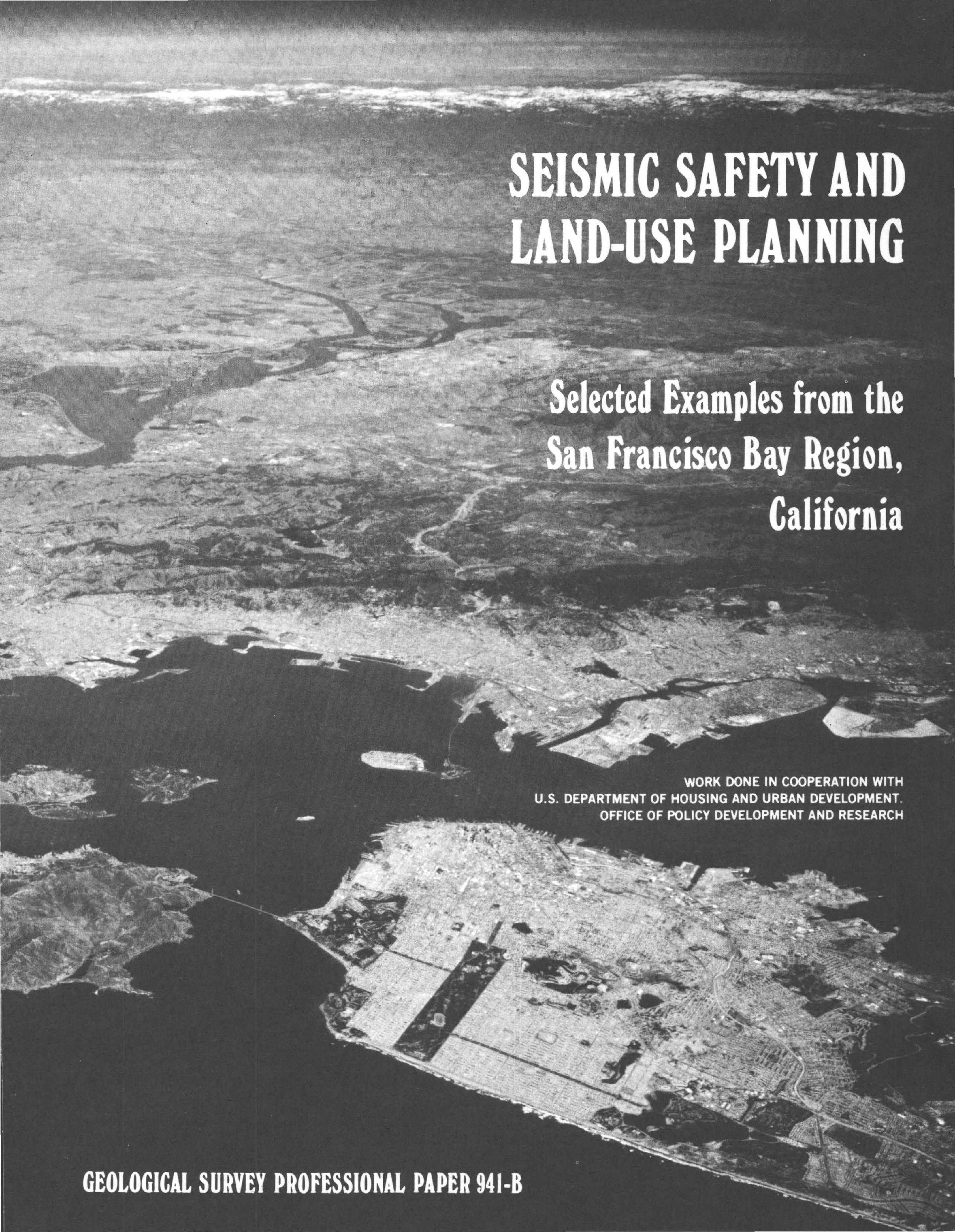

SEISMIC SAFETY AND LAND-USE PLANNING

Selected Examples from the San Francisco Bay Region, California

WORK DONE IN COOPERATION WITH
U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT.
OFFICE OF POLICY DEVELOPMENT AND RESEARCH

GEOLOGICAL SURVEY PROFESSIONAL PAPER 941-B

COVER PHOTOGRAPH of San Francisco Bay Region taken April 14, 1972, at altitude of 65,000 feet from U-2 aircraft. Courtesy National Aeronautics and Space Administration (Ames Research Center, Moffett Field, Calif.) Front shows city of San Francisco and Golden Gate at bottom, San Francisco Bay and city of Oakland in middle, Sacramento-San Joaquin Delta and crest of Sierra Nevada at top. Back shows Bolinas Lagoon and trace of San Andreas fault at bottom, San Pablo Bay in middle, Sacramento valley and crest of Sierra Nevada at top.

Seismic Safety and Land-use Planning—Selected Examples from California

By M. L. BLAIR *and* W. E. SPANGLE, WILLIAM SPANGLE *and* ASSOCIATES

BASIS FOR REDUCTION OF EARTHQUAKE HAZARDS,
SAN FRANCISCO BAY REGION, CALIFORNIA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 941-B

Methods for using seismic zonation and hazard mapping in land-use planning and regulation

Jointly supported by the U.S. Geological Survey and the Department of Housing and Urban Development, Office of Policy Development and Research, as part of a program to develop and apply earth-science information in support of land-use planning and decisionmaking

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data

Blair, M. L.
Seismic safety and land-use planning–selected examples from California.

(Basis for reduction of earthquake hazards, San Francisco Bay region, California) (Geological Survey professional paper ; 941-B)
Bibliography: p. B80-B82.
Supt. of Docs. no.: I 19.16:941-B
1. Seismology–California. 2. Land use–Planning–California.
I. Spangle, W. E., joint author. II. Title. III. Series. IV. Series: United States. Geological Survey. Professional paper ; 941-B.
QE535.2U6B56 363.3'4 79-20292

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock Number 024-001-03231-7

FOREWORD

This report is a product of the San Francisco Bay Region Environment and Resources Planning Study, an experimental program that was designed to facilitate the use of earth-science information in regional planning and decisionmaking. The study, conducted from 1970 to 1976, was jointly supported by the U.S. Geological Survey, Department of the Interior, and the Office of Policy Development and Research, Department of Housing and Urban Development. The Association of Bay Area Governments actively participated in the study and also provided liaison with other regional agencies and with local governments.

Although the study was focused on the nine-county 74,400-square-mile San Francisco Bay region, it explored a problem common to all communities: how best to plan for orderly development and growth and yet conserve our natural resource base, insure public health and safety, and minimize degradation of our natural and manmade environment. Such planning requires that we understand the natural characteristics of the land, the processes that shape it, its resource potential, and its natural hazards. These subjects are chiefly within the domain of the earth sciences—geology, geophysics, hydrology, and the soil sciences—and information from these sciences can help guide growth and development. But the mere existence of information does not assure its effective use. Relatively few planners, elected officials, or citizens have the training or experience needed to recognize the significance of basic earth-science information, and many of the conventional methods of presenting earth-science information are ill-suited to their needs.

The San Francisco Bay Region study has aided planners and decisionmakers by: identifying important geologic and hydrologic problems that are related to growth and development; providing the earth-science information that is needed to solve these problems; interpreting and publishing findings in forms understandable to and usable by nonscientists; establishing avenues of communication between scientists and users; and exploring different ways of applying earth-science information in planning and decisionmaking. More than 100 reports and maps have been produced. These cover a wide range of topics, such as flood and earthquake hazards, unstable slopes, engineering characteristics of hillside and lowland areas, mineral and water resources, solid and liquid waste disposal, erosion and sedimentation, and bay-water circulation patterns.

Seismic safety and land-use planning—selected examples from California is one of the final reports in the San Francisco Bay Region study. The authors are city and regional planners and have participated in the seismic-safety planning of several California communities. In this report they discuss the earth-science data needed for effective planning and the methods that can be used by local and regional government to reduce earthquake risk to acceptable levels. Much of the discussion is illustrated with examples drawn from experience in California where seismic-safety planning is mandated by State law. Although public attitudes, procedures, and legal requirements differ in other states, the basic earth-science needs and the planning strategies discussed are relevant wherever earthquake hazards are an issue in decisions related to public policy.

This report is the companion volume of an earlier publication, *Studies for Seismic Zonation of the San Francisco Bay Region* (U.S. Geol. Survey Professional Paper 941–A), which dealt chiefly with the geologic and hydrologic causes of earthquake damage. For conformity with the earlier report, and because the scientific literature on earthquakes customarily uses metric values, measurements in this report are expressed in metric terms followed by their English equivalents.

Robert D Brown Jr.

Robert D. Brown, Jr.
Project Director
San Francisco Bay Region Study

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By M. L. Blair and W. E. Spangle, William Spangle and Associates

ABSTRACT

Earthquakes are inevitable, but their damaging effects can be greatly reduced. Land-use planning and management based on maps showing hazards and seismic zones can be particularly effective in reducing loss of life, as well as injury and property damage from earthquakes.

Many Federal, State, and areawide programs encourage and support city and county actions to reduce seismic risk. The Federal government provides funds for seismic research, directs emergency preparedness activities, provides disaster relief, considers seismic hazards in program administration, and subsidizes insurance in tsunamiprone areas. Among the States, California's program for reducing seismic risk is the most comprehensive. Through various State agencies, California provides data on seismic hazards, establishes structural standards, regulates construction and operation of certain critical facilities, maintains an emergency preparedness plan, and requires cities and counties to prepare seismic safety plans. Although areawide agencies can reduce seismic risk in many ways, those in the San Francisco Bay region do so primarily by establishing procedures and criteria for project review to ensure that seismic hazards are considered.

Effective local planning to reduce seismic risk is based on an evaluation of the nature and degree of risk—risk being defined as a function of the nature, severity, and frequency of seismic hazards and of the exposures of persons and property to those hazards. Assessing risk starts with recognizing the overall seismicity of the area and identifying the potential for ground shaking, landsliding, liquefaction, surface rupture, and flooding. A "design earthquake" is then selected as a basis for predicting, as precisely as possible, the location and severity of the various seismic effects. Cultural features are inventoried and mapped, special attention being given to facilities such as large dams whose failure could be catastrophic, facilities necessary for disaster response, and high-occupancy structures. Using this information, the degree of seismic risk can be established and expressed in terms of potential dollar loss, deaths, and injuries, population exposure, relative risk, or scenarios describing the probable effects of a design earthquake. Plans and regulations can then be formulated to reduce risk to a level the public is willing to accept.

Local land-use planning and regulation can be used to reduce seismic risk, particularly in undeveloped or sparsely developed areas. Many cities and counties in California are successfully integrating plans to reduce seismic risk into their general planning programs. Methods include considering seismic hazards in analyzing land capability, developing land-use policy and regulations consistent with seismic risk, and establishing project review procedures to ensure consideration of seismic hazards in land-use decisions and land-development practices. Plans and programs to reduce seismic risk can also be formulated to respond to scientifically valid earthquake predictions and to direct postearthquake reconstruction.

INTRODUCTION

> Then the thunder crashed and rolled, and lightning flashed; and there was a great earthquake of a magnitude unprecedented in human history.
>
> The great city of "Babylon" split into three sections, and cities around the world fell in heaps of rubble***
>
> And islands vanished and mountains flattened out***
>
> (Revelations 16: 18–20)

Earthquakes have inspired fear and awe throughout man's time on earth. Often attributed to the "wrath of God" or vengeful spirits, earthquakes dramatically confront man with the insignificance of his power before the forces of nature. As Charles Darwin (as quoted in Elders, 1974, p. 20) observed in 1835 when the ground convulsed beneath him during an earthquake in Chile:

> A bad earthquake at once destroys our oldest associations; the earth, the very emblem of solidity, has moved beneath our feet like a thin crust over a fluid;***one second of time has created in the mind a strange idea of insecurity, which hours of reflection would not have produced.

Indeed, individuals are virtually helpless during the course of an earthquake. They must "ride it out" wherever they happen to be at the time the earthquake strikes. But helplessness is confined to those seconds when the ground is shaking; man has the knowledge and ability to avert many of the damaging effects of earthquakes.

The basic premise of this report is that actions can and should be taken to lessen the impact of earthquakes in seismically active areas. Based on geologic and seismologic data, land uses and design and occupancy of structures can be adjusted to reduce significantly the loss of life, injury, and damage from earthquakes. Failure to make these adjustments will result in needlessly high costs in human suffering and property damage when the as yet unpredictable, but inevitable, earthquakes occur.

PURPOSE AND SCOPE

A major aim of the San Francisco Bay Region Environment and Resources Planning Study has been to gather information on the complex effects of earthquakes and to present such information in a form directly applicable to land-use planning and decisionmaking. A report edited by Borcherdt (1975) presents the earth-science phase of this study. It consists of a series of scientific articles defining earthquake hazards and methods of predicting their relative severity throughout a planning area.

Seismic zones delineating the different effects of earthquakes, ranked in terms of relative severity, are identified in the Borcherdt report. Such seismic zonation provides the geological and seismological basis for relating land-use plans and regulations, structural design criteria, construction practices, and emergency response plans to recognized earthquake hazards.

A map or set of maps may be prepared showing zones having a similar degree of hazard. In conjunction with maps of cultural features, these hazard maps indicate areas where the same kinds of risk-reduction methods may be successfully applied. The seismic zones indicate the wide geographic variation in the effects and local geologic conditions. If areas subject to severe effects can be accurately identified, land use and development decisions can reflect potential risk; and significant loss of life, injury, and damage can be avoided.

This report is a companion volume to the Borcherdt report (Professional Paper 941–A) and shows how information on seismic hazards can be effectively incorporated into land-use planning and decisionmaking to reduce seismic risk. The first report (Professional Paper 941–A), was written by earth scientists to present the state-of-the-art for seismic zonation of the San Francisco Bay region. This report (Professional Paper 941–B), is written by planners, and it outlines possible applications of seismic hazard information with emphasis on land-use planning and regulation.

Success in increasing seismic safety requires an interdisciplinary effort including earth scientists, engineers, and planners. To be useful, scientific and engineering data must be translated to a form understandable to planners and public policy makers. In some cases, the engineer can serve as an intermediary between scientist and planner. Engineering interpretations relate seismic information directly to issues of project feasibility, structural design, and cost; thus they provide an important input to planning decisions.

However, in dealing with broader relationships of land-use patterns and intensities of seismic hazards, the planner must draw more directly from basic geologic and seismologic information. A communication bridge between scientist and planner must be established. This report is an attempt to establish such a bridge. In this report, the seismologic information needed by planners is summarized as simply as possible consistent with accuracy. Although written by planners, the report was carefully reviewed by earth scientists at the U.S. Geological Survey, ensuring that the geologic information is presented and interpreted correctly.

Seismic hazards are briefly defined to provide the background for a discussion of ways of improving seismic safety. Federal, State, and areawide roles in response to seismic hazards are summarized, and examples are given of specific State and regional programs drawn from California and the San Francisco Bay region.

A systematic approach to assessing seismic risk is set forth, and examples of various techniques are summarized. Typical planning responses of local government to seismic risk are shown to relate to the nature of the hazard and the level of development in areas identified as hazardous. Examples of local planning actions are presented wherever possible.

The geologic information upon which this report is based pertains to the San Francisco Bay region, thus, most of the planning examples are drawn from this area. The methods of developing and interpreting information and the ways to improve seismic safety used by bay region governments are, however, directly applicable to other areas of the country with similar seismic hazards and governmental organizations. Planners and decisionmakers in most earthquake-prone areas of the United States may find that this report provides a useful framework on which to base their ongoing planning activities.

OVERVIEW OF SEISMIC HAZARDS

Knowledge of the nature and cause of earthquakes and their effects has increased tremendously in the last decade. Seismology has both contributed to, and benefited from, a revolutionary new concept—the theory of plate tectonics. According to this theory, the earth's lithosphere or outer shell is formed of a mosaic of a dozen or more rigid plates in constant motion relative to each other (Dewey, 1972, p. 56). Most of the world's large-scale active geologic processes—vulcanism, mountain building, formation of oceanic trenches, and earthquakes—are concentrated at or near plate boundaries (Press, 1975, p. 15).

Records of seismic activity have been important in the development of the plate tectonic theory. As shown in figure 1, recorded earthquake epicenters, which tend

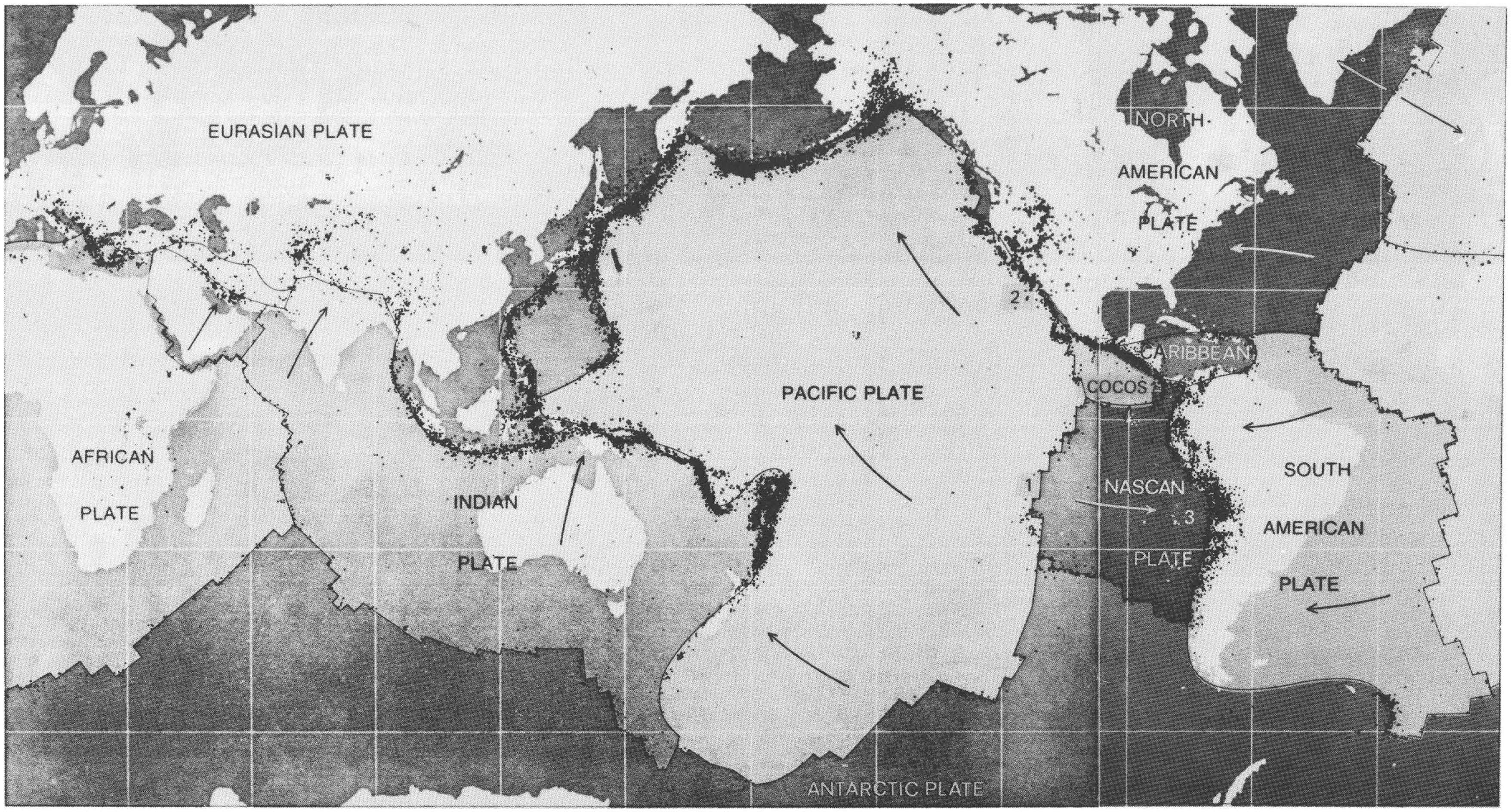


FIGURE 1.—Plate boundaries and epicenters of 30,000 earthquakes recorded between 1961 and 1967. The numbers mark an example of each boundary: 1 is a midoceanic ridge axis boundary forming the East Pacific Rise; 2 is a transform boundary defined by the San Andreas fault; and 3 is a subduction zone along the west coast of South America. The arrows show direction of movement (Press, 1975, p. 16).

to cluster along plate boundaries, have been used to locate these boundaries. The concept of plate tectonics in turn provides a long-missing explanation of the underlying cause of earthquakes occurring along plate boundaries according to Press, (1975, p. 15),

stresses build up where the relative motion of the plates is resisted by frictional forces. When the stress increases to the point where it exceeds the strength of the rocks of the lithosphere or overcomes the frictional forces at the boundary of a plate, fracturing occurs and an earthquake results.

Plate boundaries are of three types, each with distinctive geologic and seismologic characteristics (Dewey, 1972, p. 57–59).

(1). Mid-oceanic ridge axes where plate boundaries are diverging. In these areas hot basaltic material is welling up from the earth's interior and cooling to form new crustal material. Here the focus of earthquakes is usually shallow (less than 70 kilometers, 43 miles).

(2). Transforms where the plates are sliding past each other. Lithospheric materials are not created or consumed along these boundaries; volcanic activity is limited, and earthquakes are shallow.

(3). Subduction zones where plates are converging, one plate diving under the other to be eventually consumed in the asthenosphere—the molten or semimolten layer of the earth's mantle beneath the solid lithosphere. This zone is associated with deep oceanic trenches and volcanic island arcs having shallow, intermediate (70–300 km, 43–186 mi), and deep (300–700 km, 160–434 mi) earthquakes; and with continental areas having primarily shallow earthquakes and high mountain ranges created by the compressive force of the converging plates.

Examples of each type of plate boundary are shown by the numbers 1, 2, and 3 in figure 1. The San Andreas fault system marks the boundary between the Pacific and North American plates. The boundary is a transform—the plates move past each other. The portion of California, including Los Angeles and part of the bay region west of the San Andreas fault is on the Pacific Plate which is moving northwest on an average of a few centimeters a year (fig. 2). At this rate it would take Los Angeles about 10 million years to come abreast of San Francisco Bay (Yanev, 1974, p. 26). Plate movement is not uniform, however; portions of the plate boundary including that passing through the bay region have been locked for many years. It is considered highly probable that these locked portions will eventually give, resulting in earthquakes.

The San Andreas fault system is part of the Circum-Pacific Earthquake Belt, sometimes called the "ring of fire". This belt, shown in figure 3, outlining the Pacific, Cocos, and Nascan plates, is where intense volcanic and seismic activity takes place. Nearly 80 percent of the world's earthquakes occur along this belt,

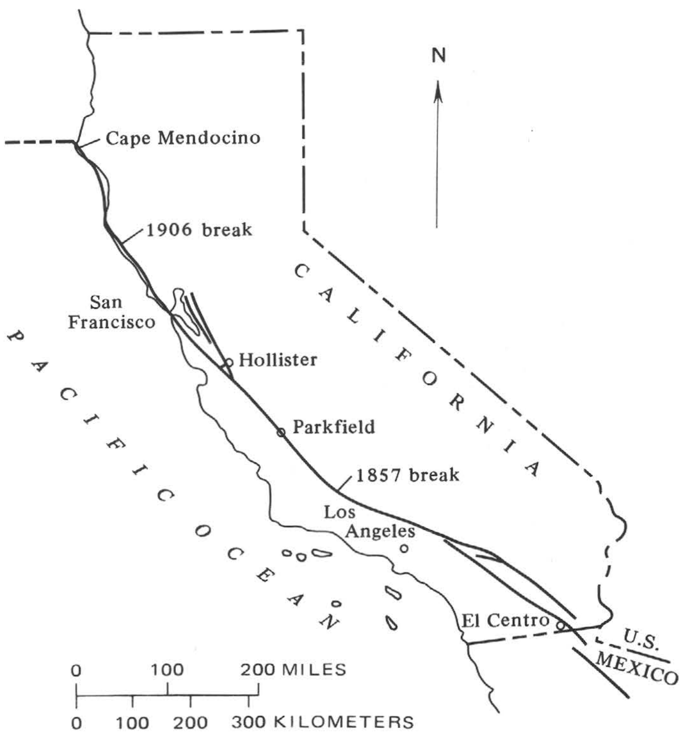


FIGURE 2.—Approximate location of San Andreas fault in California.

accounting for the relatively high seismicity of the west coast of North America.

Not all earthquakes can presently be explained by plate movements. Midplate earthquakes, hundreds of miles from known plate boundaries, do occur, and scientists are not yet agreed on their causes. In North America the most widely felt earthquakes ever recorded were centered in New Madrid, Missouri. The largest of these shocks was felt nearly everywhere in the United States east of the Rocky Mountains (U.S. Geological Survey, 1971, p. 4).

Figure 4 shows a map of relative seismicity in the United States by S. T. Algermissen (1969). This seismic risk map of the United States is based on the known distribution of damage from earthquakes. It has been incorporated into the 1973 Uniform Building Code as the basis for recommending differing structural standards for risk zones 1, 2, and 3. The map indicates that most of the country can expect at least minor damage from earthquakes.

SEISMIC HAZARDS DEFINED

An understanding of plate tectonics is useful in explaining why and where earthquakes are likely to occur. And information based on experience from past earthquakes, as summarized in the seismic risk zone map of the United States, gives an overall picture of the relative seismicity of different parts of the country.

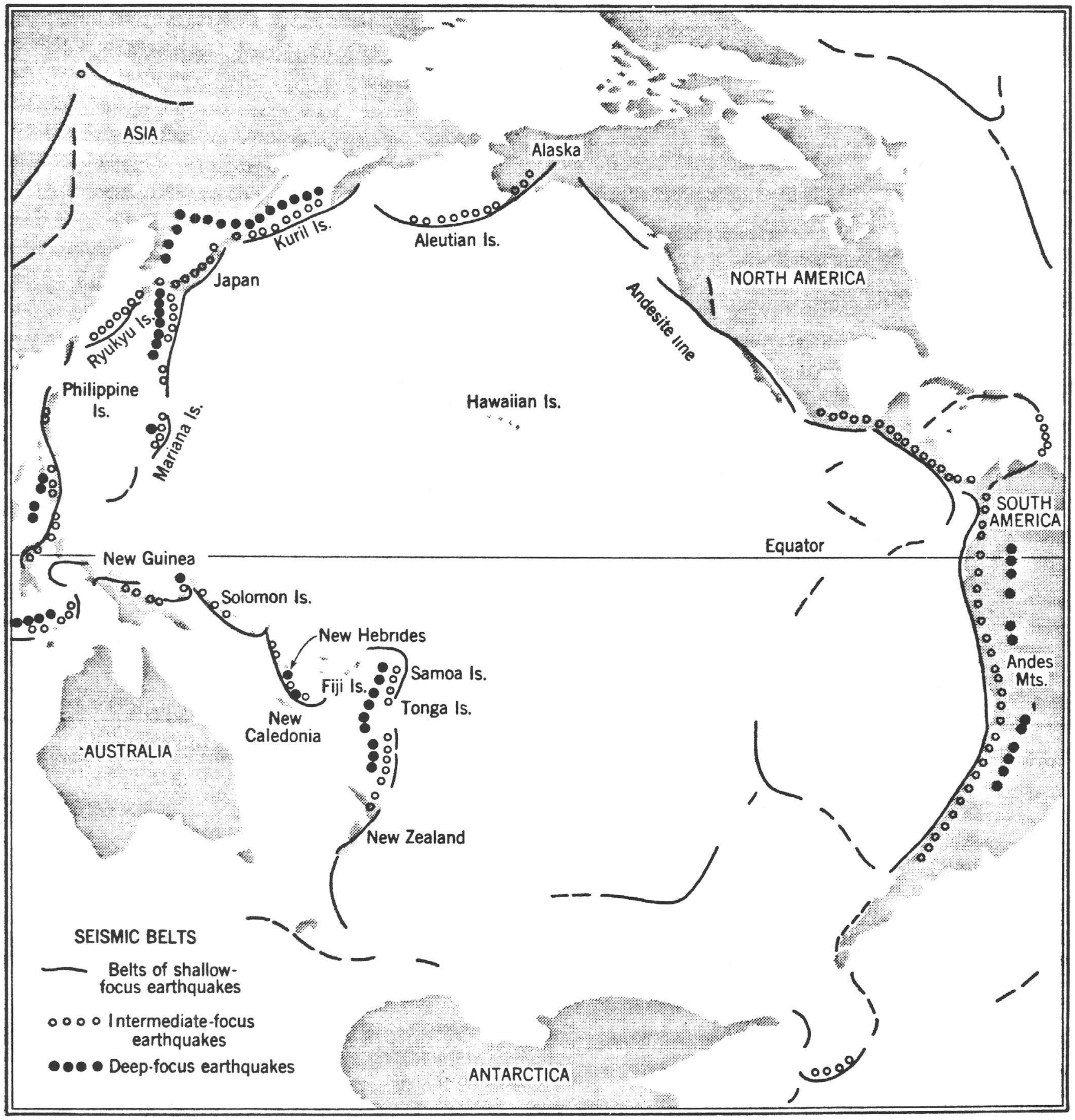


FIGURE 3.—The circum-Pacific Earthquake Belt showing shallow, intermediate, and deep focus earthquakes (figure adapted from Strahler, 1971, p. 443).

However, this is only the tip of the iceberg in defining earthquake hazards.

An earthquake unleashes a complex chain of natural events often catastrophic, and difficult to predict. The major geologic effects of earthquakes include surface faulting (ground rupture), ground shaking, ground failure, and flooding from tsunamis and seiches. These earthquake hazards are defined below.

SURFACE FAULTING

Faults are "planes or surfaces in earth materials along which failure has occurred and materials on opposite sides have moved relative to one another in response to the accumulation of stress" (Nichols and Buchanan-Banks, 1974, p. 2). Fault movement does not always extend to the surface of the earth, but when it

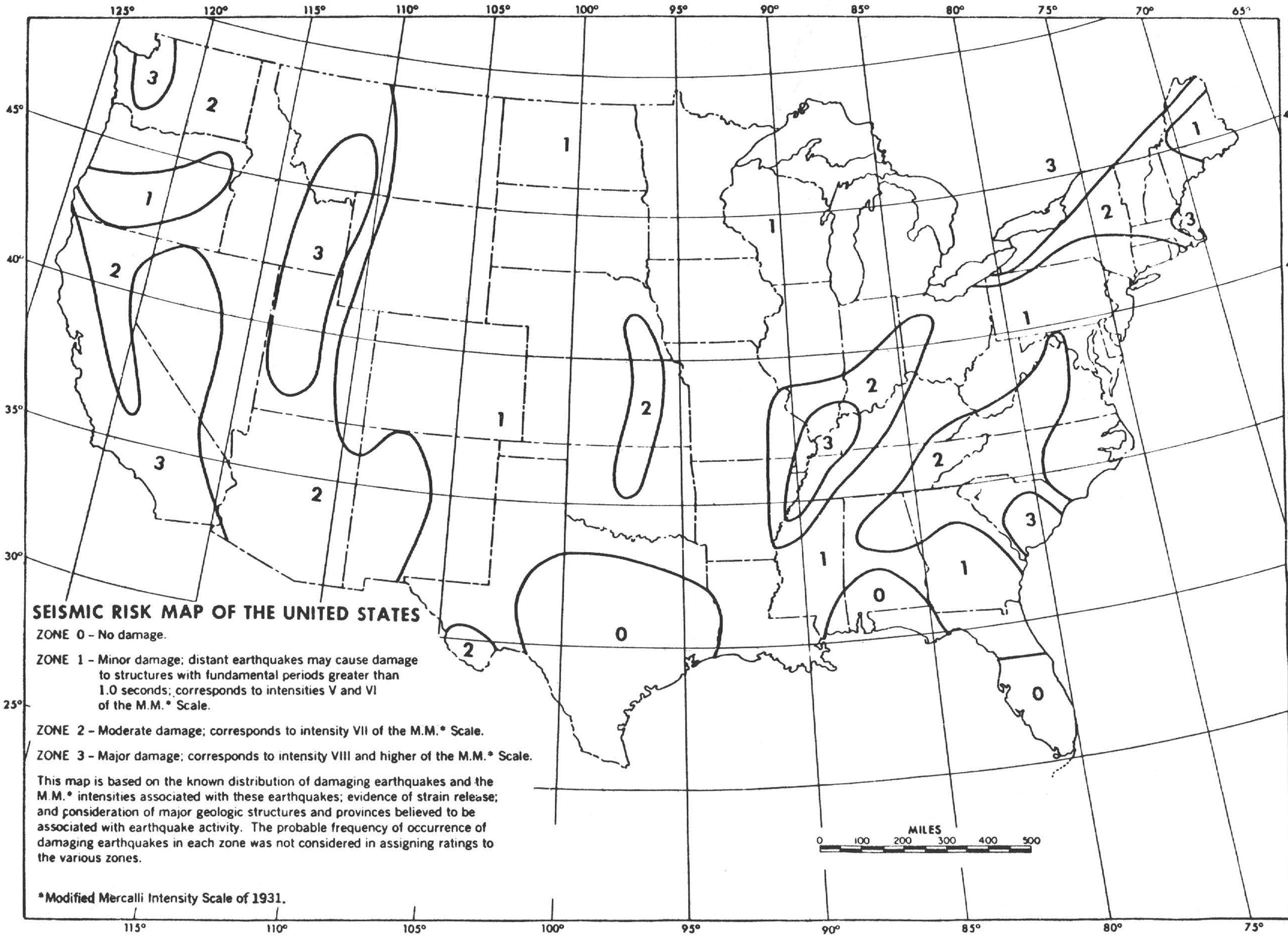


FIGURE 4.—Seismic risk zones of the United States based on damages associated with historic earthquakes (Algermissen, 1969).

does, surface movement often produces a line or narrow zone of visible features such as scarps, grabens (trenches), fractures, and "mole tracks" or pressure ridges. The vertical or horizontal displacement that accompanies surface faulting can destroy structures located astride the fault.

