attenuation pattern(s), plot on geologic map)
   (d) Plotting of damage pattern on geologic map for better correlation between Modified Mercalli Intensity and geology (Evernden et al., 1973)
   (e) Settlement and its effects on lifelines
   (f) In-place soil parameters and ground failures (such as relative density

versus liquefaction) (Finn, 1972)
(g) Relationship between main fault and subsidiary faulting
(h) Effects of near-surface water table (Gutenberg, 1957; Gaus and Sherif, 1972)
(i) Development of a methodology to identify Modified Mercalli Intensity

2. Formation and damage due to local waves (Kachadoorian, 1965)
3. Secondary permanent effects (submarine)
4. Location and recognition of submarine active faults
5. Measurements of post-earthquake fault creep

ACCELERATION

Commentary: There is a relationship, although tenuous (Ambraseys, 1973), among ground acceleration and distance from source (Housner, 1965; Milne and Davenport, 1969; Cloud and Perez, 1969; Schnabel and Seed, 1973), regional and local geology, orientation to source, and, to an even lesser degree, magnitude (Donovan, 1973; Page et al., 1972). In general, distance has an effect of attenuation of the seismic waves by geometric spreading and frictional attenuation. Frictional attenuation accounts for the greater damping of the higher frequencies (Bolt, 1970; Lastrico, 1970).

Studies of earthquakes in the central United States by Nuttli (1972) and others have shown that attenuation is a function of regional geology. It is obvious from observation of isoseismal maps that earthquakes of comparable Richter magnitude (size) will be felt over larger areas east of the Rockies than in the western United States. Nuttli (1973) attributed this in part to the low attenuation of short-period waves and to the less complex geology of the area. Furthermore, he stated that for similar earthquakes, the central United States will experience smaller accelerations but larger ground displacements.

Sites covered by thick, poorly consolidated, sediments may substantially affect ground motion (Ambraseys, 1973; Borcherdt, 1970; Seed and Idriss, 1969). Effects may be increased if a high ground-water table is present (Gutenberg, 1957; Seed, 1968). Nearer to the source, accelerations in such poorly consolidated materials are in part depressed due to energy-absorbing ground movements (Table IV-2, Zone A). However, as strain levels decrease with distance, thick sediment accumulations tend to amplify certain high frequencies of ground motion relative to rock sites (Table IV-2, Zone B) (Borcherdt, 1970; Donovan, 1973). The amplification is greatest in horizontal directions.

In close proximity to the fault (strike-slip movement), ground accelerations (horizontal component) tend to be larger perpendicular to the fault. Observations of this type were made after the Parkfield (Hudson and Cloud, 1967) and Managua (Matthiesen and Knudson, 1973) events, and later were calculated by analytical techniques (Johnson et al., 1973).

Knowledge concerning the relationship between magnitude and peak acceleration is sorely inadequate (in part due to the lack of near-field instrumental data). This suggests that available empirical formulae should be used with caution (Ambraseys, 1973). Large (peak) accelerations alone are of little value for engineering design,[1] because they are generally in a frequency

[1]Newmark (1973) noted that objects which move upward relative to the ground surface require acceleration of the objects greater than 1 g; however, this may not mean the acceleration of the ground is greater than 1 g.

range considered too high to be important (Donovan, 1973). The area under the peak and the general level of accelerations (repeatable highs) are important parameters (Ploessel and Slosson, 1974).

Summary Outline:
1. Peak and general level accelerations as a function of orientation to source magnitude, type of faulting, radiation pattern, travel paths, distance, regional and local geology, and water-table depth
2. Relative ground motion over very short distances (within the dimensions of large engineered structures)
3. Nature of ground acceleration (direction of motion, etc.) close to and at distance from fault

DURATION OF MOTION

Commentary: Bolt (1973) defined "bracketed duration" at a particular frequency as the elapsed time between the first and last acceleration excursions greater than a given level (say 0.05 g). Observation of strong-ground-motion records, with the above definition in mind, indicates that duration of motion is a complex function of magnitude, distance, local site geology, and possibly other factors.

Early work by Gutenberg (1957) indicated that at large distances from the source, duration of motion will increase with distance for those sites on thick deposits of alluvium. Page et al. (1972), using additional and more recent data close to the source, observed that for similar earthquakes, there may be a decrease in duration with distance (as noted for all small-to-moderate earthquakes) up to a certain distance, whereupon the duration will increase. Dispersed surface waves and local geology play important roles in effect.

Soil strength studies have indicated that duration of motion is very important in soil response, as noted in the 1964 Alaska earthquake (Eckel, 1970). During the 1964 event, Anchorage, 80 miles from the epicenter, sustained major damage due to large landslides which began moving only after several minutes of ground shaking (eye-witness accounts). Ground deformations of this type are believed to be due to soil failures (often liquefaction), exhibiting an inverse relationship between intensity and duration of motion.

Summary Outline:
1. Correlation of duration of motion (from strong-motion records) as a function of magnitude, distance, local geology, and depth to water table
2. Relative importance of duration of motion and ground failures as a function of local geology
3. Duration of motion, damage to engineered structures, and arrival of P, S, Love, and Rayleigh waves

TOPOGRAPHIC, FOCUSING, AND RESONANCE EFFECTS

Commentary — Topographic Effects: Influence on seismic waves, due to topographic highs, is varied and difficult to define because of the lack of recorded data. Boore's (1972) studies indicated that the effects are important if (1) the incident wave lengths are comparable to the size of the topographic feature, and (2) the topographic feature's slopes are relatively steep. Reviewing recorded motions of aftershocks (as in San Fernando in 1971) and a cavity collapse following a Nevada test site detonation, Davis and West (1973) concluded that amplification can occur at the crest of a mountain. However, the motion along the flanks is very complex and as a result, amplification or attenuation may occur. The Pacoima Dam record from the 1971 San Fernando earthquake is a case in point for possible topographic influence. The instrument was located on a steep-sided narrow ridge in the San Gabriel Mountains, and recorded several peak accelerations greater than 1 g. Assuming that the record was a true representation of the ground motion, Boore (1972) believed that the large accelerations were due to the presence of the mountain and not to the narrow ridge.

Commentary — Focusing Effects: Focusing of seismic waves is believed to occur when waves of different types are refracted as they pass through major discontinuities in rock type, with irregular contacts (Schnabel, 1971; Trifunac, 1971; Jackson, 1971; Dezfulian and Seed, 1969). If this occurs, the "topography" of the basement complex may be responsible for isolated areas of heavy damage. Jackson (1971) believes that this effect may in part be responsible for the damage that occurred in Skopje, Yugoslavia, in 1963 (Leeds, 1964, indicated local geology was of prime importance) and in Caracas, Venezuela, in 1967 (Seed, 1972, and Espinosa and Algermissen, 1972, feel that resonance was responsible). Buried topography at the basement complex may also have been a factor in the damage pattern of the 1971 San Fernando shock (Oakeshott, 1975).

Commentary — Resonance Effects: Predominant periods of ground motion are related to magnitude and total fault displacements (Housner, 1973; Hudson and Udwadia, 1973), distance, and local geologic (and topographic?) conditions. Housner (1973) stated that the longer the duration of fault movement, the greater the amplitude of the long-period waves generated. With distance, the predominance of the long-period waves is increased due to frequency-dependent frictional damping.

If high strain levels are induced in Quaternary sediments, a low shear modulus may result, therefore developing a longer fundamental period for the soil deposit (Seed and Idriss, 1969). By this and other means, local geology has an effect on predominant periods of motion. Predominant peaks occur on very young, soft soils, such as noted in Mexico City and on San Francisco Bay muds (Borcherdt, 1970).

Theoretical studies combined with observations of damage (35 miles from the epicenter) in the 1967 Caracas, Venezuela, shock (Seed et al., 1970) indicated that under the right geologic-structure system (similar natural periods), considerable damage can occur to the structure. Espinosa and Algermissen (1972) performed a spectral amplification study using aftershocks of the 1967 event and found that in the period range of the damaged building, the sites did amplify the ground motion. Similar resonance effects, causing considerable damage, have been noted in other earthquakes at distances up to 185 miles (Steinbrugge and Moran, 1957). Unfortunately, at great distance, there is little known about the relative importance of body and surface waves on potential resonance effects. There is some evidence that surface waves may be more sensitive to variations in layer thickness than body waves (other things being equal).

Summary Outline:

1. Apparent focusing of energy due to subsurface geology, wave guides, and wedge or boundary effect
2. Existence and importance of shadow zones
3. Relative importance of focusing and resonance in alluvial valleys (both appear to occur in alluvial valleys with buried irregular basement complex surfaces)
4. Importance of topographic effects on landslides and engineering structures
5. Any areas of "anomalous" high or low damage
6. Effects of topography, focusing (basement-complex geometry), and resonance as a function of distance, magnitude, and seismic wave type (body and surface waves)
7. General travel path effects (regional geology) such as reflection and refraction

PLANNING: THE DUTIES OF GEOSCIENTISTS

PRE-EARTHQUAKE DUTIES

One of the essential tasks in the study of earthquakes is preparedness before the next major earthquake occurs. Every effort must be made to have trained personnel and necessary equipment available and ready to go into the field within hours after the event. Otherwise, much of the critically needed information, particularly in populated areas and areas of shallow submarine earthquakes, will be destroyed, and most of the major aftershocks will go unrecorded.

Following is a brief discussion of the preparation duties of geoscientists prior to an earthquake.

Duties of the Seismologist

The tasks of the observatory seismologist can be properly performed only if there is an *adequate distribution of seismographic stations* in the area of the destructive earthquake. It is, therefore, necessary for all concerned to provide steady support for the operation of long-term seismographic station networks.

There is also a scientific requirement that computer programs which will rapidly and effectively perform the necessary studies of aftershock distribution, magnitude, and fault-plane solutions be ready at the various seismological observatories. Such programs should also be available at the National Center for Earthquake Research of the U.S. Geological Survey, so that there is no delay in gaining access to the information if the earthquake occurs at an unusual time in an unusual place in the country.

Contingency plans must be worked out by seismological groups to provide public information and for post-earthquake studies. Priority is dictated by the demand of various professions, including engineering, for information on location, the history of earthquakes in the area, and the likely course of aftershock sequences. These contingency plans should contain public presentations which would help the public cooperate with the teams performing the on-site inspection of various locations in the days following the main earthquake.

Seismographic and geophysical instrumentation to record variations of earth parameters near the earthquake source are urgently needed. In this category comes a range of strong-motion instruments placed in carefully designed arrays and locations (Cloud and Hudson, 1961). The program would include borehole strong-motion instruments placed at several depths with varying geologic conditions and at possible marine sites such as offshore oil platforms. A liquefaction instrumentation experiment should be mounted at sites where results might be anticipated within a reasonable time. Sites such as Oakland and Long Beach, California, and Seattle, Washington, fulfill the requirements of convenient profile (moderate thickness of soft soils on bedrock), and frequent earthquake occurrences. A 5- to 10-year program at each of the three sites would hopefully generate at least two sets of records.

Further attention must also be given to the pre-event placement of tide gauges along the coastlines and on the large lakes in the likely regions of earthquake occurrences.

Duties of the Geologist

Primary pre-earthquake duties of the geologist are to coordinate the collection of geologic and topographic maps and aerial photographs useful for post-earthquake damage surveys and a thorough understanding of the regional geologic setting (Table IV-3). These maps and photos are invaluable to scientific teams entering a stricken area. They aid in the collection of data and have proven useful for rescue and damage-mitigation work.

The geologist should pay special attention to the collection of maps for areas of high occurrence of earthquakes, nuclear powerplants, and strong-motion instrument sites.

A long-range goal of the geologist is the preparation of a geologic atlas/inventory/bibliography for possible sites of future destructive earthquakes. This project will be initiated as part of the Implementation Phase of the "Learning from Earthquakes" project, with the cooperation of local and national geological surveys, professional societies, and universities (see discussion of data banks in Section I, Planning Guide).

The qualified engineering geologist should also consider how his skills can be utilized by local government officials in the assessment of geologic hazards existing after a major earthquake (Hansen et al., 1975; California Division of Mines and Geology Interim Earthquake Response Plan, 1973).

Duties of the Geodesist

The results of geodetic studies can provide scientists in the fields of geology and seismology, or the engineer, indications of crustal movement which might be quite extensive or perhaps quite trivial. The classical technique involves data from which an initial position of a point may have been determined; after some period of time, a redetermination of the same position is made. If these two determinations differ, the magnitude and direction of the changes of position may be considered a movement vector indicating what has taken place.

The problem of applying geodetic information to studies of crustal movement, whether it is induced by local subsidence or is a large area affected by major earth movement, is to see what data are available which provide an indication of position at some time in the past, to note the effect of new geodetic observations, and to compare the new resulting positions with the old. In the detailed analysis of resultant movement vectors, considerable information may be derived which may show the type of land movement.

Table IV-3: General Geologic Information

Report by: ____________________ Address: ____________________
Occupation: ____________________ Home or business phone: ____________
Date of report: ____________________

Regional Geomorphology:

Description of geomorphic province in which earthquake occurred:

Major geomorphic features and lineations (relationship to rock type):

____

Topographic map(s): ____________________
Stream patterns: ____________________
Relief: Maximum ____________(m) Average ____________(m)
Average slope inclinations: ____________________
Locations of specific sites (described in Table IV-5): ____________

____

Regional Geology

Description:

Regional tectonic setting (including tilting, warping, depression, uplift, etc.)

Regional fault system (importance of causative fault in region system)

Types of faults, tectonic relationships (maps and cross-sections)

Major rock types and their distribution (geologic map)

Volcanic activity

Ground water:

Nature, (free, confined, perched, etc.): ____________
Map of ground-water levels based on *depth* to ground water
Water levels in wells (note changes): elevation: ____________
depth: ____________
location: ____________

Earth materials:

Geologic map of area:

Cross-section delineating distribution of earth materials and geologic structures (at least one through the focus, if possible)

Complete description of earth materials (include comments on geologic age, type of material, composition [%], texture [% grain size if applicable], consolidation, moisture content, porosity, permeability, cementation, structure, origin, etc.); especially note type and distribution of Quaternary sediments

The key to these movement studies must always be a framework of geodetic stations on the periphery of, or exterior to, the suspected moving area. These framework stations must exhibit stability; that is, current observations compared with those performed in the past must indicate that these established stations have not moved. Sometimes an error analysis must be made of the field observations to ensure that movements of small magnitude are not considerably less than the allowable error of observation; if this is not considered, fictitious movement might be inferred from the data.

The recommendation for programs at a local level to ensure a continuing supply of data which might be usable in the event of future earthquakes would include (1) an inventory of all existing horizontal and vertical control movements in the ground today, and (2) a central depository (data bank) of such information which is available to anyone needing it.

This inventory should include, among other items, a detailed description of the monuments concerned, the organization that established each, and a brief note listing the type of survey upon which each establishment was based. For horizontal control monuments, the latitude, longitude, and x,y plane coordinates on the appropriate plane-coordinate mapping system should be listed. Also of use to field surveyors attempting to recover such monuments would be information such as existing intervisibility with other stations.

With regard to vertical control monuments, known more commonly as benchmarks, a listing should be kept indicating the name and type of organization establishing the point, the date of establishment, and the various elevations determined by successive observations in subsequent years. Whereas only a relatively small percentage of horizontal control points indicates a change of position, it is known that benchmark data in California are quite commonly listed with apparent changes in elevation by successive releveling on the same monument. Without this inventory and subsequent listing in a data bank, unnecessary duplication of work may result.

Studies of earthquakes in recent years have been assisted by having such information quickly available for any agency and individuals desiring to make reobservations. There are many technical survey problems involved, such as whether the monument used should be solely for geodetic purposes or whether it should double as a monument defining a cadastral position. Examples of the latter are centerline monuments established by the agencies who performed the original survey upon the highway system, section corners, and others of similar types originally established by the Bureau of Land Management (formerly the General Land Office). The latter in effect define the cadastral control for all lands which were originally public in nature. Also in California, major corner monuments were established for large rancho holdings that never came under the public lands system.

After considerable review and listing of data in a central, open-to-the-public agency, the next problem is that of defining a program for systematic reobservation. This will result in discovering unsuspected moving areas within the concepts of stability in nonmoving areas; it will also uncover small errors or perhaps even large mistakes that unfortunately might exist in any geodetic system. This program is costly and, generally speaking, can be performed only by a public agency.

Continuance of this work can be brought about only by making use of the latest technology available. In recent years this has been aided by the following:

1. Use of an optical theodolite which permits greater speed and precision in determining orientation

2. Use of electronic optical distance-measuring devices which permit the accurate determination of distances to a degree of precision heretofore accomplished only by slow, tedious Invar taping
3. Taking advantage of radio communication and helicopter transportation for control work in remote mountain areas

To these three items should be added a fourth, namely the advantages of the computer systems which permit the drudgery and overwhelming volume of data to be reduced and adjusted within a reasonable time period. A fifth item of major importance, in light of present theories on earthquake prediction, would be to perform gravity surveys at the same time as the geodetic measurements are being made. Because elevation is a critical measurement needed for gravity surveys, the simultaneous measurement of the two (geodesy and gravity) potentially could add to our knowledge of earthquakes.

POST-EARTHQUAKE DUTIES

Following a major earthquake, it is important to draw upon a pool of specialists experienced in earthquake investigations for membership on Reconnaissance Teams. The prime concern of these teams will be to make a quick survey to determine the needs for further studies and the establishment of an instrument network for aftershock and geophysical studies. Reconnaissance Teams will be multidisciplinary, comprising engineers, geoscientists, and social scientists. It is important that various members communicate with each other at least daily to coordinate their activities and exchange information.

Table IV-4 is a list of some of the basic tectonic data which the Reconnaissance Team should collect and make available for immediate dissemination. Hopefully, this information will establish in part the need for future study and will provide information for the general public.

The following is a brief look at the types of duties the seismologist, geologist, and geodesist should be responsible for during post-earthquake studies.

Duties of the Seismologist

Seismologists have both specific and overall tasks to perform after a damaging earthquake. In the first place, seismologists must record on their seismographs the onset of the seismic waves and calculate the location of the focus (hypocenter) and magnitude of the earthquake. This information must be made available as quickly as possible to the field workers and the public.

Following this work the seismologist is usually busy recording the location and magnitude of aftershocks, which may in themselves be damaging to weakened structures. His knowledge of aftershock sequences often enables him to make reasonable predictions as to the course they may follow. The detailed location of the sequences defines the extent of the source, in many cases, and hence gives important information to studies by geologists in the field along fault systems.

Field inspection of the damage area by seismologists is also very valuable. First, it provides the seismologists with a better understanding of the measurements and reports which come from the other professions, and secondly, it enables the seismologists to stimulate additional measurements which may be crucial to understanding the ground-motion variability involved.

Table IV-4: Basic Tectonic Earthquake Data

Report by: ____________________ Address: ____________________
Occupation: ____________________ Home or business phone: ____________
Date of report: ____________________
Date of earthquake: ____________________
  Main Shock: ____________________
  Major Aftershock(s): ____________________
  Foreshock(s): ____________________
Time earthquake occurred: ______________ Local: __________ (UCT)
Magnitude: ____________________ (coordinates Universal Time)
Maximum intensity: __________ (MMI or general damage estimate)
Duration of strong motion (X0.05g): ____________________ (sec)
  Instrument location: ____________________
Location of epicenter (instrument or field survey location):
  Latitude: ______________ Longitude: ______________
  City: ______________ Township: ______________
  County: ______________ Range: ______________
  State: ______________ Section: ______________
  Country: ______________
Focal Depth: ______________
Surface faulting: Yes ( ) No ( ) Location: ______________
Type of faulting: __________ Strike: __________ Dip: __________
Length of fault rupture (maximum): ____________________ (km)
Fault separation or slip (maximum):
  Horizontal: ____________________ (m)
  Vertical: ____________________ (m)
  Oblique: ____________________ (m)
  Location: ____________________ (m)
Distance of damage area from epicenter: ____________________ (km)
Distance of damage area from fault rupture: ____________________ (km)

The seismologist also brings to the study of destructive earthquakes the theory of their causation and the knowledge of wave effects, propagation paths, and ground motions which are required for a general synthesis.

Seismologists will need to calculate focal mechanisms from the first motions and other wave properties. These mechanisms must be correlated with the field measurements of strike and dip of any faults which appear at the surface and with the subsurface geology. The mechanisms are now also being correlated in an important way with the strong-motion accelerometer measurements obtained in the very near field.

Enhanced recordings of aftershocks have become important in terms of specification of the dislocation zones in the crust. Portable field seismographs must be put into place within a few hours around the main source region of the destructive earthquake in order to record major aftershocks. In some cases, it becomes urgent to place additional instruments at sites of important engineering and local geologic structures and of variable topography and earth materials.

Recently, telemetering sonobuoy hydrophones have proven very useful in studies of seismicity at sea or beneath or near any major water body (Bradner and Brune, 1974; Reid et al., 1975; Northrop, 1974). After the 1973 Pt. Mugu, California, earthquake, five unmodified SSQ38A or SSQ41A U.S. Navy telemetering sonobuoys were dropped into the sea from a DC3 aircraft. The sonobuoys were free-floating and locations were carefully tracked. The data were recorded by instrumentation in the aircraft which consisted of a commercial 152-174 megacycle VHF receiver for each sonobuoy channel and two 2-channel strip-chart recorders to accept the output from the receivers. Time marks were made manually. The advantages of this technique for aftershock recording are obvious. Such instrumentation can be put into operation anywhere in the world within a few hours. Such equipment should be readily available for future earthquake investigations.

The ability to predict future earthquakes in an area involves a complete specification of the parameters of past earthquakes. These seismological parameters include the measurement of fault offset and the length of the ruptured fault as seen at the surface. In addition, measurements and rates of afterslip, changes in water level, local tilting of ground surface, and measurements of crustal strain must be detailed.

A current theory of earthquake cause involves the dilation of rocks in the highly strained area preceding the earthquake. After the earthquake, there is partial relaxation of the dilational conditions. Seismologists must, therefore, be concerned more and more with measurements of water levels in wells and other, perhaps yet undetermined, gauges of water behavior.

Near the sea coasts and large lakes, measurements of tsunami action, seiches, and local waves are a major seismological responsibility. Tide-gauge records must be recovered as quickly as possible, and various field studies must be made which would indicate seiche action in lakes and reservoirs.

The seismologist as a geophysicist may also be responsible for measurements of important geophysical parameters having to do with earthquake prediction and subsequent occurrence of earthquakes in an area. These include, in brief, measurements of fluctuations in the geomagnetic field, in the electrical conductivity of rocks in the area, in variations in the P- and S-wave velocities through the source region, and in the crustal strain as indicated by changes in levels and by triangulation.

Duties of the Geologist

Geology is, first of all, a field science, and it is by field observations that the geologist makes his most valued contribution after an earthquake. Immediately after a moderate-to-great earthquake, armed with the latest seismic parameters of the earthquake (Table IV-4) and his knowledge of the regional geology and tectonics (Table IV-5), the experienced geologist is the best consultant on an initial aerial reconnaissance. He can orient flights to take advantage of structural trends, known active and geologically recent faults, and topography; to recognize and spot new fault traces, ground ruptures, and landslides; and to organize the taking and collecting of aerial photographs[1] (Garofalo and Wobber, 1974).

On the ground, the geologist observes and interprets all surface features of faulting and ground effects. His initial observations are concentrated on the fault trace. Here is the last opportunity — before some of the delicate surface features are partially destroyed — to determine the nature, attitude, and scale of faulting. Neither the field observations of the geologist nor the fault-plane solutions of the seismologist uniquely determine the strike and dip of the fault plane. Data from both, however, can usually define the important fault parameters.

Ground shaking is the predominant ground effect accompanying earthquakes, in terms of structural damage and its direct cause of injuries and loss of life. The shaking itself is a seismological problem. However, the geologist is best equipped to map and study the geological phenomena (such as ground cracking, compaction, settling, all manner of landsliding, mud volcanoes, mud, sand, and water geysers, and other indicators of liquefaction; shattered ridges; and other local evidence of ground acceleration) which accompany and result, in part, from ground shaking.

The strong-motion records obtained by the seismologist may be related to local and regional geology by the geologist.

The geologist is uniquely responsible for information and maps on the rock formations, stratigraphy, structural geometry of the bedrock units, and tectonic setting of the earthquake, both in the epicentral area and the regional tectonic province. He works with seismologists and other geophysicists in geological interpretation of their data. Knowledge of the fault systems — their characteristics and ages — and the deformational history and crustal strain pattern of the earthquake area is vital to understanding earthquake history and mechanism. An earthquake is not an isolated event, but fits into a pattern and history of regional tectonics and strain accumulation.

Ideally, regional and local geologic maps and data are available at the time of an earthquake, but such data are rarely complete and in the best usable form. Apart from the geologic features of the earthquake fault and the ground effects, geologists will find it necessary to restudy the geology of the earthquake area to "fill in the gaps" (see Table IV-5).

Table IV-5 is a list of data that should be collected at sites of particular interest. *It is not intended that Table IV-5 be used for every site.* Therefore it may be necessary to use the 1956 version of the Modified Mercalli Intensity Scale (see Planning Guide, page 10) at sites where detailed observations are impossible.

[1] In the event of a major earthquake, affecting a very large area, consideration should be given to detailed aerial reconnaissance and photo coverage to facilitate the geological investigations and possibly for the purpose of instituting statistical sampling techniques for data collection.

Table IV-5: Description of Local "Site" Geology[1]

Report by: ______________________ Address: ______________________
Occupation: ______________________ Home or business phone: ____________
Date of report: ____
Location of Site: ____________ Latitude ____________ Longitude ____________
Important landmarks in relation to site: ______________________
Street address: ____
City: ____________ State: ____________ Country: ____________
Township: ________ Range: ____________ Section: ____________
If under water, note depth: ______________________________(m)
Current velocity: ______________________________(m/sec)
Direction: ______________________________
Wave height: ______________________________(m)
Distance and direction to causative fault: ____________________(km)
Distance and direction to fault rupture: ____________________(km)
Distance to epicenter: ______________________________(km)
Dimensions of site: ____________(m) x ____________________(m)

Types of Engineering Structures on the Site, If Any:
Date of design: ______________ of construction ______________
Building code in force: ______________________________________
Instrument location on site or near site (type): ______________
Maximum acceleration (structure, basement or free field): __________g
Repeated high acceleration (general level): ____________________g
Duration of strong shaking (×0.05 g): ____________________secs
Sketch site, with structure(s) location, on back of sheet.
Very brief description of damage and reference complete damage report.

Earth Materials (type, age, thickness, depth below surface, density, degree of consolidation, relative density, cementation, size of clastic material, moisture content, etc.):
Artificial fill (how constructed, age, type of compactive effort, applicable building codes)
Regolith (soil type, grain size, sorting, relative density) Holocene sediments
Pleistocene sediments
Bedrock (Tertiary or older sedimentary rock)
Seismic bedrock (if refraction survey data available)
Basement complex (dense, crystalline igneous or metamorphic rock)
Describe: depth: ______(m)
Degree of weathering: ______________________________________

Water Table Information:
Depth to water table:
Perched: ____________________(m)
Confined: ____________________(m)
Unconfined: ____________________(m)
Post-earthquake variations in water table: ____________________(m)

Description of grading sites, including slopes, cut or fill, height, slope angle, orientation of slope (N, S, E, W), available geology and soils reports, code in effect at time of grading, enforcement of code? Date site graded.

Draw geologic cross-section through site, down to basement complex, if possible. At least two sections, perpendicular to each other.

Geomorphology of site. Describe relation to larger area.

[1]To be used only at sites of special interest. Appropriate checklists of primary and secondary effects should be filled out for each site described.

Duties of the Geodesist

The prime objective of the geodesist is to determine the extent of the tectonic and compactive movements which have occurred as a direct result of the earthquake, or that may be precursors of an earthquake. The task of establishing these movements requires considerable time and effort, and must be performed on a regional basis. These data then can be used by engineers and scientists to study the effects on biological organisms, drainage basins, harbor and port installations, and other major engineering structures where permanent ground movements are important.

The geodesist must continue to coordinate his efforts with engineers, geologists, and seismologists as new areas of study come to light which require more detailed surveys; for instance, the development of local strain maps (in only a very few instances have there been enough precise coordinates — vertical and horizontal control — to permit a close delineation of land surfaces before and after an earthquake). Detail and frequency of repetition of horizontal and vertical measurements have for the most part been insufficient to construct accurate "before and after" maps of the land surface in an earthquake area.

DATA COLLECTION

This subsection classifies major specific topics which need direct quantitative field observations (by geologists, engineers, seismologists, and geodesists) on the relationship between geology (source, travel path, and local geology) and damage sustained by geologic and engineering structures during moderate-to-major earthquakes.

The following checklists were established around a classification of macroseismic effects of tectonic earthquakes proposed by Richter (1958). It is hoped that the tables, supplemented by the checklists, appendices, and glossary, will be easy to understand and that their use will lead to collection of data that will be useful for many years (the importance of items on each checklist will vary depending on the earthquake studied; therefore the order in which the items appear is not critical). Larger copies of the checklists, suitable for reproduction for field use, are included at the back of this book.

Reference should be made to subsections on Soils and Lifelines in Section III, the Engineering Field Guide (pages 75 and 64).

List sources of data and the date that data were obtained. Whenever possible, use maps, careful sketches, and precise location descriptions.

The Geoscience Field Guide checklists follow. Table IV-5 should be consulted for all sites of particular interest.

Primary Features of Tectonic Earthquakes

Report by: ______ Address ______
Occupation: ______ Home or business phone: ______
Date of report: ______

Regional Earth Movements — Tectonic Origin

Post-earthquake geodetic measurements to determine
- Uplift
- Subsidence
- Regional and local tilting and ground warping (leading to the development of regional and local strain maps)

Post-earthquake gravity measurements
Post-earthquake P- and S-wave velocity measurements (from aftershocks)
Pre-earthquake P- and S-wave velocity measurements

Causative Fault Considerations

Name of fault: ______ Location: Latitude ______ Longitude ______
Type of fault: ______ *Direction of movement:* ______
Total length of causative fault: ______ (km)
Length of entire fault related to ruptured fault: ______ (km)
Total length of rupture: ______ (km)
Width of rupture zone: ______ (m)
If underwater, note depth: ______ (m) Sea conditions: ______
Current velocity: ______ (m/sec) Direction: ______
Wave height: ______ (m)
Amount of fault separation (slip?):
Horizontal: ______ (m) Oblique: ______ (m)
Vertical: ______ (m) Location of measurement: ______
Fault; strike: ______
dip: ______
Width of fault trace: ______ (latest rupture)
Expression of fault trace (continuity, straight, curved, sinuous, single or multiple), mole track, scarps, graben, parallel or en echelon fractures, sag pond, other: ______
Slickensides, gouge, fault breccia, other: ______
Relationship of fault scarp formation and height to local geology, bedrock structure and geomorphology: ______
______ Location: ______
(Draw geologic cross-section of fault to "basement rock" indicating nature of earth materials on each side of fault)
Relative offset as a function of depth: ______ Location: ______
Faulting (original displacement or renewed displacement on old fault trace)? ______
______

Any additional displacements on nearby or subsidiary faults (mainshock or major aftershock)? ______
______

Primary Features of Tectonic Earthquakes (continued)

Evidence of fault creep:
  Location: ____________ Amount: ____________ (m)
  Sense of Movement: ____________
  Foreslip or afterslip? ____________ Relation to aftershocks: ____________
Width of old fault zone through which new faulting took place: ____________ (m)
Compression or tension features: ____________
Change of offset (along fault) with increase of distance from epicenter (energy center): ____________
____________ (m)
Damage to engineering structures (type): ____________
Water table depth; one side of fault: ____________ (m) Other: ____________ (m)
Geologic structure on each side of fault (map units, bedding and/or joint attitudes, other faulting): ____________
____

Secondary Effects

Report by: ____________ Address ____________
Occupation: ____________ Home or business phone ____________
Date of report: ____________
Landslides, Lateral Spreading, and Submarine Slope Failures
  Show failures on geologic/topographic map:
    Location: Latitude: ____________ Longitude: ____________
  Estimated area involved in movement:
  ____________ m^2, quantity: ____________ m^3
  Type of movement: ____________
  Original slope angle: ____________ Ridge orientation: ____________
  Natural or man-made slope: ____________
  Pressure ridge and/or graben development:
    width: ____________
    length: ____________
    depth: ____________
  Direction of movement: ____________ Rate of movement: ____________
  Amount of movement: ____________ (m) ____________ (km)
  Precipitation conditions preceding slide: ____________
  Geology:
    Type of earth materials in slope: ____________
      Strike: ____________ Dip: ____________
    Joint system:
      Strike(s): ____________
      Dip(s): ____________

Secondary Effects (continued)

Fault(s):
  Strike(s): ____
  Dip(s): ____
  Relation of fault(s) to local geologic structure and stratigraphy?
Depth of weathering: ____
Degree of saturation (w/c): ____
Ground cracking pattern: ____
New slide or reactivated old slide: ____
Cause of failure (liquefaction or?): ____
Time of failure relative to start of ground motion: ____
Type and extent of damage to engineering structures and foundation materials due to:
  Slope failures: ____
  Active earth pressure problems: ____
  Foundation failures: ____
  Blockage of transportation routes: ____
  Other lifelines: ____
Turbidity current formation?
  Size, speed, distance traveled, geologic setting and origin: ____
  Damage to engineered structures: ____

Settlement

Cause of settlement (compaction, consolidation or liquefaction): ____

Earth materials involved: ____
  (Age, type, sorting, grain size and water content, depth to water table, thickness, artificial fill including age and type of consolidation)
Amount and extent of settlement: ____
Amount and extent of differential settlement: ____
Type and extent of damage to engineered structures (buried, surface, lifelines, artificial fill, other): ____

Presence of mud or sand boils: ____

Ground cracking

Location: ____
Length: ____ m
Width: ____ m
Depth: ____ m
Spacing: ____ m
Attitude: ____
Type of surface materials (age, thickness, etc.): ____
Artificial fill? (age, type of construction, materials, and degree of compactive effort): ____

Secondary Effects (continued)

Relationship to landslides: ______
Relationship to engineered structures: ______
  Surface structures (type): ______
  Buried structures (type): ______
Extension features: ______
Compression features: ______
Topographic effects (shattered ridge tops?): ______
  (Take note of geometry, including overall dimensions, of slope, draw geologic cross-section)
Damage to engineered structures: ______

Hydrologic Effects

Elevation change(s) in water wells: ______ m
Elevation change(s) in artesian wells: ______ m
  Change(s) in pressure: ______
Damage to pump stations (water elevation change may be due to lack of pumping?): ______
______
Salt water intrusion: ______
Changes in stream or spring flow: ______
Increased sediment transport (streams): ______
Formation of sag ponds: ______
Flooding (areas of settlement, subsidence, liquefaction): ______
Dam failure (inundated areas): ______
Check all continuously recording gauges, tide stream, etc. ______
Benchmarks and lakes (tiltmeter): ______
Temperature changes in ground and/or spring water: ______

Tsunamis

Location: ______ (place of origin)
Origin time: ______ (Local & UTC)
Arrival time and location: ______ (Local & UTC)
Distance from origin: ______ (km)
Number: ______
Frequency (period): ______ (sec.)
Wave height: ______ (m)
Run-up: ______ (m)
Geologic factors
  Configuration of coastline: ______
  Slope of continental shelf: ______
  Depth of continental shelf-break: ______
  Offshore islands, their location: ______
  Distance from causative fault: ______ (km)

Secondary Effects (continued)

Distance from epicenter: ______________________ (km)
Damage to engineered structures: ______________________
Type of structure: ______________________
Nature of damage: ______________________

Seiches

Water body affected (lake, bay, harbor, other): ______________________
Dimension: ____________ (m) x ____________ (m)
Depth: ____________ (m)
Orientation of major and minor axis of water body: ______________________
Bathymetric map available? ______________________

Wave:
Direction of seiche motion in relationship to shape of water body:
Run-up: ____________ (m) Location: ____________
Height: ____________ (m) Location: ____________
Period: ____________ (sec)
Time: start: ______________________ (local & UTC)
stop: ______________________ (local & UTC)

Distance to fault rupture: ______________________ (km)
Distance from epicenter: ______________________ (km)
Geology, geomorphology of area: ______________________
Shape of basin: ______________________
Depth and type of materials in basin, etc.: ______________________
Damage to engineered structures: ______________________
Type of structure: ______________________
Nature of damage: ______________________

Local Waves (due to nearby submarine slope failures, sliding of surface earth materials, or ice into a water body)

Type of water body (lake, bay, harbor, etc.): ______________________
Arrival time: ______________________ (Local & UTC)
Number of waves: ____________
Period: ____________ (sec)
Run-up: ____________ (m)
Height: ____________ (m)
Geologic setting (where slope failure occurred): ______________________
Geologic setting (where wave damage occurred): ______________________
Distance from slope failure: ______________________
Damage to engineered structures: ______________________
Type of structure: ______________________
Nature of damage: ______________________

Recommendations for Further Work

Report by: ______________________ Address ______________________

Occupation: ______________________ Home or business phone: ______________________

Date of report: ______________________

Location: ______________________ Why needed? ______________________

Trenching and/or boreholes:

Where, how deep, how many? ______________________ Why? ______________________

Instrument installation (type and number): ______________________

Aftershock studies:

Location: ______________________

Engineering importance: ______________________

Type of fault mechanism: ______________________

Topographic effects: ______________________

Geology and soils: ______________________

Water well monitoring (elevation and chemical composition): ______________________

Geophysical surveys (Duke, 1969; Murphy, 1972): ______________________

Refraction (surface, down hole or cross hole): ______________________

Reflection: ______________________

Gravity, magnetic and heat flow: ______________________

Geodetic surveys:

Strain maps (crustal): ______________________

Measurements of afterslip: ______________________

Local tilting: ______________________

Submarine studies:

SCUBA diving teams (engineering geologist and structural/soils engineer): ______________________

____

Need ship and/or helicopter: ______________________

Precision Depth Recorder, Side-Scan Sonar and Seismic Reflection Profiler (Dixon and Wilson, 1974): ______________________

____

Fluctuations in geomagnetic readings: ______________________

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APPENDIX IV-A: MANPOWER AND EQUIPMENT LIST

Trained Personnel

- Engineering geologists
- Geologists
- Engineering seismologists
- Seismologists
- Geodesists
- Surveyors
- Soils engineers
- Structural engineers
- Lifeline engineers

Equipment

- Maps — geologic, topographic, street, and highway
- Low- and high-altitude aerial photos — LANDSAT images
- Brunton compass (pocket transit), tape measurer, pick and shovel, flashlight, and AM-FM radio (battery-powered)
- Photographic equipment — film and flash
- Two-way radio
- Foundation plans for major structures and lifelines
- Refraction and gravity survey equipment
- Drill rig, back hoe, bulldozer
- L-7 Aftershock Instruments (6 to 10 or more)
- Small-diameter closed-circuit TV camera
- For underwater investigations:
  - Precision Depth Recorder (PDR)
  - Side-Scan Sonar (SSS)
  - Seismic Reflection Profiler (SRP)
  - Precision navigation system
  - Brunton compass and tape measurer (waterproof)
  - Photographic equipment (waterproof)
  - Closed-circuit TV equipment (waterproof)
  - SCUBA and related diving equipment
  - Underwater writing slates and/or tablets
  - "Mini sub"
  - Diving support boat
  - Oceanographic research vessel
  - Hydrographic charts

APPENDIX IV-B: GEOLOGIC MAP AND CROSS-SECTION SYMBOLS[1]

FAULT SYMBOLS

Introduction: The following fault symbols are designed to remove the ambiguity resulting from failure of traditional symbols to distinguish between fault *slip* and fault *separation.* Where a linear geologic element is displaced the *actual* relative movement (slip) can be determined (e.g., displaced intersection of dike and bed). Generally, however, where a tabular geologic element is displaced only *apparent* relative movement (separation) can be determined. Thus, for example, these symbols provide for the important distinction between normal fault (only separation known) and normal slip fault (slip known). Refer to "Dual Classification of Faults," Masson L.Hill (1959). A.A.P.G. Bull., v. 43, p. 217-21.