Faults are often classified according to the direction of movement and whether movement is predominantly horizontal or vertical. Figure 5 shows the four types of fault movement. The San Andreas fault is a right-lateral strike-slip fault.

GROUND SHAKING

Ground shaking usually causes the most widespread damage (Nichols and Buchanan-Banks, 1974). Ground shaking contributes to losses not only directly through vibratory damage to manmade structures, but also indirectly by triggering secondary effects such as landslides or other kinds of ground failure.

GROUND FAILURE

Most ground failure from earthquake shaking results in displacement in the ground surface due to loss of strength of underlying materials. Earthquake shaking may jar loose basically unstable hillside materials. Other kinds of ground failure also accompany earthquakes. The most common result from liquefaction—a process by which saturated, clay-free sands or silts are transformed from a solid to a liquid state. Ground failure occurs when the liquefied material is not confined and flows out toward a "free face". Several forms of ground failure may be caused by liquefaction. In the San Francisco Bay region, laterally spreading landslides are likely to occur (Youd and others, 1975). Lateral spreading is "movement of a soil mass down a mild slope with resulting cracks, fissures, and differential settlements within and near the margins of the slide mass." (Borcherdt, 1975, p. A94). Any type of ground failure can cause severe damage to manmade structures.

TSUNAMIS AND SEICHES

Tsunamis are large ocean waves generated by offset of the sea floor caused by faulting or large submarine landslides. Huge waves, which can travel thousands of kilometers at velocities of 500–650 km/hr (300–400 mi/hr), can be generated by such undersea movement. Far at sea, these waves are low and kilometers long; as they approach shore, they begin to drag on the bottom, slow down, and pile up, sometimes reaching heights of 15m (50 ft) or more. The effects of tsunamis are in part determined by the configuration of the local shoreline and the sea bottom (Nichols and Buchanan-Banks, 1974).

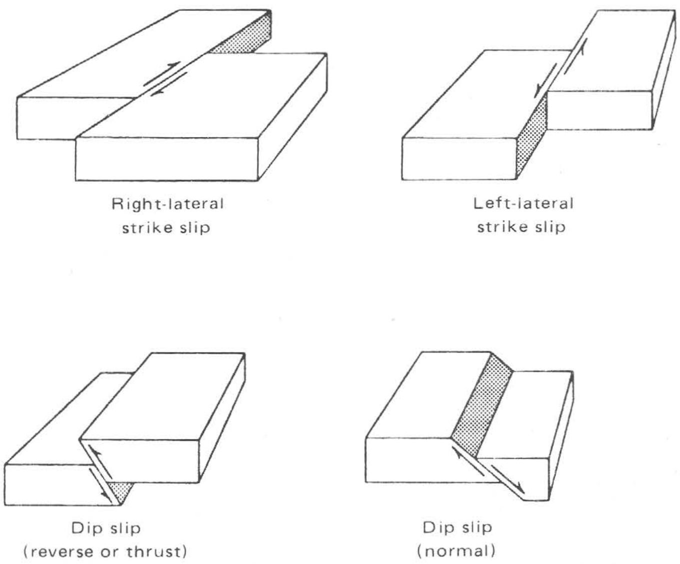


FIGURE 5.—Four types of fault movement, characterized by the sense of movement relative to the fault and to the horizontal. Most faults in the bay region show right-lateral strike slip, the characteristic sense of movement for the San Andreas fault. Movement on oblique-slip faults has both strike- and dip-slip components (Borcherdt, 1975, p. A12).

Seismic seiches, or earthquake-generated standing waves, occur within enclosed or restricted bodies of water (lakes, reservoirs, bays, and rivers). They are periodic oscillations ("sloshing") of water in such bodies. Seiches may raise and lower a water surface by anywhere from a few centimeters to many meters, causing severe flooding and damage from wave action. Catastrophic flooding can also result during an earthquake from dam failure or from large-scale landsliding into a reservoir or bay.

EARTHQUAKE DAMAGE

Singly or in combination, the various seismic hazards can raise havoc with the natural and manmade environment. In a matter of seconds, a hillside may be sheared in two, whole towns may be leveled, and the lifelines of communities may be ruthlessly disrupted.

The structures destroyed and damaged by an earthquake provide scientists and engineers with examples for the study of seismic hazards and their effects on different kinds of structures and facilities. Most of our information concerning the damaging effects of earthquakes comes from detailed studies carried out in the aftermath of an earthquake.

The moderate San Fernando earthquake (6.4 on the Richter scale) has proved especially informative because the development patterns and population density in the damaged area are characteristic of suburban areas throughout California and other western states.

Buildings, other structures, and public utilities varied in age and structural design and were built or installed under a variety of code regulations and standards. Therefore, the observed effects of this earthquake helped to determine the kind of damage that can be expected from moderate earthquakes in many areas in the western United States.

The San Fernando earthquake was caused by movement along the San Fernando fault, a north-dipping thrust fault (fig. 6). At the surface, fault movement was as much as 1.8 meters (6 feet) horizontally and 1.8 meters (6 feet) vertically. The earthquake triggered strong ground shaking, and ground failure (cracking, liquefaction, and landslides), causing 58 deaths and over $500,000,000 in structural damage (California State Legislature, Joint Committee on Seismic Safety, 1974, p. 215). The loss of life would have been considerably greater if the earthquake, which occurred at 6:01 a.m., had occurred later in the day when more cars were on the road, and more people were walking along the streets.

Study of the San Fernando earthquake showed that earthquake forces in the most heavily shaken area of the San Fernando Valley far exceeded those used as a basis for building-code structural standards, and were considerably beyond those anticipated by many engineers for a moderate earthquake (Steinbrugge and others, 1971). In areas experiencing the strongest ground shaking, many modern, supposedly earthquake-resistant structures collapsed or were severely damaged. In other areas damage was within expected limits.

The major effects of the San Fernando earthquake are summarized below.

DAMAGE TO BUILDINGS

Woodframe dwellings meeting current building-code standards performed relatively well (fig. 7*A*). One-story dwellings performed better than two-story dwellings. Mobile homes were poorly braced and consequently were damaged (fig. 7*B*); however, total losses were extremely rare (Steinbrugge and others, 1971, p. VII).

Unreinforced masonry buildings performed poorly, not only in the area of strong shaking, but also in areas, including downtown Los Angeles, 24–40 kilometers (15–25 mi) from the epicenter (California State Legislature, Joint Committee on Seismic Safety, 1974, p. 215).

In the area hardest hit, light industrial buildings with wood roofs supported by "tilt-up" reinforced concrete or by reinforced unit masonry exterior walls (brick or hollow concrete block) suffered damage averaging nearly 18 percent of building value (fig. 7*C*). These buildings sustained an average loss of less than 3 percent for the San Fernando Valley as a whole (Steinbrugge and others, 1971, p. VII).

The ability of high-rise buildings to withstand ground shaking was only partially tested, because the nearest ones were 24–40 km (15–25 mi) from the earthquake epicenter. In general, modern steelframe and reinforced-concrete highrise buildings performed well structurally. However, nonstructural damage to interior partitions, windows, ceilings and light fixtures, elevators, and air conditioning and emergency power equipment was considerable. In downtown Los Angeles (about 24 km (15 mi) from the San Fernando Valley) most highrise buildings, built before more stringent structural standards were enacted after the 1933 Long Beach earthquake (M6.3) did not perform well; losses ranged from 5 to 26 percent of market value (Steinbrugge and others, 1971).

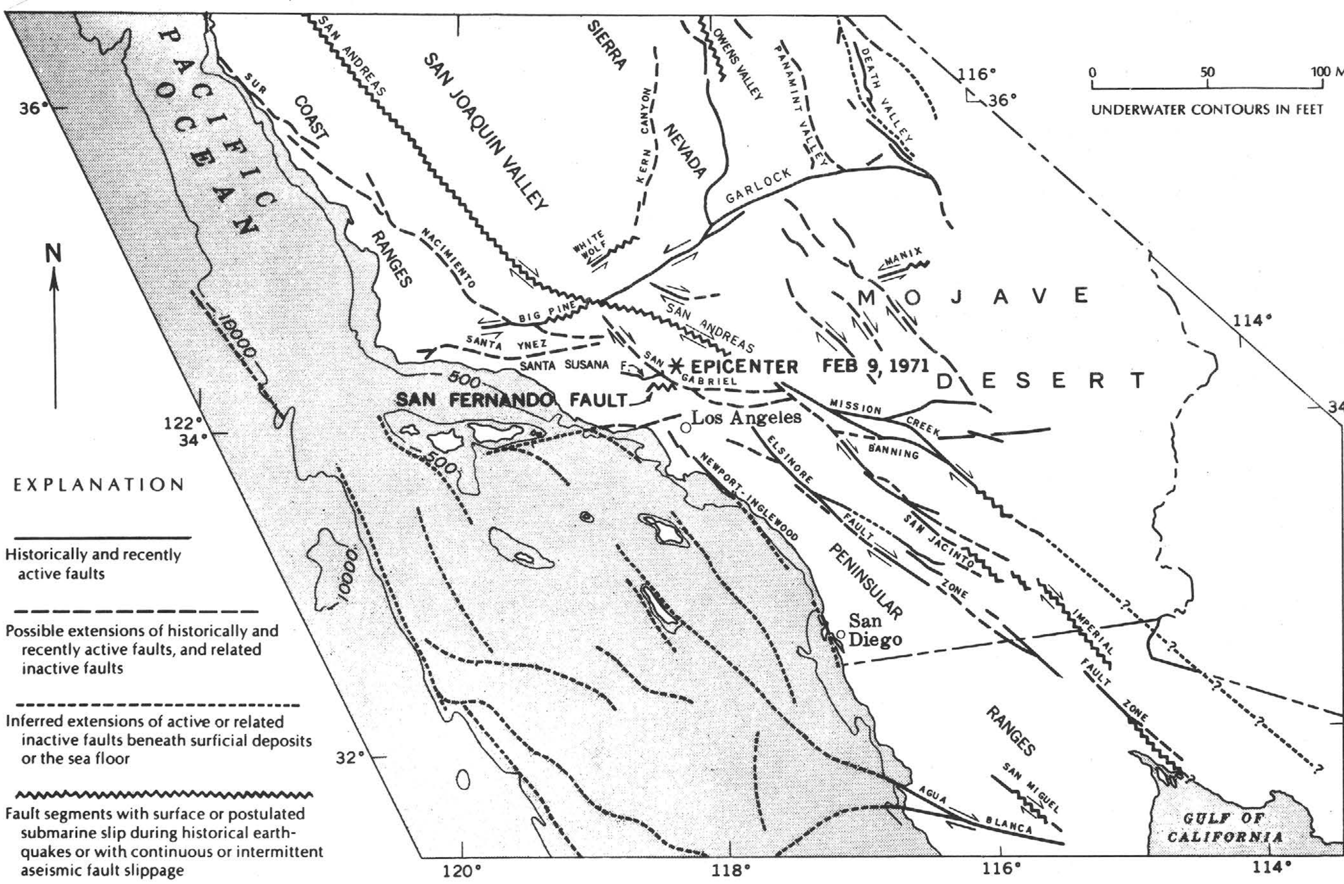
In the area of strong ground shaking, four major hospitals were damaged, did not remain functional, and were evacuated (fig. 8*A* and *B*). One of these hospitals was a pre-1933 structure, but the other three were built since 1960 in accordance with modern codes (California State Legislature, Joint Committee on Seismic Safety, 1974, p. 216).

Schools built according to provisions of the Field Act (see section on "Structural Standards") fared well, in contrast to schools built prior to 1933 and not modified to meet the earthquake provisions of that act.

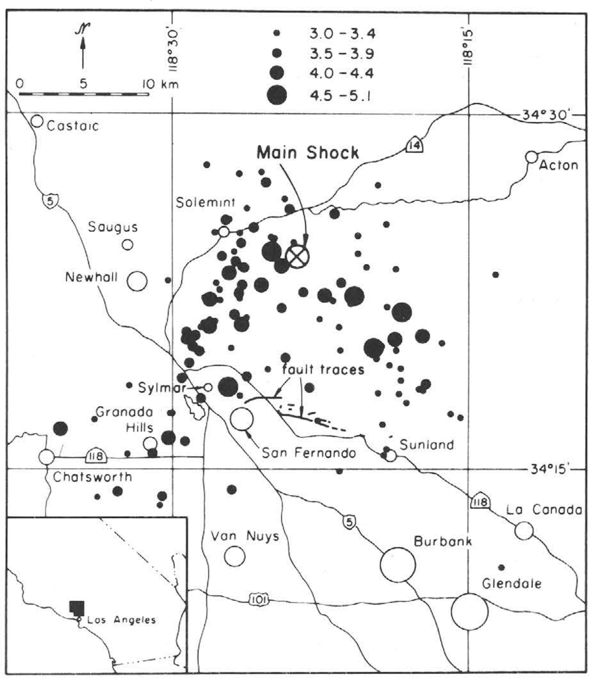
DAMAGE TO DAMS

Two hydraulic-fill earthen dams in the area of strong shaking were damaged. Damage to the lower Van Norman Dam (fig. 9) reduced effective dam height by about 9 m (30 ft). Fortunately, the water level was about 10½ m (35 ft) below the crest, and massive failure of the dam was avoided. Had the water level been higher, an area inhabited by 80,000 people would have

FIGURE 6.—Faults in southern California and epicenters associated with San Fernando earthquake. *A*, Major historically and geologically recent active faults in southern California (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 7). *B*, Epicenters of the main shock and aftershocks of magnitude 3.0 and greater of the San Fernando earthquake, February 9 through March 1, 1971. The earthquakes were located along a north-dipping thrust fault and are shallow toward the south edge of the map and deep toward the north (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 17). ▶


PACIFIC OCEAN
SAN ANDREAS
SAN JOAQUIN VALLEY
SIERRA NEVADA
KERN CANYON
OWENS VALLEY
PANAMINT VALLEY
DEATH VALLEY
SUR
COAST RANGES
GARLOCK
NACIMIENTO
WHITE WOLF
MANIX
MOJAVE DESERT
BIG PINE
SANTA YNEZ
SANTA SUSANA F.
SAN GABRIEL
EPICENTER FEB 9, 1971
SAN FERNANDO FAULT
Los Angeles
MISSION CREEK
BANNING
ELSINORE FAULT ZONE
NEWPORT-INGLEWOOD
SAN JACINTO
PENINSULAR RANGES
IMPERIAL FAULT ZONE
San Diego
SAN MIGUEL
AGUA BLANCA
GULF OF CALIFORNIA
N
500
10000
18000
0 50 100 MILES
UNDERWATER CONTOURS IN FEET
36°
34°
32°
122°
120°
118°
116°
114°
EXPLANATION
Historically and recently active faults
Possible extensions of historically and recently active faults, and related inactive faults
Inferred extensions of active or related inactive faults beneath surficial deposits or the sea floor
Fault segments with surface or postulated submarine slip during historical earthquakes or with continuous or intermittent aseismic fault slippage

A


3.0 - 3.4
3.5 - 3.9
4.0 - 4.4
4.5 - 5.1
0 5 10 km
118°30'
118°15'
34°30'
34°15'
Castaic
Main Shock
Acton
Solemint
Saugus
Newhall
fault traces
Sylmar
Granada Hills
San Fernando
Sunland
Chatsworth
La Canada
Van Nuys
Burbank
Glendale
Los Angeles
14
5
118
101

B

FIGURE 7.—Damage to small buildings caused by the San Fernando earthquake. *A*. Almetz Street, between Veterans Administration and Olive View (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 214).

been inundated (California State Legislature, Joint Committee on Seismic Safety, 1974, p. 216). Other dams constructed by hydraulic-fill procedures are located throughout California and in other states where earthquakes are likely to occur. Those in California have been reexamined by the California Division of Dam Safety since the San Fernando earthquake, and some have been modified or have had allowable reservoir water levels reduced.

DAMAGE TO UTILITIES

Within the area of strong shaking, utilities were severely damaged. Displacement along the San Fernando fault cut or damaged underground water, sewer, and gas pipes. Damage also occurred from ground shaking, landslides, and liquefaction (California Legislature Joint Committee on Seismic Safety, 1974, p. 216). In addition, electric substations suffered heavy damage (fig. 10). Communication systems were damaged, hindering effective response by fire trucks and other emergency services. The telephone system was severely overloaded, and service was disrupted when equipment toppled in the central telephone office in Sylmar. Automatic alarm systems suffered from unreadable signals, equipment overload, destroyed lines, and insufficient staff to meet the demands of the postearthquake situation (Steinbrugge and others, 1971, p. VIII).

DAMAGE TO TRANSPORTATION SYSTEMS

The freeway system in the area of strong ground shaking was severely damaged. Forty-two bridges or overpasses were damaged and five collapsed. The interchange between the Golden State and Foothill freeways collapsed completely, killing two persons (fig. 11). Damage to the highway and road systems totaled over $36 million (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 5).

FIRE

Lack of strong winds and combustible materials helped to keep the postearthquake fires under control. Firemen quelled 109 earthquake-related fires. Losses from fire exceeded $1 million (Steinbrugge and others, 1971, p. VIII).

The San Fernando earthquake was a devastating experience for the people of southern California. Realizing that a higher magnitude earthquake or one on a fault closer to a major urban area would have had even more catastrophic effects, the State Legislature and many State and local agencies began to review their actions and operations in terms of seismic risk.

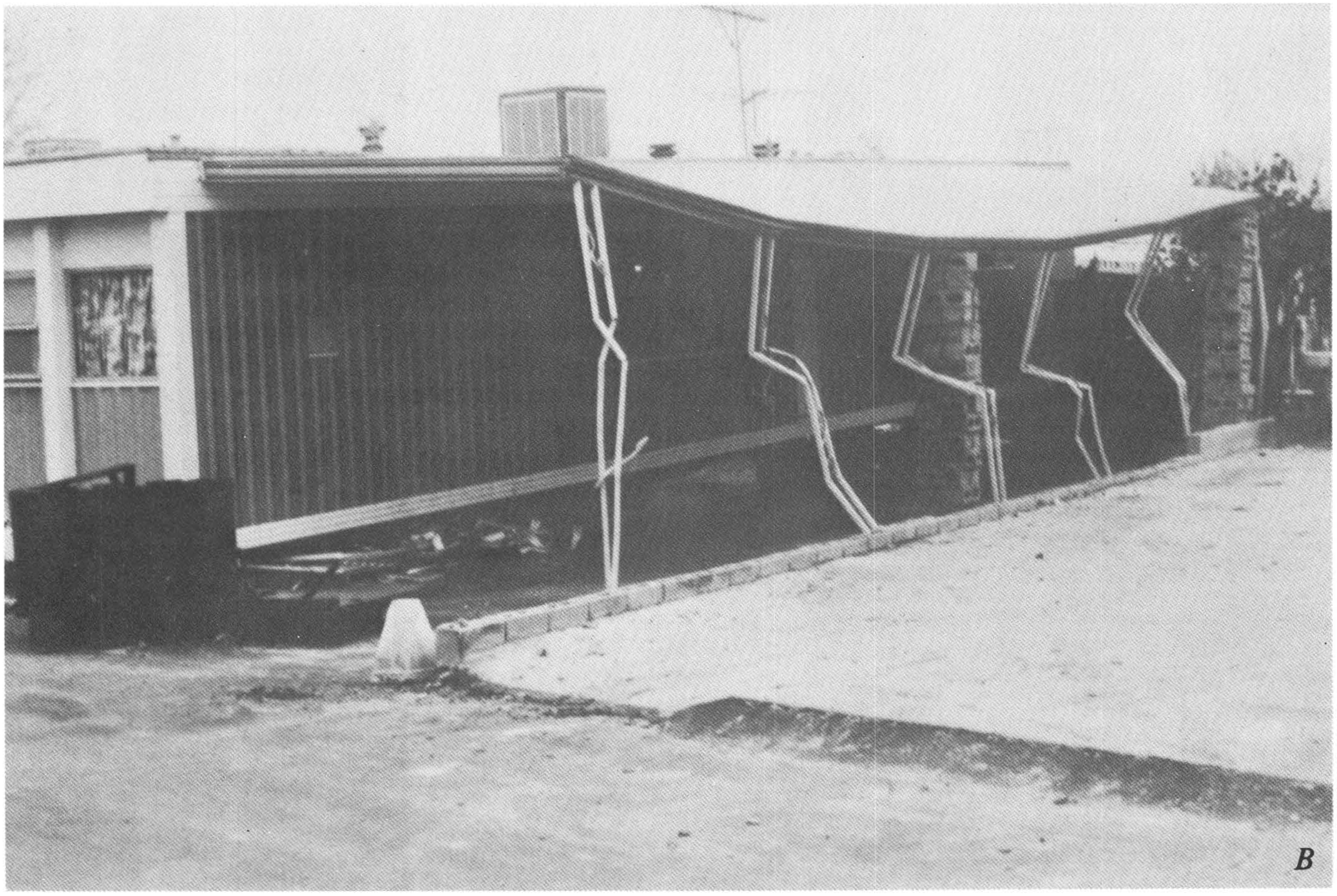


FIGURE 7 (Continued).— *B*, Mobile home shifted off its foundations (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 219).

Many of the actions undertaken in California to increase seismic safety stem from the sobering experience of the San Fernando earthquake.

EARTHQUAKE MAGNITUDE AND INTENSITY

The severity of an earthquake can be expressed in terms of magnitude or intensity. Magnitude is an objective measure of the size or energy release of an earthquake at its source. The magnitude rating of an earthquake is based on seismic wave amplitude recorded by a seismograph, of specified type, calculated to be 100 km (62 mi) from the epicenter. On the Richter scale, magnitude is expressed as Arabic whole numbers and decimals. The scale is logarithmic; the wave amplitude of each number on the scale is 10 times greater than that of the previous whole number. Thus the wave amplitude of an earthquake of Richter magnitude 4 is 10 times greater than that of a Richter magnitude 3.

Energy release from an earthquake can be calculated from the measured wave amplitude. As the scale is structured, energy release, or earthquake size, increases approximately 32 times for each larger whole number on the scale. Thus the amount of energy released from a magnitude 4 earthquake is 32 times greater than from a magnitude 3.

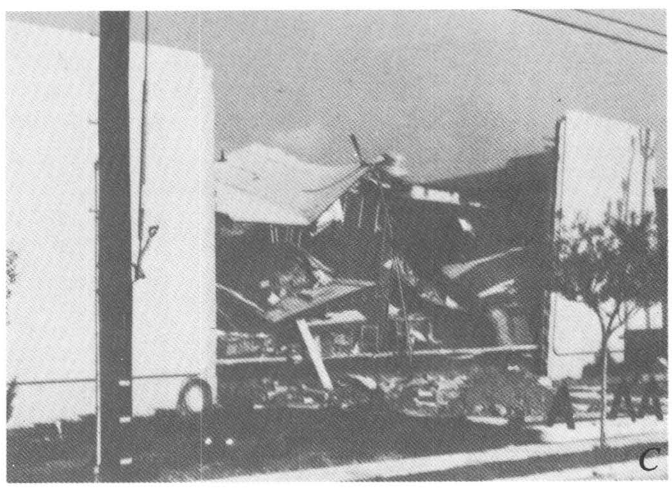


FIGURE 7 (Continued).—*C*, Tilt-up wall panel failed, bringing down portions of the roof and mezzanine floor, Arroyo light industrial tract (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 202).

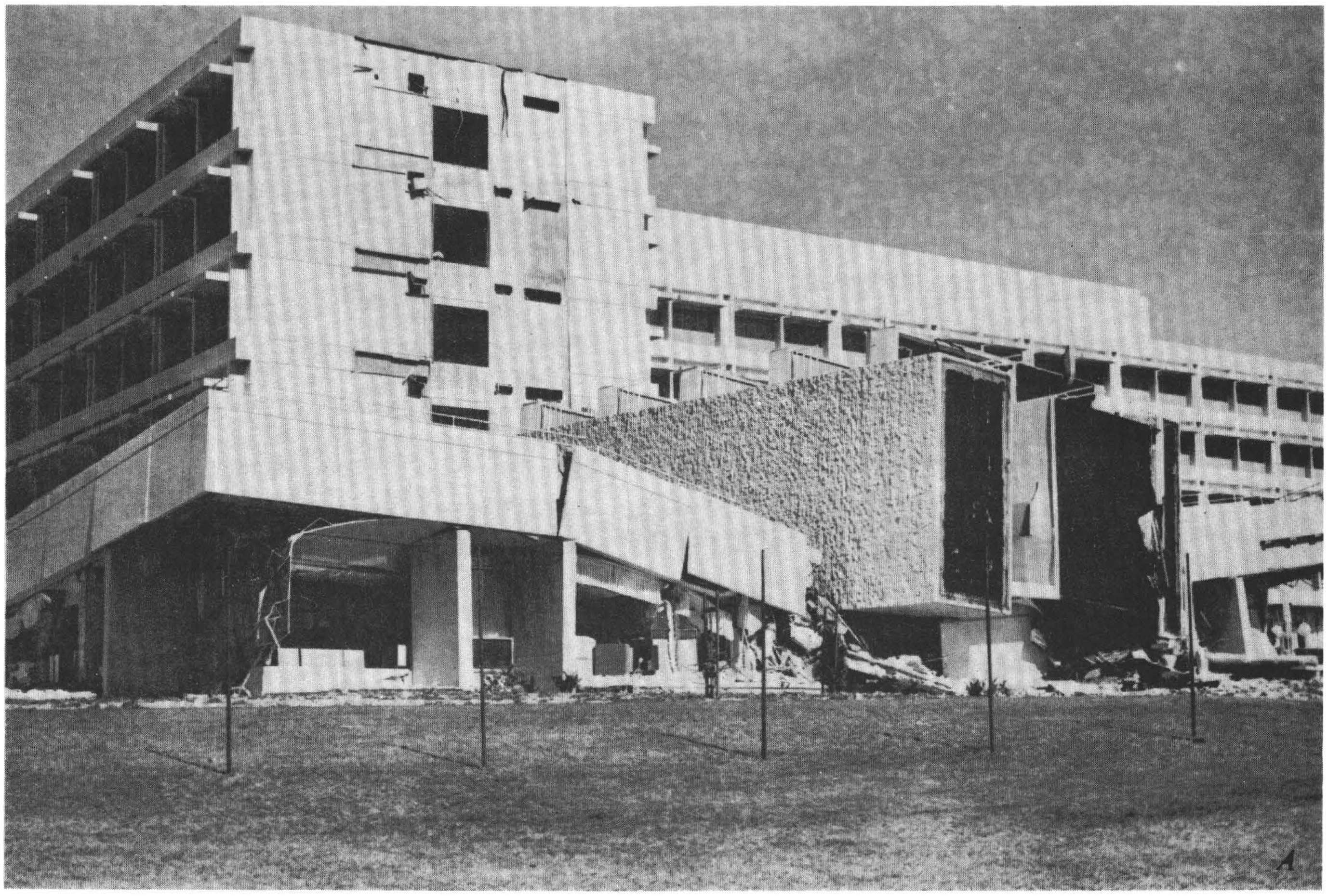


FIGURE 8.—Damage to hospitals caused by the San Fernando earthquake. *A*, Southwest corner of Medical Treatment Building of Olive View Hospital, completed in 1970. South stair tower overturned and collapsed on one-story portion, roof at stair tower is center right (Steinbrugge and others, 1971, p. 45).

The logarithmic nature of the Richter scale is often misunderstood; consequently, the actual difference in size or energy release (and potential for damage) between earthquakes of different magnitudes is often underestimated. Table 1 shows the relationship between differences in magnitude and differences in earthquake size.

The Richter scale expresses relative values. The actual amount of energy released from a large magnitude earthquake is dramatically higher than from a moderate earthquake. Figure 12 shows the relationship between magnitude and energy measured in tons of TNT.

The Richter scale is open ended with no upper limit. However, the physical strength of the earth's crust probably defines the upper limit of the scale. Even the most durable geologic formations are considered likely to break before strain builds to the point that a 9 magnitude earthquake could occur. The largest recorded earthquake was magnitude 8.9.

Intensity ratings are a totally different way of expressing earthquake severity. Intensity is a subjective measure of the observed effects of an earthquake. Although there are several intensity scales, the Modified Mercalli intensity scale, in use since 1931, is the most common. On this scale, intensity is expressed in Roman numerals from I to XII. Table 2 outlines the Modified Mercalli intensity scale. On this scale intensities are based on human reactions, the nature of the structural damage, and the geologic effects. At any given location, intensity from an earthquake varies with magnitude, distance from the fault, and local geologic conditions.

Figure 13 shows the intensity pattern of the 1971 San Fernando earthquake. Intensity was highest (XI) near the epicenter, decreasing gradually with distance from the fault. However, the width and shape of the intensity bands reflect geologic conditions. Because of this dependence of intensity on local geology, earthquakes of the same magnitude may produce quite dif-

FIGURE 8 (Continued).— *B*, Air view of Veterans Administration Hospital. Collapsed portion constructed in 1926 before earthquake resistive design was required (Steinbrugge and others, 1971, p. 55).

FIGURE 9.—Slide damage to lower Van Norman Dam (California State Legislature, Joint Committee on Seismic Safety, 1972, p. 29).

ferent intensities and intensity patterns. Magnitude and intensity are measures of different aspects of an earthquake and are related to each other only in the general sense that maximum intensities tend to increase with magnitude.

PROFESSIONS INVOLVED IN SEISMIC RISK REDUCTION

Reducing seismic risk through land-use planning entails a coordinated effort on the part of professionals from many fields. Land-use planners, seismologists, geologists, engineering geologists, civil engineers, soils engineers, structural engineers, architects, and building inspectors all have direct or indirect roles to play. In addition, the contributions of lawyers, public administrators, economists, and other social scientists can be major. The overlap in responsibility and expertise among these professions complicates assigning a precisely defined role to each.

In practice, the role of each professional is tailored to the strengths of the individuals involved and the na-

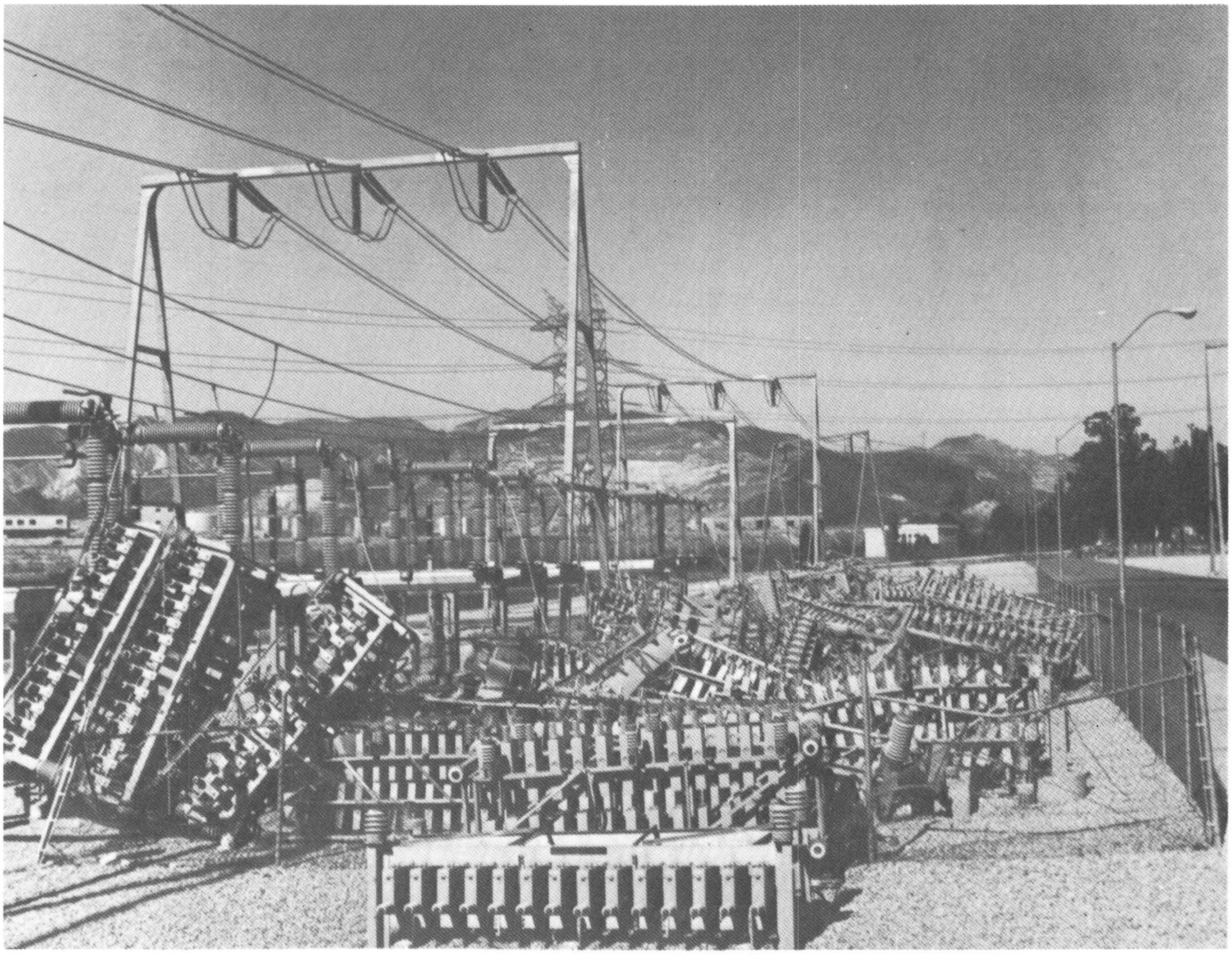


FIGURE 10.—Sylmar Converter Station—collapsed condenser banks (U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, p. 248).