General Symbols

——— Fault trace, for maps and sections.

– – – – Approximately located trace, for maps and sections.

– ? – – – Conjectural trace, for maps and sections.

.... Concealed map trace; Conjectural (. . ? . .).

—▲— Dip direction; Amount (▲60), approximate amount (▲25±), conjectural direction (▲?).

Relative slip direction; Conjectural (?); Slip plunge ( ), approximate plunge (25±).

Note: Fault trace may be distinguished from other geologic contacts by weight or color of line, or by labeling with name or symbol, as desired. Slip plunge is vertical angle measured downward from horizontal to net slip.

Slip Symbols for Maps

(Add direction and amount of dip, direction of relative slip, and slip plunge, if and where known.)

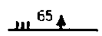
Thrust slip fault. Triangles on relatively overthrust block; Fault dips>45°.

Reverse slip fault. Rectangles on relatively elevated hanging wall block; Fault dips >45°. Dip direction is shown here.

[1] From American Geological Institute, February 1956-August 1957.

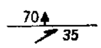
Appendix IV-B (continued)

FAULT SYMBOLS



Normal slip fault. Barbs on relatively depressed hanging wall block; Fault dip and direction of relative slip are shown here.

Right-lateral slip fault. Arrows shown sidewise relative movement of block opposite the observer.

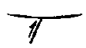


Left-lateral slip fault. Fault dip and slip plunge are shown here. If dip-slip and strike-slip components were nearly equal, the name reverse left-lateral slip fault would be appropriate.

Note: Triangles, rectangles, and barbs may be shown as appropriate and convenient along the map trace of the fault. However, none of these symbols should be used on maps unless some evidence of at least the approximate orientation of slip is obtained.

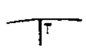
Slip Symbols for Sections

Thrust slip fault. Arrow shows principal relative movement component; Fault dips <45°.



Reverse slip fault. Fault dips >45°.

Normal slip fault.



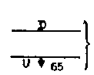
Right-lateral slip fault. Principal relative movement component of block toward observer is shown by the letter T.

Left-lateral slip fault. Letter A (away) and arrow (downward) show relative movement components. If these components are nearly equal, the name normal left-lateral slip fault is used.

Note: Single barb arrows and letters (T and A) may be shown on either side of the section trace of the fault, as appropriate and convenient. However, none of these symbols should be used on sections if only separation is determined.

Separation Symbols for Maps

(Add direction and amount of slip, if and where known.)

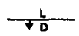


Dip separation-apparent relative movement in fault dip; D-downthrown or U-upthrown. Normal fault has dip toward downthrown block; Reverse fault has >45° dip toward up-

Appendix IV-B (continued)

thrown block (illustrated); Thrust fault has <45° dip toward overthrown block.

Strike separation—apparent relative movement in fault strike of block opposite the observer. Right-lateral fault, R; Left-lateral fault, L.

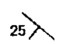


Dip and strike separations nearly equal. A normal left-lateral fault is illustrated.

Note: Letters indicating separation may be shown as appropriate and convenient on either side of the fault trace. The symbols (+) and (-) may be substituted for U and D but none represents any component or slip. Separation symbols are not needed for sections, and are only occasionally necessary for maps because the displacement of tabular geologic elements is usually obvious.

Remarks: The essential function of these proposed fault symbols is to let geologists clearly indicate where information on fault slip has been determined, and not allow them to indicate slip where only separation is known. As customary, only those symbols which are used on a particular geologic illustration need be shown in the legend.

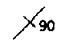
Bedding



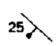
Strike and dip of beds

Horizontal beds

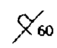
Approximate strike and dip



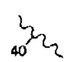
Strike of vertical beds



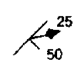
Strike and dip where upper bed can be distinguished, used only in areas of complex overturned folding



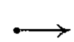
Strike and dip of overturned beds



Generalized strike and dip of crumpled, plicated, crenulated, or undulating beds



Strike and dip of beds and plunge of slickensides

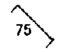


Apparent dip

Appendix IV-B (continued)

Foliation and Cleavage

Strike and dip of foliation

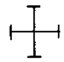


Strike and dip of cleavage

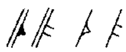
Strike of vertical foliation

Strike of vertical cleavage

Strike of horizontal foliation



Horizontal cleavage



Alternative symbols for
other planar elements

The map explanation should always specify the type of cleavage mapped.

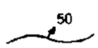
Contacts

Definite contact

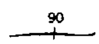
Approximate contact

Inferred contact

Concealed contact

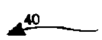


Contact, showing dip

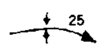


Vertical contact

Folds

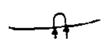


Anticline, showing trace of axial plane and bearing and plunge of axis



Syncline, showing trace of axial plane and bearing and plunge of axis

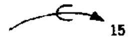
Overturned anticline, showing trace of axial plane, direction of dip of limbs, and bearing and plunge of axis



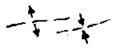
Overturned syncline, showing trace of axial plane and direction of dip of limbs

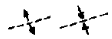
Appendix IV-B (continued)

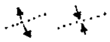
Plunge of minor anticline, showing degree of plunge

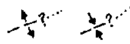


Plunge of minor syncline, showing degree of plunge


Approximate axis

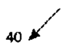

Inferred axis


Concealed axis



Doubtful axis, dotted where concealed

Lineations

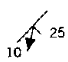


Bearing and plunge of lineation

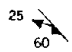

Vertical lineation


Horizontal lineation


Double lineation



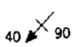
Strike and dip of beds and plunge of lineation



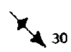
Strike and dip of foliation and plunge of lineation

Strike and dip of beds showing horizontal lineation

Strike and dip of foliation showing horizontal lineation



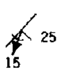
Vertical beds, showing plunge of lineation



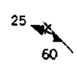
Vertical foliation, showing plunge of lineation

Vertical beds, showing horizontal lineation


Vertical foliation, showing horizontal lineation



Strike and dip of beds, showing rake of lineation



Strike and dip of foliation, showing rake of lineation

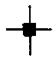
Appendix IV·B (continued)

Generalized strike of folded beds, or foliation, showing plunge of fold axes.

Joints

Strike and dip of joint

Strike of vertical joint



Horizontal joint

Strike and dips of multiple systems

Cross-Sections

overthrust

underthrust

Low angle fault

normal fault

vertical

reverse fault

High angle fault

A, *movement away*

T, *movement toward*

Horizontal movement in tear or shear fault

Klippe

Fenster or window

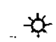
Oil & Gas Wells

Well location

Dry hole

Oil well

Oil and gas well



Gas well

Appendix IV-B (continued)

Oil well, with show of gas

Gas well, with show of oil

Dry hole, with show of oil

Dry hole, with show of gas

Dry hole, with show of oil and gas

Abandoned oil well

Abandoned gas well

Abandoned oil and gas well

Abandoned oil well,
gwith show of gas

Abandoned gas well,
with show of oil

Shut-in well

SLOPE FAILURE SYMBOLS

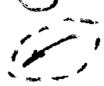
Slope failure, arrows show direction of movement.

Minor slope failure, arrow indicates direction of movement.

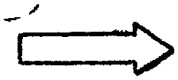
SEISMIC SEA WAVE SYMBOLS

Seiches and local waves

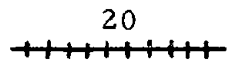
Known



Probable subaqueous slide

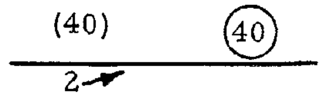


Direction of movement of initial seismic sea wave;
dashed where uncertain.



Shoreline showing damage from seismic sea waves or probable seismic sea waves. Numeral indicates maximum runup height, in feet, above post-earthquake mean lower low water.

Shoreline showing damage from locally generated waves or waves of unknown origin.



Inferred direction of wave movement (arrow), relative magnitude of damage (numeral at base of arrow, Appendix IV-D), and runup height of waves in feet above water level at time of earthquake (numeral on shore in parentheses or circled). Parentheses around runup height indicates estimated or reported amount; all others were measured.

APPENDIX IV-C: LANDSLIDE CLASSIFICATION

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK		SOILS	
FALLS		*ROCKFALL*		*SOILFALL*	
SLIDES		ROTATIONAL	PLANAR	PLANAR	ROTATIONAL
	FEW UNITS	*SLUMP*	*BLOCK GLIDE*	*BLOCK GLIDE*	
					BLOCK SLUMP
	MANY UNITS		*ROCKSLIDE*	*DEBRIS SLIDE*	*FAILURE BY LATERAL SPREADING*
FLOWS		ALL UNCONSOLIDATED			
		ROCK FRAGMENTS	SAND OR SILT	MIXED	MOSTLY PLASTIC
	DRY	*ROCK FRAGMENT FLOW*	*SAND RUN*	*LOESS FLOW*	
	WET		*RAPID EARTHFLOW*	*DEBRIS AVALANCHE*	*SLOW EARTHFLOW*
			SAND OR SILT FLOW	*DEBRIS FLOW*	*MUDFLOW*
COMPLEX		COMBINATION OF MATERIALS OR TYPE OF MOVEMENT			

Nomenclature of the parts of a landslide (see drawing at right)

(Left)
Varnes, 1958

(Right)
Eckel, 1958

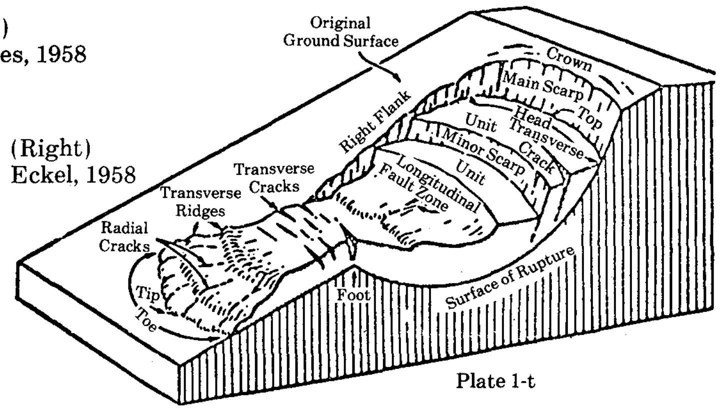


Plate 1-t

MAIN SCARP—A steep surface on the undisturbed ground around the periphery of the slide, caused by movement of slide material away from the undisturbed ground. The projection of the scarp surface under the disturbed material becomes the surface of rupture.

MINOR SCARP—A steep surface on the disturbed material produced by differential movements within the sliding mass.

HEAD—The upper parts of the slide material along the contact between the disturbed material and the main scarp.

TOP—The highest point of contact between the disturbed material and the main scarp.

FOOT—The line of intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface.

TOE—The margin of undisturbed material most distant from the main scarp.

TIP—The point on the toe most distant from the top of the slide.

FLANK—The side of the landslide.

CROWN—The material that is still in place, practically undisturbed, and adjacent to the highest parts of the main scarp.

ORIGINAL GROUND SURFACE—The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated.

LEFT AND RIGHT—Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown.

APPENDIX IV-D: SEISMIC WATER-WAVE INTENSITY SCALE[1]

1. Brush combed and scoured in direction of wave travel. Small limbs broken and minor scarring on trees. Runup heights only a few feet above extreme high-water level. Some wooden structures floated from foundations.
2. Trees and limbs less than 2 inches in diameter broken. Small trees uprooted. Driftwood and finer beach deposits thrown up above extreme high-water level. Piling swept from beneath some structures and wooden structures floated off their foundations. Runup reached about 25 feet on steep shores.
3. Trees and limbs as much as 8 inches in diameter broken; some large trees overturned. Rocks to cobble size eroded from intertidal zones and deposited above extreme high-water level. Soil stripped from bedrock areas. All inundated structures except those of reinforced concrete destroyed or floated away. Heavy machinery moved about. Maximum runup height 55 feet.
4. Trees larger than 8 inches in diameter broken, uprooted, and overturned. Boulders thrown above extreme high-water line. Loose rocks on cliffs torn loose. All structures and equipment damaged or destroyed in inundated areas. Maximum runup height 70 feet.
5. Extensive areas of total destruction of vegetation. Boulders deposit 50 feet or more above normal extreme high-water level. Maximum runup height 170 feet.

[1] From Plafker, 1969. Note: "Runup elevation" is the elevation above the tide level (at the time of the tsunami) reached by the wave (Weigel, 1970).

APPENDIX IV-E: UNIFIED SOIL CLASSIFICATION

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)				Group Symbols	Typical Names	Information Required for Describing Soils
Coarse-grained soils More than half of material is larger than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to naked eye)	Gravels More than half of coarse fraction is larger than No. 7 sieve size (for visual classification, the 1 in. size may be used as equivalent to the No. 7 sieve size)	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbols in parentheses. For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics Example: *Silty Sand,* gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)
			Predominately one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures	
			Plastic fines (for identification procedures, see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures	
	Sands More than half of coarse fraction is smaller than No. 7 sieve size	Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	SW	Well graded sands, gravelly sands, little or no fines	
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines	
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see ML below)	SM	Silty sands, poorly graded sand-silt mixtures	
			Plastic fines (for identification procedures, see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures	

Appendix IV-E (continued)

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)					Group Symbols	Typical Names	Information Required for Describing Soils
	Identification Procedures on Fraction Smaller than No. 40 Sieve Size						
		Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)			
Fine-grained soils More than half of material is smaller than No. 200 sieve size	Silts and clays liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains: color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture, and drainage conditions Example: *Clayey silt,* brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
		Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity	
	Silts and clays liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity	
Highly Organic Soils		Readily identified color, odor, spongy feel and frequently be fibrous texture			Pt	Peat and other highly organic soils	

APPENDIX IV-F: GEOLOGIC TIME SCALE

Era		Period	Epoch
	CENOZOIC	QUATERNARY (lasted 0-3 million years)	Holocene (0-11,000 ± years) Pleistocene (11,000-3 million years)
	CENOZOIC	TERTIARY (lasted 67 million years)	Pliocene Miocene Oligocene Eocene Paleocene
70 million years ago	MEZOZOIC	CRETACEOUS	
135 million years ago	MEZOZOIC	JURASSIC	
180 million years ago	MEZOZOIC	TRIASSIC	
225 million years ago	PALEOZOIC	PERMIAN	
	PALEOZOIC	PENNSYLVANIAN	
	PALEOZOIC	MISSISSIPPIAN	
	PALEOZOIC	DEVONIAN	
	PALEOZOIC	SILURIAN	
	PALEOZOIC	ORDOVICIAN	
	PALEOZOIC	CAMBRIAN	
600 million years ago Late Precambrian			
1,800 million years ago Early Precambrian			
4,500 million years ago . . . ORIGIN OF EARTH			

APPENDIX IV-G: SUMMARY OF CALIFORNIA DIVISION OF MINES AND GEOLOGY (CDMG) INTERIM EARTHQUAKE RESPONSE PLAN (REFERENCE ONLY)

1. Basic seismological information is received directly from the University of California, Berkeley (UCB) in the north and from the California Institute of Technology (CIT) in the south by the headquarters office of CDMG (Sacramento) and the nearest of three District Offices (located in Sacramento, San Francisco, and Los Angeles). CDMG will assemble sets of topographic maps.

2. Representatives of the appropriate District Office will arrange an aerial reconnaissance to locate surface faulting and other effects, particularly those involving any notable geologic hazard to people or public works.

3. CDMG headquarters and the affected District Office are to maintain close contact with the State Office of Emergency Services (OES) and liaison with EERI, the U.S. Geological Survey, CIT, UCB, the State Department of Water Resources, and the State Department of Transportation.

4. One or more field cars with two-way radios and field gear will be maintained by each District Office. Contact from each field party is to be made every 2 hours with the District Office or Clearinghouse.

5. CDMG is to serve as the information clearinghouse for post-earthquake geologic and seismologic investigations by all organizations, *and to coordinate closely with the engineering information clearinghouse activities of EERI, including prearranging for or arranging concurrently for field headquarters space and communications for EERI in CDMG field headquarters facilities.*

6. *CDMG is to arrange jointly with EERI for an information exchange (co-ordination) meeting of investigating scientists and engineers on the evening of the earthquake's occurrence, if feasible, or otherwise on the second evening. The CDMG representative will chair this meeting.*

7. CDMG is to organize internally for field investigation after an earthquake.

APPENDIX IV-H: GLOSSARY[1]

acceleration, maximum — see maximum acceleration

accelerogram — the record from an accelerograph showing acceleration as a function of time

accelerometer — an instrument for measuring acceleration

active earth pressure — the minimum value of lateral earth pressure exerted by soil on a structure, occurring when the soil is allowed to yield sufficiently to cause its internal shearing resistance along a potential failure surface to be completely mobilized

active faults — those which have shown historical activity; includes such faults as the San Andreas, San Jacinto, and Newport-Inglewood; see also potentially active faults

aftershock — an earthquake, usually a member of an aftershock series, following the occurrence of a large earthquake (mainshock); the magnitude of an aftershock is commonly smaller than the mainshock

airborne magnetometer — an instrument carried by an aircraft which is used to measure variations in the earth's magnetic field

alignment array — an initially straight row of monuments set at right angles across an active fault trace; progressive fault slip is observed by repeated observation of horizontal displacement of these monuments from their initial positions relative to each other

alluvium — a general term for the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries, during relatively recent geologic times; generally unconsolidated

amplification — the increase in earthquake ground motion that may occur to the principal components of seismic waves as they enter and pass through different earth materials

amplitude — maximum deviation from mean or center line of a wave; "height" of a seismic wave

amplitude spectrum — amplitude-versus-frequency relationship such as is computed in a Fourier analysis

angle of internal friction — angle between the abscissa and the tangent of the curve representing the relationship of shearing resistance to normal stress acting within a soil

anomaly — deviation or inconsistency of a specific land feature from uniformity with the larger area

aquifer — a formation, group of formations, or part of a formation that is water-bearing and of economic importance

aquifer, confined — see confined aquifer

aquiclude — a formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring

arc — a long, narrow triangulation or trilateration network; generally a chain of quadrilateral survey figures

artesian water — ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground

artificial fill — earth and other types of materials either nonengineered or engineered (properly placed and compacted) placed by man

[1]Definitions are from the American Geological Institute, 1972, and others. Included here are geologic, seismologic, and many soils engineering terms.

attenuation — dying out (decay); reduction of amplitude or change in wave due to energy dissipation or distance with time

Atterburg limits — see liquid limit and plastic limit

attitude (of rock structures) — a term including the terms dip and strike; the attitude of the flat surface of a sedimentary bed, whether inclined or not, is referred to the horizontal plane; dip is its slope inclination (in degrees) from this plane and is measured with a clinometer; strike is the bearing on the line of intersection of its surface with the horizontal plane; the terms may also apply to faults, veins, and dikes, or any natural plane surface

avalanche — a large mass of snow or ice and accompanying materials moving rapidly down a steep slope; soil or rock movements, as in debris avalanche

basement complex — a name commonly applied to metamorphic or igneous rocks underlying the sedimentary sequence

basement rock — see basement complex

bed — the smallest division of a stratified series; marked by a more or less well-defined plane from its neighbors above and below

bedding — a term which signifies the existence of beds (strata) or laminae in rocks which are generally of sedimentary origin

bedding plane — in sedimentary or any stratified rock, the division planes which separate the individual layers, beds, or strata

bedrock, geologic — a general term for rock that underlies soil or other unconsolidated superficial materials

bedrock, seismic — see seismic bedrock

benchmark — a permanent marker which designates a point of known elevation

blockguide — see Appendix IV-C, referring to landslides

blockslump — see Appendix IV-C, referring to landslides

body waves — waves propagated in the interior of a body, i.e., compression and shear waves; the P and S waves of seismology

bore hole — a hole drilled into the earth for exploratory purposes

clastic — in petrology, a textural term applied to rocks composed of fragmental material derived from preexisting rocks or from the dispersed consolidation products of magmas or lavas

clay — the term carries three implications: (1) particles or very fine size, less than 1/256 mm; (2) a natural material with plastic properties; (3) a composition of minerals that are essentially hydrous aluminum silicates

cohesionless soil — a soil that when unconfined and air-dried has little or no strength

cohesive soil — a soil that when unconfined and air-dried has considerable strength and that has significant cohesion when submerged

colluvium — loose cohesionless soil material, or loose rock deposited by creep, landslides, and surface wash

compaction — decrease in volume (void space) of sediments as a result of compression

complex landslides — movement by a combination of two or more of the three principal types of movement (fall, slide, or flow)

compression wave — see P wave

consolidated material — soft or hard rock which requires some medium of loosening at the excavation site before it can be handled; the more loosening required (i.e., blasting as opposed to bulldozing) the more consolidated the material

consolidation — reduction in volume and increase in density, often by removal of intergranular water contact (geologic) — a plane or irregular surface between two different types or ages of rocks

core sample — a relatively undisturbed cylindral sample of rock or sediment resulting from drilling

creep — the imperceptibly slow and more or less continuous down-slope movement of regolith

creep, fault — see fault creep

creepmeter — a displacement meter for measuring creep; it actually measures the change in distance between two monuments (generally about 10 m apart) on opposite sides of a fault trace; typically, the instrument provides a continuous chart recording of displacements

critical damping — the minimum viscous damping that will allow a displaced system to return to its initial position without oscillation

cyclic loading test — laboratory test in which the stress to which a specimen is subjected is reversed from extension to compression and vice versa over a number of stress applications

damping — (1) the dissipation of energy with time or distance; (2) resistance which slows down oscillation, expressed as a percentage of critical damping

damping, geometrical — see geometrical damping

debris, avalanche — see Appendix IV-C, referring to landslides

debris, flow — see Appendix IV-C, referring to landslides

debris, slide — see Appendix IV-C, referring to landslides

deformation of rocks — a change in the original form or volume of rock produced by faulting, folding, or other tectonic forces

depth-of-focus class — a set of earthquakes occurring within a specified depth interval; three common classes are common shallow (0 to 70 km), intermediate (70 to 300 km), and deep (300 to 700 km)

deviator stress — the difference between the major and the minor principal stresses in a triaxial test

differential settlement — nonuniform or uneven lowering of the ground surface

diffraction — (1) scattered energy which emanates from an abrupt irregularity of rock type, where faults cut reflecting interfaces; (2) interference produced by scattering at edges; (3) the phenomenon in which energy is transmitted laterally along a wave crest; when a portion of a wave train is interrupted by a barrier, diffraction allows waves to propagate into the region of the barrier's geometric shadow

digital filters — filtering data numerically in the time domain by summing weighted samples at a series of successive time increments

dilatancy — the expansion of cohesionless soils when subjected to shearing deformation; the swelling of a land surface as a precursor to an earthquake

dilatation — a parameter of strain which is equal to the change in area per unit area; it may be thought of as an omnidirectional extension or contraction; see also dilatancy

dip — see attitude

dip slip — fault displacement parallel to the dip of the fault surface

direct shear test — a shear test in which soil or rock under an applied normal load is stressed to failure by moving one section of the soil container relative to the other section

dispersion — the dependence of the propagation velocity on wave length or frequency which causes the shape of a disturbance to change continually as time goes on; in an unlimited medium there will be a continual spreading out of the disturbance into trains of waves

double amplitude — total excursion or overall height of wave (peak to peak, crest to trough) or, for a sinusoidal wave, twice the amplitude

dredge sample — a highly disturbed sample of ocean-, lake-, or river-bottom sediments

dynamic soil properties — those soil properties which affect the response of soils subjected to cyclic loading conditions

earth pressure at rest — the value of earth pressure when the soil mass is in its natural state without having been permitted to yield or without having been compressed

earthquake — group of elastic waves propagating in the earth, set up by transient disturbance of the elastic equilibrium of a portion of the earth; earth shaking

earthquake, design basis — see design basis earthquake

earthquake, maximum credible — see maximum credible earthquake

earthquake, maximum possible — see maximum possible earthquake

earthquake, operating basis — see operating basis earthquake

earthquake, safe shutdown — see safe shutdown earthquake

effective stress (intergranular pressure) — the average normal force per unit area transmitted from grain to grain of a soil mass; this stress is effective in mobilizing internal friction

elastic limit — the maximum stress that a material can withstand without undergoing permanent deformation either by solid flow or by rupture

elasticity — the property or quality of being elastic; that is, an elastic body returns to its original form or condition after a displacing force is removed

elastic strain — deformation per unit of length produced by load on a material, which vanishes with removal of the load

epicenter — the point on the earth's surface vertically above the focus of an earthquake

extensometer — (1) instrument used for measuring small deformations, deflections, or displacements; (2) instrument used for measuring changes caused by stress in a linear dimension of a body

factor of safety — available strength divided by applied load

falls — mass in motion travels most of the distance through the air; includes freefall, movement by leaps and bounds, and rolling of rock and debris fragments without much interaction of one fragment with another

fault — an earth fracture or zone of fracture along which the rocks on one side have been displaced in relation to those of the other side

fault, active — a fault along which historic movement has taken place, or one that a competent geologist considers active

fault block — a body of rock bounded by one or more faults

fault creep — very slow periodic or episodic movement along a fault trace, not always accompanied by earthquakes; fault slip or slippage

fault scarp — the cliff formed by a fault; fault scarps which have been modified by erosion since faulting are called fault-line scarps

fault set — two or more parallel faults within an area

fault slip — the true relative displacement of formerly adjacent points in the fault plane

fault system — two or more fault sets formed at the same time

fault surface — the surface along which dislocation has taken place

fault trace — the intersection of a fault and the earth's surface as revealed by dislocation of fences, roads, or by ridges and furrows in the ground

fault zone — instead of being a single clean fracture, a fault may be a zone hundreds or thousands of feet wide; the fault zone consists of numerous interlacing small faults or a confused zone of gouge, breccia, or other material

fault, inactive — see inactive faults

fault, normal — see normal fault

fault, reverse — see reverse fault and thrust fault

fault, right-lateral — see right-lateral fault

fault, thrust — see thrust fault

faulting — the movement which produces relative displacement of adjacent rock masses along a fracture

fines — portions of soil finer than no. 200 (74 microns) U.S. standard sieve

finite element analysis — an analysis which uses an assembly of elements which are connected at a discrete number of nodal points to represent a structure and/or a soil continuum

fissure — crack, break, or fracture in the rocks

flows — movement within displaced mass such that the form taken by moving material or the apparent distribution of velocities and displacements resembles those of viscous fluids; slip surfaces within moving material are usually not visible or are short-lived

focal depth — depth of an earthquake focus (hypocenter) below the ground surface

focus — the point within the earth which marks the origin of the elastic waves of an earthquake; synonymous with hypocenter

fold — a bend in rock strata

force — resultant of distribution of stress over a prescribed area; an action that develops in a member as a result of loadings given in kips or tons

formation — a rock body or an assemblage of rocks which have some character in common; applied to a particular sequence of rocks formed during one epoch; a rock unit used in mapping

Fourier transforms — the formulae which convert a time function (seismic record) into the frequency domain

fracture — break in rocks due to faulting, folding, or other geologic processes

free field — the number of seismic wave peaks which pass through a point in the ground in a unit of time; usually measured in cycles per second

frequency, natural — see natural frequency

gaging station — section in a stream channel equipped with a gage and facilities for measuring the flow of water

geodetic — refers to investigation of any scientific questions relating to the shape and dimensions of the earth

geodetic measurements — controls on location (vertical and horizontal) of positions on the earth's surface of a high order of accuracy, usually extended over large areas for surveying and mapping operations

Geodimeter — the tradename for one of the most common electro-optical distance-measuring instruments; often used generically to denote all such instruments; it is capable of measuring distance with an error less than 1 ppm (this amounts to 1 mm in 1 km)

geologic hazards — geologic features or processes that are dangerous or objectionable to man and his works; they may be natural phenomena or man-induced phenomena

geologic map — map showing distribution of formations, folds, faults, and mineral deposits by appropriate symbols

geologic section — a graphic representation of geologic conditions along a given line or plane of the earth's crust

geology — the science which treats of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing
geometrical damping — that component of damping which occurs due to the radial spreading of energy waves with distance from a given source
geomorphology — the branch of geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of land forms
geophone — sensing device used to measure electronically the rate of travel of sound or shear waves transmitted through the earth from a known source
geophysical exploration — a variety of indirect methods for determining structure and composition of underground geological formations
geophysical surveys — the use of one or more physical techniques to explore earth properties and processes
geostatic — capable of sustaining the pressure of the weight of overlying earth materials
geothermal — of or pertaining to the heat of the interior of the earth
gouge — finely ground rock material occurring between the walls of a fault, the result of grinding movements
grab sample — a random unoriented sample which gives indication of the composition only
graben — down-thrown block of earth material, or a trench produced by faulting or landsliding
grain size — a term relating to the size of mineral or soil particles that make up a rock or a soil
gravel — natural accumulation of small rounded stones and pebbles over 2 mm in diameter, or a mixture of sand and small stones
ground cracking — cracks usually occurring in stiff surface materials resulting from differential ground movement or desiccation
ground failure — a situation in which the ground does not hold together, such as in landsliding, mud flows, and liquefaction
ground response or motion — a general term which includes all aspects of motion (acceleration, particle velocity, displacement, stress, and strain) usually resulting from a nuclear blast or an earthquake
ground strength — the limiting stress that ground can withstand without failing by rupture or continuous flow
ground water — water beneath the surface of the ground in a saturated zone
grout — a pumpable slurry of cement or a mixture of cement and fine sand commonly forced into a borehole to seal crevices in a rock
hard rock — rock which requires drilling and blasting for its economical removal
harmonic — a frequency which is a simple multiple of a fundamental frequency; the third harmonic, for example, has a frequency three times that of the fundamental
Holocene — the time period from the close of the Pleistocene or glacial epoch through the present; synonymous with Recent; about the last 11,000 years
hummocky — lumpy land, in small uneven knolls; this condition may be a sign of previous extensive landsliding
hydrograph — a graph showing the level, flow, or velocity of water in a river at all seasons of the year
hypocenter — see focus
hydroseism — seismically induced water-level fluctuations, other than tsunamis or seiches
hydrostatic pressure — the pressure in a liquid under static conditions; the

product of the unit weight of liquid and the difference in elevation between the given point and the ground-water elevation

inactive faults — identifiable faults which do not meet any of the criteria listed under active faults

inelastic deformation — permanent deformation of materials either by flow, creep, or rupture

intensity — a nonlinear measure of earthquake size at a particular place as determined by its effect on persons, structures, and earth materials; the principal scale used in the United States today is the Modified Mercalli, 1956 version; intensity is a measure of effects, as contrasted with magnitude which is a measure of energy

interface — the common surface separating two different media in contact

intermediate principal stress — the principal stress whose values are neither the largest nor the smallest of the three principal stresses

interstitial water — water contained within the minute pores or spaces between the small grains or other units of rock

isoseismal line — an imaginary line connecting all those points on the surface of the earth where an earthquake shock is of the same intensity

joint — a surface or fracture that divides a rock and along which there has been no visible movement parallel to the surface

landfill — a place where solid waste or earth is dumped, usually in the disposal of garbage or to create new land for development; see sanitary landfill

landslide — general term that denotes downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations thereof

lateral spreading — nearly horizontal land failure; a horizontal landslide

left-lateral fault movement — generally horizontal movement in which the block across the fault from an observer has moved to the left

linear viscoelastic medium — a medium for which the relationship between stress and strain can be expressed as a linear one between stress, strain, and their nth-order temporal derivatives

liquefaction — transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure

liquid limit — moisture content at which the soil passes from a plastic to a liquid state

lithology — the description of rock composition and texture from observation of hand specimens or outcrops

local "site" geology — the soil, rocks, and structures that comprise the vertical geologic section at a particular site; local geology

local wave — water wave produced by areal or submarine slope failures that occur during earthquakes

loess — a wind-blown silt or silty clay having little or no stratification

loess flow — see Appendix IV-C, referring to landslides

Love wave — a surface seismic wave associated with layering in which the vibration is transverse to the direction of propagation, with no vertical motion

magnitude — the rating of a given earthquake is defined as the logarithm of the maximum amplitude on a seismogram written by an instrument of specified standard type at a distance of 100 km from the epicenter; it is a measure of the energy released in an earthquake; the zero of the scale is fixed arbitrarily to fit small earthquakes; the scale is open-ended but the largest known earthquake magnitudes are near 8.75; every upward step of one magnitude unit means a 32-fold increase in energy release; thus, a magnitude 7 earthquake releases 32 times as much energy as does a magnitude 6 earthquake; magnitude differs from intensity

mainshock — the largest-magnitude earthquake in a series

major principal stress (see principal stress) — the largest (with regard to sign) principal stress

mantle — the layer of the earth between the crust and the core

mass-wasting — a variety of processes by which masses of earth materials are moved by gravity either slowly or quickly from one place to another

maximum acceleration — maximum excursion measured on an accelerogram

maximum credible earthquake — the most potentially damaging (strongest) earthquake that could ever occur on a given fault; the magnitude of such an event is usually obtained by using a deterministic approach, employing the principle that the length of the fault rupture is proportional to the magnitude of the earthquake caused by the rupture

maximum probable earthquake — the largest earthquake that, on a statistical basis, will occur during a given period of time (commonly 100 years)

meizoseismal — said of or pertaining to the maximum destructive force of an earthquake, i.e., meizoseismal area is the area of strong shaking

meteoric water — water in or derived from the atmosphere

micro-earthquake — a very small earthquake having a magnitude of 2.0 or less on the Richter scale

microseismic event — an earthquake or man-induced vibrations observable only with instruments

microtremor — a feeble earth tremor resulting from natural or man-made forces

minor principal stress (see principal stress) — the smallest (with regard to sign) principal stress

model — a concept from which one can deduce effects that can then be compared to observation, which assists in developing an understanding of the significance of the observations

Modified Mercalli — see intensity

mudflow — see Appendix IV-C, referring to landslides

multiple — seismic energy which has been reflected more than once

mutiplet — several earthquakes occurring close together in space-time, with comparable magnitudes

natural frequency — a constant frequency of a vibrating system in the state of natural oscillation

natural oscillation — an oscillation of a vibrating system which may occur in the absence of an external force

normal consolidation — soil element that is at equilibrium under the maximum stress it has ever experienced

normal fault — vertical movement along a sloping fault surface in which the block above the fault has moved downward relative to the block below; a tensional fault

normal stress — that stress component normal to a given plane

noise — (1) any undesired signal; a disturbance which does not represent any part of a message from a specified source; (2) energy which is random; (3) disturbances in observed data due to inhomogeneities in surface and near-surface material

oceanography — embraces all studies relating to the sea

operating basis earthquake (OBE) — for a reactor site, that earthquake which produces the vibrating ground motion for which those structures and systems of the nuclear powerplant necessary for continued operation without undue risk to the health and safety of the public are designed to remain operable; the maximum vibration ground acceleration of the OBE is equal to at least one-half that of the safe shutdown earthquake

outcrop — that part of a geologic formation (rock) or structure that appears at the surface of the earth

overburden — deposits that overlie bedrock, or rock materials that overlie useful rock or ore

overconsolidated — soil at equilibrium under a stress less than that to which it was once consolidated

overconsolidation ratio (OCR) — the ratio of the maximum past pressure or stress to which a soil has been subjected to the computed value of vertical effective pressure or stress existing in the field at present

particle acceleration — the time rate of change of particle velocity

passive earth pressure — the maximum value of lateral earth pressure

penetrometer — a soil-sampling device which is pushed or driven with a hammer into the undisturbed soil at the bottom of a boring

perched ground water — unconfined ground water separated from an underlying main body of ground water by an unsaturated zone

perched water table — the water table of a body of perched ground water

period — that time (t) for one cycle; the time for a wave crest to traverse a distance equal to one wave length, or the time for two successive wave crests to pass a fixed point

period, natural — see natural period

period, predominant — see predominant period

permafrost — permanently frozen ground

permeability — the capacity in a rock or unconsolidated material for transmitting a fluid

photogrammetry — the art and science of obtaining reliable measurements from photographs

physiography — a description of existing nature as displayed in the surface arrangement of the globe, its features, atmospheric and oceanic currents, climate, and other physical features

piezometric — refers to the surface to which the water from a given aquifer will rise under its full head

plastic deformation — under some conditions solids may bend instead of shearing or breaking as a result of seismic and geologic forces

plastic flow — a continuous and permanent change of shape in any direction without breakage

plastic limit — moisture content at which the soil passes from a solid to a plastic state

plasticity index — the numerical difference between the liquid limit and the plastic limit; these limits are determined in the laboratory by standard tests and serve as a basis for estimating the relative plasticity of a given soil sample

Poisson's ratio — the ratio of the lateral linear strain to the longitudinal linear strain with the elastic behavior of a material subjected to axial load

pore water pressure — pressure or stress transmitted through the pore water (water filling the voids of the soil)

porosity — the proportion, usually stated as a percentage, of the total volume of a rock material or regolith that consists of pore space or voids

porous — containing pores, voids, or other openings which may or may not be interconnected

potentially active faults — those (based on available data) along which no known historical ground-surface ruptures or earthquakes have occurred;

these faults, however, show strong indications of geologically recent activity; potentially active faults can be placed in two subgroups that are based on the boldness or sharpness of their topographic features and the estimates related to recency of activity:

1. Subgroup One — High Potential
   a. Offsets affecting the Holocene deposits (age less than 10,000-11,000 years)
   b. A ground-water barrier or anomaly occurring along the fault within the Holocene deposits
   c. Earthquake epicenters (generally from small earthquakes occurring close to the fault)
   d. Strong geomorphic expression of fault origin features (e.g., faceted spurs, offset ridges, or stream valleys or similar features, especially where Holocene topography appears to have been modified)
2. Subgroup Two — Low Potential
   This subgroup is the same as 1 a, b, or d above, with the exception that the indications of fault movement can only be determined in Pleistocene deposits (less than 2 million to 3 million years old)

precision depth recorder (PDR) — an echo (depth) sounder having an accuracy better than 1 in 3000

predominant period — a number representing the time between seismic wave peaks to which a building on the ground is most vulnerable, usually measured in seconds

pressure, hydrostatic — see hydrostatic pressure

pressure ridge — raised structure at top of slope failure, or the ridge formed in a compressional or thrust fault

principal stress — stresses acting normal to three mutually perpendicular planes intersecting at a point in a body, on each of which the shearing stresses are zero

pulse — a waveform whose duration is short compared to the time scale of interest and whose initial and final values are the same (usually zero); a seismic disturbance which travels like a wave but does not have the cyclic characteristics of a wave train