FIGURE 11.—Collapses at interchange between Golden State and Foothill freeways (Steinbrugge and others, 1971, p. 8).

TABLE 1.—*Magnitude/size comparisons between any two earthquakes*

[K.R. Lajoie, written commun., 1976]

If the difference in *magnitude* between two earthquakes is . .	Then the difference in *size* between the two earthquakes is . .
Difference in Magnitude	Difference in Energy (Size)
5	32,000,000
4	1,000,000
3	32,000
2	1,000
1	32(31.6)
0.9	22.4
0.8	16.0
0.7	11.2
0.6	8.0
0.5	5.6
0.4	4.0
0.3	2.8
0.2	2.0
0.1	1.4

Example 1: An M7.5 is 1.4 times larger than an M7.4
Example 2: An M8.0 is 5.6 times larger than an M7.5

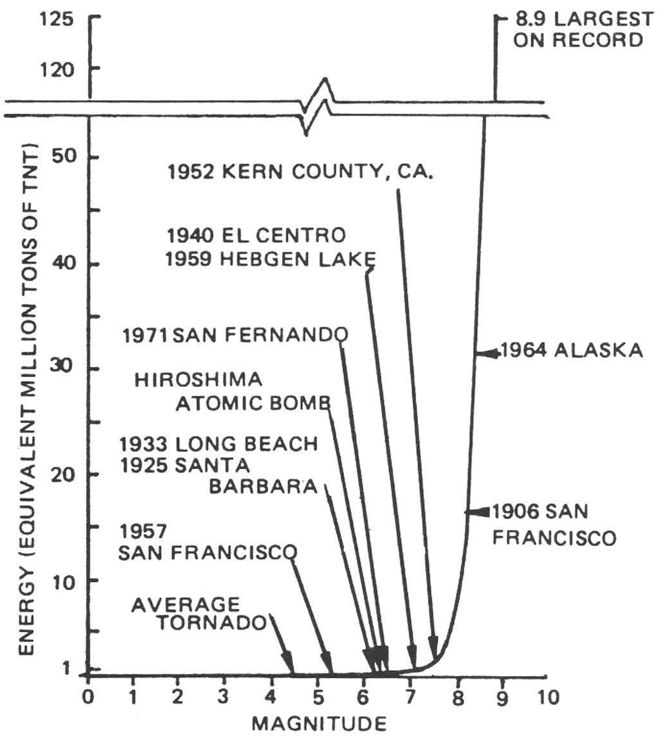


FIGURE 12.—A dramatic demonstration of the vast differences in force or energy release between moderate earthquakes, such as San Fernando, and great earthquakes, such as San Francisco in 1906 and Alaska in 1964. Note the incredible span between these latter great earthquakes and the magnitude 8.9 shocks, which are the largest on record (Yanev, 1974, p. 41).

ture of the particular problems to be addressed. A core of professional competence usually defines each professional's primary responsibility; but in a well-functioning interdisciplinary team each professional ventures to the limits of his area of competence fully recognizing the probability of overlap with other

TABLE 2.—*Modified Mercalli intensity scale*

[1956 version, by Richter, as reported in Nichols and Buchanan-Banks, 1974]

I. Not felt
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 heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing. 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[1] cracked.
VII. Difficult to stand. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken at roof line. Damage to masonry D, including cracks; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.
VIII. Steering of automobiles 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 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 and liquefaction.
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 in the air.

[1]Masonry A: Good workmanship and mortar, reinforced designed to resist lateral force.
Masonry B: Good workmanship and mortar, reinforced.
Masonry C: Good workmanship and mortar, unreinforced.
Masonry D: Poor workmanship and mortar and weak materials, like adobe.

professionals. The extent of direct involvement of specialized professionals in a particular plan to reduce seismic risk depends on the nature of the problems involved.

In addition to the contributions of individual professionals, the professional societies make substantial contributions in examining the role of their members in reducing seismic risk and in supporting related research. Many of the professional societies also are examining ways to improve interdisciplinary collaboration. For example, ICED (Interprofessional Council on Environmental Design), which includes engineers, architects, landscape architects, and planners, provides for voluntary development of interdisciplinary trust and understanding among these professionals. ICED

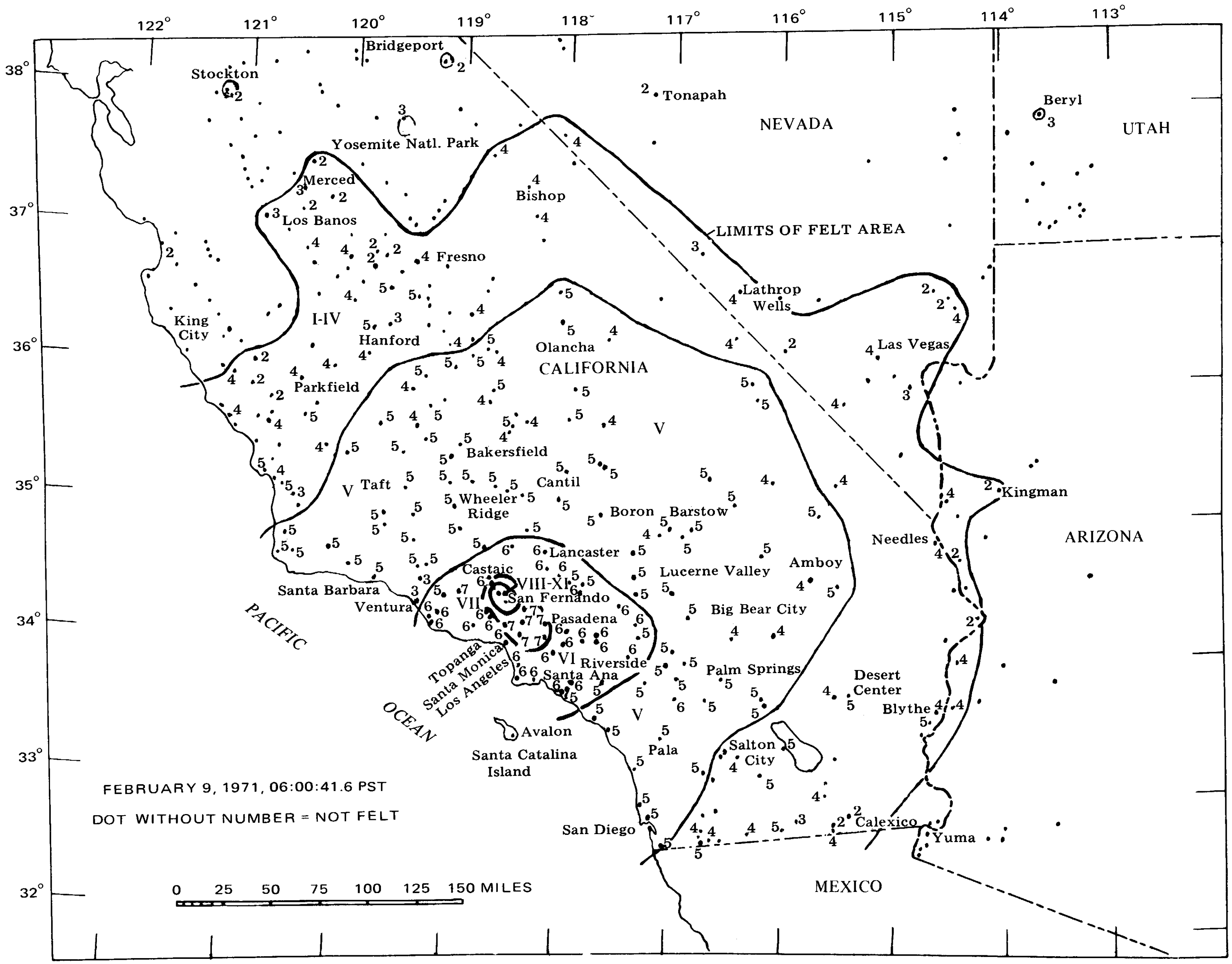


Figure 13.—Intensity distribution of San Fernando earthquake of February 9, 1971 (Scott, 1973, p. 24).

has issued a Guide to Interprofessional Collaboration in Environmental Design to aid its members who are engaged in interdisciplinary projects (ICED, 1974).

Land-use planning is a young profession and has roots in the "design professions." Many land-use planners come into planning with design training or experience. Land-use planners, as a group, thus have had closer ties to engineering, architecture, and landscape architecture than to the earth sciences. However, in recent years because of increasing costs associated with failure to recognize geologic conditions in land development, planners and other design professionals are working more closely with earth scientists and are using more earth-science information. Earth scientists have become increasingly aware of the value of their information and expertise to land-use planning. For example, AEG (Association of Engineering Geologists), through meetings, conferences, and publications has provided a substantial body of information that contributes to a better understanding of the role of the engineering geologist (and earth scientists generally) in relation to others concerned with reducing seismic risk. The publication of the proceedings from their annual meeting in 1973 includes papers by authors from many fields.

The integration of physical and economic planning was addressed in a paper (Lakshmanan, 1972) commissioned by the U. N. Centre for Housing, Building and Planning. This paper provides useful insights to some of the problems planners face in working with professionals from other fields and gives some general guides to interprofessional collaboration. Lakshmanan (1972 writes:

> It is fair to suggest, that in the current state-of-the-art, no such overarching framework for integrative economic and physical planning is available. The complexity of issues involved does not hold out much promise for such integrative models in the near future.
>
> A policy of learning by doing and willingness to adapt action with experience is warranted. This is a social learning process, learning while doing, with a willingness to experiment without excessive commitment. The approach is to focus an interdisciplinary team of physical and economic planning skills on a broad issue. This will require new planning roles and skills in social, economic, and physical design, a good appreciation of implementation processes, and knitting together the separate planning systems into a broader developmental planning system.

LAND-USE PLANNING

The land-use planner employed by a public agency has responsibility for developing plans, regulations, and procedures to guide and control the physical development pattern of a planning area. In responding to seismic risk through land-use planning, the planner can be a key coordinator drawing information from scientists and engineers, developing recommendations for public policy, interacting directly with elected decisionmakers and the public, and reviewing and evaluating land-development proposals. All of these functions require an ability to draw information from other disciplines, apply it appropriately to the planning problems at hand, and aid the earth scientists in communicating their scientific and technical knowledge to the public. In these tasks, the land-use planner will need to interact directly or indirectly with many professions.

In a simple geologic setting with low-intensity development, a team consisting of a land-use planner and an engineering geologist frequently is adequate to address the problems related to seismic risk. As intensity of development increases or the seismic hazards become more complex, additional, more specialized professionals will need to be involved in addressing the problems. The scope and role of key professionals dealing directly with, or making direct application of, earth-science information in the discharge of their own professional responsibilities are discussed below.

GEOLOGY, ENGINEERING GEOLOGY

The geologist or engineering geologist frequently works directly with the land-use planner in simple situations and, for more complex problems, advises on programs, data requirements, and areas of expertise needed on the interdisciplinary team. Geologists and engineering geologists have the same basic education and frequently have somewhat similar experience. Engineering geology is a specialization within geology, emphazing application of geologic information to engineering problems. Many other specializations are recognized within the geologic profession, and some are particularly important in analyzing specific seismic risk problems.

The geologist, as researcher and interpreter, may be a primary member of a team working on seismic risk reduction through land-use planning, or he may provide the information used by others. In either case his work is basic in formulating public policy, developing land-use regulations and project review procedures, and reviewing development proposals. Some local agencies in California have added geologists to their staffs or contracted for geologic services as needed to assist the land-use planner in identifying and responding to geologic problems.

The engineering geologist brings to the land-use planning team training and experience in the interpretation of geologic conditions affecting safety and economy of engineering works. He provides a bridge between earth-science researchers, land-use planners, engineers, and architects concerned with seismic safety policy and its application.

Geologists are responsible for compiling maps of seismic hazard zones and collaborating with land-use planners and engineers in relating levels of risk exposure in hazard zones to land uses and critical facilities. They also collaborate in assessing probable damage to existing development in relation to seismic hazards.

Information developed by seismologists dealing with the forces, lines of direction, periodicity, and other characteristics of earthquakes is fundamental to evaluation of the seriousness of seismic problems in any given area. This information is the starting point for land-use planning to reduce seismic risk, However, the planner, and others on the land-use planning team, usually depend on published information with geologist, engineering geologist, or structural engineer serving as interpreter.

CIVIL ENGINEERING

Civil engineering is a broad profession with several well-recognized areas of specialization, such as soils, structural, foundation, sanitary, and transportation. However, many civil engineers are engaged in general practice and have experience with a wide range of civil engineering problems. With this breadth of experience the civil engineer can, with collaboration from members of the planning team, provide perspective on the general nature of the engineering problems that are likely to result from an earthquake. The civil engineer can also help identify the engineering specialty needed to address seismic risk problems in particular situations.

SOILS ENGINEERING

Soils engineering, a branch of civil engineering, deals with the mechanical properties of soil and their effects on structures. The soils engineer draws information from soils science, geology, and hydrology and applies it to specific engineering problems. He carries out side investigations and recommends design and construction solutions to soil problems such as expansiveness, erodibility, and soil creep. Soils engineers prepare soils reports on specific development proposals; they may also be employed by public agencies to review and evaluate soils reports prepared by others. Soils engineers work closely with engineering geologists and civil, foundation, and structural engineers on particular design problems. The soils engineer can provide valuable assistance in identifying the limits particular soils may place on aseismic construction.

STRUCTURAL ENGINEERING

Structural engineering is another specialization within civil engineering. This branch of engineering is responsible for designing structures. The structural engineer collaborates in the design of major public facilities and assesses the need for, and costs of, structural measures to mitigate problems associated with particular sites.

ARCHITECTURE

Architecture is the science and art of designing buildings to blend form and function with safety. The architect charged with responsibility for preparing plans and specifications and providing on-site supervision during construction must work within design parameters recommended by engineering geologists and soils and structural engineers to produce a safe building. On any particular project, his interaction with the land-use planner is primarily as a member of a design team, frequently as the lead professional with responsibility for coordinating the team effort.

BUILDING INSPECTION

All the efforts of the professionals can be seriously compromised unless building inspection is carefully and expertly carried out. The building inspector is the public official responsible for seeing that building code provisions are adhered to. He reviews final construction plans and inspects construction to insure that local code requirements are met. In carrying out his duties, the building inspector, who often is not an engineer, relies on the engineering or public-works department personnel or consulting structural engineers for evaluation of seismic safety and other aspects.

The land-use planner is often in the position of coordinating the work of these professionals to assist in developing plans and policies, framing regulations, establishing review procedures, and reviewing development proposals. Timing may be critical. Basic geologic information is needed early to identify and evaluate seismic hazards and to assist in developing appropriate policies and regulations. The contribution of the engineers is needed primarily at the time of project design and review. A structural engineer, however, is also needed during the formulation of seismic safety plans to give a general evaluation of the safety of existing and proposed structures in the area.

GOVERNMENTAL FRAMEWORK FOR REDUCING SEISMIC RISK

Governmental agencies at all levels have a part in reducing seismic risk. Under the present system, risk reduction through land-use planning is carried out primarily by local governments. However, the operations of local agencies affect and are affected by the planning and decisionmaking of government agencies at Federal, State, and regional levels. These government agencies often preempt or influence local decisionmaking by imposing requirements for funds, criteria for programs, shared responsibility for specific functions such as transportation, and regulations such as those concerning environmental quality or the content of local plans.

To an increasing extent, local governments are dependent on Federal and State funds to carry out their responsibilities. This means that plans and programs developed at the local level are often framed with an eye not only to locally expressed objectives and concerns, but also to Federal and State funding requirements. Thus, individual governmental decisions become part of a network of decisions made by other agencies, at different jurisdictional levels over a period of time. Because of increasing political, economic, and legal interdependency, effective planning by local government often depends on complementary decisions of other local, Federal, State, and regional agencies.

The following sections outline the major Federal, State, and regional programs and activities that provide the context for local seismic-safety planning in the San Francisco Bay region. Programs directly or indirectly influencing local land-use planning are emphasized. The description of State programs is limited to California because California has gone further than other states in enacting programs to reduce seismic risk. The description of area-wide activities is similarly limited to agencies in the San Francisco Bay region. Such focusing on California and the bay region allows discussion of actual plans and programs illustrating various methods of reducing seismic risk consistent with the powers and responsibilities of typical state and regional governmental agencies.

FEDERAL PROGRAMS

The Federal government has a broad constitutional mandate to protect the health, safety, and welfare of the residents of the United States. Direct Federal efforts to reduce risk from seismic hazards have evolved from the Federal commitment to provide disaster relief to states and localities devastated by earthquakes. With increasing urbanization of seismically active areas, particularly the west coast, the potential cost of disaster and recovery assistance, borne primarily by the Federal government, is awesome. The moderate San Fernando earthquake of 1971 caused property damage estimated at more than a half billion dollars. Federal aid including grants and loans exceeded $450,000,000. Approximately $135,000,000 was allocated from the President's Disaster Fund—an amount larger than for any natural disastr since the fund's establishment (U.S. Senate, 1971, p. 71; U.S. Office of Emergency Preparedness, 1971 and 1972, p. 179).

Expenditures of this magnitude have focused attention on the need to reduce future damages. In 1970, a Task Force on Earthquake Hazard Reduction was established by the Office of Science and Technology (since disbanded) to "develop an appropriate national action program for the reduction of the human suffering and property damage attendant upon an earthquake***" (U.S. Office of Science and Technology, 1970, p. 1). Table 3 lists the Task Force's high-priority recommendations.

These recommendations provide a framework for Federal involvement in seismic-hazard reduction. Not all of the recommendations are currently being carried out in a consistent, coordinated program, but many have been incorporated into the activities and pro-

TABLE 3—*High-priority recommendations of the Task Force on Earthquake Hazard Reduction*

[U.S. Office of Science and Technology, 1970, p. 5]

A. *Significant benefits probably beginning to accrue in the short term (less than 5 years after beginning of recommended action):*	
A–1:	Engineered earthquake resistance for new governmental facilities.
A–2:	Engineered earthquake resistance for new nongovernmental facilities.
A–3:	Seismicity (or risk, or probability) maps.
A–4:	Earthquake geologic hazards maps.
A–5:	Urban planning to minimize seismic hazard.
A–6:	Earthquake hazards abatement in older facilities.
A–7:	Cost-benefit studies.
A–8:	State and local government role in geologic hazards reduction.
A–9:	Federal total plan for immediate response.
A–10:	Federal responsibility in reconstruction.
A–11:	Federal responsibility in earthquake insurance.
A–12:	Strong motion equipment and analyses.
A–13:	Full-scale testing.
B. *Significant benefits probably beginning to accrue in the intermediate term (5–10 years after beginning of recommended action):*	
B–1:	Applied research on seismic design criteria.
B–2:	Postearthquake analyses.
B–3:	Fault mapping, dating, and specialized geologic mapping.
B–4:	Local seismic networks.
B–5:	State responsibility in earthquake hazards reduction.
B–6:	Newly discovered hazards and older construction.
B–7:	Taxes and tax reform.
C. *Significant benefits probably beginning to accrue mainly in the longer term (10 years or more after beginning of recommended action):*	
C–1:	Basic research in earthquake engineering.
C–2:	Earthquake prediction research.
C–3:	Earthquake control research.
C–4:	Geodetic research.
C–5:	Worldwide seismic network continuation.
C–6:	Tsunami hazard research.
C–7:	Basic research in seismology.
C–8:	Basic research on causes and mechanisms of crustal failure.

grams of several Federal agencies. At present the Federal Government has four major functions in reducing risks from future earthquakes: conducting or funding research and providing technical information, encouraging emergency preparedness and providing disaster relief, considering seismic hazards in program administration, and requireing insurance. Each of these Federal functions is discussed below.

RESEARCH AND TECHNICAL INFORMATION

Federal agencies which sponsor research and provide technical information concerning seismic hazards include the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and the National Science Foundation.

U.S. GEOLOGICAL SURVEY

The USGS (U.S. Geological Survey) is responsible for carrying out the seismic research and hazard mapping recommended by the Task Force on Earthquake Hazard Reduction. The USGS publishes maps of faults, evaluates their degree of activity, and compiles and maintains records of historical and recent seismic activity. Geologists and seismologists investigate the relationship of geologic structure to seismic wave amplification and ground shaking, liquefaction potential, and other seismic hazards. Post earthquake analysis is carried out in the field by USGS professionals in cooperation with investigators from universities, professional organizations, and other groups.

The USGS also investigates the feasibility of earthquake prediction and control and is responsible for issuing official earthquake predictions. The USGS administers EROS (Earth Resources Observation System) to evaluate the application of data obtained from remote sensing. A few previously unknown faults have been identified from remote sensing imagery from high-altitude aircraft and satellites, but most known faults have been recognized and mapped by geologists in the field.

On May 22, 1974, Congress enacted Public Law 93–288 (88 Stat. 143), which is known as the "Disaster Relief Act of 1974" to provide

> an orderly and continuing means of assistance by the Federal Government to State and local governments in carrying out their responsibilities to alleviate the suffering and damage which results from***disaster****

By subsequent redelegations of authority, the Director of the Geological Survey was

> empowered to exercise the authority, functions, and powers granted by Section 202 of the Disaster Relief Act of 1974 with respect to disaster warnings for an earthquake, volcanic eruption, landslide, mudslide, or other geological catastrophe.

(Federal Register, vol. 42, no. 70, p. 19292, Tuesday, April 12, 1977). Section 202 (a) of the Act states that "The President shall insure that all appropriate Federal agencies are prepared to issue warnings to State and local officials." In addition, Section 202 (b) states that

> The President shall direct appropriate Federal agencies to provide technical assistance to State and local governments to insure that timely and effective disaster warning is provided.

The Federal Register statement cited (p. 19292) describes the Survey's

> capabilities and limitations for advance recognition and warning of various kinds of geologic-related hazards and the procedures proposed to carry out the responsibilities delegated under the Act.

The USGS has undertaken several pilot studies in urban areas, such as the San Francisco Bay Region Environment and Resources Planning Study, to provide geologic and seismologic information for use in land-use planning and decisionmaking. Under the Earth Sciences Applications Program, several projects, similar to the San Francisco Bay Region Study, have been undertaken to provide earth-science information for use in land-use planning. Studies have been completed of the Greater Pittsburgh area, Connecticut River Valley, Washington-Baltimore region, and the Phoenix-Tucson area. Still underway (in 1977) are projects in the Puget Sound area, in the Front Range Corridor in Colorado, and in Fairfax County, Virginia.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA National Oceanic and Atmospheric Administration) is responsible for setting up and maintaining a tsunami warning system for coastal areas of the United States. The agency's previous functions with respect to solid-earth geophysics have been assumed by the U.S. Geological Survey, but NOAA still maintains and provides data related to seismology.

NATIONAL SCIENCE FOUNDATION

The NSF (National Science Foundation) provides funds for research by colleges and universities, nonprofit research organizations, and other groups in all the scientific disciplines. Under its program, Research Applied to National Needs, NSF has funded research to investigate the social and engineering aspects of seismic-hazard reduction. Such projects have included studies of the impacts of hazard-mitigation measures and the potential impact of improved capability to predict earthquakes.

EMERGENCY PREPAREDNESS AND DISASTER RELIEF

The Civil Defense Preparedness Agency and the Federal Disaster Assistance Administration are the agencies most directly responsible for emergency preparedness and disaster relief.

Civil Defense Preparedness Agency. The main objective of the CDPA (Civil Defense Preparedness Agency), established within the Department of Defense in 1972, is to improve prospects for survival of the population in the event of a nuclear war. A secondary objective "is to improve the readiness of State and local governments to respond to peacetime emergencies" (U.S. Civil Defense Preparedness Agency, 1974, p. 6). In this connection, the agency provides planning assistance to state and local governments to develop their natural disaster preparedness plans and capabilities and plays a key role in coordinating Federal state, areawide, and local emergency response plans. Among other activities, the CDPA funds emergency planning efforts of other government agencies, makes surplus Federal property and equipment available for emergency response, and operates emergency warning and communications systems.

Federal Disaster Assistance Administration. The FDAA (Federal Disaster Assistance Administration), in the Department of Housing and Urban Development, is responsible for "programs concerning disaster research, preparedness, readiness evaluation, disaster relief, and recovery, and coordination of other agency disaster assistance activities (U.S. Office of the Federal Register, 1973, p. 253). The agency publishes the Federal Earthquake Response Plan which outlines the Federal Government's role in response to a major earthquake. FDAA administers the Disaster Relief Act of 1974 enacted to help State and local governments alleviate the suffering and damage caused by floods, tsunamis, earthquakes, mudslides, and other emergencies and major disasters. The Disaster Relief Act of 1974 provides for financial and technical assistance to the states to develop plans, programs, and regulations for hazard reduction, disaster preparedness, and disaster relief. The act requires that property to be replaced, repaired, or restored with the assistance of Federal relief funds be insured, if insurance is available, against future losses. To receive any disaster loan or grant, a state or local government must agree to evaluate natural hazards in the disaster area and take actions to mitigate the hazards, such as control of land-use and construction practices (U.S. Congress, 1974, Sec. 406).

PROGRAM ADMINISTRATION

Federal officials who administer Federal and Federally funded programs have an opportunity to influence decisions related to seismic safety. The extent to which this is done often depends on how legislation and regulations are interpreted by administrators.

Two Federally mandated procedures provide the basic framework for consideration of seismic risk in administering Federal and Federally funded programs: (1) review procedures set forth by the U.S. Office of Management and Budget (A–95), and (2) environmental impact assessment required by the National Environmental Policy Act of 1969.

A–95 REVIEW

A–95 review procedures are designed to implement the Intergovernmental Cooperation Act of 1968 by insuring that Federally funded projects are consistent with State, areawide, and local planning objectives. Under these procedures applicants for Federal funds for a wide variety of projects must notify designated State and regional clearinghouse agencies which review proposed projects for consistency with State, areawide, and local plans and programs. The clearinghouse agency forwards the project description to any affected agencies for their review and comment. The comments are only advisory, but a Federal agency must defend in writing any decision to fund a project which has received a negative review. This procedure at least assures that the review comments of affected public agencies are considered.

Comments may be made concerning the natural characteristics of a proposed project site. In seismically active areas, the nature and extent of seismic hazards are an appropriate and necessary subject of comment in the A–95 review process.

ENVIRONMENTAL IMPACT ASSESSMENT

The NEPA (National Environmental Policy Act) of 1969 requires that an EIS (environmental impact statement) be prepared for proposed legislation and for other Federal actions that may significantly affect the quality of the human environment. The statement must describe the environmental impact of the proposed action, identify adverse and unavoidable environmental effects, list alternatives to the proposed action, describe how local short-term uses of man's environment are related to maintaining and enhancing long-term productivity, and identify any irreversible and irretrievable commitments of resources.

Guidelines and procedures for preparing environmental impact statements are issued by the CEQ (Council on Environmental Quality) and administered by the EPA (Environmental Protection Agency). The current guidelines (Council on Environmental Quality, 1973) help Federal agencies prepare environmental impact statements and require that environmental factors, such as seismic hazards, be explicitly considered before most Federal actions. To the extent possible, environmental impact assessment and A–95 review are coordinated.

PROGRAMS OF THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Although most Federal activities are subject to A–95 review and environmental impact assessment requirements, each agency develops its own operating procedures to carry out the intent of the legislation and regulations. The programs of HUD (Housing and Urban Development) support planning, community development, and housing activities of many state, areawide and local governments throughout the country. The way these programs are administered can affect seismic safety in HUD-assisted activities and projects.

The Housing and Community Development Act of 1974 (U.S. Dept. of Housing and Urban Development, 1975b) combined several HUD programs covering urban renewal, neighborhood development, and public facilities into a single program funded with Community Development Block Grants. Local community development programs are subject to A–95 review, and individual projects funded with Community Development Block Grants are subject to environmental impact assessment. In reviewing applications, HUD may challenge statements of fact and program decisions related to seismic safety, and it may require additional information from the applicant. Implications of the community development program and proposed projects should be evaluated in the review of applications for Community Development Block Grants.

Under the Comprehensive Planning Assistance Program (Section 701 of the Housing and Community Development Act of 1974), HUD provides grants to cities and counties, and metropolitan, regional, and State planning agencies. Grants may be used for planning to mitigate and reduce hazards, among other activities. All agencies applying for grants must adopt a land-use element by August 23, 1977 (U.S. Department of Housing and Urban Development, 1975a, p. 36862). The land-use element must identify areas where growth should and should not take place giving comprehensive consideration to environmental factors. Planning activities supported by these grants must be conducted in accord with the National Environmental Policy Act of 1969 (Public Law 91–190). HUD (U.S. Department of Housing and Urban Development, 1975a, 36860) specifies that each agency shall:

(1) Identify salient elements of the natural and the man-made environments, their interrelationships, and major problems and/or opportunities they present for community development;
(2) Assess those environmental factors which will:
   (i) Minimize or prevent undue damage, unwise use, or unwarranted pre-empting of natural resources and opportunities;
   (ii) Recognize and make prudent allowance for major latent environmental dangers or risks (e.g., floods, mud slides, earthquakes, air and water pollution); and
   (iii) Foster the human benefits obtainable from use of the natural environment by wise use of the opportunities available (e.g., use of natural drainage systems for park and recreational areas,

HUD has also issued Minimum Property Standards which define minimum levels of acceptable design and construction for Federally subsidized housing and for housing approved for Federally insured mortgages. Where earthquakes are a recognized hazard, the standards require a comprehensive soil investigation, special foundation design, and structural design to withstand lateral forces in accord with the latest Uniform Building Code (U.S. Dept. of Housing and Urban Development, 1973).

INSURANCE

The Task Force on Earthquake Hazard Reduction recommended studies of the feasibility of offering earthquake insurance at actuarial rates (U.S. Office of Science and Technology, 1970, p. 26). Private earthquake insurance has been available since the early 1900's, but relatively few property owners have purchased it. For example, of the more than half a billion dollars in property damage caused by the San Fernando Earthquake, only about $46,000,000 was covered by insurance (Baker, 1971, p. 31).

The potential for expanding private insurance coverage is limited, because insurance companies are required to maintain reserves sufficient to meet obligations in the event of a major earthquake. Property owners have also been reluctant to assume the extra cost of earthquake insurance, although it is relatively low. Table 4 lists typical costs of earthquake insurance in California in 1974 for residential buildings according to risk classes which are based on structural type. A deductible amounting to 5 percent of the building value usually applies.

Several proposals for Federal action to increase the extent of insurance coverage for damage from earthquakes and other natural disasters have been made, but, to date, the only direct Federal response has been enactment of the National Flood Insurance Program in 1968 (Public Law 90–448) as amended in 1973 (Public Law 93–234). Under this program, an individual must purchase flood insurance to be eligible for any kind of Federal financial assistance, including loans from Federally insured or regulated institutions, for acquisition of property or construction in identified special flood-hazard areas. The insurance is available at rates presently subsidized by the Federal Government in participating communities which have adopted and enforced land use and development controls to reduce the flood hazard.

Areas subject to flooding from tsunamis are included in the program. When the Federal Insurance Adminis-

TABLE 4.—*Cost of earthquake insurance for residential buildings*

[Yanev, 1974, p. 234]

Class of risk	Building description	Cost per $1,000 coverage
I	Small wood-frame and frame stucco buildings (less than four stories).	$1.50
II	Steel-frame and reinforced poured-concrete buildings.	$2.50
III	Reinforced concrete-frame (columned) buildings and other reinforced shear-wall masonry buildings.	$3.00
IV	Wood-frame buildings with masonry veneers or other liabilities.	$3.50
V	Steel-frame and reinforced concrete-frame buildings with segmented mansonry walls (brick, concrete block, etc.).	$3.50
VI	Single-family dwellings (less than three stories) of reinforced masonry; other reinforced masonry buildings with liabilities.	$4.00
VII	Unreinforced brick and larger reinforced masonry buildings without steel or concrete framing.	$7.50
VIII	Unreinforced masonry, masonry-veneer, or adobe buildings.	$25.00

tration of the Department of Housing and Urban Development (U.S. Federal Insurance Administration, 1975, p. 13429) has identified such "coastal high hazard areas," the community:

Must provide that all new construction or substantial improvements within the designated coastal high hazard area be located landward of the reach of the mean high tide; Must provide that all new construction and substantial improvements within the designated coastal high hazard area be elevated on adequately anchored piles or columns to a lowest floor level (including basement) at or above the 100-year flood level and securely anchored to such piles or columns: Must provide that all new construction and substantial improvements within the designated coastal high hazard area have the space below the lowest floor free of obstructions or are constructed with "breakaway walls" intended to collapse under stress without jeopardizing the structural support of the building so that the impact on the building of abnormally high tides or wind-driven water is minimized. Such temporarily enclosed space shall not be used for human habitation; Must prohibit, within the designated coastal high hazard area the use of fill for structural support; Must prohibit, within the designated coastal high hazard area, the location of any portion of a new mobile home park, expansion to an existing mobile home park, and any new mobile home not in a mobile home park.

These regulations are designed to encourage land-use decisions that minimize losses caused by flooding from the sea.