P wave — compressional wave = longitudinal wave; body wave in which the direction of the particle motion is the same as the direction of wave propagation; wave velocity is commonly measured in geophysical refraction surveys to define the contact between and dynamic properties of competent layers (high-velocity materials) and softer or less competent layers (low-velocity materials), such as bedrock and soil overburden; see body waves

random noise — energy which exhibits only a small degree of phase coherence or continuity between successive receiving channels; by adding together in elements, random noise can be attenuated by a factor (square root n)

rapid earth flow — see Appendix IV-C, referring to landslides

Rayleigh wave — a type of seismic wave propagating along the surface, one type of ground roll; particle motion is elliptical and retrograde in the vertical plane containing the direction of propagation and its amplitude decreases exponentially with depth

reflection — the return of a wave incident upon a surface to its original medium

refraction — the deflection of a wave due to its passage from one medium to another of different density

regional geology — the geology of a relatively large area

regolith — the layer of mantle of loose, incoherent rock material, of whatever origin, that nearly everywhere forms the surface of the land and rests on the bedrock
relative density — the ratio of (1) the difference between the void ratio of a cohesionless soil and the loosest state and any given void ratio to (2) the difference between its void ratios in the loosest and the densist states
remote sensing — the acquisition of information or measurement of some property of an object by a recording device that is not in physical or intimate contact with the object under study; the technique employs such devices as the camera, lasers, infrared and ultraviolet detectors, microwave and radio frequency receivers, radar systems, and others
residual soil — a soil deposit formed by the decay of rock in place
resonance — induced oscillations of maximum amplitude produced in a physical system when an applied oscillatory stress and the natural oscillatory frequency of the system are the same
response spectrum — a plot of the maximum response of a family of idealized, linear, single-degree-of-freedom, damped, spring mass systems, subjected to a prescibed forcing function, plotted as a function of the undamped natural frequency of the spring mass system
reverse or thrust fault — vertical to nearly horizontal movement along a sloping fault surface in which the block above has moved upward or over the block below the fault
right-lateral fault movement — generally horizontal movement in which the block across the fault from an observer has moved to the right
rock fragment flow — see Appendix IV-C, referring to landslides
rockslide — see Appendix IV-C, referring to landslides
safe shutdown earthquake — for a reactor site, that earthquake which produces the vibratory ground motion for which structures and systems of the nuclear powerplant necessary to shut down the reactor and maintain the plant in a safe condition without undue risk to the health and safety of the public are designed to remain functional
sag ponds — ponds occupying depressions in the land surface along faults; the depressions are due to uneven settling of the ground or other causes
sand — particles of sediment having a size range of 1/16 mm to 2.0 mm
sand boils — turbid upward flow of water and some sand to the ground surface resulting from increased ground-water pressures when saturated cohesionless materials are compacted by earthquake ground vibrations; characteristic of liquefaction
sandrun — see Appendix IV-C, referring to landslides
sand or silt flow — see Appendix IV-C, referring to landslides
sanitary landfill — a disposal area for solid wastes where the wastes are compacted and covered daily by a layer of impermeable material such as clay
saturated soil — soil with zero air voids; a soil which has its interstices or void spaces filled with water to the point where runoff occurs
scarp — a cliff, escarpment, or steep slope of some extent formed by a fault or a cliff or steep slope along the margin of a plateau, mesa, or terrace
scarp, fault — see fault scarp
scattering — the irregular and diffuse dispersion of seismic energy caused by inhomogeneities in the medium through which the energy is traveling
sediment — solid material, both mineral and organic, that, in suspension, is being transported, or has been moved from its place of origin
sedimentary rocks — rocks formed by the accumulation of sediment in water

(aqueous deposits) or from air (eolian deposits); a characteristic feature of sedimentary deposits is a layered structure known as stratification or bedding

seiche — a free- or standing-wave oscillation of the surface of water in an enclosed or semi-enclosed basin (lake, bay, or harbor)

seismic — pertaining to shock waves within the earth produced by earthquakes, or in some cases artificially produced shock waves

seismic bedrock — naturally occurring earth materials, found either at or below the ground surface, that have a shear wave velocity of 2500 feet per second or over; used in mathematical models for ground-motion studies

seismicity — a measure of the probability of an earthquake occurrence in an area

seismic reflection profiler (SRP) — instrument similar to echo sounder which uses low-frequency (instead of high-frequency) sound in pulses for less attenuation traveling through sediment layers

seismic sea wave — see tsunami

seismic velocity — the rate of propagation of seismic waves in earth materials (usually measured in feet per second)

seismograph — an instrument for recording earthquake or seismic waves; the record made by a seismograph is called a seismogram

seismology — the science of earthquakes and the study of seismic waves

seismometer — a device which detects vibrations of the earth, and whose physical constants are known sufficiently for calibration to permit calculation of actual ground motion from the seismographic record

separation — apparent rather than relative displacement in a fault

settlement — the subsidence of artificial material due to compaction, consolidation, or liquefaction

settlement, differential — see differential settlement

shadow zone — little or no direct penetration of seismic waves

shattered ridge tops — area of heavy ground cracking at the crest of a topographic high

shear — a mode of failure whereby two adjacent parts of a solid slide past one another parallel to the plane of contact; to subject a body to shear, similar to the displacement of the cards in a pack relative to one another

shear strength — the stress or load at which a material fails in shear

shear wave — a body wave in which the particle motion is perpendicular to the direction of propagation

side-scan sonar (SSS) — makes a continuous graphic record of the sea floor (similar to a shaded relief map)

silt — a fine-grained sediment having a particle size intermediate between that of fine sand and clay, between 1/16 mm and 1/256 mm in diameter

slickensides — a polished and smoothly striated surface that results from friction along a fault plane

slip, dip — see dip slip

slip, fault — see fault slip

slow earth flow — see Appendix IV-C, referring to landslides

slump — see Appendix IV-C, referring to landslides

soil — see regolith

soil, cohesionless — see cohesionless soil

soil, cohesive — see cohesive soil

soil dynamics — the study of the engineering properties of soils as they are affected by transient impulsive loading

soil, residual — see residual soil

spectrum — the amplitude and phase angle characteristics as a function of frequency for the components of a seismic wavetrain or wavelet, filter response characteristic

spectrum, amplitude — see amplitude spectrum

strain — deformation resulting from applied force; within elastic limits strain is proportional to stress

strain-dependent property — that property of soil, the magnitude of which depends on the magnitude of the induced strain

strain, elastic — see elastic strain

strain meter — an instrument for measuring deformation due to stress or force; in geophysical applications, the quartz-rod extensometer is most commonly used; this instrument typically operates over a base 10 to 30 m long and has a sensitivity of 0.001 ppm or better; it actually measures change in distance between two monuments, the quartz rod serving as a constant-length reference

strata — sedimentary rock layers

strata, unconsolidated — see unconsolidated strata

standing wave — a wave produced by simultaneous transmission in opposite directions of two similar waves resulting in fixed points of zero amplitudes called nodes

strength, ground — see ground strength

strike — see attitude

strike-slip — fault displacement parallel to the strike of the fault

stress — force per unit area

stress, effective — see effective stress

stress, principal — see principal stress

strong motion — ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes, or total-time single-component acceleration (+ or -) was above 0.05 g.

structural — pertaining to, part of, or consequent upon the geologic structure, as, a structural valley

structural feature — features produced in the rock by movement after deposition, and commonly after consolidation, of the rock

submergence — a term which implies that part of the land has become inundated by the sea

subsidence — sinking or lowering of a part of the earth's crust

subsidiary faulting — generally minor faulting associated with major fault breaks

surface waves — energy which travels along or near the surface, ground roll; includes Rayleigh, Love, hydrodynamic, Stoneley, and other waves

swarm — an earthquake series in which no one event is sufficiently larger than the others to be classified as the mainshock

S wave (shear wave, transverse wave) — eddy wave in which the particle motion is at right angles to the direction of wave propagation

talus — the heap of coarse rock waste at the foot of a cliff or a sheet of waste covering a slope below a cliff

tectonic — pertaining to or designating the rock structure and external forms resulting from the deformation of the earth's crust; pressures causing such deformations often result in earthquakes

texture — the physical appearance of a rock, as shown by size, shape, and arrangement of the mineral particles in the rock

thrust fault — see reverse fault

tiltmeter — an instrument for measuring change in the attitude or slope of the local ground surface

time-dependent response analysis — structural dynamic analysis where the displacement and force response history of a structure is determined from an earthquake time acceleration history record; the maximum forces and displacements of the structure are determined through superposition of the significant modal responses of the structure or numerical techniques

topographic effect — the amplification or deamplification of seismic waves due to the presence of a topographic high (knoll, hill, mountain, etc.)

topography — the physical features of the land, especially its relief and contour

trace, fault — see fault trace

translational movement — see lateral spreading

travel path — the course along which seismic waves propagate from the source outward

tsunami — a sea wave produced by large areal displacements of the ocean bottom, often the result of earthquakes or volcanic activity; also known as a seismic sea wave

turbidity current — a relatively rapid, downslope, underwater density current which may be generated by a seismic disturbance which causes a slumping of sediment on the slope and starts a flow of sediment and water

unconsolidated strata — rocks consisting of loosely coherent or uncemented particles, whether occurring at the surface or at depth

undrained shear strength — the shear strength of a soil in which the pore water is not allowed to escape from the specimen during testing

undisturbed sample — a soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to it

urban geology — the application of geology to problems in the urban environment

vane shear test — an in-place shear test in which a rod with thin radial vanes at the end is forced into the soil and the resistance to rotation of the rod is determined

velocity — a vector quantity which indicates time rate of motion; often refers to the propagation rate of a seismic wave without implying any direction; when used in this sense the term is not a vector

viscoelastic medium — a stress-strain relationship in which the stress is a function of both strain and strain-rate, though not necessarily proportional to both

viscosity — the cohesive force existing between particles of a fluid which cause the fluid to offer resistance to a relative sliding motion between particles; internal fluid friction

void ratio — the volume of the voids divided by the volume of the solids

water table — the upper limit or surface of the zone of saturation of ground water

water table, perched — see perched water table

waveform — a plot of seismic displacement as a function of time

wave guide — a region, usually a layer, in the solid earth that tends to channel seismic energy

wave height — the difference in elevation between adjoining wave crests and troughs

wave length — the distance between successive similar points on two wave cycles

weathering — response of materials that were once in equilibrium within the earth's crust to new conditions at or near contact with water, air, and

living matter; with time the materials change in character and decay to form soil
wedge effect — unusual ground motion that occurs at the edge of alluvial valleys
white noise — random energy containing all frequency components in equal proportions
yield stress — a stress at which the stress-to-strain relationship becomes non-proportional

APPENDIX IV-I: METHODOLOGY FOR SUBMARINE OBSERVATION OF FAULTS AND RELATED EARTHQUAKE PHENOMENA

PRE-EARTHQUAKE PREPAREDNESS

All of the duties or activities of the earthquake investigation team that should be performed before an earthquake for land sites should also be performed, as appropriate, for submarine areas. Geologic, topographic and hydrographic maps and charts of key areas should be collected, and a list of personnel trained and/or experienced in earthquake investigation and marine investigation should be available and periodically updated. Strong-motion seismographs should be installed wherever possible in seismically active offshore areas. Plans of these instrumented offshore structures as well as non-instrumented offshore structures in such active areas (such as oil well platforms in the Santa Barbara Channel) should be available. There should be a continuing effort to improve bathymetric mapping and geodetic control of the sea floor, just as on land.

A great deal of specialized equipment is required for investigating submarine earthquakes. The type of equipment necessary varies somewhat depending on where the earthquake occurs. Depth of the fault trace below the sea surface is important, but many other factors such as sea conditions, water temperatures, abundance of hazardous marine animals, water clarity, and nature of the sea floor, may influence the type of equipment necessary.

It is not appropriate here to list all possible types of equipment that may be necessary to investigate submarine earthquakes and faulting at any location in the world. The following is a general description of basic equipment needs. This basic equipment would be supplemented or modified, depending on the local environment of the earthquake to be investigated.

Submarine observations can be made by Self-Contained Underwater Breathing Apparatus (SCUBA) divers to a reasonable maximum working depth of about 40 m. Although SCUBA divers can work deeper, the time on the bottom (unless saturation techniques are employed) is so greatly limited that it generally would not be feasible. In addition, with greater depth, the hazard to the diver rapidly increases. As most of the earthquake investigators will be professional scientists and engineers rather than professional divers, they generally will not be experienced or qualified at greater depths.

In addition to basic SCUBA gear, the investigators should be equipped with underwater writing slates, a digging tool (a large diving knife or "abalone iron" will usually be sufficient), plastic protractor and scale, Brunton compass enclosed in waterproof case, and underwater cameras and associated equipment. A small boat ranging from 5 m to 20 m in length will usually be necessary for diver support. An accurate depth recorder and other electronic equipment discussed below would be valuable aids on the boat, but are not absolutely necessary. Generally, local fishing boats will be available and serve well for diver support. If no such boats are available, inflatable outboard boats could be readily delivered by airplane to any area.

One major difficulty with underwater investigation is accurate location. The simplest and most accurate method for divers locating themselves within relatively limited areas is by first accurately locating a well-anchored float (or boat) on the surface by land sitings and triangulation, or by some type of precision navigation system. From the anchored float, a line marked in meter intervals can be extended to the area of investigation. Precise location is then obtained by noting distance and direction from the anchored float.

When searching an area for earthquake-related phenomena, where visibility is limited, the same arrangement described above can be used. The diver simply holds onto the line and swims in larger and larger circles.

Although it is possible to make notes underwater, it is difficult, and extensive use should be made of underwater cameras to record the observations. In addition, immediately after each dive, the dive-team members should get together and write (or record) a complete set of notes of their observations.

Divers should always employ a buddy-team approach: that is, two divers in the water at the same time. While this team approach is commonly used for safety reasons, it is most important for observational accuracy. Generally a backup team of two more divers should be available at the surface. Thus, the minimum manpower for such SCUBA investigations should be four or more divers. It would be very helpful if one of the divers is from the local area and is experienced in diving in the area of investigation.

For faults and features below a depth of 40 m, direct observations can be made from "mini-submarines." Such vessels can generally work easily down to a depth of 300 m and some can work deeper. The main problem would be transporting the "mini-sub" to the area of investigation within a reasonable amount of time. Direct observations of faulting to great depths could be made by a few specially built vessels. There is a real question, however, if the time, hazard, and expense involved could be justified for direct observations in depths greater than 300 m. After the Niigata, Japan, earthquake, a submarine was used by Japanese seismologists in an attempt to observe visually the fault scarp adjacent to Awashima Island (Bolt, 1967).

Continuous seismic profiling and Side-Scanning Sonar systems should be used for all preliminary search work in water depths of 10 m or greater, for most work deeper than 40 m, and for all work deeper than 300 m. Such equipment is readily available and provides excellent data on bottom, topographic, and subbottom conditions. A recent paper by Dixon and Wilson (1974) provides a summary of the engineering geology use of such equipment.

In terms of the size of the area to be covered, geophysical tools are the most economical. A balanced and useful geophysical package for investigating submarine faulting and secondary earthquake effects consists of a continuous Seismic Reflection Profiler (SRP), a Side-Scan Sonar (SSS) system, and a Precision Depth Recorder (PDR). The SRP provides a continuous subbottom profile of the geologic conditions along the vessel's route. The SSS gives a continuous graphic record (approaching a shaded relief map) of the sea floor on either side of the survey vessel's track. PDR provides an immediately readable precise bottom profile along the vessel's path. Precision navigation equipment is also a must. For areas within 80 km of shore, compact mobile units accurate to within 3 m are available. These microwave positioning units usually require two shore-based responder stations and an onboard omnidirectional antenna and interrogator.

SRP systems vary greatly in depth of penetration and degree of resolution. Systems commonly used for petroleum exploration can penetrate thousands of feet of sediment and rock, but lack precision and resolution near the surface. For earthquake investigation, only very minimal (30 m to 300 m) subbottom penetration will usually be necessary. However, it may be useful at times to have the capability of deeper subbottom penetration to better understand the nature of the fault plane and bedrock structure on either side of the fault at depth. Many SRP systems have the capability of readily changing the depth of penetration by changing the energy source. The energy source is commonly an air gun or pulsating electrical discharge. The larger the energy input, the deeper the penetration. New techniques which employ several energy sources simultaneously generally can obtain good resolution in the top 5 m to 15 m and penetration to a few hundred meters.

As part of pre-earthquake preparation, a list of persons capable of investigating submarine earthquake phenomena should be prepared. Persons selected from this group should be added to the EERI investigation team whenever appropriate. In addition, governmental agencies, universities, and private organizations that have appropriate geophysical equipment and/or vessels should be enlisted to aid in submarine earthquake investigations.

POST-EARTHQUAKE METHODOLOGY

Whenever a submarine earthquake occurs, it should be determined immediately at what depth surface faulting and secondary effects may have occurred. If within the range of SCUBA, the EERI investigation team should contain SCUBA divers. It is extremely important that where faulting or secondary effects may have occurred at depths less than 30 m, the investigation should be performed as quickly as possible. At these shallow depths, currents and sediment transport could quickly remove any signs of earthquake activity.

If it is likely faulting or secondary effects occurred at depths greater than 10 m, a vessel with appropriate geophysical equipment (SRP, SSS) should survey the entire area. Possible survey patterns would vary based on what was known of the geology of the area and any fault plane solutions which may have been made. In general, the ship's search pattern should be perpendicular to the strike of geologic structures and to any suspected fault trace.

Data gathered by the above means can be placed on appropriate forms for regional or site investigations and primary and secondary effects noted. These forms appear in the Geoscience Field Guide. As there is a lack of post-earthquake submarine observations, the precise nature of what will be observed is not known. It seems probable, however, that many geological phenomena associated with earthquakes occurring under water are not greatly different than on land. Where bedrock is exposed, "ground surface" faulting, landslides, rockfall, and shattered ridges will probably occur, just as on land. Numerous very large submarine landslides are known and it is likely that many were triggered by earthquakes (Normark, 1974).

In areas where moderate to thick accumulations of sediment overlie bedrock, conditions will be different. The primary controlling factors will probably be the generally poorly consolidated and totally saturated nature of sediment. Ground surface faulting may or may not occur in such areas, just as it sometimes does not occur in areas on land covered with thick accumulations of sediment (alluvium). If ground surface faulting does occur, it will be very ephemeral. The only indication of surface or near-surface faulting may be a gradual elevation difference over tens of meters as poorly consolidated, saturated sediment probably will not hold a fault scarp and will flow to an angle of repose. Slumps may occur in the sediment wherever inclines exist, but may not be widespread (California Division of Mines and Geology, 1973). Turbidity or density currents may be generated. Any surface expression of submarine liquefaction will be of interest. Mud or sand "volcanos" or craters will probably occur. Submarine craters were observed after the Pt. Mugu, California, earthquake in 1973, but were thought not to be related to liquefaction (California Division of Mines and Geology, 1973). Small craters were also observed off of Malibu Beach after the 1971 San Fernando earthquake. These were related to gas release from an unknown source (Clifton et al., 1971). The succession of submarine cable breaks after the Grand Banks earthquake of 1929 led many scientists into the early 1950's to speculate that they were caused by turbidity currents. Later work, however, indicates that the cable breaks were most likely produced by temporary spontaneous liquefaction of the sediments, causing the cables to sink deeply into the temporarily liquified slope and break as a result of distribution and stretching (Shepard, 1963).

V. SOCIAL SCIENCE FIELD GUIDE

INTRODUCTION

PURPOSE

A major problem with much of the past social science research on disasters is that it has proved to be largely "noncumulative" in the sense of succeeding studies building on a foundation of previous findings. In part this can be attributed to the fact that a common set of questions has not been asked about disasters in general or even about different disasters of the same type (i.e., hurricanes, tornadoes, or earthquakes). Although several disaster studies have been individually excellent, the field is moving forward neither as quickly nor as easily as might be the case if disaster research had at least a minimally accepted framework or a common set of questions. This Field Guide is an attempt to make a modest beginning toward remedying this situation. Its purpose is to provide social scientists engaged in or about to engage in earthquake research with at least a minimal set of topics of foci that appear to merit attention in a disaster situation. Although such topics or foci are designed specifically with large, damaging earthquakes in mind, they are easily relevant to other types of disaster situations as well.

A word of caution must be added about what this Field Guide *is* and *is not.* It *is* a set of suggestions on topics or questions about which disaster researchers need to know more if they hope to contribute eventually to a reduction of the losses that result from damaging earthquakes. It is *not* a "finished" document in the sense of being a data-gathering instrument for immediate field use. Those who consider using this Field Guide will have to develop (preferably before entering the field) their own specific instruments to rigorously research the topics and questions suggested here, as the following discussion is designed to remain at a general level.