Federally insured or regulated institutions such as banks or savings and loan companies are not permitted to provide funds to substantially modify or purchase existing structures within coastal high-hazard areas unless the property is insured under the program. When more accurate maps of hazard areas are released, the insurance will be available at actuarial rates which will reflect the flood risk.

STATE ROLE–CALIFORNIA

Officials in nearly every agency of California State government need to consider seismic safety in carrying out their duties. The location and construction of public facilities, management of State lands, provision of services, and delegation of powers and responsibilities to local governments should all reflect an awareness that damaging earthquakes are inevitable. Few, if any, populated areas of the State are free from the risk of a major earthquake, and most large population centers are less than 80 kilometers (50 miles) from faults that can generate earthquakes (Jennings, 1975).

Although the historical record and geologic knowledge are insufficient to precisely establish the frequency of future earthquakes, one estimate is that California can expect a great earthquake (Richter magnitude greater than 7.7) every 60–100 years, a major earthquake (Richter magnitude 7.0–7.7) every 20 years, and a moderate earthquake (Richter magnitude 6.0–6.9) every 8–10 years (California State Legislature Joint Committee on Seismic Safety, 1974, p. 200).

LEGISLATION AND ADVICE

The State legislature and, more recently, various advisory bodies, have led in defining and coordinating California's role in reducing seismic risk.

CALIFORNIA LEGISLATURE

Legislative actions to reduce seismic risk have almost always followed damaging earthquakes. The most far-reaching actions followed the earthquakes of 1933 in Long Beach, 1964 in Anchorage, Alaska, and 1971 in San Fernando. Below is a brief chronology of legislative actions linked to each of these earthquakes. Details of key legislation are provided in relevant sections.

After the 1933 Long Beach earthquake, the legislature adopted the Field Act establishing seismic standards for the construction of school buildings and the Riley Act setting forth lateral force requirements for certain other buildings.

After the 1964 Anchorage, Alaska, earthquake and in response to two conference reports on this major earthquake, the legislature in 1969 established the Joint Committee on Seismic Safety to advise it on earthquake hazards.

After the 1971 San Fernando earthquake the Governor appointed the Governor's Earthquake Council, and the Legislature intensified support for the Joint Committee on Seismic Safety and passed several seismic-safety bills. The major acts include the Alquist-Priolo Special Studies Zones Act to reduce risk from fault rupture; the Hospital Safety Act to strengthen construction standards for hospitals; the Dam Safety Act to require evaluation of the safety of dams, mapping of potential inundation areas, and preparation of evacuation plans; and an amendment to the Government Code requiring each county and city to adopt a seismic safety element as part of its general plan.

GOVERNOR'S EARTHQUAKE COUNCIL

In January 1972 the GEC (Governor's Earthquake Council) was established to recommend measures to reduce future earthquake losses. The recommendations presented in the Council's report of November 21, 1972 closely parallel those of the Federal Task Force on Earthquake Hazard Reduction and emphasize measures which can be undertaken administratively by the executive branch of State government. Table 5 summarizes the major recommendations and responsible agencies (California Governor's Earthquake Council, 1972, p. 5–15).

JOINT COMMITTEE ON SEISMIC SAFETY

The Joint Committee on Seismic Safety was established by the State Legislature in 1969 as an outgrowth of studies following the 1964 Anchorage, Alaska, earthquake. The committee's purpose was to "develop seismic safety plans and policies and recommend to the Legislature any legislation needed to minimize the catastrophic effects upon people, property, and operation of our economy should a major earthquake strike any portion of California" (California State Senate, 1969, Senate Concurrent Resolution No. 128 of 1969, Resolution Chapter 378). The committee, composed of four senators and four assemblymen, relied on the technical and professional expertise of more than 70 persons who served on five advisory groups: engineering considerations and earthquake sciences; disaster preparedness; postearthquake recovery and redevelopment; land-use planning; and governmental organization and performance.

The San Fernando earthquake also spurred the Joint Committee's efforts. A special subcommittee was formed to conduct a postearthquake investigation, and the resulting report provided a basis for many of the Committee's legislative recommendations (California State Legislature, Joint Committee on Seismic Safety, 1972). The reports and recommendations of the advisory groups and the committee's basic legislative recommendations are contained in its final report, *Meeting the Earthquake Challenge,* published in January 1974 (California State Legislature, Joint Committee on Seismic Safety, 1974). The Committee's recommendations, which emphasize legislative action, are summarized in table 6.

Perhaps the most important recommendation of both the Joint Committee on Seismic Safety and the Governor's Earthquake Council was to create a permanent organization within State government to coordinate State efforts to improve seismic safety.

SEISMIC SAFETY COMMISSION

In July 1975, the California Seismic Safety Commission was established by the Legislature. The 17-member commission includes geologists; structural, civil, mechanical, and soils engineers; architects; planners; representatives of local government; and State legislators. The Commission's responsibilities as stated in the California Government Code, (1974, Sec. 8897) are:

(a) Setting goals and priorities in the public and private sectors;
(b) Requesting appropriate state agencies to devise criteria to promote seismic safety;
(c) Recommending program changes to state agencies, local agencies, and the private sector where such changes would reduce the earthquake hazards;
(d) Reviewing reconstruction efforts after damaging earthquakes;

TABLE 5.—*Recommendations of the Governor's Earthquake Council*

[Adapted and summarized from California Governor's Earthquake Council, 1972, pp. 5—15]

Subject Area	Recommended Actions	State Agencies Responsible
Research, provision of information	Support basic seismological research. Support research in earthquake engineering. Fund expanded seismographic network. Develop procedures and provide funds for postearthquake studies. Prepare earthquake geologic hazard maps, seismicity maps. Disseminate earthquake-related information.	OES (Office of Emergency Sevices). UCB (University of California at Berkeley). CDMG (California Division of Mines & Geology). EERI (Earthquake Engineering Research Institute).[1] DGS (Department of General Services).
Critical structures	Assess safety of public utility systems and dams.	PUC (Public Utilities Commission). DWR (Department of Water Resources).
Emergency preparedness and response	Mandate local disaster plans including evacuation procedures. Coordinate Federal, State, areawide, and local disaster plans. Require disaster training in schools. Assess emergency operations including medical and communication capabilities.	OES (Office of Emergency Services).
Land-use planning	Provide incentives and technical guidance for preparation of seismic safety element. Consider local earthquake risk in public improvement projects. Require geologic reports on private and public projects in seismically active areas.	Department of Conservation. Office of Planning and Research.
Insurance	Mandate inclusion of disaster coverage in standard fire insurance policies. Encourage insurance industry to advise policyholders of disaster coverage.	Department of Insurance.

[1]EERI is a private, nonprofit organization.

TABLE 6.—*Summary of recommendations of the Joint Committee on Seismic Safety*

[Adapted and summarized from California State Legislature, Joint Committee on Seismic Safety, 1972]

Subject Area	Recommended Actions
Land-use planning	Provide for effective State review of local seismic safety elements. Require geologic and soils reports for subdivision and construction activity of substantial scope. Permit seismic and geologic hazards to be considered "blighting" conditions making an area eligible for redevelopment funds. Provide for preplanning of postearthquake redevelopment. Require evaluation of geologic and seismic hazards in environmental impact statements. Employ land-use controls to reduce seismic hazards. Discourage public investment in hazardous areas. Provide purchasers of real estate with property reports disclosing seismic and geologic hazards.
Building Construction	Upgrade engineering standards and building code provisions. Assist local agencies in enforcing building code standards. Develop programs to train building officials and other ocal personnel in seismic design. Provide geologists, engineers, public safety officials, and others with reasonable protection from liability.
Abatement of hazardous buildings	Develop hazard abatement program concentrating on pre-1933[1] buildings. Inventory potentially hazardous buildings.
Critical and high exposure facilities	Enforce seismic safety measures in construction of schools, hospitals, and emergency facilities. Review safety of high-rise structures and dams.
Emergency preparedness measures	Ensure that local emergency plans are prepared and maintained as required. Establish procedures for review and approval of such plans. Conduct disaster exercises to test response. Increase allocation to State Emergency Fund. Require communities to prepare postearthquake reconstruction plans.
Research	Increase support of basic and applied research.
Insurance	Require purchasers of residential buildings to carry earthquake insurance. Explore with Federal Government the possibility of comprehensive disaster insurance.

[1]Explained on p. B 10.

(e) Gathering, analyzing, and disseminating information;
(f) Encouraging research;
(g) Sponsoring training to help improve the competence of specialized enforcement and other technical personnel;
(h) Helping to coordinate the seismic safety activities of government at all levels; and
(i) Establishing and maintaining necessary working relationships with any boards, commissions, departments, and agencies, or other public or private organizations necessary to further an effective seismic safety program for the state.

To carry out these responsibilities, the Commission (California Government Code, 1974, Sec. 8898) may:

(a) Review state budgets and review grant proposals, other than those grant proposals submitted by institutions of postsecondary education to the federal government, in earthquake-related activities and to advise the Governor and Legislature thereon;
(b) Review earthquake-related legislation proposals, to advise the Governor and Legislature concerning such proposals, and to propose needed legislation;
(c) Recommend the addition, deletion, or changing of state agency standards when, in the commission's view, the existing situation creates an undue seismic hazard or when new developments would promote seismic safety, and conduct public hearings as deemed necessary on the subjects.

Beginning in January 1977, the Commission's duties were expanded to include advising the State Mining and Geology Board regarding Special Studies Zones (see p. B25) and the State Geologist regarding the State Strong-Motion Instrumentation Program.

RESEARCH AND INFORMATION

The CDMG (California Division of Mines and Geology) within the Department of Conservation (California State Legislature, Joint Committee on Seismic Safety, 1974, p. 190) has the responsibility to provide:

(1) information pertaining to earthquake and other geologic hazards, (2) to conduct, with city and county governments or Federal and other State agencies, large-scale geologic investigations ***to identify and delineate***geologic hazards in and adjacent to metropolitan areas, (3) to organize and monitor a strong-motion instrumentation program in the State, and (4) to quickly identify potential post-earthquake geologic hazards, particularly weakened slopes that could be activated by aftershocks.

The division is headed by the State Geologist and operates under the policy direction of the State Mining and Geology Board.

California Division of Mines and Geology produced the *Urban Geology Master Plan for California* (Alfors, 1973). This report estimates, for the period 1970–2000, losses due to geologic hazards, the amount of losses that could be averted by applying current information and technology, and the cost of applying loss-reduction measures. Earthquake losses are estimated to be $21 billion from 1970 to 2000. Approximately half of the losses could be averted by applying existing risk-reduction measures. The cost of applying loss-reduction measures is estimated to be about 10 percent of the total projected losses. The study was intended to help establish State priorities for measures to reduce losses from geologic hazards.

California Division of Mines and Geology also administers the Alquist-Priolo Special Studies Zones Act (Chapter 7.5, Division 2, Public Resources Code, 1972 as amended 1974 and 1975). Under this Act, the State Geologist maps special studies zones along potentially active and recently active fault traces. The zones are ordinarily less than 396 meters (a quarter-mile) wide unless special considerations indicate the need for a wider zone. Once the Special Studies Zones maps have been officially issued by CDMG, local jurisdictions must require geologic reports prior to approval of most new construction within the zones. Individual geologic reports are not required, however, for projects consisting of no more than one single-family, wood-frame home not exceeding two stories.

The California Division of Mines and Geology, under the direction of the State Mining and Geology Board, establishes criteria and policies for content and review of the geologic reports, for revising the Special Studies Zones maps to reflect new geologic information, and for city and county compliance with provisions of the Act. Through contracts with cities and counties, CDMG also provides geologic information for seismic safety and safety elements of the general plan and for other planning purposes.

STRUCTURAL STANDARDS

The State OAC (Office of Architecture and Construction) in the Department of General Services administers the California Field Act (Education Code Sections 15451–15465), which was passed after the 1933 Long Beach earthquake destroyed or seriously damaged many buildings and almost all public schools in the area. The Field Act specifies structural standards for construction of new public school buildings and requires that an architect or structural engineer prepare plans and supervise construction of school buildings. The act does not apply to State colleges and universities or private schools. Similar provisions relating to other major buildings are set forth in the Riley Act, also adopted in 1933.

The Field Act has been amended several times as the technology of designing and building earthquake-resistant structures has improved. Sections added to the Education Code in 1967 require inspection of pre-Field Act school buildings. Those found to be unsafe were to be replaced or brought up to code standards by June 1975, but some school districts have been granted additional time to meet the new requirements because of financial problems. Schools built since the Field Act was passed in 1933 have performed well during earthquakes (U.S. Office of Emergency Preparedness, 1972, p. 76).

California legislation, also adopted in 1967, requires geologic and engineering investigations of any site proposed for a school building "to preclude siting of a school over or within a fault, on or below a slide area, or in any other location where the geological characteristics are such that the construction effort required to make the site safe for occupancy is economically unfeasible..." (Education Code, Section 15002.1 1967).

The OAC (Office of Architecture and Construction) also develops and enforces standards for hospital construction under contract with the Department of Health as required by legislation enacted in 1972 (California Health and Safety Code, 1972, Sec. 15000–15023). This legislation was passed after the San Fernando earthquake damaged four major hospitals so severely that they had to be evacuated; fifty of the fifty-eight deaths attributed to the San Fernando earthquake resulted from collapse or damage to hospital buildings. OAC provides architectural and engineering services to State departments in the design and construction of State buildings and other facilities and prepares and administers the State's building regulations contained in Titles 17, 21 and 24 of the California Administrative Code. Since 1971, the Uniform Building Code has been adopted by reference as part of Title 24 of the California Administrative Code.

The Appendix of the 1927 Uniform Building Code, published by the International Conference of Building Officials, included suggested lateral-force design requirements to increase structural resistance to earthquake ground motion. Lateral-force provisions have been modified several times subsequently, largely in accord with recommendations of the SEAOC (Structural Engineers Association of California). Sections 17958 and 17922 of the California Health and Safety Code, enacted in 1975, require cities and counties to adopt the most recent edition of the Uniform Building Code. Section 2312, Chapter 23, Earthquake Regulations, of the 1976 Uniform Building Code (International Conference of Building Officials, 1976, p. 132–150) contain the lateral-force requirements which apply in seismically active areas of the country.

Building code requirements typically are minimum standards which apply to all structures regardless of differing geologic conditions. Local jurisdictions may enact requirements more stringent than those of the Uniform Building Code and some jurisdictions, notably Los Angeles and Long Beach, have attempted to relate building standards to geologic conditions of the site. Such codes are technically more difficult to prepare and administer, but as stated by Yanev (1974, p. 53) "***it makes no sense to continue to build seemingly sound structures on unsound ground."

CRITICAL FACILITIES

DEPARTMENT OF WATER RESOURCES

The DWR (State Department of Water Resources) is responsible for constructing and operating the State Water Project and for the safety of non-Federal dams in California (California State Legislature, Joint Committee on Seismic Safety 1974). Under the Alquist Dam Safety Act (Government Code, Section 8589–5, 1973), DWR and the OES (Office of Emergency Services), identify dams whose failure might lead to injury or loss of life. The owner of a dam so identified must prepare a map showing the extent of potential flooding from dam failure at full reservoir capacity. OES must review and approve all such maps, which then serve as the basis for emergency evacuation plans drawn up by local governments with advice from the State.

CALIFORNIA DEPARTMENT OF TRANSPORTATION

The CalTrans (California Department of Transportation), within the Business and Transportation Agency, is responsible for building and maintaining the State highway system and for planning a balanced transportation system. Earthquake-resistant design of highway facilities, particularly overpasses and bridges, is essential to prevent collapse and possible loss of life during an earthquake and to maintain the flow of traffic following an earthquake. The vulnerability of freeway overpasses was dramatically illustrated by the San Fernando earthquake. As a result, more stringent design standards for new construction and reconstruction were instituted by the Department of Transportation, and additional engineering research was strongly recommended (California Division of Highways, September 1971). In addition, existing highway structures are being evaluated and strengthened as funds permit.

More directly related to land-use planning, the Department also recommends that more attention be paid to seismic hazards in locating highways and interchanges. As stated in its report (California Division of Highways, 1971, p. 5–6) on the San Fernando earthquake:

> Early in the route location process, active and inactive faults should be mapped. A general assessment of the seismic risk of various areas within the study zone should then be prepared.
>
> Consideration must be given to the location of major interchanges. They should be sited outside of heavily faulted areas wherever feasible. Where seismic activity is highly probable, consideration should be given to avoiding complex multi-level interchanges in favor of simple designs with short span structures and maximum use of embankment.
>
> Early recognition of seismic risk might lead the planner to modify alignment or grade in order to minimize high cuts, fills, and bridge structures in a given area. Where a freeway must pass through a highly seismic area, the best and safest plan will generally be the simplest: close to the original ground, with simple, square bridge structures.

These recommendations were incorporated into the Department's Highway Design Manual of Instructions in March 1975 (Section 7–110.4).

EMERGENCY PREPAREDNESS AND DISASTER RELIEF

The OES (Office of Emergency Services), within the Governor's office, was established by the Emergency Services Act (Chapter 7, Division 1, Title 2 of the Government Code, 1970). The act requires OES to coordinate the emergency activities of all State agencies.

The OES develops and maintains the State Emergency Plan as required by Section 301b of the Federal Disaster Relief Act. This plan provides a framework for individual State agency and local government plans as well as specifying procedures for delivery of Federal aid.

The Emergency Plan also requires that contingency plans be prepared for specific potential emergencies, including earthquakes. The State Earthquake Response Plan, published by OES, meets this requirement. OES also coordinates postdisaster damage assessment and provides the Governor with information needed to declare an emergency or request Federal disaster assistance. The California Earthquake Prediction Evaluation Council, an advisory body to OES composed of geologists, seismologists, and geophysicists, reviews and evaluates specific information which could lead to an earthquake prediction. If the Council finds a significant possibility that an earthquake is imminent, OES provides preparedness and response information to State agencies and local governments and may provide public information to help individuals prepare for an earthquake.

LAND-USE PLANNING AND REGULATION

Many states have authorized local units of government to plan and regulate future development, but few states require local planning. In California, all cities and counties are required by State law to prepare and adopt a general plan which includes at least the following elements: land use, circulation, housing, conservation, open space, seismic safety, noise, scenic highways, and safety. California law further requires that zoning and subdivision of land be consistent with the adopted general plan. The State Attorney General, a resident, or a property owner may bring suit against a city or county to force compliance with the consistency provision of State law.

In accord with a recommendation of the Joint Committee on Seismic Safety, the requirement for a seismic safety element was enacted soon after the San Fernando earthquake.

Section 65302(f) of the Government Code requires:

A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.

The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure and seismically induced waves.

This legislation provides the basic framework in California for local seismic safety planning requiring, in effect, that cities and counties consider seismic hazards in formulating and implementing the general plan. The CIR (Council on Intergovernmental Relations) (now disbanded) issued guidelines to assist local governments in preparing State-required general plan elements. The guidelines (California Council on Intergovernmental Relations, 1973, p. IV–24, 25) for preparing seismic safety elements suggested:

A. A general policy statement that:
   1. Recognizes seismic hazards and their possible effect on the community.
   2. Identifies general goals for reducing seismic risk.
   3. Specifies the level or nature of acceptable risk to life and property (see safety element guidelines for the concept of "acceptable risk.").
   4. Specifies seismic safety objectives for land use.
   5. Specifies objectives for reducing seismic hazard as related to existing and new structures.
B. Identification, delineation, and evaluation of natural seismic hazards.
C. Consideration of existing structural hazards. Generally, existing substandard structures of all kinds (including substandard dams and public utility facilities) pose the greatest hazard to a community.
D. Evaluation of disaster planning program.
   For near-term earthquakes, the most immediately useful thing that a community can do is to plan and prepare to respond to and recover from an earthquake as quickly and effectively as possible, given the existing condition of the area. The seismic safety element can provide guidance in disaster planning.
E. Determination of specific land-use standards related to level of hazard and risk.

The seismic safety element is related to several other required plan elements. As stated in guidelines prepared by the Council on Intergovernmental Relations (California Council on Intergovernmental Relations, 1973, p. IV–27):

The seismic safety element contributes information on the comparative safety of using lands for various purposes, types of structures, and occupancies. It provides primary policy inputs to the land use, housing, open space, circulation and safety elements.

Within this legislative context, several State agencies and programs influence land-use planning with respect to seismic hazards. Of particular importance are the Office of Planning and Research and the guidelines of the California Environmental Quality Act, as discussed in the following sections.

OFFICE OF PLANNING AND RESEARCH

The OPR (Office of Planning and Research), responsible to the Governor, develops long-range State goals and policies for land use and environmental quality, evaluates State agency plans and programs for environmental impact, issues guidelines for preparing mandatory general plan elements (a function assumed from CIR), and provides assistance to local governments in preparing general plans.

In 1972, the office published *Environmental Goals and Policies* setting forth recommended State actions to reduce environmental pollution and to protect environmental resources. The report recommends that areas subject to strong earthquake shaking, tsunamis, and fault displacement be designated as areas of "critical concern". In such areas guidelines should be formulated "to encourage orderly development and protection from natural calamities while minimizing adverse impact upon people or resources***" (California Office of Planning and Research, 1973, p. 3).

CALIFORNIA ENVIRONMENTAL QUALITY ACT

The California Environmental Quality Act of 1970, based on the National Environmental Policy Act, requires an EIR (Environmental Impact Report) for all public and private projects or actions which may have a significant effect on the environment and which involve a discretionary decision by a public agency. State guidelines and procedures for preparing EIR's are issued by the California Resources Agency. The guidelines specify that impacts which "pose long-term risk to health or safety" be evaluated (California Resources Agency, December 1974, Section 15143, p. 19). Although not specifically mentioned in the act or guidelines, seismic hazards are usually considered in the environmental impact assessment.

AREA-WIDE PLANNING—SAN FRANCISCO BAY REGION

The nine-county San Francisco Bay region is highly vulnerable to earthquake damage. A major earthquake on any of the faults traversing the region would have devastating impact on the entire area. Thus, planning to reduce seismic risk and to increase the ability to respond to an emergency is appropriately a regional concern. The responsibilities of regional agencies (those with a jurisdictional area encompassing parts of more than one county) related to seismic safety are briefly described in the following sections.

ASSOCIATION OF BAY AREA GOVERNMENTS

ABAG (Association of Bay Area Governments) is the only regional agency covering the entire nine-county bay area that is responsible for comprehensive planning. Established in 1961 to develop plans and policies pertinent to region-wide problems, ABAG is a voluntary association of city and county governments. Implementation of ABAG's regional plans and policies depends on decisions by State and Federal agencies, other regional agencies, and local governments. However, because ABAG is the A–95 review clearinghouse agency for the San Francisco Bay region, it can indirectly influence other governmental decisions through reviewing requests for Federal funds. Because many projects are competing for limited funds, a negative finding by ABAG, although advisory, is likely to be heeded by the funding agency. ABAG also reviews Federal projects proposed for the region for consistency with areawide plans.

ABAG is giving increasing emphasis in its planning program to seismic concerns. A report presented to the Regional Planning Committee in May 1976, *Areas of Critical Environmental Concern* (ABAG, 1975a), lists policies and criteria for identifying critical land and water areas. Areas with known earthquake-related problems are among the critical areas and, according to policy, should be protected from premature or extremely dense development (ABAG, 1975a, p. 44).

These areas include:

1. Lands within 50 feet of a known active fault trace, as shown on Special Studies Zones Maps;
2. Lands subject to severe ground shaking shown as categories A and B on the map of maximum earthquake intensities (Borcherdt and others, 1975);
3. Lands likely to liquefy in a major earthquake as mapped by Youd, Nichols, Helley, and Lajoie (1975).

The report further recommends that land uses within 50 feet of a fault trace be limited to agriculture, recreation, secondary streets, and parking and that development in areas of severe ground shaking meet or exceed the requirements of the most recent uniform Building Code. Critical structures should be located, whenever possible, in the less hazardous areas.

A land capability analysis (Laird and others, 1979) prepared by ABAG as part of the San Francisco Bay Region Study illustrates a method of analyzing land capability for a demonstration area of about 100 square miles in the Santa Clara Valley. The cost of damage or mitigation measures per acre which can be expected from geologic hazards is estimated for selected land uses. Such seismic hazards as ground shaking, surface rupture, dam failure, dike failure, liquefaction, and landslides are considered. The report relies on information similar to that compiled for the entire San Francisco Bay region by Borcherdt, Gibbs, and Lajoie (1975). The report is described more fully on pages B72–B73.

In a related effort, ABAG undertook a project sponsored by the Federal Civil Defense Preparedness Agency to assemble information on disasters and disaster mitigation, to outline a method of evaluating risk, and to clarify ABAG's role in civil preparedness. (ABAG, 1975b)

A committee formed to prepare a civil preparedness plan for ABAG concluded that ABAG should have no operational role in disaster response, but that ABAG should offer technical assistance to member jurisdictions in ways to reduce hazards, prepare for disasters, and plan for postdisaster recovery.

ABAG prepared "A Method for Evaluating Hazards" (ABAG, 1975b) to help local governments set priorities for disaster preparedness.

It sets forth a procedure for describing and analyzing hazards and suggests ways a local jurisdiction can decide which hazards are important, what measures can effectively reduce them, and appropriate priorities for action.

The theme of ABAG's annual General Assembly in February 1976 was earthquake preparedness and response. Following a two-day conference (including Federal, State and local government staff members, elected officials, representatives from private industries and citizens) the Assembly adopted a resolution "making earthquake preparedness and response a high ABAG program priority" (Laird and others, 1979) and directing the Executive Board to define an ABAG program emphasizing legislation and advocacy; planning and technical assistance; and public information and education. As a result, ABAG has appropriated $30,000 for 1976–77 for the following work program:

Legislative advocacy
- a. Monitoring proposed earthquake related legislation; preparing comments as appropriate.
- b. Working with staffs of State legislative committees, advocating legislation that would assist local governments' preparedness efforts.

Technical assistance to local governments
- a. Offering information and assistance to member governments in using previous ABAG work to upgrade and improve their seismic safety programs.
- b. Assisting local governments in using the findings and methods contained in the ABAG Land Capability Analysis Report to improve local seismic safety programs.

Plan and project review
- a. Completing plan and project review procedures and policies on seismic safety.
- b. Conducting plan and project reviews, and preparing review comments in relation to seismic safety policies and programs.

Legal research

a. Cataloging legal research into responsibilities and liabilities of local jurisdictions for earthquake damage.

ABAG is also seeking additional funds to augment the program and to implement some of the recommendations.

To carry out policies and criteria related to seismic safety, ABAG relies on its project review powers. ABAG's (1973) procedures for regional clearinghouse review of environmental impact statements contain checklists of environmental impacts associated with eight different types of projects and include an inventory of mapped environmental information. The procedures also set criteria for determining regional impact. The importance of seismic hazards, such as historically active faults, high ground-shaking potential, and liquefaction potential are recognized, and sources of geologic and seismological information are listed.

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION

The BCDC (San Francisco Bay Conservation and Development Commission) is a State agency created by the State Legislature. BCDC was authorized to prepare a comprehensive plan for San Francisco Bay and its shores and to control development within its area of jurisdiction. The plan was adopted by the State Legislature, and BCDC became a permanent agency charged with carrying out the plan. The adopted plan has legal status and serves as a guide in the review of projects. BCDC shares jurisdiction over land-use decisions with the cities and counties which retain normal land use and building-permit controls. However, with certain minor exceptions, a permit from BCDC is required for all projects within its area of jurisdiction. Thus it, in effect, holds veto power over any project proposal in conflict with the San Francisco Bay Plan.

The BCDC plan and its project-review activities reflect a strong concern for seismic safety. The agency's jurisdiction consists primarily of tidelands, marshes, salt ponds, and diked and filled land underlain by bay mud. Such land is subject to particularly severe seismic ground shaking, liquefaction, differential settlement, and flooding. Yet in spite of these hazards, diking and filling of the baylands to accommodate urban uses has occurred and continues to be a problem. As stated in the San Francisco Bay Plan (San Francisco Bay Conservation and Development Commission, 1969, p. 2):

As the Bay Area's population increases, pressures to fill the Bay for many purposes will increase. New flat land will be sought for many urban uses because most, if not all, of the flat land in communities bordering the Bay is already in use—for residences, businesses, industries, airports, roadways, etc. Past diking and filling of tidelands and marshlands has already reduced the size of the Bay from about 680 square miles in area to little more than 400. Although some of this diked land remains, at least temporarily, as salt ponds or managed wetlands, it has nevertheless been removed from the tides of the Bay.

Despite the risks involved, the State recognizes that some bay filling may be desirable or necessary if the benefits outweigh the disadvantages. The San Francisco Bay Plan recommends approval to fill if one of the following four conditions is met: (1) the filling is in accord with the bay plan policies as to the bay-related purposes for which filling may be needed (such as, ports, water-related industry, and water-related recreation) and is shown on the bay plan maps as likely to be needed, (2) the filling is in accord with bay plan policies as to purposes for which some fill may be needed if there is no other alternative (such as, airports, roads, and utility routes), (3) the filling is in accord with the bay plan policies as to minor fills for improving shoreline appearance or public access, (4) the filling would provide for new public access to the bay on privately owned property and for improvement of shoreline appearance—in addition to what would be provided by the other bay plan policies—and the filling would be for bay-oriented commercial recreation and bay-oriented public assembly purposes. The question of safety of the fill must also be addressed before BCDC can issue a permit for filling.

With respect to the safety of fills, the plan (San Francisco Bay Conservation and Development Commission, 1969, p. 15) makes the following findings:

Virtually all fills in San Francisco Bay are placed on top of Bay mud which presents many engineering problems. The construction of a sound fill depends in part on the stability of the base upon which it is placed. Safety of a fill also depends on the manner in which the filling is done, and the materials used for the fill. Similarly, safety of a structure on fill depends on the manner in which it is built and the materials used in its construction. Construction of a fill or building that will be safe enough for the intended use requires (1) recognition and investigation of all potential hazards—including (a) settling of a fill or a building over a long period of time, and (b) ground failure caused by the manner of constructing the fill or by shaking during a major earthquake—and (2) construction of the fill or building in a manner specifically designed to minimize these hazards. While the construction of buildings on fills overlying Bay deposits involves a greater number of potential hazards than construction on rock or on dense hard soil deposits, adequate design measures can be taken to reduce the hazards to acceptable levels.

Policies to reduce potential earthquake damage to structures built on filled land include (San Francisco Bay Conservation and Development Commission, 1969, p. 17):.

1. The Bay agency should appoint a Fill Review Board consisting of geologists, civil engineers specializing in soils engineering, structural engineers, and architects competent to and adequately empowered to (a) establish and revise safety criteria for Bay fills and structures thereon, (b) review all except minor projects for the adequacy of their specific safety provisions, and make recommendations concerning these provisions, (c) prescribe an inspection system to assure placement of fill according to approved designs, and (d) gather, and make available, performance data de-

veloped from specific projects. These activities would complement the functions of local building departments and local planning departments, none of which are presently staffed to provide soils inspections.

2. Even if the Bay plan indicates that a fill may be permissible, no fill or building should be constructed if hazards cannot be overcome adequately for the intended use in accordance with the criteria prescribed by the Fill Review Board.
3. To provide vitally needed information on the effects of earthquakes on all kinds of soils, installation of strong-motion seismographs should be requried in all future major land fills. In addition, the Bay agency should encourage installation of strong-motion seismographs in other developments on problem soils, and in other areas recommended by the U.S. Coast and Geodetic Survey, for purposes of data comparison and evaluation.

The proposed Fill Review Board was established as the Engineering Criteria Review Board, composed of geologists, structural engineers, civil engineers, soils engineers, and other professionals as recommended in the plan. The board reviews and evaluates soils and geologic reports submitted by applicants for permits to fill. Significant improvement in the seismic engineering of fills and design of structures has resulted from the board's insistence on a thorough evaluation of geologic hazards at a project site (San Francisco Bay Conservation and Development Commission, 1974a, p. 8).

The policies and review procedures incorporated into the bay plan provide the means to assure that development within BCDC's jurisdiction is carried out in accordance with an acceptable degree of risk. However, as stated in a report of the Bay Plan Evaluation Project (San Francisco Bay Conservation and Development Commission, 1974b, p. 19) a "more precise definition of what level of risk is acceptable for design of structures on the Bay" is needed. Such a definition requires a detailed risk analysis involving both seismic and nonseismic hazards.

CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION

The CCZCC (California Coastal Zone Conservation Commission) and subordinate regional commissions were created by State legislation adopted, by initiative, in 1972. The CCZCC, working with the six regional commissions, prepared a plan for the future of the California coastal zone. While the plan was being prepared, the commissions controlled all development, through a permit process, to ensure consistency with the objectives of the establishing legislation and the emerging plan policies. Coastal areas of the bay region are represented by two regional commissions: Central (San Mateo County) and North Central (San Francisco, Marin, and Sonoma Counties).

The California Coastal Plan was adopted by the CCZCC in September, 1975, and forwarded to the Governor and State Legislature in December, 1975. In 1976, the California Coastal Act was enacted, establishing the policies and governmental mechanism for ensuring wise use of the State's coastal areas. The act requires local governments within the coastal zone to adopt local coastal programs to implement the policies of the Coastal Act. It is stated in one policy that new development shall "minimize risks to life and property in areas of high geologic, flood, and fire hazard," and shall "assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area***" (California Public Resources Code, 1976, Sec. 30253).

Local coastal programs are to be submitted to the appropriate regional commission for certification. After the local coastal programs in a region have been certified, or by January 1, 1981, the regional commissions are to be disbanded. The State Coastal Commission is to designate sensitive coastal resource areas which require special protection in local coastal programs. To remain in force after two years, the designations must be affirmed by the State Legislature.

Permits for specific coastal zone developments will be required, and the Coastal Act establishes procedures to be followed before and after a local coastal program is certified. Guidelines for preparing local coastal programs will be issued by the State Coastal Commission in Spring 1977. In keeping with the policy framework in the act, full consideration of seismic and other geologic hazards is likely to be required of local programs.

METROPOLITAN TRANSPORTATION COMMISSION

The MTC (Metropolitan Transportation Commission) was created to coordinate development of regional transportation facilities. It was charged with preparing and adopting a Regional Transportation Plan dealing with major highways, mass transit, transbay bridges, airports, and harbors. It must also develop a transportation improvement program and a financial program for carrying it out.

MTC also cooperates with ABAG in the A–95 review process by providing comments related to transportation. MTC's approval is *required* for certain projects including transbay bridges, public multicounty transit systems on exclusive rights-of-way, all applications from local governments or districts for State or Federal funds related to transportation, and construction of the State Highway System. In addition to the project-review function, MTC administers the public transit funds derived from State and local sales taxes on gasoline for the nine bay region counties.

MTC adopted the Regional Transportation Plan in 1973 and revisions on several subsequent occasions.

With respect to seismic safety, the plan recognizes the importance of the transportation system to postearthquake evacuation, rescue, and relief efforts. Accordingly, the following policy was adopted: "Earthquake and seismic technology shall be used in the planning, location and construction of new transportation facilities" (Metropolitan Transportation Commission, 1974, p. 14). This policy ensures that seismic hazards are considered in the review of transportation projects undertaken by MTC.

EVALUATING SEISMIC RISK

Seismic safety planning is the process of evaluating seismic risk and formulating public policy to reduce that risk. Methods of evaluating seismic risk are described in this section; formulating public policy is discussed in the following section. To evaluate risk, it is necessary to understand the distinction between hazard and risk. A seismic hazard is an effect of an earthquake such as surface faulting, ground shaking, a tsunami, liquefaction, landsliding, and other forms of ground failure. Seismic risk is the exposure of individuals and structures to potential injury or damage from seismic hazards. For example, the presence of an active fault is clearly a hazard; however, the degree of risk depends on the location, type of construction, and occupancy of structures with respect to the fault. Given present knowledge of seismic phenomena, little can be done to modify the hazard, that is, control tectonic processes, but much can be done to control risk or exposure to seismic hazards. This is the purpose of seismic safety planning.

Risk evaluation consists of: evaluating seismic hazards, and assessing the degree of exposure of individuals and structures to those hazards. The techniques and specifics of the evaluation may differ, but the basic procedure is becoming fairly well established. Figure 14 outlines the usual steps in evaluating risk from seismic hazards. Each step is described briefly in the following sections.

IDENTIFYING SEISMIC HAZARDS

The first step in evaluating risk in any area is to determine the potential for damaging earthquakes by reviewing the seismic history of the area and identifying any active or potentially active faults. Such faults are identified from historic, geologic, or seismic evidence of surface displacement (Borcherdt, 1975, p. A5).

Evaluating earthquake potential or seismicity of an area requires information concerning:
(1) the location of faults capable of generating damaging earthquakes, (2) the magnitude of earthquakes anticipated on these faults, (3) the amount of fault displacement anticipated, (4) the nature and areal distribution of deformation accompanying earthquakes or fault movement; and (5) the frequency of recurrence of earthquakes on a known fault (Borcherdt, 1975, p. A29).

Work done in the bay region provides an example of the necessary first step in evaluating regional seismicity. Here some 30 faults have been identified as being active or potentially active and therefore potentially capable of producing damaging earthquakes (Borcherdt, 1975, p. A30). These faults have been mapped at scales ranging from 1:250,000 to 1:24,000 and their earthquake potential evaluated. These data provide a detailed description of the seismicity of the bay area (Borcherdt, 1975, fig. 3 and table 1). As in this example, where damaging earthquakes can be expected, the various seismic hazards need to be identified and evaluated.

The following discussion of individual seismic hazards in the San Francisco Bay region illustrates this process. The discussion is based almost entirely on the technical data in Part A of this report, and major topics are keyed to pages in Part A (Borcherdt, 1975).

SURFACE RUPTURE (A6–A12; A25–A30)

Faults which have displaced the surface of the earth in the recent geologic past can be expected to do so again and are classed as active or potentially active. Not all earthquakes result in surface rupture and, in any one earthquake, surface rupture is unlikely to occur along the full length of a major fault. Also the likelihood and amount of potential surface displacement vary for different faults and even for different segments of the same fault. However, because even small vertical or horizontal displacements can severely damage structures astride a fault, planners should consider rupture a hazard on all the identified active or potentially active faults in the San Francisco Bay region. Special geologic investigations to determine the nature and amount of anticipated displacement are needed to locate and design those utility lines and other lifelines which must cross a fault.

Surface rupture along active faults may also result from fault creep—a process consisting of slow, intermittent, or fairly continuous fault movement which can amount to as much as an inch per year. It is usually recognized by surface evidence such as offsets and breaks in curbs, sidewalks, streets, fences, and

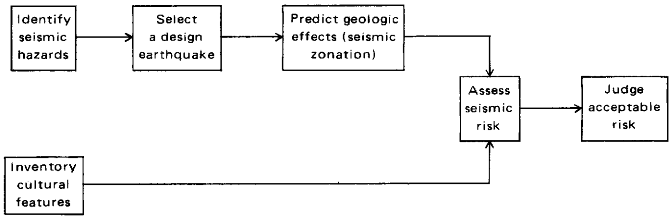


FIGURE 14.—Steps in evaluating seismic risk.

other structures. The presence of creep and its rate can be verified by installing and monitoring instruments along the fault.

Another aspect of evaluating hazard from surface rupture is defining the width of the zone of surface deformation associated with fault displacement (Borcherdt, 1975, p. A25). Precise delineation of this zone may require extensive subsurface investigation (usually including trenching) to locate all active traces and other evidences of surface deformation. Such information is seldom available, so the width of the zone is commonly estimated from geologic evidence or from historic records.

Widths of zones of deformation are discussed (Borcherdt, 1975, p. A25) in these terms:

Until proved otherwise by geologic site investigations, prudence suggests zone widths of 184 m (600 ft) for the largest strike-slip faults and 1,800 m (6,000 ft) for the largest dip-slip faults. In the San Francisco Bay region, most dip-slip faults are relatively short (less than 16 km or 10 mi), and for these, narrower zone widths are appropriate.

GROUND SHAKING (A52–A57)

Ground shaking is a major cause of earthquake damage. The severity of shaking depends on the magnitude and type of movement, distance from the fault, and local geology. The most violent ground shaking generally occurs in a fairly narrow band adjacent to the fault and the intensity of shaking tends to decrease with distance from the fault, but local geologic conditions may modify this pattern. That unconsolidated sedimentary deposits may amplify bedrock motion and produce strong ground shaking far from the fault is evident in the damage patterns of many major earthquakes. Borcherdt (1975, p. A64) states:

***The effects of ground shaking are expected to be least for sites underlain by bedrock, intermediate for those sites underlain by alluvium, and greatest for those sites underlain by artificial fill and bay mud.

In the bay region, the relative potential ground shaking can be estimated from the damage patterns of the 1906 earthquake, from empirical studies of amplification of bedrock motion in different earth materials, and from the predicted relationship between distance from the fault and intensity. Current estimates of the potential for shaking are given by Borcherdt, Gibbs, and Lajoie (1975).

LIQUEFACTION (A68–A74)

Liquefaction is the transformation of a loose, water-saturated, granular material (such as sand) from a solid to a liquid state. It can be caused by ground shaking and may in turn cause major ground failure. The relative potential for liquefaction in the southern San Francisco Bay region was mapped (Borcherdt, 1975, p. A70) using the following criteria:

The liquefaction-potential criteria can now be summarized as follows: Saturated clay-free granular sediments with relative densities less than 65 percent are considered to have high liquefaction potential, even in a moderate earthquake; clay-free granular sediments with relative densities greater than 90 percent are considered to have low liquefaction potential, even in a major earthquake; and saturated clay-free granular sediments with relative densities between 65 and 90 percent have moderate liquefaction potential that depends on intensity and duration of ground shaking and textural properties of the sediments.

"Potential" is the key word here. For liquefaction to occur, liquefiable materials must be within about 30 meters (100 feet) of the surface, saturated, and subjected to strong ground shaking. In addition, ground failure from liquefaction occurs only if the liquefied materials are not confined. For some geologic units, like bay mud, geologic site investigations are necessary to determine that a particular site is not underlain by liquefiable materials.

LANDSLIDING (A75–A87)

Earthquakes may trigger many landslides, particularly during the wet season. The potential for landsliding is a function of basic slope stability and is highest in unconsolidated, soft sediments or surficial deposits; on steep slopes; where seasonal rainfall is high; where vegetation is shallow rooted or sparse; where erosion rates are high; and where ground shaking is intense. Maps showing relative slope stability for the entire San Francisco Bay region are available at a scale of 1:125,000 (Nilsen and Wright, 1979). These maps evaluate relative landslide potential on an areawide basis. Although they do not predict which landslides will move in an earthquake, they do show those areas in which landslides are most likely. Geologic site investigation is needed to pinpoint the landslide potential within these areas.

FLOODING (A93–A94)

Earthquakes may cause flooding from tsunamis and seiches. The susceptibility of a coastal area to tsunami damage depends on local topography and elevation with respect to the potential size and direction of incoming waves. Potential tsunami runup areas can be generally delineated, and are often based on a maximum probable event. Potential runup areas in the San Francisco Bay region are mapped by Ritter and Dupre (1972).

The hazard from seiches is more difficult to evaluate. Generally speaking, any area adjacent to a large reservoir, lake, or other enclosed body of water is susceptible to flooding from seiches. Overtopping of dams or shoreline flooding can also be generated by landslides falling into bodies of water. The potential depends on the location of unstable slopes with respect to lakes, reservoirs, and bays.

Major flooding may be caused by the failure of dams or dikes during an earthquake. Areas around the southern San Francisco Bay are particularly susceptible to flooding from dike failure. Many dikes are built mostly of fine-grained sediments dredged from the bay and are located on deposits of bay mud. Such dikes are particularly prone to failure during an earthquake. The areas susceptible to flooding from dike failure vary with tidal level at the time of an earthquake, but they have increased in size over the years because of ground subsidence brought about by the withdrawal of ground water in the south bay area.

In accordance with the Alquist Dam Safety Act (see section on "Critical facilities"), areas which would be flooded in the event of dam failures have been mapped throughout California. These areas are extensive in the San Francisco Bay region and are of significant concern because of their size and location. Studies are being made to identify more specifically the likelihood of individual dam failure in the event of a major earthquake. It is also essential to evaluate the probable depth and velocity of flood waters and, where areas below dams are developed, the length of warning time residents may have.

SELECTING THE DESIGN EARTHQUAKE

The severity of seismic hazards is directly related to several characteristics of earthquakes. Information concerning possible earthquake magnitude and location are needed to estimate the possible surface rupture, ground shaking, ground failure, and flooding in an area. The hypothetical earthquake that is used as the basis for assessing seismic effects is called the design earthquake. Criteria for establishing the magnitude of the design earthquake are described below.

Maximum earthquake magnitude and frequency can be estimated, based on:

> (1) the geologically determined rate of slip and historic records of ground deformation, (2) the seismic history of the fault and the surrounding tectonic regime, (3) geologic evaluation of the tectonic setting, and (4) the empirically derived relation between magnitude of earthquakes and fault length or other parameters (Borcherdt, 1975, p. A17).

It is realistic to assume that the largest historic earthquake can recur on the same fault or a geologically similar fault and that potential magnitude increases with fault length. Based on seismic history and fault-length relations, assuming that half the fault length would break in a maximum magnitude earthquake, the largest expected earthquake on the San Andreas fault is 8.5 on the Richter scale and, on the Hayward fault, 7.0–7.5 (Borcherdt, 1975, p. A10).

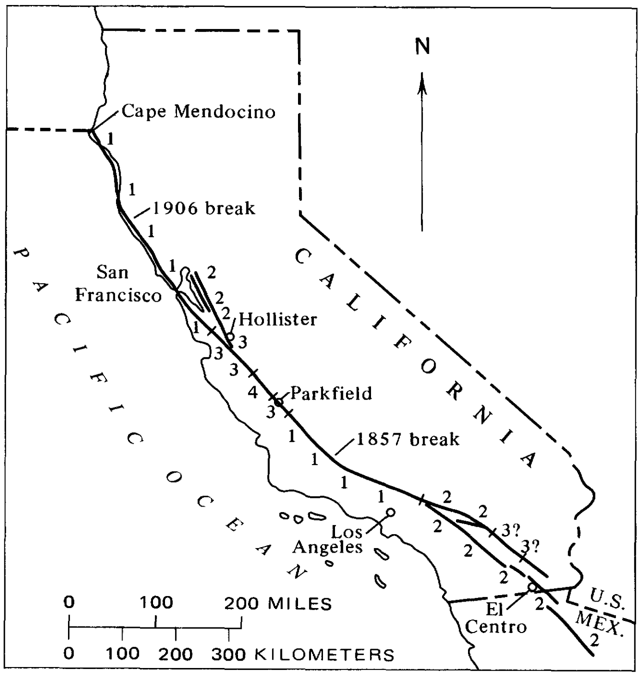
A magnitude at, or close to, the maximum expected is usually chosen for the design earthquake in evaluating risk for planning purposes. Because earthquake effects cannot yet be predicted in detail, a conservative approach based on the largest magnitude foreseen by competent geologists is prudent, especially when planning for areas or structures with intensive use or for facilities which are critical to the safety and continued functioning and recovery of a community during and after an earthquake.

Choice of size of the design earthquake is also influenced by projected frequency of occurrence. If an earthquake of maximum magnitude can be expected to occur once every thousand years, for example, one of lesser magnitude may be reasonably chosen for the design earthquake. However, recurrence intervals, particularly for major earthquakes, are difficult to determine; the historic record is too short, and even careful geologic studies do not always clearly define recurrence intervals.

Although magnitude and frequency appear to be related linearly—small earthquakes occur more often than large ones (Chinnery and North 1975, p. 1198)—this relationship is a poor guide for evaluating risk, because in a given area the pattern is highly variable. Different segments of the same fault may behave differently. For example, the segment of the San Andreas fault running through Marin County and the San Francisco peninsula has been relatively quiet since 1906, whereas the same fault near Hollister is the source of frequent relatively small earthquakes. Figure 15 shows the maximum magnitude, maximum strike slip (horizontal displacement), and recurrence interval estimated for different segments of the San Andreas fault (Wallace, 1970, p. 2881).

The magnitude chosen for the design earthquake should not necessarily be the maximum magnitude that may be expected on the fault segment closest to the planning area. For example, the Hollister area may experience more damage from a magnitude 8 on the fault segment to the north than from a magnitude 6 on a closer segment of the fault. All faults and fault segments near the planning area need to be carefully evaulated in selecting the design earthquake. Because damaging effects are related to the length of fault displacement which in turn is related to the length of the fault, the design earthquake is usually the maximum event expected on the largest active fault affecting an area.

A design earthquake may represent the expected effects of a single large earthquake or a series of earthquakes of different magnitudes. The design earthquake does not indicate the overall seismicity or susceptibility to damage from lesser magnitude earthquakes or from earthquakes on other nearby faults. However, if appropriate measures are taken to reduce



Behavior category	1	2	3	4
Maximum magnitude	7-8+	6-7	5-6	<5
Maximum strike slip (m)	1.2-10	0.3-1.2	0.1-0.3	<0.1
Recurrence interval (yrs)	100-1000	10-100	<10	>10

FIGURE 15.—Behavior of different segments of San Andreas fault (Wallace, 1970, p. 2881).

risk from the design earthquake, risk from lesser events are correspondingly reduced.

PREDICTING GEOLOGIC EFFECTS

Predicting the effects of a design earthquake involves relating information available on the seismic hazards to the design earthquake. Since the seismic hazards are closely related to geologic conditions, the evaluation depends on the level of detail and accuracy of the basic geologic mapping. Predicting the geologic effects of an earthquake in a given area is termed "seismic zonation", which is defined as "the delineation of geographical areas with different potentials for surface faulting, ground shaking, flooding, liquefaction, and landsliding during future earthquakes of specific size and location" (Borcherdt, 1975, p. A1). Such studies are essential in evaluating risk for planning purposes.

The geologic effects of a postulated earthquake of magnitude 6.5 on the San Andreas fault are predicted (Borcherdt, 1975, p. A88–A95) along a demonstration profile extending from Sky Londa west of the fault on the San Francisco peninsula across the bay to Coyote Hills (fig. 16). The moderate magnitude of 6.5 was chosen because reliable strong-motion data obtained within 50 km (31 mi) of the causative fault were available for earthquakes of moderate size (magnitude 5.0–6.9) but not for magnitude 7.0 and larger earthquakes. With such data it is possible to statistically predict ground-motion values for competent geologic materials (ranging from bedrock to firm alluvium) for sites at distances greater than 10–20 km (6–12 mi) from the causative fault (Borcherdt, 1975, p. A32).

The maximum magnitude expected along this segment of the fault is 8.5, and a magnitude closer to this would usually be used for the design earthquake for planning in the area of the demonstration profile. However, the methods used to predict the geologic effects of a 6.5 M earthquake are the same as for an 8.5, and any ranking of geographic areas on the basis of relative hazard would be the same. An 8.5 M earthquake would cause more severe effects over a larger area than a 6.5.

Figure 17 shows the predicted geologic effects of the postulated 6.5 M earthquake along the demonstration profile. The method described can be applied to other large areas in the San Francisco Bay region where comparable geologic information is available. This information was translated into a series of hazard maps for use in assessing seismic risk by extending the several geologic effects to areas with similar underlying geologic material in an area roughly centered along the profile.

Figure 18 shows the generalized geology of the area crossed by the demonstration profile and zones of potential surface deformation for the postulated earthquake. A surface-rupture length of 40 km (25 mi) plus or minus about 10 km (6 mi) is postulated on the San Andreas fault (see fig. 16). Displacement on the San Andreas of about 1 m (3 ft) is estimated. The zone of potential surface deformation can vary in width from a few meters to a few tens of meters. The hatched lines in figure 18 showing deformation zones are not to scale; they simply indicate that surface deformation is not necessarily confined to the line depicting the fault location. The zone of predicted surface deformation should be considered highly hazardous in a risk evaluation. Structures within it could experience severe damage from displacement of the ground and from intense shaking; however, detailed investigations may reveal sites within the zone which can accommodate structures with acceptable safety.

GROUND SHAKING

Predicting relative severity of ground shaking is one of the most difficult tasks of seismic zonation. Two steps are involved in estimating relative ground shaking at the surface: predicting bedrock shaking, and predicting amplification of bedrock shaking in unconsolidated deposits. Shaking was predicted for four sites

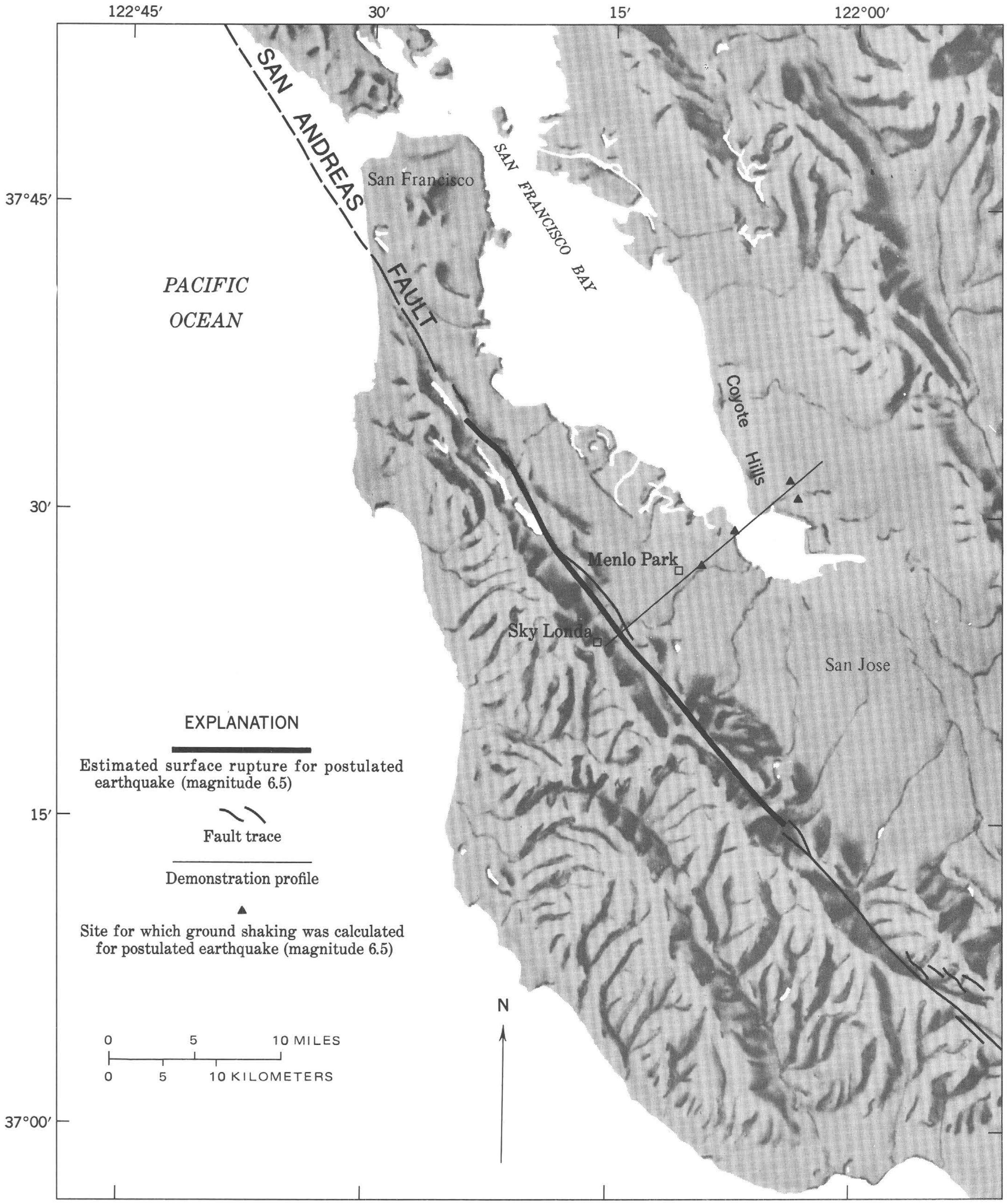


FIGURE 16.—Location of demonstration profile and estimated length of surface rupture associated with a postulated earthquake of magnitude 6.5 on the San Andreas fault, southwestern San Francisco Bay region (Borcherdt, 1975, p. A89).

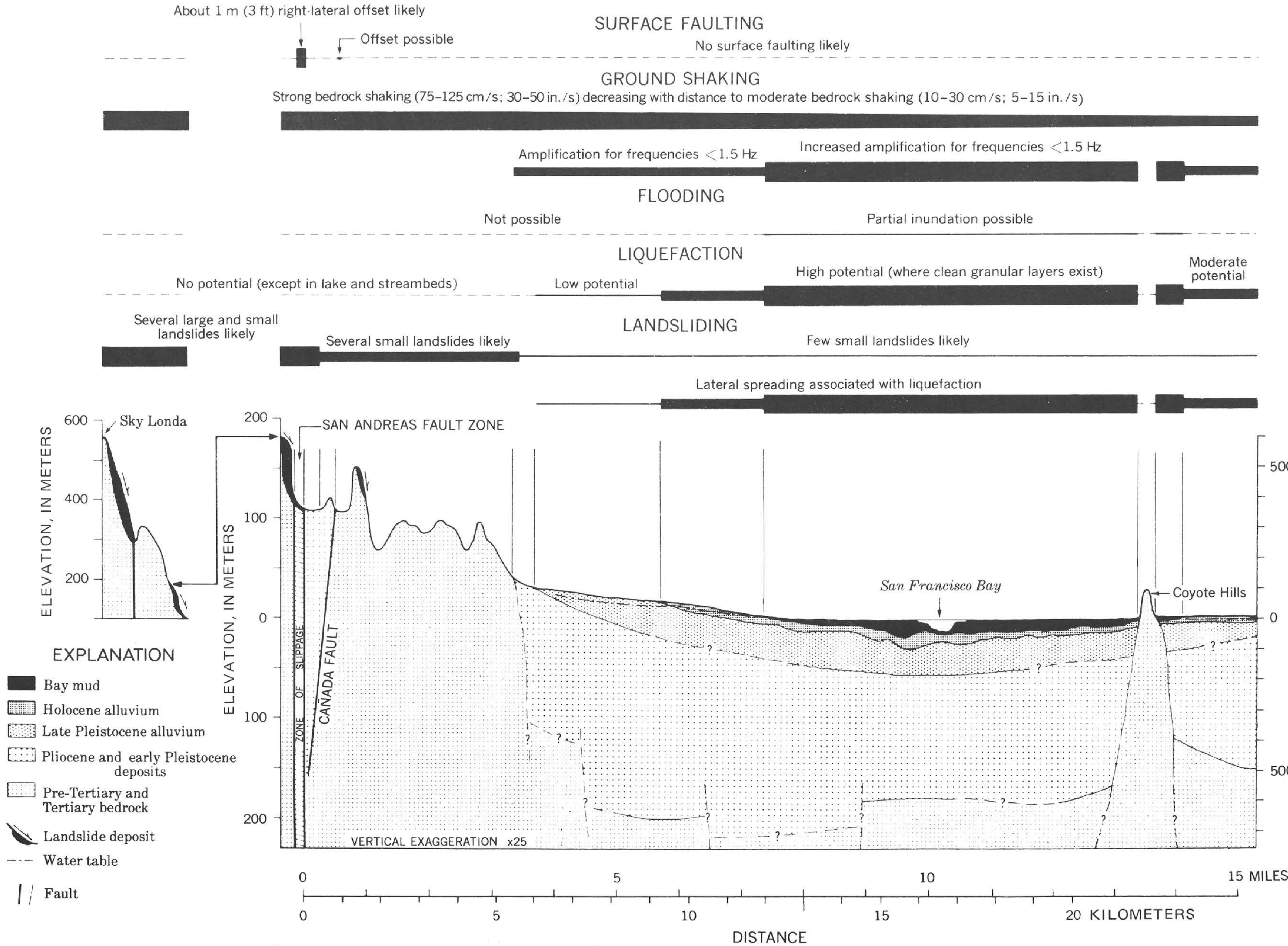


FIGURE 17.—Predicted geologic effects of a postulated earthquake (magnitude 6.5) on the San Andreas fault (see fig. 16 for location of demonstration profile and estimated length of surface rupture). The severity of each earthquake effect is indicated qualitatively by thickness underlining and quantified to the extent permitted by the current state of the art or seismic zonation on a regional scale. The severity of the predicted earthquake effects generally depend on the type of underlying geologic material. Geologic cross section compiled by K. R. Lajoie (Borcherdt, 1975, p. A91).

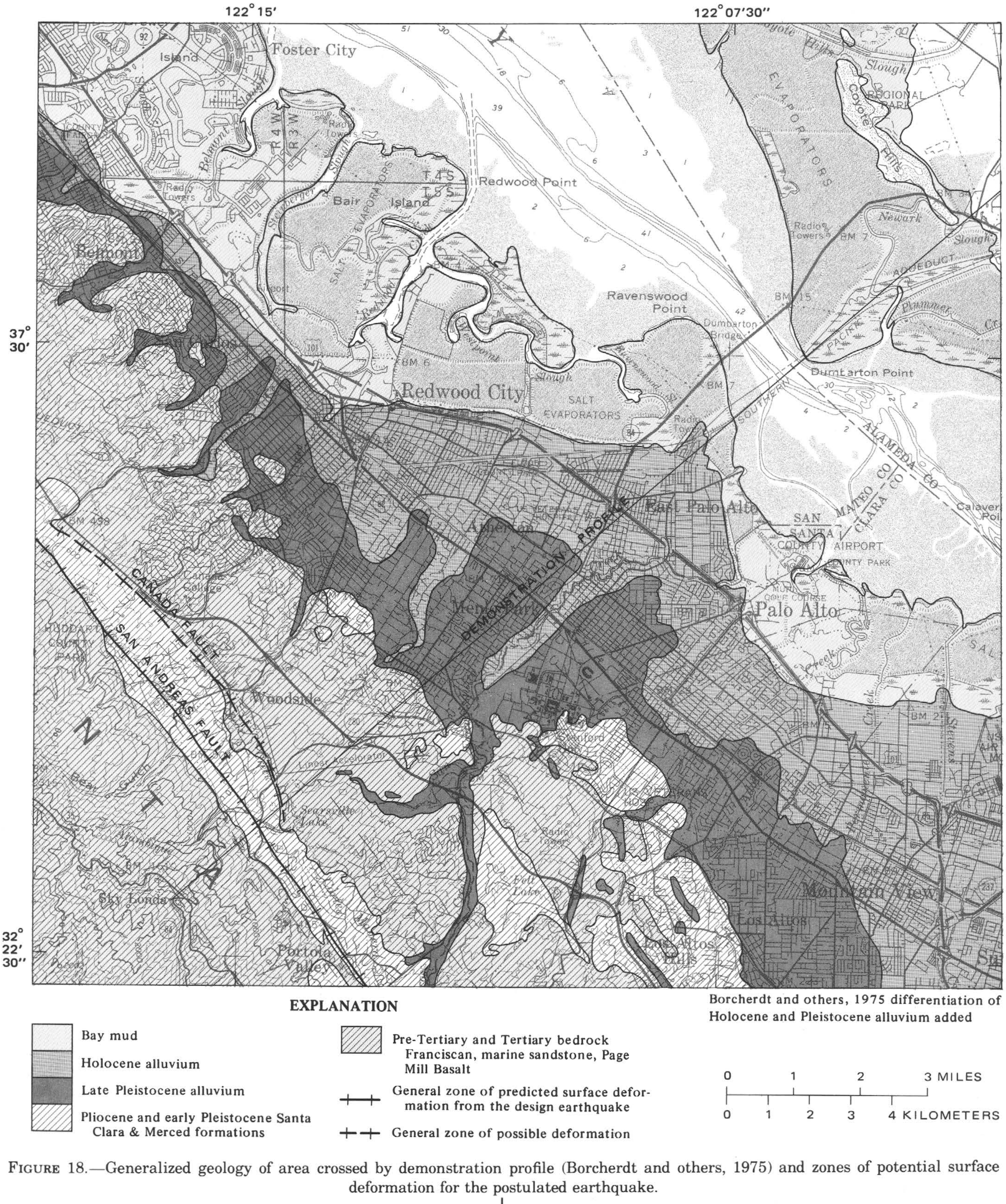


FIGURE 18.—Generalized geology of area crossed by demonstration profile (Borcherdt and others, 1975) and zones of potential surface deformation for the postulated earthquake.

along the demonstration profile (fig. 19). Site 1 is 9 km (5.6 mi) from the fault; site 2, 14 km (8.7 mi); and sites 3 and 4, 22.5 km (13.1 mi).

Bedrock motion is estimated to be 75–125 cm/s (30–50 in./s) at site 1, decreasing with distance from the fault to 10–30 cm/s (8–12 in./s) at sites 3 and 4.

However, bedrock motion is amplified by the unconsolidated materials present at sites 2 and 3. This amplification of bedrock motion depends on the frequency and varies with the nature of unconsolidated deposits and the distance from the earthquake source. Figure 19 shows the potential for amplification of bedrock motion in the area crossed by the demonstration profile. As stated by Borcherdt (1975, p. A93):

> The model calculations suggest that a substantial amplification of bedrock shaking in the frequency range below 1.5 hertz could be expected for all parts of the demonstration profile underlain by alluvial deposits, with increased amplifications for the parts underlain by bay mud. The predicted amplifications are large enough to suggest that ground shaking for frequencies below 1.5 hertz may be stronger at the sites underlain by bay mud and alluvium than at sites underlain by bedrock much closer to the fault.

LIQUEFACTION AND LATERAL SPREADING

Relative potential for liquefaction and lateral spreading from the postulated earthquake is illustrated in figure 20. Liquefaction potential is considered highest where beds or lenses of clay-free granular sediments occur within the bay mud. Lateral spreading, which is the most common kind of ground failure to result from liquefaction in the San Francisco Bay region, is the movement of soil mass toward a free face or down a gentle slope. Cracks, fissures, and differential settlement in or near the margins of the slide mass commonly result from lateral spreading (Borcherdt, 1975, p. A94).

LANDSLIDING

The relative stability of upland slopes, as mapped by Nilsen and Wright (1979) is shown in figure 21. The slope stability categories shown are based on geology and slope and are independent of earthquakes. But an earthquake during the wet season could be expected to trigger more and larger landslides than normally occur. Unstable areas like those between Sky Londa and the San Andreas fault are susceptible to earthquake-induced landslides even in the dry season, and small landslides can be expected where slopes are moderately unstable (Borcherdt, 1975, p. A94).

FLOODING

For the postulated earthquake, flooding is most likely to occur from the failure of earthen dikes located on bay mud along the margins of southern San Francisco Bay. The extent of potential flooding depends on topography and the tide level at the time of dike failure. Figure 22 shows possible flooding throughout the bay mud unit extending inland to the 1850 bay shoreline. Flooding could extend farther inland in some areas if ground subsidence has occurred. For the postulated earthquake, flooding from tsunami runup, seiches, or dam failure is not considered likely in the area shown in figure 22.