Finally, it should be emphasized that this Field Guide is designed to aid data-gathering efforts in the period immediately following an earthquake (the so-called "emergency phase") rather than in the longer term restoration and reconstruction periods, although some suggestions are made in that direction as well.

USERS OF THE GUIDE, I: RECONNAISSANCE TEAM

After an earthquake, it is normal procedure for at least one and perhaps several Reconnaissance Teams to visit the impact area in order to establish local contacts, collect preliminary information, and evaluate the possibilities for further research, but the exact number, size, and composition of these teams will obviously depend on the severity and extent of the earthquake damage and on the characteristics of the impact area(s). As these Reconnaissance Teams are extremely important, especially given the great variability in disaster situations and the fragile nature of social science data in this area, considerable effort is made here to orient these teams to some very crucial tasks that must be accomplished before any later team can effectively design further research efforts. In most cases the information that a Reconnaissance Team brings back has a tremendous influence on the scope and direction of the eventual in-depth research, as well as often being intrinsically interesting in its own right. Too often, however, the Reconnaissance Team enters the field with an insufficiently coherent plan of operation.

USERS OF THE GUIDE, II:RESEARCH TEAM

This Field Guide will be used in different ways by those individuals who find themselves doing or about to do post-earthquake-disaster social science research, but exactly *how* it will be used will depend on the background and interests of the researchers themselves. For the more experienced, the Field Guide is intended to be more of a checklist or thought-provoker for use in the preparation of field instruments than as a definitive guide on the selection of topics. However, it is hoped that the set of foci and questions framed here would be attractive to and researched by such experienced users in addition to whatever specific topics or questions of their own they may wish to explore. Hopefully, then, there will always be at least one set of topics explored in social science research on earthquakes regardless of the unique interests of the researchers involved.

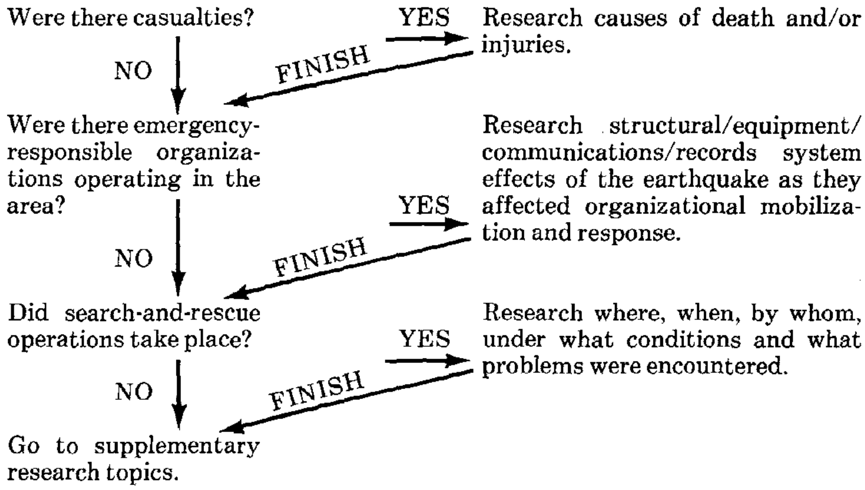
For those not specifically trained or experienced in disaster research but who find themselves doing it, this Field Guide should provide enough in the way of topics and questions, and is intended to suggest methods to begin to design significant and interesting, if limited, research. A brief overview of the principal disaster literature that should be helpful to the relatively inexperienced user is included in the Appendix. A closing section of this Field Guide outlines a few possible supplementary topics which may be of interest. It bears repeating, however, that the purpose of this document is to provide at least a minimal set of foci or questions for *all* researchers to explore in post-earthquake studies, regardless of the degree of their prior training or field experience.

RESEARCH PRIORITIES

The orientation of this Field Guide is to suggest research that will result in findings that have "engineering application," and in practice this means that the independent variable is earthquake-caused or earthquake-related damage to structures, equipment, communications, lifelines, records, and other physical systems with specific reference to how such damage affects the following dependent variables in order of priority:

1. Deaths and injuries among the affected populace
2. Operations (mobilization/response) of emergency-responsible organizations
3. Search-and-rescue activities

In practice this means that the following decision sequence would be followed in determining research topics:



Following from this decision sequence and the concern for research with engineering application, the mandate of the social scientist doing post-earthquake research is to come up with findings that will help pinpoint causes of death and injury, lapses or problems in organizational response, and difficulties in search and rescue so that future suffering and dislocation in a disaster may be removed or ameliorated. The underlying assumption is that if specialists in design, engineering, construction, and organizational behavior know *specifically* what and where the problems are in areas germane to their expertise, they can recommend solutions. It must be admitted, however, that actual implementation of any such recommendations is an entirely different — and problem-laden — domain. Nevertheless, the research mandate remains unaffected.

Since there must be a close relationship between the engineering and social science efforts, it is recommended that investigators in these two disciplines work closely in the field.

It should be noted that if "search and rescue" is broken out here as a separate research focus, this is actually doing some violence to the logic of a disaster situation. Normally, if there are casualties there is or has been search and rescue, and it is likely that at least some of it has been carried out by personnel belonging to emergency-responsible organizations. Thus, although there are certain aspects of search-and-rescue activity which merit research on their own (and which will be discussed further on), if *any* of the above are found, then all will probably be found. It is for this reason that the priorities are suggested. They should help order the expenditures of time and effort in the field.

It is also obvious that there is a declining relevance to "engineering applications" as one moves down the priority list, especially when one reaches search-and-rescue activities. Nonetheless, with a broad interpretation of the research mandate there can be little doubt that findings even in this area could have important indirect linkages to engineering problems. At any rate, the topics and questions suggested here only represent a proposed common "core" for earthquake research, and will almost certainly be supplemented by users of this Field Guide. In that sense, the search-and-rescue focus can be viewed as the transition point to other research (some suggestions on which will be made below).

In addition to the above priorities, there is also a time delimiter which sets some boundaries for the research, especially with regard to the top two priorities: the causes of casualties, and the operations of emergency-responsible organizations. Primary interest is in what may be termed the "immediate post-impact emergency period," and probably the best criterion for deciding when this period has ended is when organized search-and-rescue activities have ceased, i.e., when it is felt that all of the dead and injured have been removed to identification or treatment areas and/or when it is felt that there is no longer any reasonable hope of finding any casualties who could be saved. Thus the causes of casualties, the response of organizations, and search-and-rescue activities are interrelated in this area as well.

This choice of research topics admittedly is concerned with the more practical aspects of human and organizational response to earthquakes, and is less concerned with the more abstract questions of "social science." To again emphasize, this is so because, for the present, the bias is for information that will help those colleagues in the engineering and geotechnical fields that are concerned with earthquakes to improve the state of *their* art so that casualties might be reduced, organizational response enhanced, and search-and-rescue made easier and more effective. Thus a defense of the research topics suggested here rests on a normatively based interest in "practical" findings and a concern for facilitating multidisciplinary work in the field.

It must be noted, however, that there is an inherent dilemma in the terms "practicality" or "relevance" of earthquake research, and the problem is a potential source of conflict in many cases between social scientists and, especially, design specialists and engineers. The question is: *Whose "engineering application" are we attempting to help?*

If we in the United States retain the criterion of research "relevant to engineering application in the United States," we automatically deem irrelevant those earthquakes which have their major impacts in the rural areas, towns, and small cities of the so-called less-developed countries. But it is a fact that many earthquakes do affect exactly those areas (e.g., in Mexico, Central and South America, the Pacific, and Asia), and yet we tend to concentrate research on one or a few major cities which have structures and organizations "most like our own."

This problem was well illustrated by the 1976 Guatemala earthquake, where engineers were drawn to the most modern areas of Guatemala City because that is where the most "relevant" (similar to those in the United States) structures were located; however, the social scientists were drawn to the rural areas and small towns because that is where the vast majority of damage and casualties occurred.

The point is that there are going to be instances in which a truly multidisciplinary team (working simultaneously together, which was not the case in Guatemala) will be sorely divided by differing conceptions of the same word: relevancy. It is strongly suggested here that -- before entering the field -- the members of the various disciplines involved in any research effort discuss and agree on the definition of "relevant engineering application." It might keep the social scientists from concentrating on the effects of rural adobe collapses while the engineers study high-rise office buildings in the capital city. Underlying such a discussion, of course, is the perennial research question: Is the concern solely for the United States, or does earthquake research have a larger responsibility? This question must be posed and answered before any investigation can get fully underway.

METHODS

Although this Field Guide can be somewhat more helpful in terms of specific data-gathering instruments for the top priority (causes of deaths and injuries), the questions are only general suggestions about what needs to be known, and they will have to be elaborated by any users of this Field Guide before entering the field. The open-ended personal interview (tape-recorded if possible and if acceptable to the subject) remains probably the best method for obtaining data in the field, but this can certainly be supplemented by documentary or other types of evidence where appropriate. It must be emphasized, however, that much depends on the rapport and consequent access that the Reconnaissance and Research Teams develop with the various officials and respondents in the field, and on the exact nature of the post-impact environment. For example, if especially good relations develop with hospital or emergency personnel, the opportunity for unusually in-depth research should be capitalized upon even if it means a sacrifice in the breadth or scope of other research. In short, flexibility and sensitivity are vital for both Reconnaissance and Research Teams, as problems and difficulties will almost certainly be encountered. But so will unusual opportunities, which is one of the reasons why this Field Guide was consciously designed to be general with regard to methods, as survey and/or interview instruments will differ from researcher to researcher and from situation to situation. Indeed, given the often scanty information available about an impact area, it is not unusual to design specific data-acquisition instruments right in the field. The hope is merely to orient such efforts toward answering certain basic but important questions about human beings and organizations caught in an earthquake and its aftermath.

ORGANIZATION OF THE FIELD GUIDE

The following subsection is a checklist of recommended tasks for the Reconnaissance Team(s). Following it is the heart of the Field Guide: each priority focus discussed in turn with a statement of the general problem, some suggestions for data collection and/or for interviewing, and a closing section on possible data sources and methodological considerations. The body of the Field Guide then closes with a brief survey of other possible research topics that might be pursued if time/money/interest is sufficient. The Appendix provides a brief overview of relevant disaster research literature and suggestions on where to go for additional information.

THE RECONNAISSANCE TEAM

PURPOSES AND TASKS

The function of the Reconnaissance Team(s) is to survey the impacted areas, define their boundaries and characteristics, explore the zones for information useful in the design of further research, indicate how later teams might support themselves in the field, and, of extreme importance, establish contacts and clearances with the administrations of relevant organizations and with the authorities in the area. Engineers and social scientists must work together in the field. Any checklist of activities for a Reconnaissance Team should thus include the following.

For a Predominantly Urban Earthquake

(1) Obtain maps (if possible from city and/or county engineer's office or from data banks) of the impact and surrounding areas and, with the help of the engineers, define zones of high, moderate, and low intensity; have knowledgeable local people roughly profile each zone (residential — individual homes, apartment blocks, mixture of the two; commercial — stores, business offices, mixed; industrial — light, heavy, primarily warehousing, mixed); identify the location, nature, size, and occupancy of important structures in the affected areas that might be of special interest: e.g., high-density apartments, hospitals, clinics, or other medical facilities, structures of emergency organizations such as those housing fire and police departments, public utilities, transportation and communication companies, and specialized relief agencies; military headquarters or barracks; important government offices or archives; and schools, jails, reformatories, or other special-purpose structures. Accurate information on these subjects will save a great deal of "familiarization time" for later teams and will provide necessary detail for designing the more in-depth research.

(2) Indicate, as well as can be determined, the zones of "secondary effects" of the earthquake, such as areas swept by fire, where power, water, or other utilities service was disrupted, where outbreaks of looting occurred, or where pestilence threatened, and the time(s) during which such interruptions or events occurred. As a corollary to this, also indicate where refugees have gathered (or have been gathered by the authorities), and the location of staging areas or coordination points in the operations of emergency and relief organizations.

(3) Using the best information available, determine those zones or areas in which large numbers of deaths or injuries occurred. Also attempt to find out where the dead were taken for identification and the injured for treatment. Moreover, with respect to the injured, it is important to find out *how* (i.e., the mode by which) they were transferred to treatment centers. Overall then, this means checking the coroner's office, public health department, hospitals, clinics, first-aid stations, and local ambulance services. Finally, one should determine how extensive are the records the coroner or the hospitals keep on the pathology of the victims or the treatment rendered the influx of patients. Since casualties are the first priority in this research, such records would be invaluable in determining causes of death and injury.

(4) Identify which emergency-responsible organizations are operating or have operated in the impact areas, in general what these organizations did or attempted to do, and approximately when each began and ended its emergency operations. One means of categorizing such organizations, based loosely on the work of Russell Dynes (1969:17-20) (see Appendix), has been on criteria of "community orientation" and the possession of "emergency resources." Such community-relevant emergency organizations include the following:

Service agencies of local government

a. Police, sheriff, or other law enforcement agencies
b. Fire
c. Public works — street and road maintenance, surveying and mapping, maintenance of public vehicles and public buildings, contracting, refuse

collection and disposal, sewage, building inspection, and similar services

Public utilities

a. Water
b. Electric power
c. Natural gas
d. Telecommunications

Transportation facilities, systems, and maintenance

a. Highway/freeway departments
b. Airports
c. Seaports
d. Rail depots and yards
e. Bus and trucking centers

Medical services

a. Hospitals
b. Public health departments, including vital statistics units
c. Coroner's office
d. Also clinics, ambulance services, blood banks, and medical societies or other medical groups planned to respond to disasters

Relief agencies

a. Federal agencies such as the Federal Disaster Assistance Administration (FDAA) or related state government agencies
b. Red Cross
c. Salvation Army
d. Local relief groups

Military assistance to civil authorities (National Guard/Regular Armed Services)

The military often serves many functions and is thus not easily categorized: public order, communications, transportation, relief supplies, health or first-aid care, and many others; its operations will have to be observed on a case-by-case basis

Mass media

a. Television and radio
b. Newspapers

Coordinating groups

a. Civil government
b. Local civil defense or emergency services agencies
c. Military

Possibilities other than the above should not be neglected, however. In several cases, heavy-equipment owners or contractors have become immediately involved in the disaster response and are therefore legitimate subjects of research. The primary question remains: *Who was involved?* After that is determined the questions on the physical effects of the earthquake can be explored by the Research Team.

If possible, an attempt should be made to arrange a brief interview with a member or members of the administration of each organization to ask (1) if there were any deaths or injuries among the organization's personnel, and, if there were deaths or injuries, where, when, and how such casualties occurred; (2) if there was any damage to any of the organization's structures, equipment, records, communications, or lifelines that presented response problems — or if there was anything that worked unusually well or proved to be especially useful; and (3) if it would be possible to do more extensive interviewing of organizational personnel at a later time.

(5) Identify those areas or zones where the greatest search-and-rescue activity took place, and attempt to determine by whom it was carried out; this should be rather easy to coordinate with item (3). It has been common in past disasters that "emergent work groups" arose rather spontaneously among families, friends, neighbors, and even strangers to do this sort of immediate work, and such groups are usually found to have done the bulk of search and rescue before organizational personnel actually arrive on the scene. The best way to research this "nonorganizational" search-and-rescue is to find one person who was involved and ask the person to name the other members of the group and to describe their activity; this process should be repeated with each named member until a complete picture emerges. More in-depth interviewing can then be done, if desired.

With regard to these informal search-and-rescue groups, if the Reconnaissance Team believes that valuable data will be lost if there is a delay in interviewing, they should move to the questions outlined in item (3) of the following section, and should do the interviewing immediately. This might well be the case if it appears that many people are moving out of the area entirely, as a result of the earthquake.

(6) In a more immediately practical vein, the Reconnaissance Team should do its best to find a place (or places) where a later Research Team could live, keeping in mind that the later Research Team will probably be in the field a much longer time than the Reconnaissance Team will have been.

For a Predominantly Rural Town/Small City Earthquake

In an earthquake where the effects have occurred over a very large area (as was the case in the 1976 Guatemala earthquake), the Reconnaissance Team has a special problem: too much area to cover for a limited time. In such a situation the tasks of the Reconnaissance Team differ somewhat from those outlined above in the previous subsection.

(1) Working with engineering team members, obtain national maps and identify the areas or provinces that were most affected in terms of both casualties and property damage. If possible, identify specific towns or cities in the affected areas which were the hardest hit.

(2) Profile the most affected areas and localities in terms of population size, ethnic or racial composition, dominant types of structures and building practices, nature of economic activity, linkages to large regional or national urban centers, and whatever else would help fellow researchers get a "feel" for the areas. All of this would help a later Research Team select localities that might be of particular interest, either intrinsically or comparatively with other localities.

(3) Identify the emergency-responsible organizations in the area, and make at least initial contacts to indicate an interest in their operations and problems so that a later Research Team would not have to enter the area "cold." Also, it is obviously important to locate operations headquarters and staging points for such organizations.

(4) It is likely that the above three tasks will consume most, if not all, of the Reconnaissance Team's time, but if resources permit, the following should be attempted: identify structures of special interest in the various localities, areas of secondary effects, locations of refugees, areas of intense search-and-rescue activity, and support facilities for a later Research Team.

To summarize, the principal job of the Reconnaissance Team(s) in either type of earthquake is to serve as a sort of "sleuth" in the impact and surrounding areas in order to collect information that will help the later

Research Team(s) focus research on the most interesting and relevant aspects of that particular post-earthquake environment. It is for this reason that so much effort is advised to be spent on defining zones of impact, characterizing them, locating high-loss areas, and identifying organizations operating in the area (this must be a joint effort between social scientists and engineers). In fact, most of the Reconnaissance Team's time should be spent defining the nature and parameters of the *physical effects of the earthquake* and just indicating potentially fruitful subjects of further research. Only if it appears that valuable data will be lost, should the Reconnaissance Team do much in-depth work itself.

Finally, it can hardly be overemphasized that the Reconnaissance Team has in its hands the heart of any future research: contacts and clearances in the field. If such access is not cultivated and respected, the chances of further research being significant or even possible are virtually nil. It should not be forgotten that social science research in a disaster area is, ultimately, about human beings under stress, and sensitivity and flexibility must be the watchwords in any contacts with them.

A COROLLARY: THE COLLECTION OF DAMAGE STATISTICS

One job requiring joint effort by engineers and economists is the collection and assessment of damage and loss statistics. It is an often-observed phenomenon that property and economic loss estimates are extremely high in the first few weeks after a disaster but decline rather markedly as more time and experienced personnel become available and more accurate assessments are made. This process of declining estimates is itself an interesting research topic, but an important job for the Reconnaissance Team in this area remains the obtaining of as much information as possible on property and economic losses that are due to the earthquake or its aftermath. Except in the case of a small earthquake (in terms of area affected), both the Reconnaissance and Research Teams will be largely dependent on local or regional authorities for such loss and damage statistics. It is not suggested that the Reconnaissance and/or the Research Teams devote themselves to the task of collecting detailed statistical information first-hand; cost in time of that would be prohibitive. Normally, however, the local authorities and/or the insurance companies gather such data on their own, and it only remains to gain access to them. Researchers should be warned, however, that this access is often extremely difficult to obtain, especially from insurance companies, and they will just have to be satisfied with whatever they can get. At any rate, estimates of the number of dead, injured, and homeless are usually released fairly quickly in most cases, as are estimates of "total dollar losses" (whatever that means), but it is important to attempt to get additional information, such as the following.

On casualties:

- Was any particular socioeconomic class hit disproportionately?
- Was damage widespread and/or especially severe (i.e., deaths or serious injuries) in any particular zones or in any particular use structures, e.g., hospitals, schools, apartments?
- Where were victims taken for treatment? (Give approximate percentages, where possible) How were they evacuated and transported to such treatment areas?

On the "homeless":

Again, disproportionately from one socioeconomic class?

Where are they now? With—

families

friends

refugee temporary housing (self-built)

refugee temporary housing (official, provided)

What is, or was, the duration of occupancy?

Self-built?_____ Official?_____

moved out of the area entirely

other ____

On property damage and economic losses:

Factories or industrial areas affected?