SEISMIC ZONATION

Figures 19–21 are hazard maps expressing the relative severity of potential earthquake hazards and, together, constitute a preliminary seismic zonation. A composite map of hazard zones can be compiled by judging the relative risk posed by each hazard. For example, the area shown in the figures is divided into high, moderately high, moderate, and low hazard zones as follows:

High: the San Andreas and Cañada fault zones, bay mud, and slope-stability category 5;
Moderately high: Holocene alluvium, slope stability category 4, and areas near the San Andreas and Cañada faults;
Moderate: Late Pleistocene alluvium, and slope stability category 3; and
Low: the remainder of the study area.

The limits of these zones are not exact; also the degree of hazard within each zone may vary locally. These local variations can be more precisely defined by more detailed investigations and mapping.

Figure 23 shows four possible hazard zones. These zones have the following characteristics:

1. Bay mud is in the highest hazard zone because it has relatively high potential for liquefaction and for lateral spreading; it is subject to strong ground shaking; and it is subject to flooding.
2. The zones of predicted surface deformation are in the highest hazard zone because structures astride a fault are vulnerable to serious damage or destruction in the event of sudden surface rupture.
3. Slopes that are unstable under nonseismic conditions are in the highest hazard zone because they are likely to fail in the postulated earthquake. Moderately unstable slopes are considered slightly less likely to fail and are in the moderately high hazard zone. Slopes that are stable or marginally stable may fail during the postulated earthquake and are in the moderate hazard zone. Other slopes are relatively stable and are in the low hazard zone.
4. Areas underlain by Holocene alluvium have moderate potential for liquefaction and lateral spreading and may have high surface ground shaking because of amplification of bedrock motion. They are in the moderately high hazard zone.
5. Although areas underlain by late Pleistocene

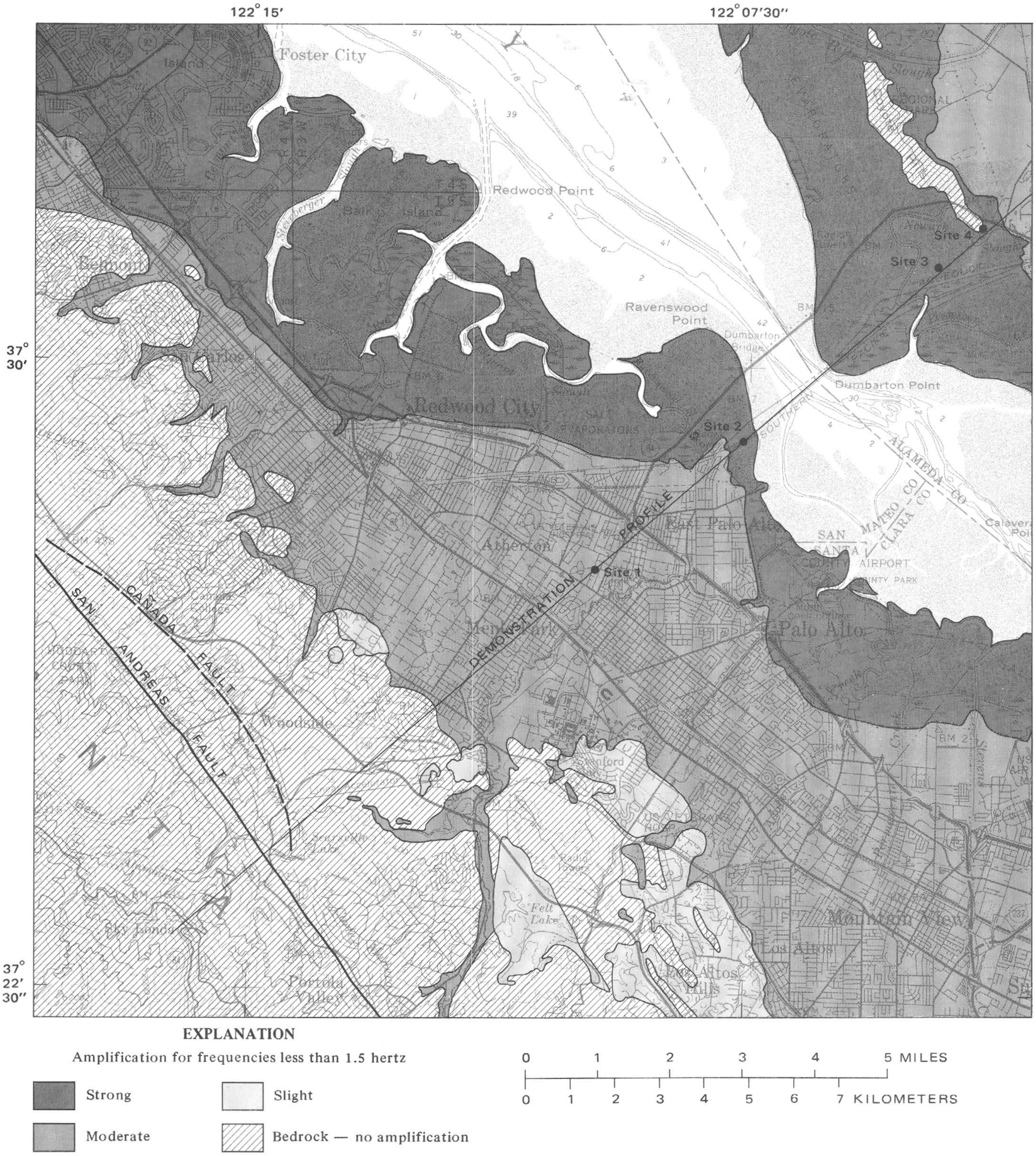
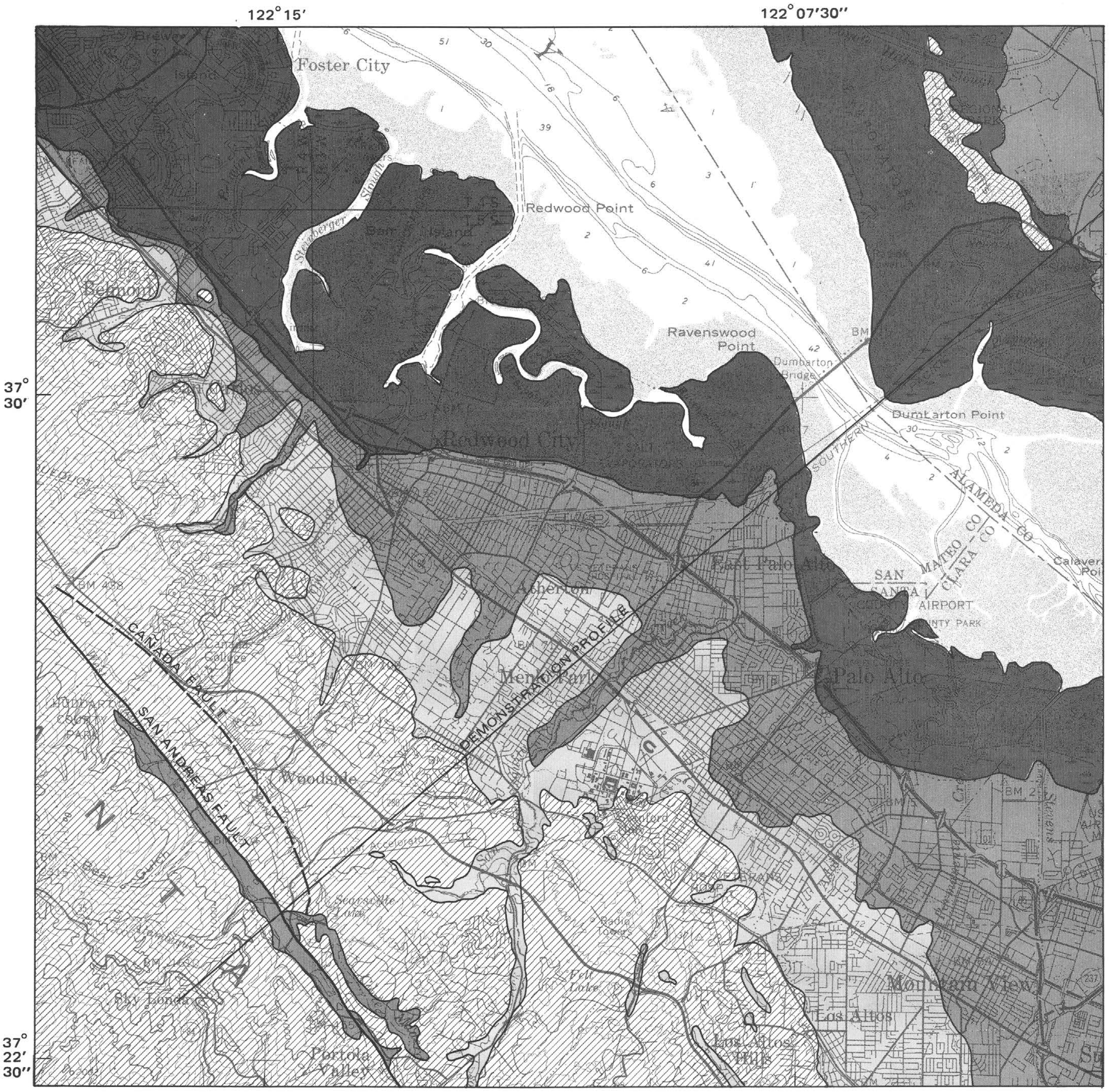


FIGURE 19.—Relative amplification of bedrock motion.

alluvium have a low potential for liquefaction and lateral spreading, bedrock motion may be greatly amplified. These areas are in the moderate hazard zone.

6. Areas next to the San Andreas and Cañada faults are in the moderately high hazard zone because of the potential for strong ground shaking.



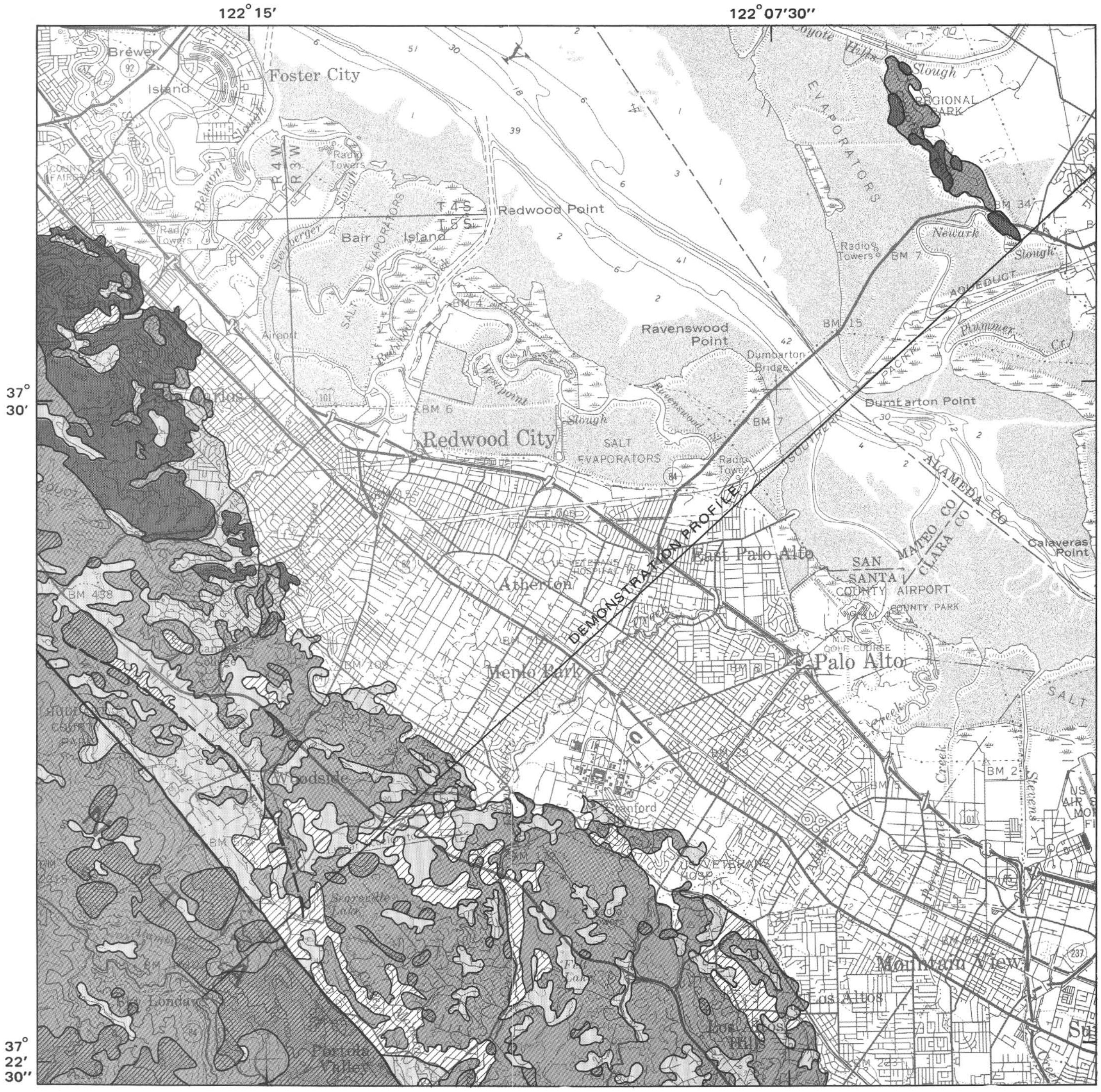
EXPLANATION

- High potential for liquefaction and lateral spreading where clay-free granular layers are present
- Moderate potential for liquefaction and lateral spreading where clay-free granular layers are present
- Low potential for liquefaction and lateral spreading where clay-free granular layers are present
- Land areas underlain by bedrock with little potential for liquefaction

0 1 2 3 MILES

0 1 2 3 4 KILOMETERS

FIGURE 20.—Relative potential for liquefaction and lateral spreading from the postulated earthquake.



EXPLANATION

- Stable
- Generally stable
- Generally stable to marginally stable
- Moderately unstable
- Unstable

0 1 2 3 4 MILES

0 1 2 3 4 5 6 KILOMETERS

FIGURE 21.—Relative stability of upland slopes.

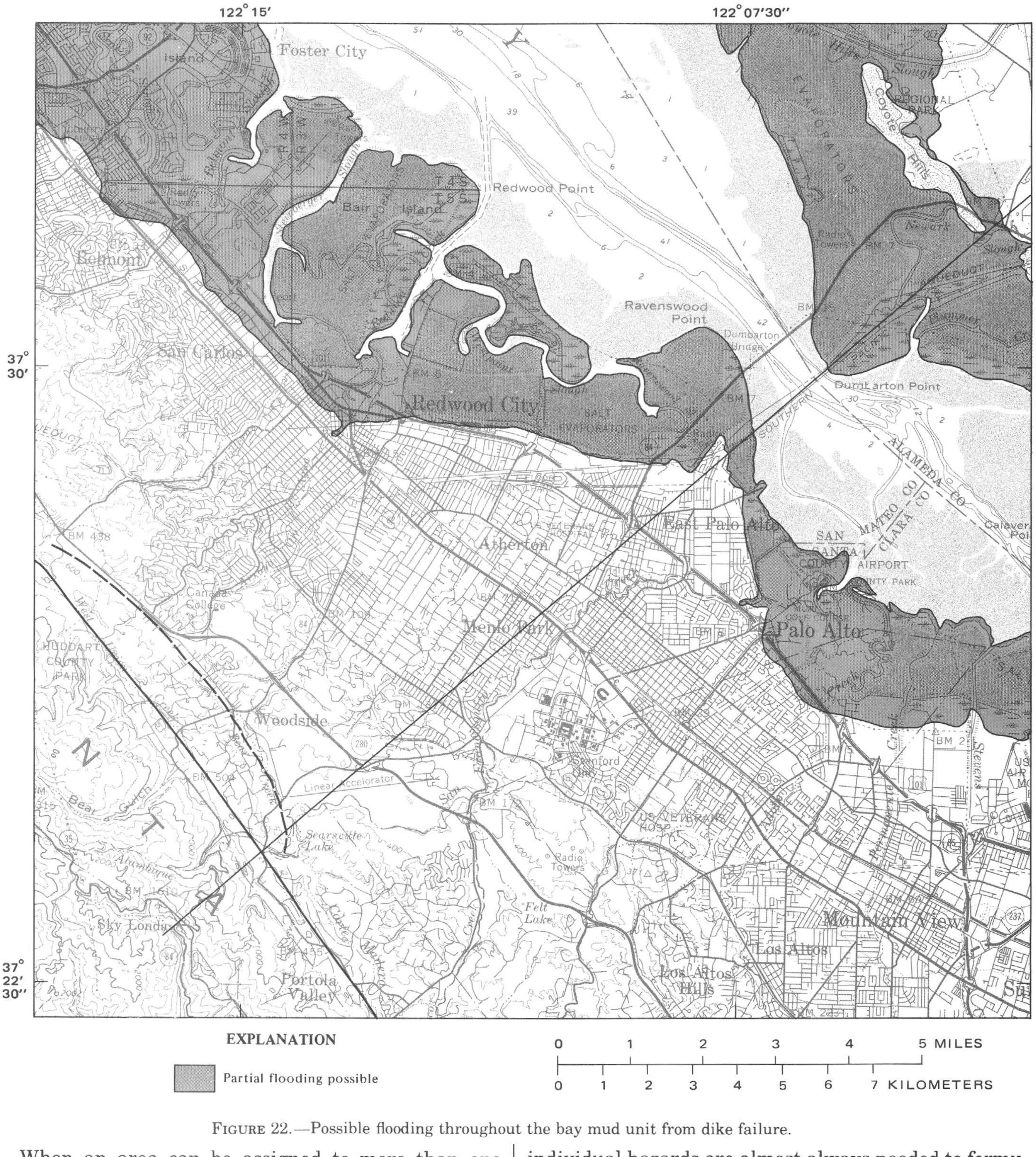


FIGURE 22.—Possible flooding throughout the bay mud unit from dike failure.

When an area can be assigned to more than one hazard zone, the highest hazard zone is shown. The resulting map (fig. 23) shows relative hazards from all the seismic effects considered. It does not show which hazard dominates at a given location. Because different measures are effective in mitigating different seismic hazards, maps showing the relative severity of individual hazards are almost always needed to formulate plans for reducing seismic risk.

The composite seismic hazard zone map provides a general overview of relative hazards from the postulated earthquake. Preparing a composite map identifies areas with multiple hazards and areas where, because the hazard is greatest, the most severe damage from

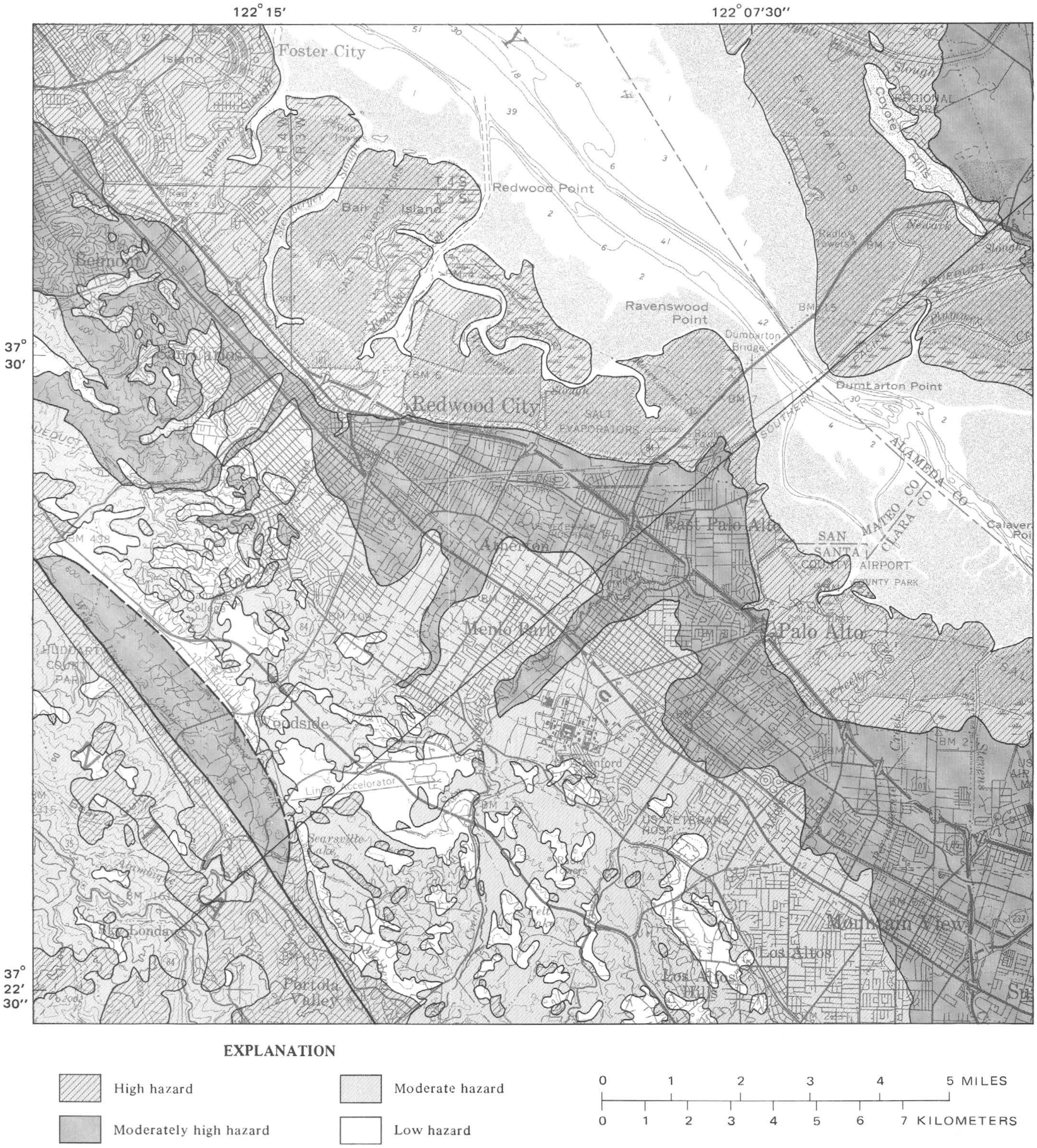


FIGURE 23.—Seismic hazard zones.

the earthquake can be expected. These areas should be carefully investigated before making land-development decisions and given particular consideration when planning for emergencies. Such a map cannot substitute for detailed investigations, but it can indicate where such investigations are most needed. The seismic hazards zone map is only as accurate as its elements. Because ground shaking is difficult to predict regionally, it is less accurately reflected in the composite map than other seismic hazards. As presented here, the map shows relative differences in amplification of bedrock motion in unconsolidated deposits, but it does not indicate differences in bedrock motion. Areas near the fault shown in the low hazard zone may, because of strong bedrock shaking, be more hazardous than indicated.

Another approach to seismic zonation, which partly avoids this problem, was suggested by Borcherdt, Gibbs, and Lajoie (1975), whose map of the South San Francisco Bay region (scale 1:125,000), shows maximum earthquake intensity for a large (7.5M–8.3M) earthquake on the San Andreas or Hayward fault. Intensities of the 1906 San Francisco earthquake are related to geologic units and distance from the fault to predict the maximum intensity throughout the region. Intensity is expressed in terms of the San Francisco Intensity Scale (table 7) developed by H. O. Wood (1908, p. 224, 225) to describe the 1906 San Francisco earthquake.

Figure 24 shows the maximum intensities predicted for the area shown in figure 23. It is not possible to tell from this map which hazards are present in a given location. High intensities may be from strong ground shaking, ground failure, or some other hazard. However, the intensity map fairly accurately depicts relative ground shaking from a large earthquake. Comparing this map with the seismic hazard zone map indicates that the intensity map probably understates landsliding and flood potential.

Hazard evaluation for risk assessment depends, first of all, on the detail and accuracy of the geologic information available for an area, but it also depends on the purpose of the evaluation, the size and diversity of the planning area, and the power of the agency undertaking the evaluation. If geologic maps are highly generalized, hazard evaluation must, of necessity, first focus on identifying those areas most likely to be hazardous, then further data can be collected and appropriate geologic information submitted with any major development proposals. Better hazard evaluations can be made as more detailed geologic data become available.

If the hazard evaluation is to be used primarily for earthquake preparedness, hazard zones based on intensity may be appropriate. For such purposes, it is more important to know the expected level of damage than the exact cause of the damage. If, on the other hand, the evaluation is to be used primarily to prepare land-use plans and regulations and to suggest measures to reduce seismic risk, it is important to evaluate each seismic hazard individually and in as much detail as the information permits.

Hazard evaluation for a geologically homogeneous region, regardless of size, can be quite generalized.

TABLE 7.—*San Francisco Intensity Scale for 1906 Earthquake*

[From Borcherdt, 1975, p. A3]

Grade	Intensity	Description
A	Very Violent	The rending and shearing of rock masses, earth, turf, and all structures along the line of faulting; the fall of rock from mountainsides; many landslips of great magnitude; consistent, deep, and extended fissuring in natural earth; some structures totally destroyed.
B	Violent	Fairly general collapse of brick and frame buildings when not unusually strong; serious cracking of brickwork and masonry in excellent structures; the formation of fissures, step faults, sharp compression anticlines, and broad, wavelike folds in paved and asphalt-coated streets, accompanied by the ragged fissuring of asphalt; the destruction of foundation walls and underpinning structures by the undulation of the ground; the breaking of sewers and water mains; the lateral displacement of streets; and the compression, distension, and lateral waving or displacement of well-ballasted streetcar tracks.
C	Very Strong	Brickwork and masonry badly cracked, with occasional collapse; some brick and masonry gables thrown down; frame buildings lurched or listed on fair or weak underpinning structures, with occasional falling from underpinning or collapse; general destruction of chimneys and of masonry, brick, or cement veneers; considerable cracking or crushing of foundation walls.
D	Strong	General but not universal fall of chimneys; cracks in masonry and brickwork; cracks in foundation walls, retaining walls, and curbing; a few isolated cases of lurching or listing of frame buildings built upon weak underpinning structures.
E	Weak	Occasional fall of chimneys and damage to plaster, partitions, plumbing, and the like.

More detail is needed to evaluate seismic hazards in geologically diverse areas where hazard potential will vary significantly throughout the area.

The power of the agency evaluating seismic hazards also affects the scope and detail of the effort. For example, a regional council of governments, with powers limited to planning and reviewing applications of local governments for Federal funds, may find generalized hazard evaluation sufficient for framing broad policies and determining what information should be submitted with applications for funds. Local governments, on the other hand, need a more detailed evaluation as basis for land-use plans, land-development regulations, project-review criteria and procedures, building-code requirements, plans for public facilities and emergency responses.

INVENTORYING CULTURAL FEATURES

Evaluating seismic hazards is only part of assessing seismic risk. The other part is assessing the vulnerability of land uses and building occupancies to earthquake

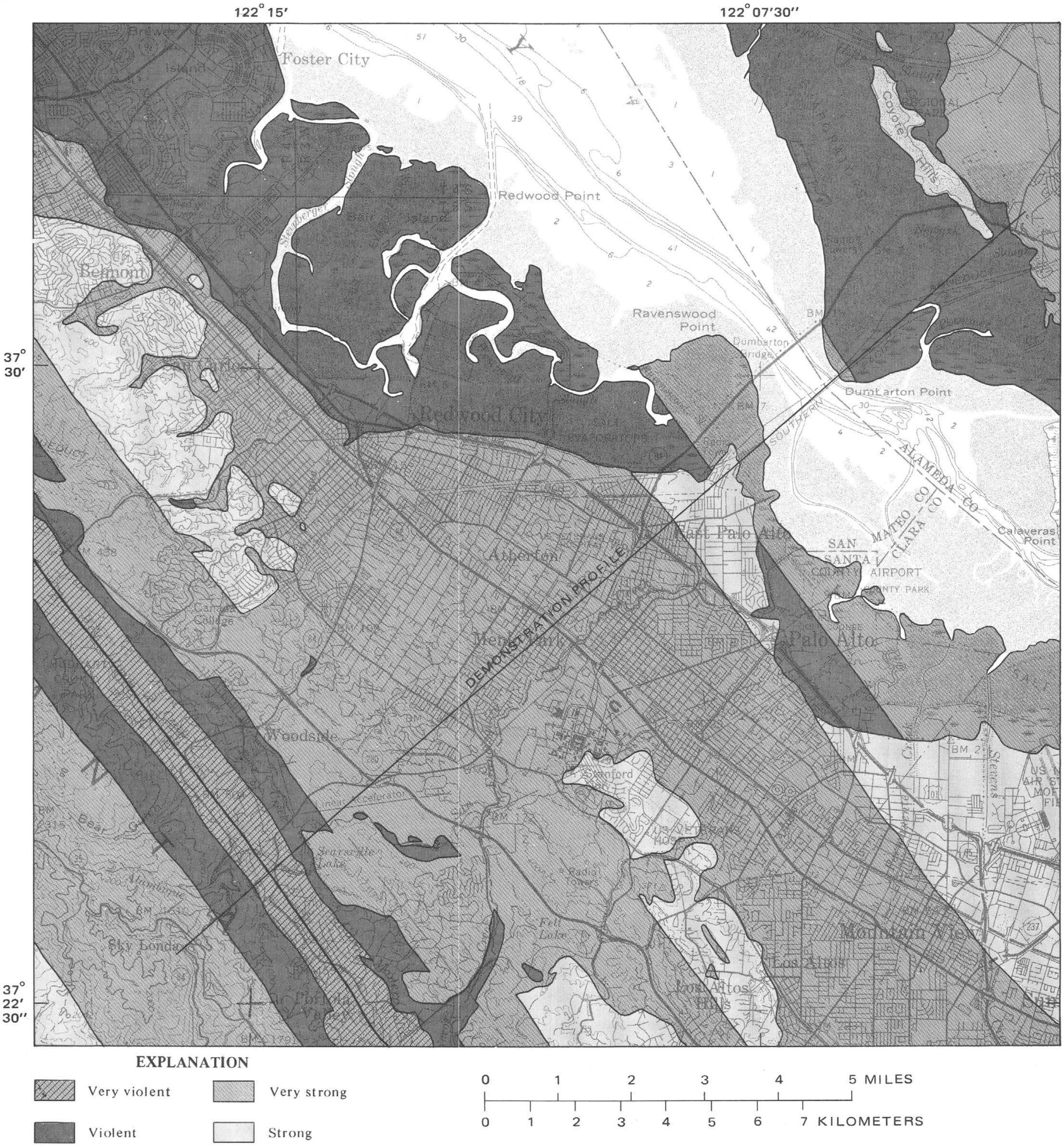


FIGURE 24.—Maximum earthquake intensity predicted on a regional scale.

damage. The next step in assessing seismic risk in the area crossed by the demonstration profile would be to inventory cultural or manmade features.

This information, considered in relation to the individual and composite seismic hazards maps, would be used to determine the exposure of structures and people to damage or death and injury from an earthquake.

Because of limitations of time and budget and the fact that the demonstration profile crosses several jurisdictions, an inventory of cultural features was not undertaken as part of this study. Instead, the key elements of such an inventory are first described in general terms, which are then followed by examples of various methods of combining hazard data with cultural data to assess seismic risk.

Risk depends on the uses of land and buildings and on the ability of a public agency to respond to a disaster. Evaluating seismic risk thus requires an inventory of (1) current land use; (2) structures with high occupancy; (3) structures that are hazardous because of age or type of construction; and (4) critical facilities including lifelines, facilities or structures needed for emergencies, and facilities and structures whose failure would be catastrophic, such as dams or nuclear power plants.

CURRENT LAND USE

Maps or aerial photographs of current land use, viewed in conjunction with hazard maps, provide an overview of risk. Data concerning the number of dwelling units, rate of occupancy, location of businesses, and number of employees are used in estimating the daytime and nighttime population of specific areas. Land use, population density, and hazard maps should be prepared at the same scale. Map overlays are particularly useful. In populous areas, computer modelling may be justified. The distinction between land uses should be fine enough to separate structural types, heights, and intensity of use. For example, residential uses should be broken down at least into single-family and multiple-family categories and into height and structural categories.

STRUCTURES WITH HIGH AND INVOLUNTARY OCCUPANCY

High-occupancy structures such as large apartment buildings, office buildings, major employment and shopping centers, theaters, auditoriums, and stadiums should be identified and noted on the hazard map. Buildings with high involuntary occupancy such as hospitals, schools, prisons, and convalescent homes form a separate and particularly vulnerable group. Most discussions of risk distinguish between a risk that is voluntarily assumed, such as the choice of a home site, and a risk that is involuntary, such as being in school or jail. Presumably structures occupied involuntarily should be safer than those voluntarily occupied. The distinction is especially important in those cases where public policy or laws require certain classes of people, such as prisoners or students, to occupy structures which have fairly high occupancy.

As a practical matter, only limited volition is possible in choosing the structure in which to work, live, or even spend leisure time. A choice of working in a relatively unsafe building or not working at all, or living in a structurally unsound house or leaving the area is often not a real choice. Most people fall somewhere between being voluntary or involuntary occupants of a building. In addition, information concerning the relative safety of structures is often not known. The relative safety of buildings is rarely considered by the job seeker, and the home seeker who would like a house designed as earthquake resistant may not be able to afford it.

Similarly, determining what occupancy rate should be classed as "high" depends upon the character of the development area. A community with predominantly low-density residential development might logically class two-story garden apartments as high occupancy in its risk evaluation. Conversely, a central city might apply that term only to structures more than 10 stories high.

The location of structures with high or involuntary occupancy can be shown on the land-use map or separately, depending on the graphic methods used. Information concerning whether occupancy is for 24 hours, daytime, or nighttime should also be noted.

HAZARDOUS STRUCTURES

Structures built before seismic safety requirements were imposed by local building code or State law need to be identified, noted on the map, and evaluated to determine if they were constructed with unsafe materials or methods. Particular attention should be given to masonry buildings. Also, poorly attached parapets, cornices, and other appendages should be noted. Failure of a building or parts adjacent to a street may be hazardous not only to occupants but to passersby. This type of information may be available from the agency or department responsible for building inspection; if not, it will need to be obtained.

LIFELINES

Lifelines are the utility services and communication and transportation lines necessary for the continued functioning of the community. Water supply lines, gas lines, electric transmission lines, telephone lines, major highways, and railway lines should all be included on the maps. Related facilities such as telephone exchanges, water and natural gas storage areas, airports, harbors, bridges, highway interchange structures, and power stations should also be identified. The location of shut-off valves, auxiliary suppliers, emergency power generators, and back-up communication systems should be noted where applicable. In addition, information on age, condition, and other factors will be needed in order to assess the likelihood of failure during an earthquake.

FACILITIES FOR EMERGENCY RESPONSE

The degree of risk partially depends on a community's ability to respond to a disaster situation. Command and communication centers, hospitals, medical offices and supply centers, fire stations, and police stations should all be noted on the maps. Buildings such as schools, churches, and theaters which could be used to provide temporary shelter or centers for dispensing emergency aid should also be identified.

Emergency resources may also be available from nearby communities under mutual aid agreements. However, because a major earthquake is likely to damage highways, communication lines, airports and other links to nearby communities, local facilities need to be sufficient to sustain a community until aid from outside can be obtained. Areas within a community which could become isolated should also be identified and evaluated for an emergency situation.

OTHER CRITICAL FACILITIES

Structures whose destruction or damage could have catastrophic effects include nuclear power plants, large dams, and storage facilities for toxic materials. These and similar facilities in, or potentially affecting, a planning area should be identified, and the area of potential damage mapped. For example, areas subject to flooding from dam failure or dike collapse should be shown on the map.

ASSESSING SEISMIC RISK

When information describing seismic hazards, land use, and the structural and disaster response characteristics of a planning area has been assembled, decisions concerning the nature and degree of seismic risk can be made. Risk can be expressed in a variety of ways and with varying degrees of precision.

DOLLAR LOSS

Estimates of the dollar loss from all earthquakes over a period of time, or from a design earthquake, can be used to express seismic risk. Alfors, Burnett and Gay (1973) have estimated the total dollar loss from earthquake shaking, fault displacement, landsliding, tsunamis, and other natural hazards which can be expected in California from 1970 to 2000 assuming current hazard mitigation practices. The total loss includes the cost of property damage, life-loss, injury, and intangible loss. The analysis explicitly relates hazard zones to population levels. Standard 7½ minute topographic quadrangles were selected as unit cells and were assigned to high, moderate, and low-hazard severity zones. The percent of population in each zone during the 30-year period is estimated, yielding an estimate of person-years exposure from 1970 to 2000. This figure is multiplied by the expected average total loss per capita per year to attain the total loss figures. The calculations for earthquake shaking are shown in table 8.

Projected total losses, 1970–2000, are $76,000,000 from fault displacement, $9,852,000,000 from landsliding, and $40,800,000 from tsunamis. Similar estimates were made of losses from other natural hazards.

Using dollars to express loss allows a comparison of total risk from several different hazards, including risk of life loss, injury, and property damage. This comparison is important in assigning priorities for public action and expenditure. It also provides a basis for determining the benefits of various risk-reduction measures if the costs of applying such measures are known. The Alfors study also estimates the cost of applying risk-reduction measures to arrive at a benefit/cost ratio for each hazard.

Alfors, Burnett, and Gay (1973) assess Statewide risk in order to maximize the benefits of State actions to reduce risk from natural hazards. More specific studies of natural hazards would be needed if such an analysis were made at the regional or local level. But in many cases the time and expense necessary to do a thorough assessment in terms of dollar losses is not justified. In addition, lack of data and lack of ability to evaluate hazards may be significant barriers to risk assessment.

DEATHS AND INJURIES

Risk can also be expressed as the expected loss of life and injury from a hazard over a period of time, or from a single event such as an earthquake of specified magnitude. The risk may be stated as a total of the expected deaths and injuries or as a rate per unit of population. Algermissen's (1972) estimates of the expected loss of life and injury from an 8.3 magnitude earthquake on either the San Andreas or Hayward fault were based on death and injury rates from historic earthquakes adjusted for types of structures and for daytime and nighttime conditions in the bay region. He estimated 2,300 deaths would result from damage or collapse of residential structures if the earthquake occurred at 2:30 a.m. when most people are at home. An additional 550 deaths would occur in hospitals if the earthquake were on the San Andreas fault, and 820 if it were on the Hayward. The largest number of deaths, 10,360, would occur with an 8.3 magnitude earthquake on the San Andreas fault at 4:30 p.m. during the evening commute period. A comparable earthquake at the same time of day on the Hayward fault would cause 6,650 deaths (table 9); deaths and injuries due to dam failure are not considered in these estimates.

TABLE 8.—*Projected total loss from earthquake shaking, 1970–2000*

[Alfors and others 1973, p. 96 and Alfors, John, oral commun., 1977]

Earthquake severity zone	Number of urban 7-½-minute quadrangles of each severity	Estimated percent of total population	Estimated person-years exposure 1970–2000	Geology Points (expectable total average loss rate) (dollars per capita per year)	Projected total loss 1970–2000
High	181	37½	289,050,000	31	$ 8,961,000,000
Moderate	242	50	385,400,000	27	10,406,000,000
Low	57	12½	96,350,000	14	1,349,000,000
Total			770,800,000		$20,716,000,000

The potential number of deaths from dam failure is horrendous. Table 10 shows the number of people exposed to risk from the failure of major bay region dams and the maximum possible and probable deaths should a dam fail during the night or day.

Estimates such as these can be used to express risk as a death rate per unit of population per unit of time. ABAG (1975b, p.14) uses estimates derived from the Algermissen study to calculate risk from an 8.3 magnitude earthquake on either fault. Assuming 6,600 deaths, a population of 5 million, and a recurrence interval of 170 years for an 8.3 magnitude event, the following calculation is made:

$$\text{Risk} = \frac{6{,}600 \text{ deaths}}{5 \text{ million population}} \times \frac{1 \text{ quake}}{170 \text{ years}}$$

$$= 7.7 \text{ deaths per year per 1 million persons}$$

Such calculations are useful primarily in comparing the risk of death from earthquakes with other natural and man-made risks. For example, the actual risk of death from all causes is about one in 100 persons per year (ABAG, 1975b, p. 14).

TABLE 9.—*Deaths and hospitalized injuries*

[Adapted from Algermissen, 1972, p. 121]

Magnitude	Time of Day	Total Deaths	Total Hospitalized Injuries
	San Andreas fault		
8.3	2:30 a.m.	2,850	10,800
	2:00 p.m.	9,460	34,400
	4:30 p.m.	10,360	40,360
7.0	2:30 a.m.	500	1,900
	2:00 p.m.	1,640	6,200
	4:30 p.m.	1,990	11,680
6.0	2:30 a.m.	25	100
	2:00 p.m.	80	320
	4:30 p.m.	100	390
	Hayward fault		
8.3	2:30 a.m.	3,120	11,600
	2:00 p.m.	7,200	28,500
	4:30 p.m.	6,650	24,900
7.0	2:30 a.m.	1,040	3,860
	2:00 p.m.	3,200	9,900
	4:30 p.m.	2,240	8,160
6.0	2:30 a.m.	330	1,220
	2:00 p.m.	730	2,600
	4:30 p.m.	700	2,550

POPULATION AT RISK

One of the simplest ways to express risk is in terms of the number of people exposed to a hazard. This can be done simply by estimating the population of each delineated seismic hazard zone. Ayre (1975) uses the generalized seismic risk map for the United States (see fig. 4, p. 10) as the basis for such an estimate. The results, shown in table 11, indicate that approximately 31 million people (15 percent of the population) live in risk zone 3—the zone with the highest seismic risk. Over half of these people live in California (17,000,000). Assessment of this type is useful only to provide an overview of risk exposure. To develop risk-reduction policies and programs at the regional or local level, hazardous areas must be delineated more precisely, and types of structures and patterns of occupancy must be studied in relation to the hazards.

In order to study risk, the City of Palo Alto (1976) took a census of population density during the day and during the night (fig. 25). Buildings with high occupancy were then located on a map together with generalized hazard zones. It became clear that buildings with high occupancy either during the day or night were located in zones of moderate or low hazard. The Palo Alto study (1976, p. 55) states:

> Measures to lessen risk to human life and property should focus upon identified areas of population concentration and be keyed to areas of greatest natural hazard and areas of known or suspected structural hazard.

RELATIVE RISK

Levels of seismic risk are commonly expressed in relative terms. The important point to remember is that a map of seismic hazard zones does not show exposure to hazards; information must include types of structures and occupancy characteristics. The term seismic risk map or zones is often used in a misleading sense.

The report by the Tri-cities Seismic Safety and Environmental Resources Study (Armstrong, 1973), illus-

TABLE 10.—*Life loss from dam failure*

[The figures represent the worst conditions as they may currently exist, assuming unsafe dams. All of these dams are (or will be) re-evaluated for safety, and appropriate corrections will be made if unsafe. From Algermissen, 1972, p. 132. Asterisks indicate figures not available.]

Dam	Maximum Possible Individuals Exposed		Maximum Possible Deaths		Estimated Probable Deaths	
	Day	Night	Day	Night	Day	Night
Lafayette	95,000	91,000	11,000	7,000	7,000	5,000
San Pablo, or Briones and San Pablo	49,000	51,000	29,000	30,000	20,000	25,000
Upper San Leandro and Chabot	86,000	109,000	50,000	52,000	30,000	35,000
Lower Crystal Springs	61,000	57,000	30,000	31,000	20,000	25,000
Calaveras, James Turner, and Del Valle	125,000	136,000	30,000	34,000	20,000	24,000
Only Calaveras	35,000	40,000	8,000	7,000	5,000	5,500
Only Del Valle	21,000	24,000	15,000	19,000	10,000	13,000
Lexington	*	72,000	*	20,000	*	15,000
Andrson and Coyote	*	18,000	*	5,000	*	3,000

trates a means of evaluating risk for a given structure or proposed project. Each of the following four factors is assigned a high, medium, or low-risk rating: geology of the general area, geology of the site, structures, and building uses. The rating for the geology of the general area is determined from the risk zones shown by Algermissen (1979). A rating of local geologic conditions is obtained by using the best information available on risk from active faults, slope stability, liquefaction, tsunamis, seiches, and ground shaking. Structural hazards are rated according to type of building construction. Table 12 lists common structural types of buildings in order of increasing susceptibility to damage in an earthquake. Table 13 provides the basis for rating various building uses. The term "ordinary" risk in table 13 applies to structures which would: resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some nonstructural damage; resist major earthquakes of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage. In most structures it is expected that structural damage, even in a major earthquake, could be limited to repairable damage (Armstrong, 1973, p. 162). Using the four risk levels, the Tri-cities study gives several examples of risk assessment for particular uses of specific sites. Table 14 is an example of one such assessment for a motor inn. Note that this seemingly simple analysis depends on quite specific information concerning seismic hazards at the site, and the structural and use characteristics of the structure. The procedure is adaptable to assessing existing risk levels or changes in risk if changes in land use are proposed. Thus risk, although not quantified, is expressed in a way that can be applied directly to many planning decisions.

SCENARIOS

Another technique for expressing risk is through a scenario, a fictional but realistic description of a disaster and the chain of related events, told in the order in which they occur.

Scenarios are especially effective in awakening public concern for seismic safety because they are dramatic. A good scenario requires accurate, specific information and should clearly identify areas and structures of greatest risk. It can serve as a basis for developing policy, and, more important, it can dramatize the need for reducing risk.

However risk is expressed, the assessment should be as clear and understandable as possible. Elaborate statistical studies of risk, although useful for some purposes, are not needed for most planning purposes. As stated in San Diego County's general plan (San Diego County, 1975, p. v–2):

> The problem with quantitative approaches lies in the complexity of principles upon which risk judgments are made. Risk is a function of the underlying lithology of the site and its proximity to an earthquake epicenter (sic) and varies with the use of the structure as well as the type, kind and quality of construction. Given those independent factors and economic and social impacts, the mechanical determination of an arbitrary level of risk is too simplistic.

Statistical expressions of risk based on historic records are particularly chancy when applied to infrequent, catastrophic events, such as major earthquakes, if the historic record is fairly short. One event greatly affects loss, injury, and death rates for years to come. Conversely, if no major earthquake has occurred during the period studied, an unduly optimistic picture of the degree of risk is conveyed.

The foregoing examples of risk assessment evaluate existing risk levels, but risk assessment needs to be a flexible tool. It can also be used to assess the risks

TABLE 11.—*U.S. population-at-risk by seismic risk zone and state*

[From Ayre, 1975]

State	Total Population	Estimated Population-at-Risk by Seismic Risk Zone			
		Zone 0	*Zone 1*	*Zone 2*	*Zone 3*
Alabama	3,444,165	1,056,000	1,126,000	1,263,000	0
Alaska	300,382	0	6,000	25,000	270,000
Arizona	1,722,482	0	0	1,742,000	30,000
Arkansas	1,923,295	0	1,473,000	166,000	284,000
California	19,953,134	0	0	2,636,000	17,317,000
Colorado	2,207,259	0	2,207,000	0	0
Connecticut	3,032,217	0	2,948,000	85,000	0
Delaware	548,104	0	548,000	0	0
Florida	6,789,443	5,503,000	1,286,000	0	0
Georgia	4,589,575	0	1,777,000	2,812,000	0
Hawaii	768,324	30,000	637,000	39000	63,000
Idaho	712,567	0	0	513,000	200,000
Illinois	11,113,976	0	9,951,000	895,000	268,000
Indiana	5,193,669	0	2,350,000	2,608,000	236,000
Iowa	2,825,041	0	2,825,000	0	0
Kansas	2,249,071	0	1,907,000	342,000	0
Kentucky	3,219,311	0	1,349,000	1,467,000	403,000
Louisiana	3,643,180	0	3,643,000	0	0
Maine	993,663	0	318,000	675,000	0
Maryland	3,922,399	0	3,734,000	189,000	0
Massachusetts	5,689,170	0	0	1,980,000	3,709,000
Michigan	8,875,083	0	8,875,000	0	0
Minnesota	3,805,069	0	3,805,000	0	0
Mississippi	2,216,912	269,000	1,674,000	217,000	57,000
Missouri	4,676,501	0	3,079,000	1,389,000	209,000
Montana	694,409	0	240,000	313,000	142,000
Nebraska	1,483,791	0	1,206,000	278,000	0
Nevada	488,738	0	0	300,000	189,000
New Hampshire	737,681	0	0	738,000	0
New Jersey	7,168,164	0	7,168,000	0	0
New Mexico	1,016,000	0	536,000	480,000	0
New York	18,236,967	0	13,211,000	2,481,00	2,545,000
North Carolina	5,082,059	0	2,172,000	2,910,000	0
North Dakota	617,761	0	618,000	0	0
Ohio	10,652,017	0	7,863,000	2,789,000	0
Oklahoma	2,559,253	0	2,399,000	160,000	0
Oregon	2,091,385	0	539,000	1,539,000	13,000
Pennsylvania	11,793,909	0	11,347,000	183,000	264,000
Rhode Island	946,725	0	84,000	863,000	0
South Carolina	2,590,516	0	0	1,577000	1,013,000
South Dakota	665,507	0	666,000	0	0
Tennessee	3,923,687	0	1,165,000	1,810,000	949,000
Texas	11,196,730	9,859,000	1,325,000	13,000	0
Utah	1,059,273	0	40,000	48,000	972,000
Vermont	444,330	0	0	444,000	0
Virginia	4,648,494	0	2,435,000	2,213,000	0
Washington	3,409,169	0	0	1,240,000	2,169,000
Washington, D.C.	756,510	0	757,000	0	0
West Virginia	1,744,237	0	1,509,000	236,000	0
Wisconsin	4,417,731	0	4,418,000	0	0
Wyoming	332,416	0	308,000	19,000	5,000
Totals	203,223,000 (100%)	16,717,000 (8%)	115,091,000 (57%)	40,442,000 (20%)	30,973,000 (15%)

inherent in proposed land use or occupancy change. Procedures for assessing risk should be designed to accommodate new information concerning seismic hazards, changes in structural conditions, occupancies, and other risk parameters.

DETERMINING ACCEPTABLE RISKS

Public actions to reduce risk involve at least an implicit determination of "acceptable risk." Acceptable risk, from the point of view of the public agency, is that level of risk at which no governmental response is considered necessary. Acceptable risk is rarely expressed in quantitative terms, but is embodied in the risk-reduction policies, regulations, and standards adopted by the public agency.

Acceptable risk is a measure of willingness to incur costs to reduce risk. Aiming for a totally risk-free environment is unrealistic; some balance must be sought between risk and the costs of reducing it. The balance actually struck by a governmental agency represents its choice of an acceptable level of risk. The choice can be made explicitly by public bodies based on evaluation

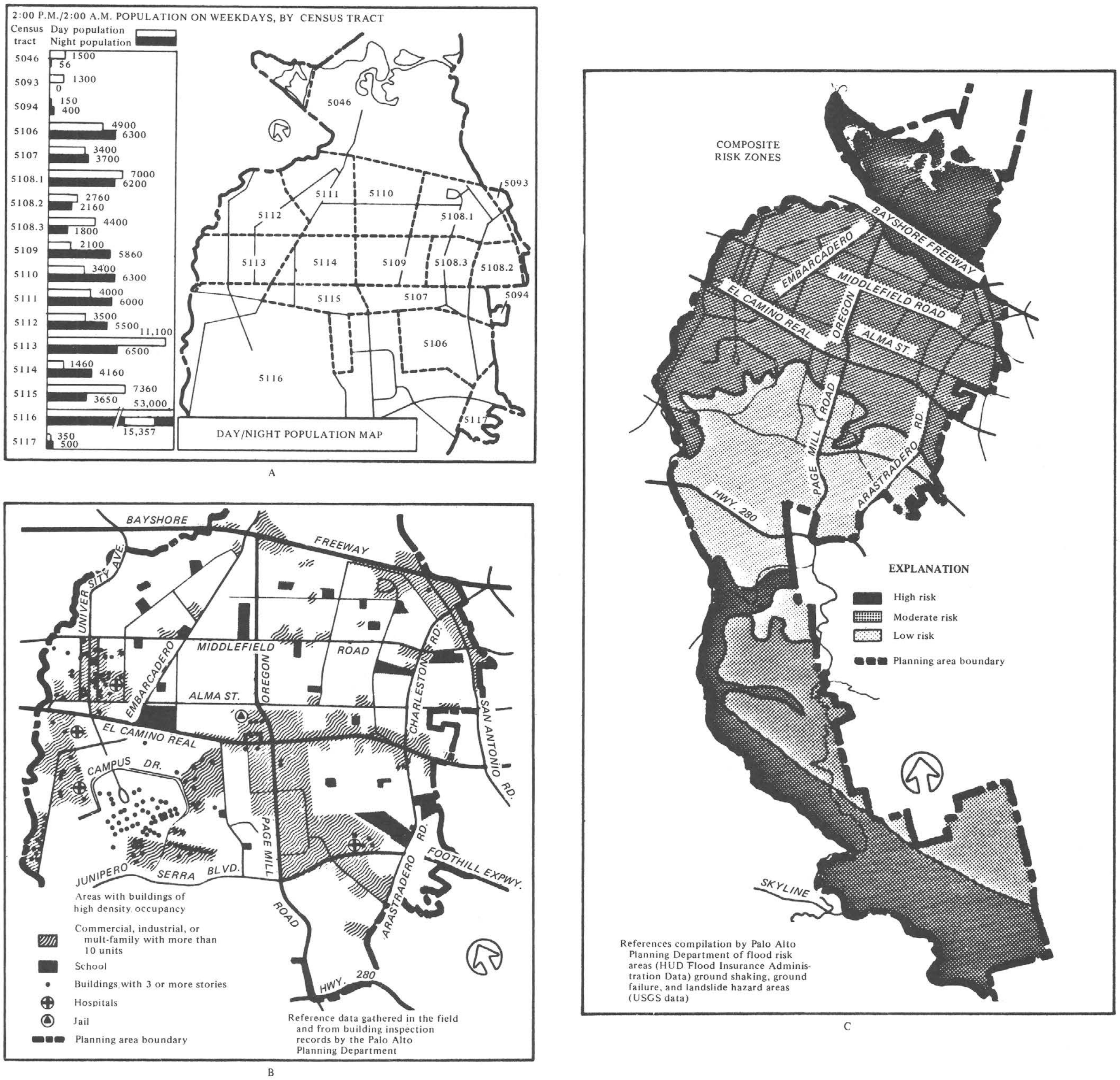


FIGURE 25.—Census of population density for Palo Alto, Calif. *A,* At 2:00 a.m., most people are in woodframe houses, structures which are likely to suffer the least damage from a great earthquake. At 2:00 p.m., people are in school, at work, on the roads, and in commercial buildings which are areas of high population density and greater structural hazard. *B,* Areas of high population density. *C,* Fault line areas have the greatest risk for manmade structures. High risk is also associated with bay mud, landslide-prone hillsides, and areas susceptible to flooding. Moderate risk areas involve potential liquefaction, ground shaking, and some flooding. Low risk areas are susceptible to some liquefaction and some ground shaking.

of the level of risk and the means and costs of reducing that risk. Such an evaluation is particularly relevant when a public agency is considering land-use plans and regulations, siting and design of major public facilities, renewal or rehabilitation of existing built-up areas, emergency-preparedness plans, and building-code requirements.

LAND-USE PLANNING AND SEISMIC SAFETY

Increasing seismic safety through land-use planning is at present primarily a function of local government, and local actions are central to reducing seismic risk. Most of the power to adopt and administer land-use and development regulations and building codes is now

TABLE 12. —*Earthquake ratings for common building types*

[This table is not complete. Additional considerations would include parapets, building interiors, utilities, building orientation, and frequency response (Armstrong, 1973, p. 167)]

Simplified description of structural types	Relative damageability (in order of increasing susceptibility to damage)
Small wood-frame structures, i.e., dwellings not over 3,000 sq. ft., and not over 3 stories	1
Single or multistory steel-frame buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	1.5
Single or multistory reinforced-concrete buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	2
Large area wood-frame buildings and other wood-frame buildings	3 to 4
Single or multistory steel-frame buildings with unreinforced masonry exterior wall panels; concrete floors and concrete roof	4
Single or multistory reinforced-concrete frame buildings with unreinforced masonry exterior wall panels, concrete floors and concrete roof	5
Reinforced concrete bearing walls with supported floors and roof of any materials (usually wood)	5
Buildings with unreinforced brick masonry having sandlime mortar; and with supported floors and roof of any materials (usually wood)	7 up
Bearing walls of unreinforced adobe, unreinforced hollow concrete block, or unreinforced hollow clay tile	Collapse hazards in moderate shocks

TABLE 13.—*Scale of risks for various building uses*

[Adapted from *Scale of acceptable Risks* of the Structural Engineers Association of California, *in* Armstrong, 1973, p. 162]

Level of risk to public	Kinds of structures
Failure of a single structure may affect substantial populations	
Extremely high	Structures whose continued functioning is critical, or whose failure might be catastrophic: nuclear reactors, large dams power inter-tie systems, plants manufacturing explosives.
High	Structure whose use is critically needed after a disaster: important utility centers, hospitals, fire, police and emergency communcation facilities, and critical transportation elements, such as bridges & overpasses; also smaller dams.
Failure of a single structure will affect primarily only the occupants	
Possible high risk to occupants	Structures of high occupancy, or whose use after a disaster will be particularly convenient: schools, churches, theaters, large hotels and other high-rise buildings housing large numbers of people, other places normally attracting large concentrations of people, civic buildings such as fire stations, secondary utility structures, extremely large commercial enterprises, most roads, alternate or noncritical bridge and overpasses.
An "ordinary" level of risk	The vast majority of structures: most commercial and industrial buildings, small hotel and apartment buildings, and single-family residences.

TABLE 14.—*Risk analysis of a motor inn*

[(From Armstrong, 1973, p. 174)]

Factors	Situation of motor inn	Risk
Geology	Tri-Cities area, several fault systems nearby.	High
Site	On fault zone, perhaps directly over fault trace. landslide adjacent.	High to very high
Structure	Multistory utilities.	Medium
Building use	Large number of occupants.	Medium to high
Total risk for all factors		High

lodged with local government. Also, the primary responsibility for emergency response by police, fire, and public works agencies is local. Local areas may be isolated after an earthquake and depend entirely on local emergency services to protect life and property for a significant period of time before outside aid is available. This section describes how local land-use planning and decisionmaking can reduce seismic risk.

THE PLANNING PROCESS

Planning is the process of devising and carrying out a course of action to reach an objective. As an organized governmental activity, planning seeks to improve the decisions of public bodies and administrators. Comprehensive planning affects the future development of an area and involves all major determinants of growth and change—economic, political, social, and physical.

To be effective for seismic risk reduction, the comprehensive planning process must result in specific land-use decisions. The process described here provides for a land-use plan as a key component of the comprehensive plan; it forms a link between more general goals and policies and the pattern of land development.

A land-use plan includes objectives, policies, and proposals for the type, pattern, and intensity of land use. It typically specifies the general location of different types of land uses, transportation lines, and public facilities. A functional plan defines needed facilities and operations for a specific function of government such as transportation, water development, flood control, or emergency response; it is more specific than a comprehensive plan and usually covers a shorter period of time. Any plan, when adopted by the governing body of an agency, becomes official public policy.

The development of comprehensive, and functional land use plans generally consists of six steps: (1) identifying problems and general goals and objectives, (2) collecting and interpreting data, (3) formulating plans, (4) evaluating impacts, (5) reviewing and adopting plans, and (6) implementing plans. These steps, shown in figure 26, are all interrelated. Plan formulation often indicates the need for additional information; additional information may reveal the need for additional information or modification of the plan.

The steps in the planning process constitute a rational, systematic approach to informed decisionmaking and are applicable to most governmental activities. The product is a logical and internally consistent plan, or set of plans and programs, to guide public and private decisions. The planning process is ongoing; it produces refinements, revisions, and new plans, and implements programs as additional information is obtained, new issues and problems are raised, or changes in public attitudes are recognized. Public participation is essential throughout the planning process. Success in implementing a plan depends on widespread public support which can only be gained if all major segments of the public participate in the planning process, and not always then.

Decisions occur throughout the process, ranging from the decision to engage in a planning effort, to the final approval of a plan and adoption of implementing regulations, programs, and procedures. Elected public officials have the final responsibility for most key policy decisions although persons in nonelective positions actually make many important day-to-day decisions.

Where earthquakes are a recognized hazard, seismic safety is an important part of comprehensive land-use and functional planning. Comprehensive plans deal with the social, economic, and physical ramifications of seismic risk and methods of reducing it; and functional plans with the procedures, actions, and resources needed for improving seismic safety in a given government function, such as transportation, water supply, and fire protection. But because the degree of seismic risk depends on the location of structures and facilities in relation to seismic hazards, the land-use plan is a key document for expressing a community's response to seismic risk; seismic safety can be addressed in every step of the land-use planning process.

IDENTIFY ISSUES AND DEFINE OBJECTIVES

Reviewing available information to identify the major land-use issues and problems helps define the scope of the plans and the limits of the planning area. The issues and problems are then analyzed in relation to existing development, current land-use plans and policies, projected economic and population growth, and other anticipated changes. Based on this analysis, a tentative set of goals, objectives, and priorities is formulated. In this step potential seismicity is evaluated to identify seismic safety problems and define objectives for reducing risk. Accounts of historic earthquake damage in the area, or regional seismicity maps such as the Seismic Risk Map of the United States (fig. 4), can indicate the relative importance of considering seismic risk in land-use planning in a given area.

COLLECT AND INTERPRET DATA

Previously compiled data are evaluated for adequacy, and a program for acquiring and interpreting new data is prepared. The data needed include descriptions of the economic, social, cultural, political, and natural characteristics of the planning area as a basis for estimating the future requirements for spe-

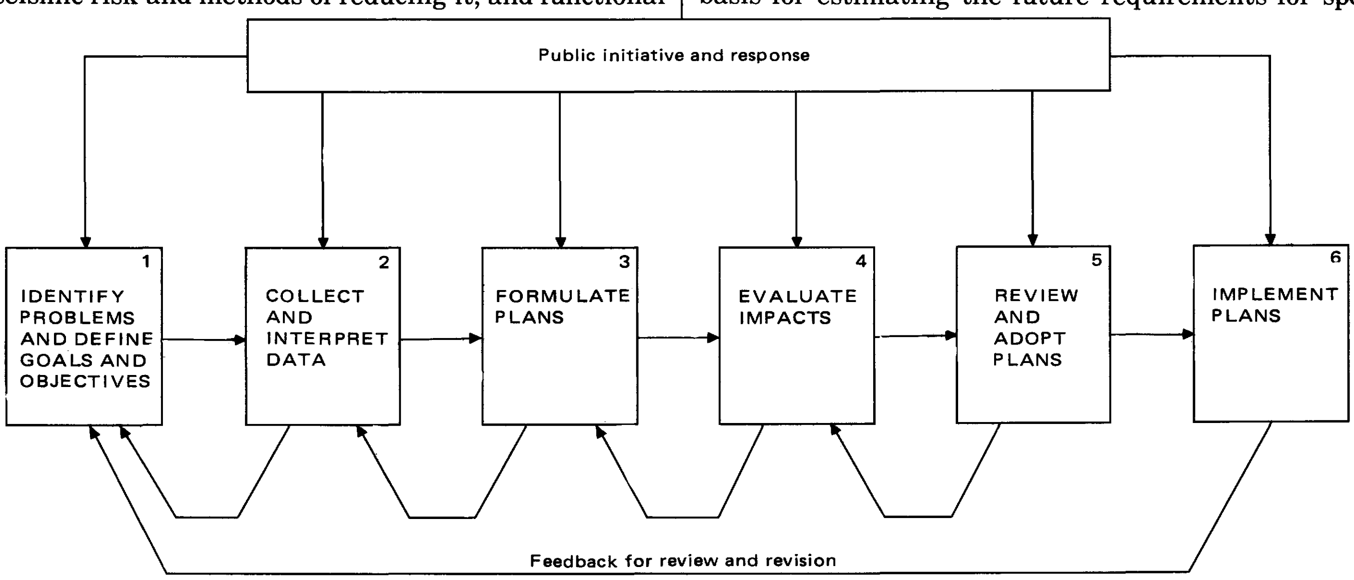


FIGURE 26.—The planning process.

cific kinds of land uses. Geologic and other information describing the natural features of the planning area is needed to describe natural hazards and resources relevant to land-use decisions.

Because collecting and interpreting data is expensive and time-consuming, this study should be closely related to the issues and objectives of the planning program. A careful analysis of available general information can pinpoint those areas where more detailed data and analyses are needed. In some instances existing development or readily identifiable physical conditions may so restrict the land-use options that little new information is needed.

The degree of seismic risk is assessed during this step. Cooperation between planners and earth scientists, particularly seismologists and geologists and structural and soils engineers, is needed to identify and evaluate seismic hazards in relation to existing and potential land and building uses.

FORMULATE PLANS

Based on data and analyses gathered in the previous step, alternative policies, criteria, standards, and proposals are evaluated for responsiveness to the goals and objectives already identified. The environmental, social, political, and economic impacts of the policies and proposals are tested as a part of the process of selecting alternatives for presentation to the policy bodies. The evaluation of the alternatives is the heart of plan formulation. The plan should provide sufficient detail and definition to guide future growth and change in the planning area. The level of detail needed depends on the complexity of the planning area, the nature of the decisions anticipated, and the authority of the agency.

Policies related to seismic hazards should be incorporated into the comprehensive plan. As previously noted, California law provides for this by requiring all city and county general plans to include a seismic safety element. This element usually consists of a description and evaluation of seismic hazards, together with policies and recommendations for improving seismic safety. These policies and recommendations should be reflected in the land use, open space, safety, circulation, and other general plan elements. The land-use/seismic risk relationships of alternative policy options should be thoroughly considered in plan formulation. Policies and critieria for seismic safety should be specific enough to provide a basis for land use and development regulations and building code requirements.

EVALUATE IMPACTS

The impact evaluation, begun as a part of plan formulation, is formalized in this step for the land-use plan (or alternatives) selected for presentation to the policy body responsible for plan approval or adoption. If formal reports on environmental impact are required, by State or Federal law, the scope of the report is well defined. The method of analysis may be either quantitative or qualitative. California law requires an environmental impact report for any plan or plan element which might have significant environmental impact.

The environmental, social, and economic impacts of proposed measures to reduce risk should also be evaluated. The loss of life and the amount of damage from an earthquake depends on the land-use pattern. To aid in the decisionmaking, the levels of risk associated with alternative land-use patterns should be stated as explicitly as possible.

REVIEW AND ADOPT A PLAN

The plan or plan alternatives and the report evaluating impact are reviewed by the legislative body of the planning jurisdiction. Public hearings are scheduled and publicized to encourage the widest possible public response to the plan proposals. In California, cities and counties are required to hold public hearings before official adoption of any element of the general plan. Although comment and criticism by individuals and institutions is sought earlier in the planning process, new questions and issues are often raised at this point and plan policies and proposals may be modified as a result.