Commercial, marketing, or distribution centers?

Private offices?

Public buildings, schools, hospitals, jails, administrative headquarters, others?

And what about estimates of unemployment due to the disaster, e.g.,

unskilled, semi-skilled, skilled } labor

shopowners/artisans/other self-employed

professional people

For example, after the December 23, 1972, earthquake which devastated Managua, Nicaragua, local authorities and other knowledgeable personnel made a considerable effort to estimate losses from this primarily urban earthquake. The introductory two pages (Tables V-1 and V-2) of a resulting document gives an idea of what can be done in this area by local experts who are careful in their work.

Table V-1: Summary of Damages Managua, Nicaragua, Earthquake, December 23, 1972[1]

1. 4,000 to 6,000 dead
2. 20,000 injured
3. 220,000 to 250,000 refugees
4. 27 km² affected by the earthquake with 13 km² totally destroyed, 14 km² damaged including the major part of the sewage system and of the light and water systems, creating a total of 7 million m³ of debris
5. 53,000 units of family housing lost or seriously damaged, the majority in the middle- and low-income groups
6. 95 percent of the small shops and factories in Managua, and 11 large factories lost or seriously damaged
7. 400,000 m² of commercial buildings and warehouses lost or seriously damaged
8. 340,000 m² of public and private offices lost or seriously damaged
9. 4 hospitals with a total 1,650 beds lost or seriously damaged

[1]From "Preliminary Evaluation of Damages as a Consequence of the Managuan Earthquake December 23, 1972," by the National (Nicaragua) Committee for Economic Reconstruction, translated by Dan Amaral, a document of Hazards Research Assessment, Institute of Behavioral Science, University of Colorado, Boulder, Colorado.

10. 740 classrooms lost or seriously damaged
11. 51,700 unemployed
12. $844.8 million in total losses

Table V-2: Estimate of Damages Caused by the Earthquake of December 23, 1972 (millions of dollars)[1]

	Buildings	Equipment and Furniture	Inventories	Emergency Costs Unrecouper-able*	Accounting Losses and Others	Subtotal
Government	22.5	9.0	1.0	38.6	30.3	101.1
Industry	3.0	15.0	2.9	2.6	17.1	40.6
Commerce	60.0	12.0	31.5	3.0	21.3	127.8
Housing	312.3	50.0	2.1	—	—	364.4
Services	28.5	11.4	4.5	4.4	—	48.8
Infra-structure	101.4	30.8	5.8	20.8	3.3	162.1
Subtotal	527.7	128.2	47.8	69.4	71.7	844.8

*This column includes cost in feeding, medicine, temporary facilities, wages, etc., which have been incurred as a result of the earthquake, as well as government income which will be lost.

[1]From "Preliminary Evaluation of Damages as a Consequence of the Managuan Earthquake December 23, 1972," by the National (Nicaragua) Committee for Economic Reconstruction, translated by Dan Amaral, a document of Hazards Research Assessment, Institute of Behavioral Science, University of Colorado, Boulder, Colorado.

The reconnaissance report on the 1976 Guatemala earthquake contained some summary tables (Tables V-3 and V-4) that show what can be done to begin characterizing a large-area, predominantly rural/town earthquake.[1]

Table V-3: Casualties: Guatemala 1976 (by Department)

Column: 1 Department	2 Estimated 1976 Pop.	3 Total Casualties	4 Dead	5 Injured	6 3/2
Chimaltenango	205,445	43,908	13,452	30,456	21.3%
Guatemala	1,232,303	19,167	3,240	15,927	1.5%
Sacatepéquez	104,732	10,349	1,556	8,793	9.8%
El Progreso	77,144	9,662	2,000	7,662	12.6%
Quiché	312,426	6,503	831	5,672	2.1%
Zacapa	110,603	2,691	693	1,998	2.4%
Other Depts.	3,457,347	4,503	596	3,907	.1%
Total, Nation	5,500,000	96,783	22,368	74,415	1.8%
Guatemala City	750,240	6,745	1,195	5,550	.9%

Table V-4: Casualties: Guatemala 1976 (Selected Towns)

1 Town	2 Department	3 Estimated 1976 Population of Town	4 Casualties in Town	5 Deaths	6 Injuries	7 4/3	8 Estimated Homeless
Chimaltenango	Chimaltenango	20,000	3,600	600	3,000	18%	96%
San Martín Jilotepeque	Same	10,000	3,657	1,000	2,657	37%	95%
Tecpán	Same	25,000	10,000	3,000	7,000	40%	100%
Comalapa	Same	20,000	8,050	3,050	5,000	40%	100%
Guatemala City	Guatemala	750,000	6,745	1,195	5,000	.9%	41% (?)
San Juan Sacatepéquez	Same	45,000	3,120	720	2,400	7%	100%
San Pedro Sacatepéquez	Same	11,000	2,387	720	1,667	22%	100%
El Progreso	El Progreso	12,000	4,800	1,300	3,500	40%	100%
El Jícaro	Same	6,500	2,910	372	2,538	45%	100%
Joyabaj	Quiché	33,000	6,097	600	5,497	18%	N.A.
Antigua	Sacatepéquez	28,000	1,528	277	1,251	5%	27%
Sumpango	Same	11,000	1,615	315	1,300	15%	—

[1]From "Social Science Reconnaissance Report: Guatemala Earthquake of February 4, 1976," for the Earthquake Engineering Research Institute, by Robert A. Olson and Richard Stuart Olson.

It should be noted that structural engineers would most likely be obtaining some of these data as well, and coordination of such efforts could reduce duplication and waste, especially if the "relevancy" issue discussed earlier has been resolved.

THE RESEARCH TEAM

This subsection begins the heart of the Social Science Field Guide: a fuller explanation of the research priorities with suggestions on how to obtain and organize the resulting data. The assumption is that the Reconnaissance Team has done at least the bulk of its job and thus that the Research Team is at least generally familiar with the impact area and has background information on approximate numbers and locations of casualties and medical receiving facilities, on operations of emergency organizations, and on the areas where search-and-rescue activities took place. If for any reason the Research Team does not have such preparatory information, it is recommended that the team do its own "reconnaissance" (as outlined in the previous subsection) before designing and proceeding with any in-depth research.

RESEARCH PRIORITY 1: CASUALTIES

Aside from the obvious reasons for making research on death and injury among human beings the top priority, the problem of identifying the *causes* of casualties has not been — but should be — systematically explored in past disaster research. There is much "folk wisdom" about the lethal effects of interior and exterior architectural additions (decoration) when they come down during an earthquake, but it is exactly that, folk wisdom. Empirically we know little but need to know much about the relative importance in causing casualties (both in terms of number and severity) of structural failure *versus* decoration *versus* equipment *versus* appliances *versus* furniture. This lack of specific information must be remedied if planners, designers, and engineers are to make any systematic attempts to reduce human losses in an earthquake. With regard to the plans for this Field Guide as they were formulated at an early stage, the veteran disaster researcher Charles Fritz noted:

> From the perspective of usefulness for future engineering applications, it would seem particularly useful to focus on the causes of death and injury among the affected populace. Most previous field studies of disaster are particularly deficient in collecting reliable data on the causes of death and the exact type and causes of injuries sustained by the victims. Future studies of earthquakes and other peacetime disasters should attempt to remedy this deficiency by careful efforts to identify the nature of the deaths and injuries and their causes. This may require working backward from the physical and physiological effect on human beings to the nature of the physical insult that produced the death or injury.

In practice it is obvious that cumulative findings in this area are going to be hampered by the fact that earthquakes (and all disasters for that matter) have idiosyncratic characteristics: specific location, nature of impact area, season of year, time of day, and severity and extent of effects, all of which will affect the human toll taken by the disaster. Furthermore, local construction practices vary, and data on casualties in adobe buildings in Managua or

Guatemala are of little relevance for most of the United States (although, however, they may be for other countries); however, casualties (in another earthquake) in the high-rise buildings of Caracas certainly were. Nonetheless, there is no choice but to build these "chance" factors into a research design as mediating variables, and, hopefully, over the long run to be able to control for them when drawing conclusions.

The following formats (Tables V-5 and V-6) are suggestions only, and it seems obvious that the Research Team will have to alter and add to these as field conditions and the nature of the post-impact environment dictate. It is felt, however, that the following information is probably the minimal necessary to begin to pinpoint causes of casualties.

One of the suggested questions, on "class of structure," points up an area where a multidisciplinary approach could be very valuable. The idea behind this Field Guide is that not only would various of the social sciences be represented on any team, but also that there would be members from the geotechnical fields as well. Most social scientists can only roughly determine the type of class of a structure — and then only by its size (high-rise, low-rise, split-level) or how it is used (home, office, apartment). But an engineer or an architect can further define a structure by *how it is built* (i.e., materials used, bracing and tying employed, design). The result, over time and several earthquakes, would be a fuller and much more accurate picture of where and under what specific conditions casualties occur. Thus, the normative concern for eventual casualty reduction provides a linkage among the disciplines that should encourage in-the-field cooperation.

One possible way to increase cross-disciplinary communication in the field would be to make it a practice always to assign at least one social scientist to work constantly with, for example, the structural engineers, and an engineer constantly to accompany the social scientists. *Separate,* nonmultidisciplinary working parties meeting together only at night or once a day are just not going to be able to question, stimulate, and learn from each other. The working teams must be integrated, no matter how hard it is at the beginning.

Pursuing the idea of a multidisciplinary approach a bit further in another direction, it may well be a good idea to have as one member of the Research Team a person who can interpret medical language in both interviews and hospital records. Medical terminology can often be totally unintelligible to a relative layman, and such a team member might well be necessary in order to obtain any data at all.

Data Sources and Problems

There are essentially three sources for the desired death and injury data: hospital/medical records and personnel, the victims themselves, and, more problematic, the recollections of rescuers who helped dig out and/or evacuate the dead and injured from the impact areas. In a relatively small earthquake with few casualties (perhaps a few dozen), it should be possible to obtain virtually all of the necessary data on injuries from the records and/or recollections of the medical personnel who treated them. In such instances the normal recordkeeping procedures are usually still intact, and the records are likely to be fairly complete. Missing or incomplete information can be added by following up with and talking to the victims themselves or to their families. Caution must be exercised here, however, as there still might be trauma associated with the earthquake and its impact.

Data on deaths are likely to be more difficult to obtain, even in a small earthquake. For those who succumb from their injuries while in a hospital,

Table V-5: Victim—Death Report

Date__________

Background

Age_____ Sex_____ Occupation ________________________

Marital status_______ Family members *(in the area at time of impact; their ages, sex, and relationship to deceased)*

Address____

At Time of Impact

Where was the victim?

Outside—where specifically (street, address)

Inside—where specifically (street, address)

Class of structure (apartment, office, home—more specific if possible)

Where in structure

Alone or with others (specify whom, if with others)

What was the victim doing?

Death

Where and when incurred

Cause of death[1]

Structural collapse

Architectural/decoration on structure

Equipment or appliances

Furniture

Post-impact secondary events (fire, smoke, trampling)

Other ____(specify)

Removal

When removed

By whom: individual

family

informal work group

emergency organization personnel

other ____________________________________(specify)

Taken where

Identification }
Autopsy } Where, when, by whom
Burial }

[1]Where possible, specify nature, size, and weight of object causing the death and the distance it travelled to impact on the victim.

Table V-6: Victim—Injury Report

Date__________

Background

Age_____ Sex_____ Occupation ____________________

Marital status_______ Family members *(in the area at time of impact; their ages, sex, and relationship to deceased)*

Address____

At Time of Impact

Where was the victim?

- Outside—where specifically (street, address)
- Inside—where specifically (street, address)
  - Class of structure (apartment, office, home—more specific if possible)
  - Where in structure
  - Alone or with others (specify whom, if with others)

What was the victim doing?

Injury

Nature

Severity

Where and when incurred

Cause of injury[1]

- Structural collapse
- Architectural/decoration on structure
- Equipment or appliances
- Furniture
- Post-impact secondary events (fire, smoke, trampling)
- Other ____(specify)

Removal

When removed

By whom:
- individual
- family
- informal work group
- emergency organization personnel
- other ____________________________________(specify)

Taken where

Treatment

First-Aid: what, where, when, by whom

Hospital

- Nature of treatment
- Duration
- When released

Long-Term Effects

Physical

Psychological (difficult to determine but worth an effort)

[1]Where possible, specify nature, size, and weight of object causing the injury and the distance it travelled to impact on the victim.

records should be available. For those who die in the impact areas during or immediately after the earthquake and who were removed to morgues or other identification centers, detailed records might well be lacking. In this case the best that can probably be done is to talk with those professional personnel in charge of receiving and autopsy (if performed) and with those who removed the bodies from the impact area. One hesitates to suggest any contact with the families of the dead as even the greatest interviewer sensitivity cannot mask the essentially blunt questions that would have to be asked, and such contact is not recommended.

In a very large earthquake with casualties perhaps running into hundreds or thousands, data-gathering problems still exist but are somewhat different from those in a small earthquake. In some countries, records on the treatment of victims (except those requiring extensive surgery) will be minimal or possibly nonexistent, and the numbers of victims who received care will be so large as to preclude individual interviews. The numbers of dead present special problems and will be discussed later.

There are two ways to handle the missing-data problem on a large number of injuries, and perhaps a combination of the two would be best. The first method is to ask the hospital or other medical personnel about the apparent locations of the victims at the time of the earthquake and the cause, nature, and severity of their injuries; at least this would be a beginning. The next step would be to select a random sample of all those victims treated by the hospital, clinic, or whatever, and then attempt to locate these people (if they are not still under care) and to interview them personally. Taking care to have a sufficiently large *N*, inferences could then be made as to the causes of injuries in the total casualty population.

If there is a large number of dead, the identification of specific causes of death becomes very problematic. Indeed, in some extreme situations where there has been either a threat of or an actual outbreak of pestilence (as in Turkey and Nicaragua, for example), mass burials have been conducted for scores of victims, with only the most rudimentary identification of even *who* was being buried. Although most post-disaster situations will not be this extreme even after a large earthquake, recordkeeping is likely to be a low priority. In such situations the only recourse is to attempt to obtain as much information as possible from hospital/medical, morgue, or emergency personnel, or from rescue/evacuation workers who removed the bodies, and to be content with whatever findings result.

It is obvious that in order to obtain these hoped-for data on deaths and injuries, good relations with hospital administrators, other medical personnel, and the coroner's office are an absolute necessity. The best way to approach the creation of such an effective working relationship is to stress that the purpose of the research is to be able eventually to reduce casualties by identifying their specific causes. It is obvious, of course, that great care need be taken and assurances given by the Research Team that they will protect the confidentiality of any medical information given by either medical authorities or the victims themselves.

It is possible that the Research Team, once in the field, will choose to employ clerical or similar casual labor to record and organize the raw data on casualties. This is, of course, reasonable and efficiency-promoting, but it must be remembered that access to local authorities will be the prime source of casualty data, and the social scientists should not allow themselves to become too removed from the data source. Consistent, onsite presence is often a prerequisite for continued research, and many questions that need immediate followup are generated by the data-collection process itself. For that reason alone, at least one member of the social science team should be onsite.

Finally, it should be noted that the psychological or mental health effects of an earthquake have not been chosen as a primary focus here. Although a legitimate topic and one that seems to arise after every major earthquake, mental health problems are somewhat out of our area of interest (their relationship to "engineering applications" seems to be tangential at best). Any mental health data that become available would obviously be useful and interesting, especially if any hospital divisions or special clinics are created (as they sometimes are) to handle earthquake-related psychological problems, but psychological research remains an area of secondary interest here.

RESEARCH PRIORITY 2: EMERGENCY ORGANIZATIONS

Assuming that the Reconnaissance Team has identified most, if not all, of the emergency-responsible organizations operating in the impact area, the Research Team can proceed with the broader and more in-depth interviewing of organizational personnel. As fits the concern for knowledge with engineering applications, the questions suggested here generally revolve around the earthquake's effects on the mobilization and response of organizations, and especially on the problems encountered in such efforts. In addition, there has been considerable interest in past disaster research on the existence and effects of what is called "role conflict," where emergency organization personnel have difficult choices to make, usually between family obligations and official disaster responsibilities. Of direct relevance here is that often it is casualties among the families or relatives of emergency personnel or serious damage to their homes that seem to affect the responses of the personnel, usually delaying their reporting for work or causing interruptions once they are on the job. Barton (1970:154-156) (see Appendix), among others, considers role conflict to be an important problem in organizational effectiveness in a disaster situation and makes several suggestions about training, equipment, and especially communications that might reduce the scope and/or the intensity of the problem. But there is still not enough data to know how much of a problem role conflict really *is*, and it is for this reason that several questions are included that should allow exploration in this area.

In terms of interview subjects, while the Reconnaissance Team presumably can concentrate its preliminary interviews on the high-level administration of the various organizations, the Research Team cannot be so restrictive. After reestablishing contacts and clearances and doing more in-depth interviews of the high-level administrators, the Research Team must attempt to interview at least a rough cross-section of all personnel. Perspectives on organizational mobilization and response are likely to change as one moves from high-level administration to middle-level office personnel to field headquarters workers and, finally, to the organizational personnel who did the actual field work in the impact area. A complete picture will not emerge — and, of course, neither will any intraorganization conflicts or disagreements — until members from all levels have been interviewed.

One more consideration needs to be mentioned. The various emergency-responsible organizations will have differing experiences with the effects of the earthquake. Some are likely to see the earthquake's effects as the effects that "*come to it,*" in a sense (hospitals, for example); others might only *encounter* problems or damage as they move into an impact area from outside (relief organizations or Federal disaster agencies are possible examples) or even might only be concerned with the "secondary" effects of the earthquake, such as fires or looting; still others, however, will have facilities, substations, or even headquarters *in* the impact area and will thus have been directly affected by both the earthquake and its aftermath. Also, it has been fairly common in past (especially rural) earthquakes that emergency organizations are found to have entered geographical areas in which they had not previously operated and/or that they have assumed new or nontraditional tasks in the emergency period. This is an important but not well understood process and can be a major source of inter- and intra-organizational conflict. It must be watched for, as it can greatly affect both internal and external evaluations of the organization's response. Although post-earthquake organizational perspectives will thus be different, it can still be expected that all organizations' behavior will be affected in some way by the results of the earthquake. It is necessary to keep these potentially differing experiences in mind as interviews are done and when they are reviewed in order properly to qualify any conclusions reached. Also, as noted earlier, the following interview suggestions will probably have to be altered and elaborated upon in light of field conditions and the differing experiences of the various organizations.

The first tasks are to get some relatively "impersonal" facts and to set out some basic questions that can then be explored in later and more personal interviews. The early, background data gathering is another notable area in which social scientists and engineers should work closely together, with the engineers being primarily concerned with the *objective* evaluation of physical damage while the social scientists concentrate more on the organizational perceptions of the damage, i.e., the *subjective* element. For example, important buildings (hospitals, offices) occasionally have been evacuated — with resulting disorganization and loss of efficiency — after sustaining relatively minor structural damage. It takes a joint effort of social scientists and engineers in this case to fully explore this phenomenon, as the interaction of physical damage and *perceptions* of that damage are extremely complex. Each subset of the Research Team will be half blind to the reality of the situation if it works alone.

Organizational Questionnaire
Background Information

Pre-impact information

- Name and official function of organization
- Number of personnel (by levels, if possible)
- Centralized (single unit) or decentralized structure?
  - Number, location, size of subunits, if decentralized
- Did the organization have prior experience with an earthquake?
  - How recently?
  - What was the extent of damage or disruption in the prior quakes?
- Did disaster response or "emergency" plans exist?
  - Were such plans practiced?
- What was the organizational status at impact?
  - Percentage of total personnel on duty?

Percentage of leadership/administration on duty?

Earthquake and aftermath

As a result of the earthquake, did the organization suffer:

- Casualties?
  - To whom? — nature, severity, cause
  - Where, when, by whom treated?
- Damages? — nature, severity, location (specify)
  - Structural
  - Equipment
    - fixed
    - mobile
  - Communications
    - intraorganizational
    - external
  - Records
  - Support services (utilities)
  - Other ________ (specify)

How did such casualties or damage affect organizational mobilization and emergency functions?

When and how did the organization (its leadership, really) learn of the disaster and its dimensions?

- Internal communications
- Informed by other organizations (which?)
- Media
- Other

Was any attempt made to contact off-duty personnel? How? By whom?

When did the off-duty personnel report for work?

- 50 percent of those off-duty
- 75 percent
- 100 percent

What was the nature of the organization's activities in the post-impact period? How did these change over time, or did they? If they changed, why? (Probe this one: was it in response to a changing environment or because of directions from above?) Did the organization or its members assume any tasks unusual for them during the emergency period?

In reestablishing services or organizing emergency operations, what priorities, if any, were apparent in the organization? If there were priorities, were they the result of a conscious choice by anyone or simply an accommodation with reality, i.e., doing what was possible because physical damage or lack of personnel precluded other action? Along the same lines, was the priority decision the result of the purely internal workings of the organization, or was it influenced by external authorities or other organizations? If externally influenced, by whom and under what conditions?

Did the organization incorporate "off the street" volunteers into emergency operations? How many? What was the final mix of professionals, regular volunteers (those who are normally activated by the organization in a disaster) and temporary volunteers? If temporary volunteers were included, were there any problems as a result?

When did the organization go off "emergency status"? Has the organization published — or allowed to be published by the media — any accounts of its activities? (Obtain if possible)

The next set of suggested questions is intended to be used in the design of the more personal interviews for individual organizational members. Some of the questions may not be relevant as one moves to different organizational levels, but this can best be determined by the Research Team in the field. Also, some of the questions may be irrelevant depending upon which organization is the subject of the interview, but again that can only be determined in the field. At any rate, the use of taperecorders should be considered for all interviews so that richness and detail are not lost when the subject "rambles." The time and cost involved in transcribing such tapes should not be taken lightly, however, and allowances for this should be made before field work is begun in earnest.

Organizational Questionnaire
Individual Respondent

Background: Pre-impact Date__________

Age________ Sex_________ Marital status________

Position in organization Years with organization

Family members in the local area (ages, sex, relationship)

Was the respondent aware of any disaster response or "emergency" plans?

If so —

- How well?
- Were they practiced?
- Were they followed? Did he/she consider them relevant or practical?

Background: Impact

Where was the respondent? (home, office, commuting, etc.)

What was the respondent doing? (working, sleeping, relaxing, etc.)

Was the respondent alone or with others? If with others —

- Who? Their relation to respondent?
- What were they doing?

Did the respondent know where his/her family was at the time? The status of the family (safe, injured)? Was the respondent conscious of any real or potential conflict between job and family? If so, how was it resolved?

Immediate Personal Response and Organizational Mobilization

The first part of this section should be developed merely by asking the respondent to relate what he or she did during the shaking and in the first few minutes afterward. If others were around, the respondent should be asked his/her impressions of their immediate behavior.

If the respondent was "off-duty" at impact—

- Was he/she contacted about going to work? When? How? By whom?
- When was the respondent able to report for work? Did anything delay him/her on the way? What was it?

If the respondent was "on-duty" at impact—

- Who took command of the situation?
- Who attempted to contact off-duty personnel? When? How? Were there any problems in this attempt?

In the respondent's opinion, how soon after impact was the organization really functioning effectively?

Perspective on Organizational Response

The purpose in this section would be to elicit the respondent's views on how the *organization's* response was affected by loss of or damage to structures, equipment, records, lifelines/utilities, communications, and the absence of various personnel. Some suggestions:

Was the respondent aware of any casualties among organizational personnel or any damage to the organization's building(s), equipment (fixed or mobile), records, lifelines, or communications (external or internal)?

In the respondent's opinion, how much did such casualties or damage affect the *organization's* mobilization, coordination, or response in general?

Was the respondent aware of any absence of key personnel during the emergency period? Who? And with what effects?

If possible, ask the respondent if he/she could *rank* in importance the following "problem areas" as each, in the opinion of the respondent, affected organizational capabilities in the emergency period:

( ) loss of or damage to structures
( ) loss of or damage to equipment or other material
( ) loss of information or records
( ) loss of or damage to communications capabilities
( ) loss of or damage to utilities/lifelines that service the organization
( ) absence of personnel — and at what levels

Is the respondent aware of anything that the organization attempted to do but could not? What was it? What accounted for the failure?

Finally, was there anything that worked unusually well, in the respondent's opinion, and thereby actually helped or increased organizational mobilization and response?

The Priorities Problem

In this area the general question would be whether the respondent was aware of any organizationally set priorities in emergency operations, and if there were such priorities, *how, when,* and *by whom* they were set. This would require asking such general questions of each respondent and then cross-checking as there may be very different answers as one moves from administration (supposedly responsible for setting priorities) to field workers (responsible for accomplishing them). Again it is important to attempt to determine the degree to which physical damage and/or lack of personnel made priorities an essentially "no choice" situation, i.e., doing what was possible because certain actions were clearly physically impossible.

Perspective on Personal Responses

Asking a "respondent" to assess his/her organization's response fastens attention on one level of analysis, but in all likelihood the respondent will have a much clearer idea of the problems that he or she *personally* faced in the emergency period — and these may well be different from his/her views on strictly organizational-level problems. Questioning should explore at least the following general topics:

What was the respondent's job during the emergency period? What were the principal problems encountered? Did he/she change jobs during the emergency period? Why?

What lacks, scarcities, or other problems affected the respondent's ability to do his/her job?

Was there anything that the respondent attempted to do but could not? What/why unable?

Was the respondent aware of any difficulty in deciding *what* to do? Did he/she receive direction? Were there any problems in this area of choice or instructions?

In the respondent's opinion, was there anything that worked especially well or that proved unusually useful in doing his/her job?

Concluding Question

One of the best and most potentially fruitful ways to close an interview is to ask something along the lines of: "If you had to do it all over again, is there anything that you would like to see changed in organization, buildings, equipment, communications, or anything else that would improve (1) the organization's and (2) your own ability to respond to a disaster?" And just let the respondent talk at will.

RESEARCH PRIORITY 3: SEARCH AND RESCUE

This third research focus is closely related to the previous two because if there are deaths or injuries, there is likely to be search and rescue, and at least some — but, as it turns out, not all or perhaps not even most — of that search-and-rescue activity is likely to be done by organizational personnel. Typically, in a post-impact disaster situation individuals in or near the impact area come together in informal, spontaneous groups to do immediate search-and-rescue work. Sometimes the members of such "emergent" groups know each other from before the disaster and sometimes they do not. Neither the reasons and processes by which they come together, organize, work, and finally disband are well understood, nor are the problems they face in carrying out their activities; yet, given their importance, they should be.

In this subject area our concern for the "engineering applications" of potential findings — while still present — begins to wane, at least by a very strict definition of those applications. The principal questions revolve around *who* did the bulk of the search-and-rescue work; the *origin* and *membership* of the informal groups, if formed; and, concerning these groups, the *problems* that they encountered in carrying out their activities, their relations with emergency organization personnel after the latters' arrival in the area, and how and when the groups dissolved. Emergency organizations that have personnel doing search and rescue will be discussed later.

As mentioned in the introduction, the best way to approach the informal work groups is to find one member, conduct the interview, and ask for as many of the names and/or addresses of the other members as he or she can remember. This process is then repeated until the group is reconstituted, at least on paper, as well as the knowledge and memories of the participants allow. Finding that initial member of any of these groups is usually a bit difficult, but some time spent talking with people in the impact area should yield at least some names to start. Also, the field personnel of some emergency and/or relief organizations might be able to furnish some names.

At any rate, assuming that some members of these groups have been located, the following interview suggestions are offered.

Search and Rescue—Emergency Work Groups
Individual Interview

Background

Age________ Sex________ Marital status________

Occupation

Location of workplace

Family members in the local area (age, sex, relationship)

At Impact

Where was the respondent? (home, office, commuting, etc.)

What was the respondent doing? (working, sleeping, relaxing, etc.)

Was the respondent alone or with others? If with others —

Who? Relationship with respondent? What were they doing?

Did the respondent know where his/her family was at the time? The status of the family (safe, injured)?

Ask the respondent to relate generally what happened during the actual shaking and how he/she and others around reacted. This will normally allow the subject to talk more easily.

Did the respondent see anyone killed or injured during the shaking? By what? (This is essentially a cross-check on Research Priority 1)

Origin and Membership of the Group

Where and when did the respondent begin to do search and rescue? What prompted him/her to do so?

Who were the other members of the group? (names and addresses if possible)

Did the respondent know any of them previously? If so —

Who? From where?

Did the group have any contact or communication with other groups, emergency personnel, or authorities that prompted them to work together? How did they organize themselves?

Were any priorities established on where to work or were any decisions made on concentration of efforts? How, when, and by whom were such decisions made?

Did anyone leave or join the group while they were working? For what reason(s)?

Problems Encountered (here is the relevance for engineering applications)

A general question to begin this section might be something along the lines of the following:

"There must have been a lot of problems that you all faced in terms of structures, equipment, utilities, training, coordination, or others while you were working. What do you remember as the major problems or dangers that you ran into?" (probe)

This could then be followed by some more specific questions:

Was there anything that the group attempted to do but could not? What was it, and what prevented them?

Was there anything that the individual respondents attempted to do but were unable? What was it, and what prevented them?

Did the group uncover any victims in their work? About how many? Was there any problem in evacuating them from the area? How were the injured evacuated?

Organizational Relations and Group Dissolution

When was the group's first contact with official emergency personnel? With which organization was the contact?

What were the "relations" between the group and the emergency organization(s) with which they had contact? (explore for perceived hostility, competition, cooperation, problems, or special successes)

How and when did the group end their search-and-rescue activities? Was it an individual or a group decision?

Conclusion

As usual, the best way to end an interview of this sort is to explore the question: "If you had to face the whole situation over again, is there anything that you would like to have or see changed in structures, equipment, utilities, communications, training, or organization that would improve (1) a group's or (2) your own ability to respond to a disaster?"

It is the concept of "emergent group" that allows the preceding section to stand on its own as a research focus, because in a light (in terms of severity) or very localized (in terms of area) earthquake it is the personnel of one or more emergency organizations that usually do search and rescue. In these latter cases, then, search-and-rescue research fits under the previous research priority, that on emergency organizations. For this reason it is only necessary to indicate here the directions in which to elaborate upon the questionnaire suggested for emergency organization personnel to complete this section.

It will probably be assumed that the Reconnaissance Team will have discovered which organizations had personnel doing search and rescue, or, failing that, that the Research Team will have uncovered some of this activity while doing the in-depth interviews outlined previously. In either case the following questions need only be developed and added to those already suggested for emergency personnel.

Search and Rescue— Emergency Organization Personnel

Where and when did they do search-and-rescue work?

How did it happen that they came to do such work, i.e., was it coincidence or an individual decision, or were they directed to do so by authorities in their organization? How, when, and by whom were priorities set for doing search and rescue?

With whom did they work while doing search and rescue?

- Volunteers (and from whence did they come)?
- Personnel from other organizations (which ones)?

What is the respondent's perspective on the principal problems or frustrations that they faced in doing search-and-rescue work? Can the respondents identify or hopefully rank those problems in terms of the following categories:

( ) structures
( ) equipment
( ) utilities
( ) communications
( ) training/organization

Did they find many victims? About how many? Were there any problems in removing and evacuating the victims? What appeared to be the causes of any observed deaths or injuries?

When and how did they terminate their search-and-rescue activity? Was it a series of personal decisions, a group decision, or on instructions?

The usual final question should probe what the respondent would like to have or see changed in terms of structures, equipment, training, communications, etc., to do a more effective job of search and rescue if he or she had to face the situation again.

As has been the case with all previous interview suggestions, it is very likely that the above will have to be added to as respondent answers will often trigger other questions on phases or subjects not dealt with here. The

Research Team, as always, is encouraged to pursue such topics as they arise as, fortunately, neither the respondents nor the taperecorder is limited by the suggested questions.

OTHER RESEARCH POSSIBILITIES

There is a multitude of supplemental research topics that could be explored in any disaster situation, and most experienced researchers will have special interests or ideas of their own. However, although now admittedly very far afield from any direct connection with engineering applications, there are three other research possibilities that would seem to merit some consideration as supplemental research. The first involves the economic reconstruction process.

The problems and processes of *economic resuscitation and long-term reconstruction* are not well understood, although effort is beginning to turn in this direction. At any rate the questions are rather general:

1. What groups or which individuals are participating in planning for economic reconstruction? Who is leading the effort?
2. What is the relationship among the economic reconstruction group and local, state, and Federal governments; relief organizations; and emergency organizations? (points of conflict? areas of interdependency or cooperation?)
3. It would be interesting to explore what each of the members of the economic reconstruction group perceives to be the principal problems facing the community in terms of economic resuscitation. This might identify real or latent conflicts within the group, and, if monitored over time, might chart the integration or disintegration of the group.
4. Where are funds being sought to finance reconstruction? And by whom? This should also be watched over time as economic opportunities — or dependencies — may change as legislation is passed or decisions made at the local, state, and Federal government levels.
5. Who and/or which groups or organizations are proposing what kind of futures for the community and its recovery? What policies are being suggested as the "best" or the "correct" ones to achieve those futures?

The questions in item 5 obviously could serve as a transition from a narrow focus on economic reconstruction to a broader focus on the entire process of reconstruction and all that it entails — planning, zoning, building codes, etc.

The two other possible supplemental topics surface as a result of asking a group of geotechnical experts on earthquakes to express themselves on what they would like to know about the human or "social" response to earthquakes. One recurring theme was a desire for some knowledge about the *conditions for panic* in a disaster situation. Although panic appears to be greatly exaggerated as a problem, a summary of the literature advances the hypothesis that three conditions are critical:

> Panic, i.e., acute fear coupled with flight or attempted flight, will most likely occur when (1) an immediate danger is perceived to be present, (2) from which an individual sees his escape routes blocked (or closing rapidly by other accounts), and (3) feels highly isolated (Drabek, Haas, and Krane, American Sociological Association, 1973:16).

The authors do make clear that this is still a tentative hypothesis, and research on causes remains to be done in those cases where there is evidence of panic.

The last additional topic that will be suggested here is another recurring theme in conversations with the geotechnical experts: *the relationship between mass media, public opinion, and "risk acceptability."* This is clearly a highly complex area that is related to the whole problem of reconstruction and could be the subject of book-length efforts, but the principal question here would appear to be the following: After a community has experienced a damaging earthquake, what is the status of public opinion on the tradeoffs between higher construction/reconstruction costs (i.e., more careful zoning, more rigorous building codes) and increased safety in a future earthquake? How and how much is this public opinion of risk acceptability affected, especially by the mass media? And finally, what is the relationship between public opinion on risk acceptability and time as the earthquake experience recedes in memory?

Other research possibilities include interorganizational relations, the role of volunteers in emergency services, the military and civil-military relations in a disaster situation, in-depth studies of specific organizations such as hospitals or public works departments or of specific "types" of victims, i.e., the elderly, teenagers, children in a disaster, hospital patients, or jail and reformatory inmates. Further reading in the literature cited in the Appendix will show how these and other topics as well have been explored in the past.

Obviously, all of the above are only general suggestions on what to do if time/money/interest is still available after completing primary research, but it is hoped that these suggestions, and this Field Guide in general, are provocative and of potential use to researchers.

A final word: Perhaps some of these "other research possibilities" seem to be intrinsically more important than the priority assigned them under the "engineering application" criterion, and perhaps even the scope of the Field Guide itself seems too narrow because of that criterion. It must be remembered, however, that this Field Guide is not designed for social scientists working alone but rather for social scientists working as part of a multidisciplinary team. In such a situation there must be a common focus or purpose for the research. Although experience may well modify it, "engineering application" is the focus that could be agreed upon at this time.

APPENDIX V-A: AN OVERVIEW OF DISASTER LITERATURE

The purpose of this Appendix is definitely *not* to do another bibliographic essay on disaster research; we have a number of good ones already. Our purpose here is merely to orient the user of this Field Guide to some basic reading in disaster research. The literature mentioned here hopefully represents a kind of "crash course" in disaster analysis for the relative novice from which further reading could be developed. For the more experienced it is obviously only a basic reference list.

One should probably begin with Charles E. Fritz's "Disaster" in Robert K. Merton and Robert A. Nisbet, *Contemporary Social Problems* (New York: Harcourt, Brace, & World, 1961) for an excellent general discussion of human and organizational problems and responses in disaster situations. This might then be followed by scanning Anita Cochran's *A Selected, Annotated Bibliography On Natural Hazards,* Working Paper #22 of Natural Hazards Research (Boulder, Colorado: Institute of Behavioral Science) which contains capsule discussions of virtually all the principal disaster research. It is 85 pages long, to give some idea of its completeness.

The next step might be to read one of the better actual field studies, William H. Form and Sigmund Nosow's *Community in Disaster* (New York:

Harper and Brothers, 1958). There are many other fine field studies, but this remains one of the most stimulating and readable.

For further reading in field studies one should probably go to the massive work on the 1964 Alaska earthquake by the Committee on the Alaska Earthquake, *The Great Alaska Earthquake of 1964: Human Ecology* (Washington, D.C.: National Academy of Sciences, National Research Council, 1970) which contains articles on many diverse subjects: human adjustment, community change, organizational response and change, economic impact, and many others.

There are two crucial works which seem to fit into any reading list about here: Allen Barton's *Communities In Disaster: A Sociological Analysis of Collective Stress Situations* (Garden City, New York: Doubleday Anchor, 1970) and Russell R. Dynes, *Organized Behavior In Disaster: Analysis and Conceptualization* (Lexington, Massachusetts: D. C. Heath, 1969). Both are survey works which try to make sense of and draw conclusions from a large number of both published and unpublished field reports and monographs. Both are extremely important as attempts to raise the conceptual and theoretical level of disaster research.

Finally, there were threee papers delivered at the 1973 meeting of the American Sociological Association, all of which are of interest but one of which is very useful as a survey and, more important, as a codification of past research and as a guide for future research emphases: Thomas E. Drabek, J. Eugene Haas, and Sigmund Krane, "System Shock: Response and Recovery." The other two papers were by J. Eugene Haas, "Anticipating Disaster: The Long View" and Dennis S. Mileti and Sigmund Krane, "Countdown: Response to the Unlikely." Fortunately, these are now available as "Human Systems in Extreme Environments: A Summary of Findings on Natural Hazards and Disasters," by Mileti, Drabek, and Haas (Boulder, Colorado: Institute of Behavioral Science, 1974).

For additional and more specific works, especially on organizations, one should probably go to the entire January/February issue of the *American Behavioral Scientist* (Volume 13, No. 3) which contains articles on disaster methodology and community priorities as well as more in-depth works on the actions in disaster situations by police and fire departments, a public works department, a general hospital, the Red Cross and Salvation Army, and the military.

With regard to economics and natural disaster, the starting point is still Douglas C. Dacy and Howard Kunreuther, *The Economics of Natural Disaster: Implications for Federal Policy* (New York: Free Press, 1969), but this has been supplemented, if not supplanted, by two articles by George W. Rogers in the already cited *Human Ecology* volume of *The Great Alaska Earthquake of 1964:* "Impact of the Earthquake on the Economy of Alaska" and the "Economic Effect of the Earthquake." These works by Rogers indicate where economic analysis of disasters will, and probably should, go.

With respect to earthquake disasters in the special subset of developing countries, two studies are of special importance: J. Eugene Haas and Robert S. Ayre, *The Western Sicily Earthquake of 1968* (Washington, D.C.: National Academy of Sciences, 1969) and Robert W. Kates et al., "Human Impact of the Managua Earthquake," *Science* (182) December 7, 1973:981-990. An interesting, if more openly impressionistic, account of the 1970 Peru earthquake is by the well-known social anthropologist Richard W. Patch, a four-part series in the *American Universities Field Staff Reports* 18 (6,7,8, and 9) in 1971.