After plan review, the plan may be adopted as an official statement of policy and a commitment to a future course of action. All states do not require that local general plans be adopted officially as does California. However, because many Federal grant programs require formally adopted plans as a condition of eligibility, the practice is expected to become more widespread. Measures needed to implement the plan must be specified and clearly understood by the legislators and their constituents and, because circumstances and priorities change, procedures for amending an adopted plan also should be established.

IMPLEMENT THE PLAN

Implementing a land-use plan depends on coordinating, scheduling, and carrying out a variety of measures. Land-use regulation alone may fail to reduce seismic risk significantly, particularly if the hazard exists primarily in developed areas. Therefore, regulations need to be combined with other measures such as public acquisition of land, urban renewal, redevelopment, and code enforcement. Implementing a plan is an intensely political process, and it directly affects the legal rights, economic and social status, and living and working environment of individuals in a community. Implementation thus depends on the active support of residents and organizations within a planning jurisdiction.

The powers to implement plans and the methods used to implement them are different for each state and for each jurisdictional level. For example, most regional agencies rely on a project review process, while local governments have broad powers to regulate land use and development, tax, acquire land, and construct and operate facilites. Despite this diversity, most implementing measures fall logically into one of three categories:

1. Controlling land use and development through zoning, subdivision, and grading ordinances, and building and housing codes;
2. Reviewing projects, both public and private, for conformity with an approved general plan and for environmental impact pursuant to State or Federal laws or regulations (such as the U.S. National Environmental Policy Act of 1969 or the U.S. Office of Management and Budget Circular A–95); and
3. Developing and executing governmental programs for acquiring land, constructing public facilities, providing public services, or redeveloping and rehabilitating substandard parts of the community.

PLANNING EXAMPLES

Examples of plans, regulations, and administrative procedures to reduce seismic risk are described below. These examples are drawn mainly from cities and counties in California. Because the State requires each city and county to adopt a seismic safety element as part of its general plan, many examples of local plans to reduce seismic risk are found in California and illustrate methods that can be used elsewhere. Most of the examples are from the San Francisco Bay region because it has an array of earthquake hazards, much scientific data that can be used for planning, and a diverse assortment of planning agencies.

Planning to reduce seismic risk varies for different earthquake hazards. Planning to reduce risk from surface rupture is reasonably straightforward where active faults are recognized and mapped, as they are in California. On the other hand, dealing with problems of ground shaking is more difficult because few maps of potential levels of ground shaking are available. Reducing risk requires adjusting both land uses and structural types to the anticipated intensity, frequency, and duration of shaking. In addition, areas of severe ground shaking are usually more extensive than the fairly narrow bands which are subject to surface rupture.

Methods to reduce seismic risk also depend on the degree of development of a planning area. Land-use planning to reduce seismic risk is most effective and least costly in areas just being considered for development.

PLANNING TO REDUCE RISK FROM GROUND SHAKING

To reduce risk from ground shaking requires the collaboration of planners, structural engineers, and earth scientists. Planners provide information about the present and future locations of high-occupancy structures, critical facilities, and hazardous structures, and the planning techniques available to control the future development. Structural engineers provide advice regarding criteria for safe building design, the safety of existing structures, and techniques to reduce existing structural hazards. Earth scientists evaluate the ground response characteristics of a postulated earthquake.

Seismic safety objectives are most likely to be attained when they coincide with other planning objectives. For example, preserving the margins of San Francisco Bay for ecological and environmental reasons is consistent with seismic safety objectives because these areas, underlain primarily by bay mud, are susceptible to severe ground shaking and several forms of ground failure. Land-use regulations are likely to receive wider public support and withstand legal challenge better if they meet more than one objective.

The result of such joint efforts can be a land-use plan in which differences in expected ground shaking levels influence the location and intensity of proposed future development. This matching can only be done in areas where there is a significant variation in predicted levels of ground shaking. Even then, it should be recognized that land-use decisions properly reflect economic, social, and political, as well as other natural conditions; a perfect match of land uses and seismic risk is rarely achieved.

Ground shaking problems can often be directly handled in undeveloped areas by requiring seismic and geologic site investigations before approving development proposals and establishing and enforcing building design and construction standards consistent with the seismic risk. In developed areas, the problems can be handled by abating existing structural hazards through removal or strengthening of parapets and other building appendages, basic structural improvement, changes in occupancy, or demolition. Examples of such plans and actions follow.

SITE INVESTIGATION AND DESIGN REQUIREMENTS

The San Jose seismic safety element (Duncan and Jones, 1974) is based on a thorough geotechnical study of the San Jose planning area by Cooper, Clark, and Associates. This study defines the complex relationship between ground-shaking characteristics and structural type and height as follows (Cooper, Clark, and Associates, 1974, p. 63):

> The effect of ground motion on buildings depends not only on the characteristics of the ground motion, but also on the characteristics of the buildings. The fundamental periods for typical single-story, 10-story, and 40-story buildings, are on the order of 0.2, 1.0, and 4.0 seconds, respectively. If a building is subjected to a series of ground vibrations having the same period as its fundamental period, large amplitude motions and high internal stresses develop. On the other hand, if the same building is subjected to base vibrations having a period very different from its fundamental period, comparatively small internal stresses will be induced. Accordingly, it is desirable to develop as great a difference as possible between the fundamental period of a building and the fundamental period of the estimated ground surface motion.

The San Jose geotechnical report divides the planning area into seven ground-response zones based primarily on depth to bedrock. Expected ranges of maximum ground surface accelerations and fundamental periods were estimated for each zone. This information can be used to highlight areas where ground-shaking characteristics could cause serious damage to particular types of structures. For example, highrise buildings may sustain more damage in areas of deep alluvium than single-story structures. The study indicates these areas where ground response may cause severe problems and where further investigation should be undertaken before development decisions are made.

The San Francisco Community Safety Plan (San Francisco Department of City Planning, 1974) evaluates the possibility of ground shaking in a similar way, observing that the effect of ground shaking on buildings can be compensated for by proper design and engineering. The report recommends "special soils-engineering and geologic investigations in areas of potentially strong ground shaking" (San Francisco, Department of City Planning, 1974, p. 23), and building code standards incorporating safety factors consistent with the building type, use, and site conditions.

ABATING STRUCTURAL HAZARDS

A particularly difficult and costly problem is the abatement of existing structural hazards. The San Francisco plan estimated the damage that would result from an earthquake similar to the one in 1906 by analyzing data on the age, use, construction type, number of stories, and floor area of existing structures in relation to the geologic conditions that affect ground motion. The damage potential of each block was classified as severe, heavy, moderate, or slight (fig. 27). Individual buildings were not analyzed. Precode, Type C buildings were also noted. Precode buildings are those constructed before 1948 when comprehensive lateral force requirements to resist earthquake shaking were included in the San Francisco building codes; Type C buildings have masonry or concrete exterior bearing walls with wood floors and roofs. More than 1,400 residential buildings with nearly 35,000 living units and 2,800 nonresidential buildings were identified as precode, Type C construction. Their density was mapped by census tract (fig. 28). At 1975 construction costs, replacing these buildings would cost more than one billion dollars (San Francisco Department of City Planning 1974, p. 20).

Objectives and policies to abate structural hazards pertain to areas where damage levels are expected to be severe such as in precode, Type C structures, (fig. 8), and in Special Geologic Study Areas (fig. 29) which have potential for ground failure or flooding. Priority is assigned to "(1) areas with high concentrations of potentially hazardous precode, Type C buildings; (2) areas with high population densities; and (3) those structures for which there is a critical community need" (San Francisco, Dept. of City Planning 1974, p. 42).

Eliminating existing structural hazards often conflicts with other community objectives and is politically difficult to achieve. Although San Francisco adopted an ordinance in 1969 requiring removal or strengthening of unsafe parapets and building appendages, little has been done to enforce the ordinance.

Concern over both private and public costs, resistance of property owners, the absence of political support, and concern for the effect on the architectural character of the city are reasons for the lax enforcement of the parapet ordinance. The Community Safety plan emphasizes preserving architectural character. Voluntary compliance with the ordinance had resulted in "a severe loss of building character and appearance" (San Francisco Dept. of City Planning, 1974, p. 56).

PLANNING TO REDUCE RISK FROM GROUND FAILURE

The most damaging forms of earthquake-induced ground failure are landsliding and failures caused by liquefaction.

LANDSLIDING

Plans and regulations to reduce risk from slope failure are similar under seismic and nonseismic conditions. Where unstable slopes are identified, land uses can be restricted, geologic investigations can be required before development is allowed, and grading and foundation design can be regulated.

The Town of Portola Valley has taken strong actions to reduce future losses from landslides. Spurred by incidents in the wet winter of 1969, the town retained a geologist to assemble the information needed to improve land-use decisions by avoiding landslide hazards. A geologic map at a scale of 1:6,000 was complied and was used to prepare a landslide potential map (officially titled the Land Movement Potential of Undis-

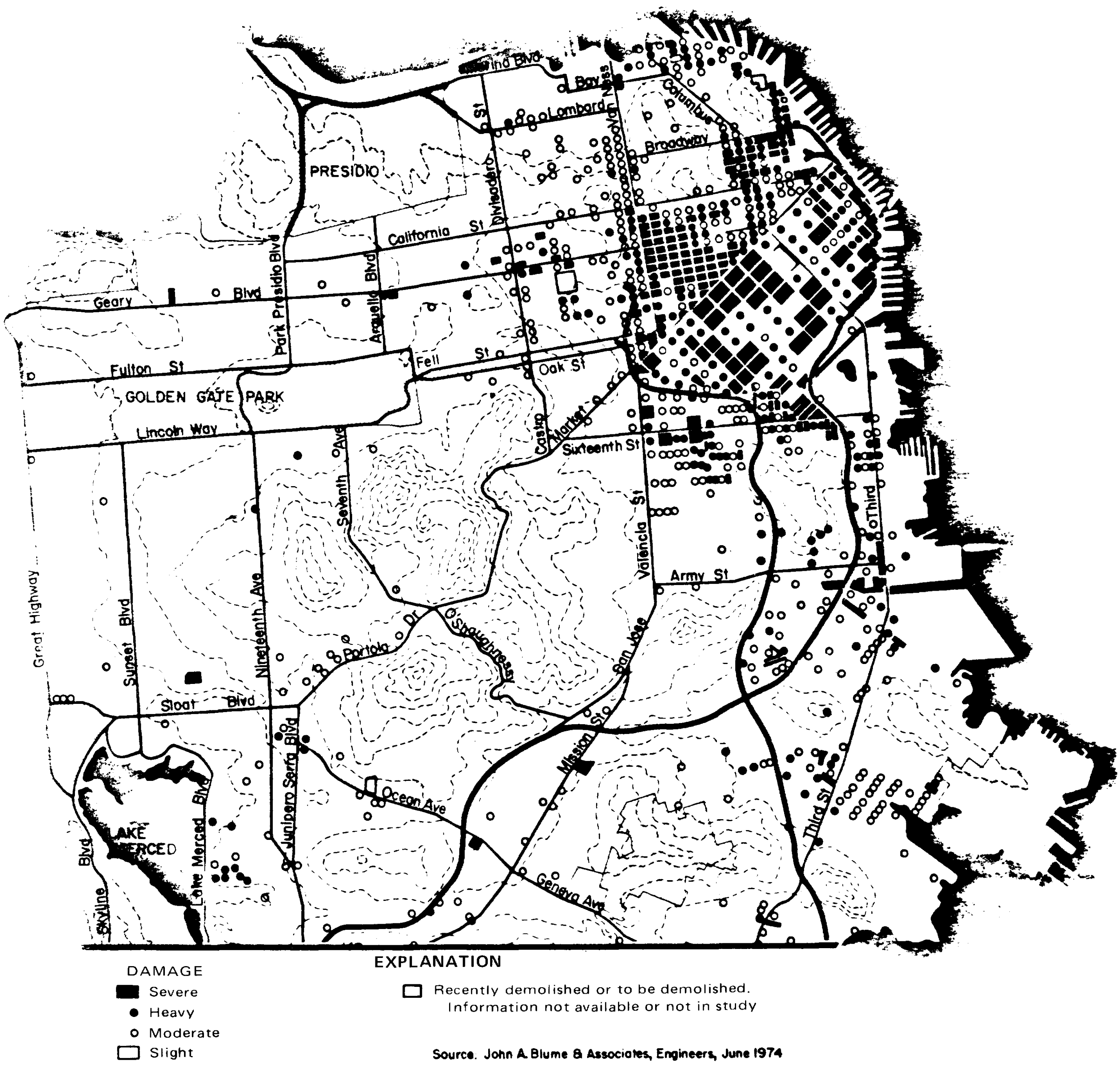
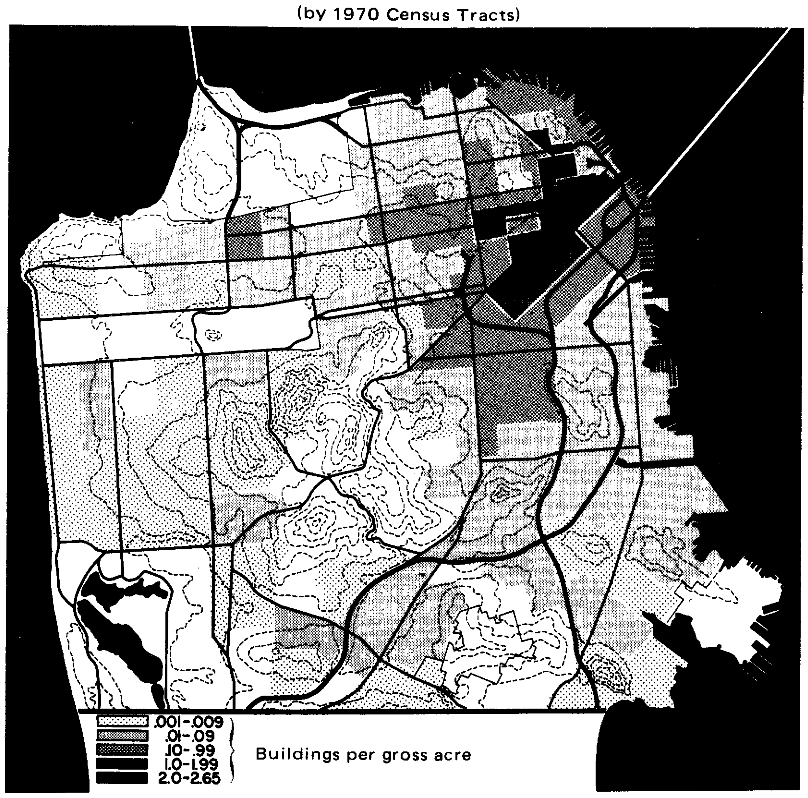


FIGURE 27.—Estimated building damage levels for a "1906-type" earthquake, San Francisco Calif. (San Francisco Department of City Planning, 1974, p. 18)

turbed Land Map) at the same scale. Provisions were added to the local zoning, subdivision, and grading ordinances, requiring that geologic information be submitted for review and approval by the Town Geologist before development. Even with the establishment of review procedures, it became evident that a consistent policy would be needed to relate the types of permissible land use to the possibilities of landslides. To assist in formulating such a policy, the town council appointed an eight-member geologic committee, chaired by the Town Geologist and composed of three geologists, two engineering geologists, a soils engineer, an attorney, and a planner. The committee recommended criteria to relate land uses to the stability categories shown in table 15. The geology map, landslide potential map, and criteria for permissible land use were adopted by resolution of the town council to guide land-development decisions. The town council felt that land-use regulation through zoning or other specific restrictions was not warranted because the landslide potential of individual parcels within each mapped category may vary, and because site investigation may

DENSITY OF PRECODE (1948) TYPE C RESIDENTIAL UNITS
(by 1970 Census Tracts)



DENSITY OF PRECODE (1948) TYPE C NON-RESIDENTIAL BUILDINGS
(by 1970 Census Tracts)

FIGURE 28.—Precode, Type C buildings in San Francisco, Calif. (San Francisco Department of City Planning, 1974, p. 53).

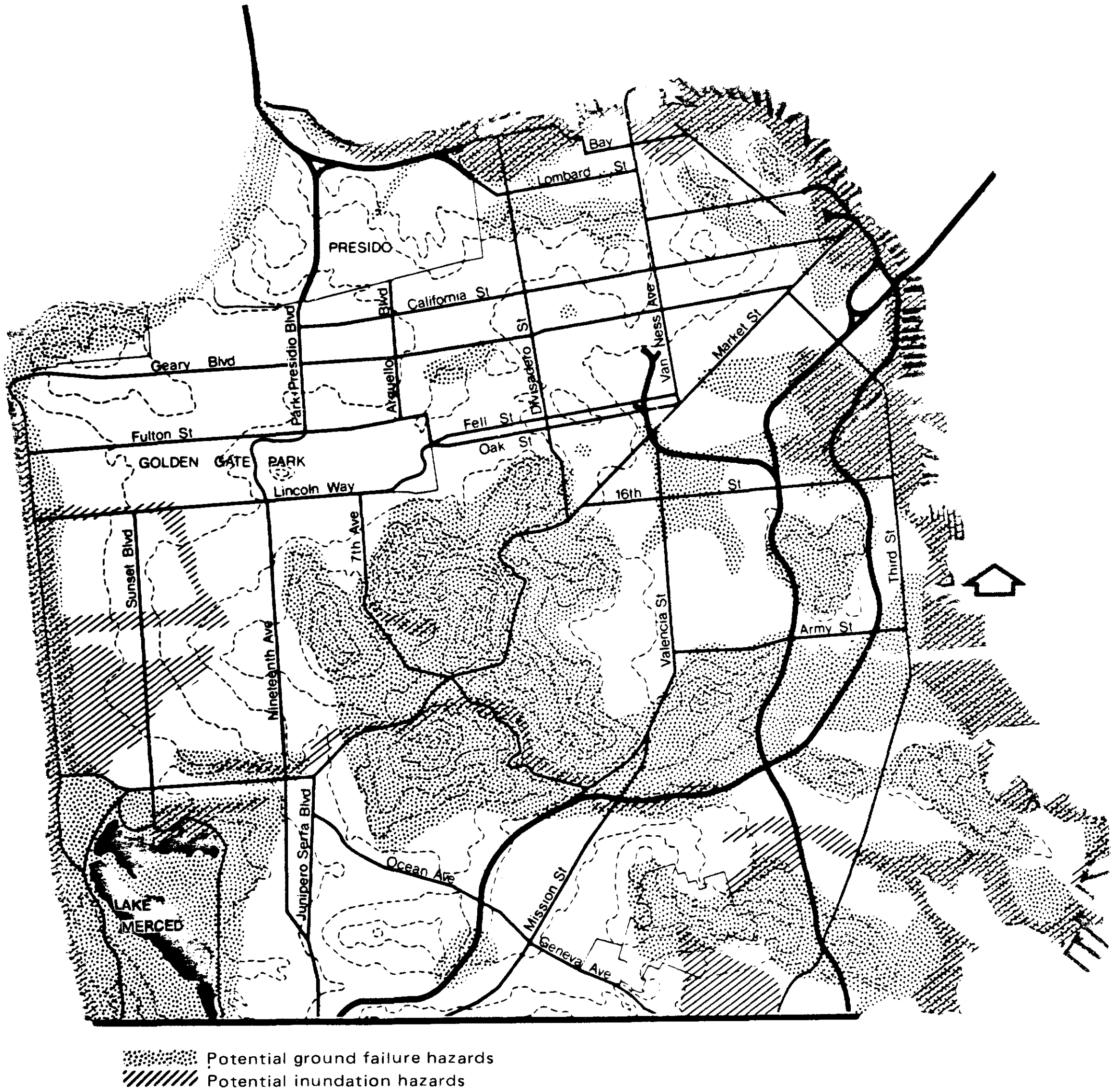


FIGURE 29.—Special geologic study areas, San Francisco, Calif. (San Francisco Department of City Planning, 1974, p. 44).

show that a given parcel is more or less stable than mapped. The resolution provides for incorporating in the official map any new information from site investigations.

Portola Valley's response to landslide problems is to avoid hazardous areas—a response consistent with the town's existing and planned pattern of low-density residential development and policies for preserving the natural environment. In jurisdictions fostering urbanization or in already intensively developed areas, special site and building design or engineering to mitigate the risk from slope failure may be emphasized.

The San Francisco Community Safety Plan includes landslide-prone areas in Special Geologic Study Areas (fig. 29). The plan (San Francisco Department of City Planning, 1974, p. 43) states:

> Special site investigations should be required in these potential hazard areas to determine the actual hazard, if any, for all proposed new development. Based upon the finding of the site investigation and determination of type and degree of hazard present, appropriate engineering design should be required to ameliorate the hazard. If proper engineering design is not technically or economically feasible, development of the site should not be permitted.

Even if it is technically feasible, mitigating landslide problems is often expensive, not only for the property owner, but also for the public agency which must maintain roads, utilities, and other essential facilities. Whenever possible, it is wise to encourage open space or low-intensity uses for landslide-prone areas.

LIQUEFACTION

Reducing risk from liquefaction is one aim of the Santa Clara County Baylands Plan (Planning Policy

Committee of Santa Clara County, 1972); this plan covers an area subject to liquefaction as well as other types of seismic and nonseismic ground failure. Geologic and structural engineering consultants identified the natural hazards of the planning area and defined their implications for land use. The resulting report divided the planning area into risk zones based on potential for settlement and ground failure under both seismic and nonseismic conditions. Table 16 lists the risk zones and the nature of the hazard in each. Figure 30 is a map of the risk zones. Table 17 relates the land and building uses to the risk zones.

The plan adopts these uses with the stipulation that any developer in the baylands provide data from test boring and sample testing in depth, to demonstrate that a proposed development site is not in a higher risk zone than shown. An Advisory Review Board was recommended to advise public agencies on the adequacy of engineering investigations, design, and construction methods in the baylands.

Based on the plan, the county adopted an ordinance requiring a soils report for all major subdivisions unless specifically exempted. Geologic reports and site investigations are required for all subdivisions on or adjacent to potentially hazardous areas as depicted on official county hazard maps. The map "Risk zones for land-use planning" (fig. 30) is one of the official hazard maps. Geologic reports are normally required for development in risk zones C and D and may be required in risk zones A and B.

PLANNING TO REDUCE RISK FROM SURFACE RUPTURE

Planning to reduce risk from surface rupture varies with the degree of development in the fault zone. In California, the Alquist-Priolo Special Studies Zones Act (see section on "Research and Information") defines minimum local actions.

The most effective way to avoid risk from surface rupture is to prevent construction of buildings for human occupancy across known active or potentially active fault traces. It is very difficult, if not impossible, to construct a building which can survive significant ground displacement without extensive structural damage. Preventing such construction depends on the accuracy and scale with which the fault has been mapped.

As better information is available, actions in addition to those based on preliminary findings can be taken.

Potential surface rupture should always be considered in site selection for critical public and private facilities, structures for human occupancy, and structural design for lifelines. Preliminary soils and geologic reports may be required with major development proposals, and detailed site investigation required if the preliminary report indicates potential hazards. A geologist is often needed to help review these reports and to help determine when more information is needed.

TABLE 15.—*Criteria for permissible land use in Portola Valley*

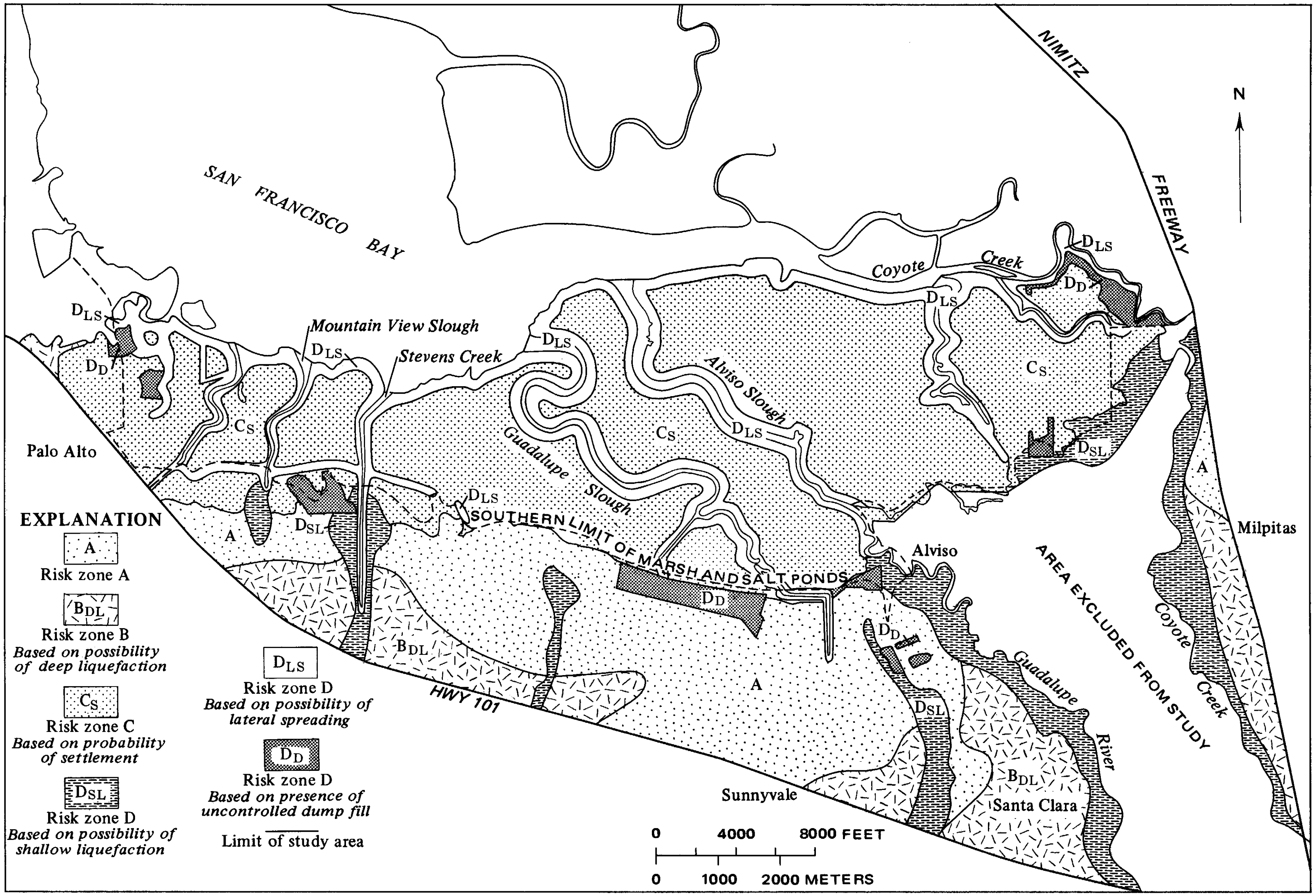
	Land stability symbol	Roads		Houses (parcel acreage)			Utilities	Water tanks
		Public	Private	¼-Ac	1-Ac	3-Ac		
MOST STABLE	Sbr	Y	Y	Y	Y	Y	Y	Y
	Sun	Y	Y	Y	Y	Y	Y	Y
	Sex	[Y]	Y	[Y]	Y	Y	Y	[Y]
	Sls	[Y]	[Y]	[N]	[Y]	[Y]	[Y]	[N]
	Ps	[Y]	[Y]	[N]	[Y]	[Y]	[Y]	[N]
	Pmw	[N]	[N]	[N]	[N]	[N]	[N]	[N]
	Ms	[N]	[N]	N	N	N	N	N
	Pd	N	[N]	N	N	N	N	N
	Psc	N	N	N	N	N	N	N
	Md	N	N	N	N	N	N	N
LEAST STABLE	Pf	[Y]	[Y]	*(Covered by zoning ordinance)*			[N]	[N]

LEGEND:	Y	Yes (construction permitted)
	[Y]	Normally permitted, given favorable geologic data and/or engineering solutions
	N	No (construction *not* permitted)
	[N]	Normally *not* permitted, unless geologic data and (or) engineering solutions favorable
	S	Stable
	P	Potential movement
	M	Moving
LAND STABILITY SYMBOLS:	br	bedrock within 3 feet of surface
	d	deep landsliding
	ex	expansive shale interbedded with sandstone
	f	permanent ground displacement within 100 feet of active fault zone
	ls	ancient landslide debris
	mw	mass wasting on steep slopes, rockfalls and slumping
	s	shallow landsliding or slumping
	sc	movement along scarps of bedrock landslides
	un	unconsolidated material on gentle slope

TABLE 16.—*Risk zones for settlement and ground failure established by subsurface conditions in the baylands of Santa Clara County*

[Adapted from Santa Clara County Planning Policy Committee, 1972]

Risk Zone	Surface Effect	Subsurface Cause
A	Little risk of settlement or ground failure	
B_{DL}	Significant settlement	Liquefaction of confined granular layer in alluvium (seismic loading)
C_S	Moderate to substantial settlement and/or differential settlement	Consolidation of bay mud or soft clay (static loading)
D_D	Substantial settlement and (or) differential settlement	Consolidation of uncontrolled dump fill or sanitary land fill (static loading)
D_{SL}	Failure of ground surface	Liquefaction of granular surface layer (seismic loading)
D_{LS}	do	Lateral spreading toward free face (seismic loading)



NOTE:
The delineation of risk zones is based on limited subsurface information. Risk zone designations could change as more detailed subsurface information becomes available.

FIGURE 30.—Risk zones for land-use planning, Santa Clara County Baylands (Santa Clara County Planning Policy Committee, 1972).

TABLE 17.—*Land and building uses appropriate for various risk zones, Santa Clara County*

[Adapted from Santa Clara County Planning Policy Committee, 1972, p. 22]

Land and Building Uses	Risk Zones A	B	C	D
Group A Buildings				
Hospitals and nursing homes	×			
Auditoriums and theatres	×			
Schools	×			
Transportation and airport	×			
Public and private office	×			
Major utility	×			
Group B Buildings				
Residential-multiple units	×	×		
Residential- 1 and 2 family	×	×		
Small commercial	×	×		
Small public	×	×		
Small schools-one story	×	×		
Utilities	×	×		
Group C Buildings				
"Industrial park" commercial	×	×	×	
Light and heavy industry	×	×	×	
Small public, if mandatory	×	×	×	
Airport maintenance	×	×	×	
Group D Buildings				
Water-oriented industry	×	×	×	
Wharves and docks	×	×	×	
Warehouses	×	×	×	
Group D Open Space				
Agriculture, marinas, public and private open spaces, marshlands and saltponds, and small appurtenant buildings	×	×	×	×

SURFACE RUPTURE—UNDEVELOPED AREAS

A draft of the San Mateo County seismic safety element lists ways to reduce risk from surface rupture based primarily on fault mapping at a scale of 1:62,500.

A portion of this map is shown in figure 31. The policy options relevant to largely undeveloped areas include:

1. "Restrict development within active or potentially active fault zones..." (San Mateo County, 1975, p. 72)
2. "Encourage the State Public Utilities Commission to establish increased design and construction standards for utility systems traversing active or potentially active fault zones..." (San Mateo County, 1975, p. 75)
3. "Prohibit development of critical use structures in any active or potentially active fault zones..." (San Mateo County, 1975, p. 77).

Geologic, seismic, and soil investigations of individual sites are recommended before making land-development decisions in the designated fault zones.

Figure 32 is an example of a Special Studies Zones map at a scale of 1:24,000. For regulatory purposes, the zone boundaries are very accurately located using a coordinate system, but the faults and the fault zones are much more complex and irregular. The fault location shown in figure 32 is derived from the 1:62,500 map (fig. 31) which in turn was based on field mapping of the fault and analysis of stereopairs of aerial photos at different scales. Direct regulation through zoning requires maps that are detailed and accurate enough to show the distance of existing and proposed structures from the fault.

The fault mapping done for Portola Valley in 1970 by W. R. Dickinson (fig. 33) provides the basis for the town's fault setback requirements adopted in 1973 (ordinance 1973–119) as part of the zoning ordinance. The ordinance prohibits structures for human occupancy within 15 m (50 ft) of a "known" fault trace. "Known" locations are based on surface expressions or subsurface studies which fix the location of the trace. No use more intensive than a single-family, one-story, wood-frame house, or house of similar earthquake-resistant design, is permitted in the band from 15 m (50 ft) to 38 m (125 ft) on either side of a known fault trace.

Setback distances for an "inferred" fault trace are larger—no structures for human occupancy are permitted within 30 m (100 ft) of the inferred location and only single-family homes are allowed for an additional 23 m (75 ft). "Inferred" locations are based on the presence of a limited number of surface or subsurface indications of a fault trace. The actual position of the "inferred" location is subject to greater error than the "known" location, and therefore the width of potential risk band is increased. A property owner may contract for detailed geologic investigation to locate an "inferred" trace more precisely. In such cases, the ordinance provides that the trace be reclassified as "known" and the setback requirement correspondingly reduced.

Outside the setback lines shown in figure 33, all proposals for development more intensive than single-family residences are reviewed by an engineering geologist employed by the town to determine if the site might be subject to significant offset or ground warping related to surface rupture.

Existing structures in the fault zone are not affected by the setback ordinance. Had the town chosen to make the fault zone into a zoning district rather than requiring setbacks, existing structures would have become nonconforming and subject to eventual removal, depending on the zoning ordinance provisions covering nonconformity.

Generally speaking, as the fault mapping becomes more precise, the area subject to regulation becomes smaller. The Alquist-Priolo Special Studies zones for Portola Valley encompass a significantly larger area

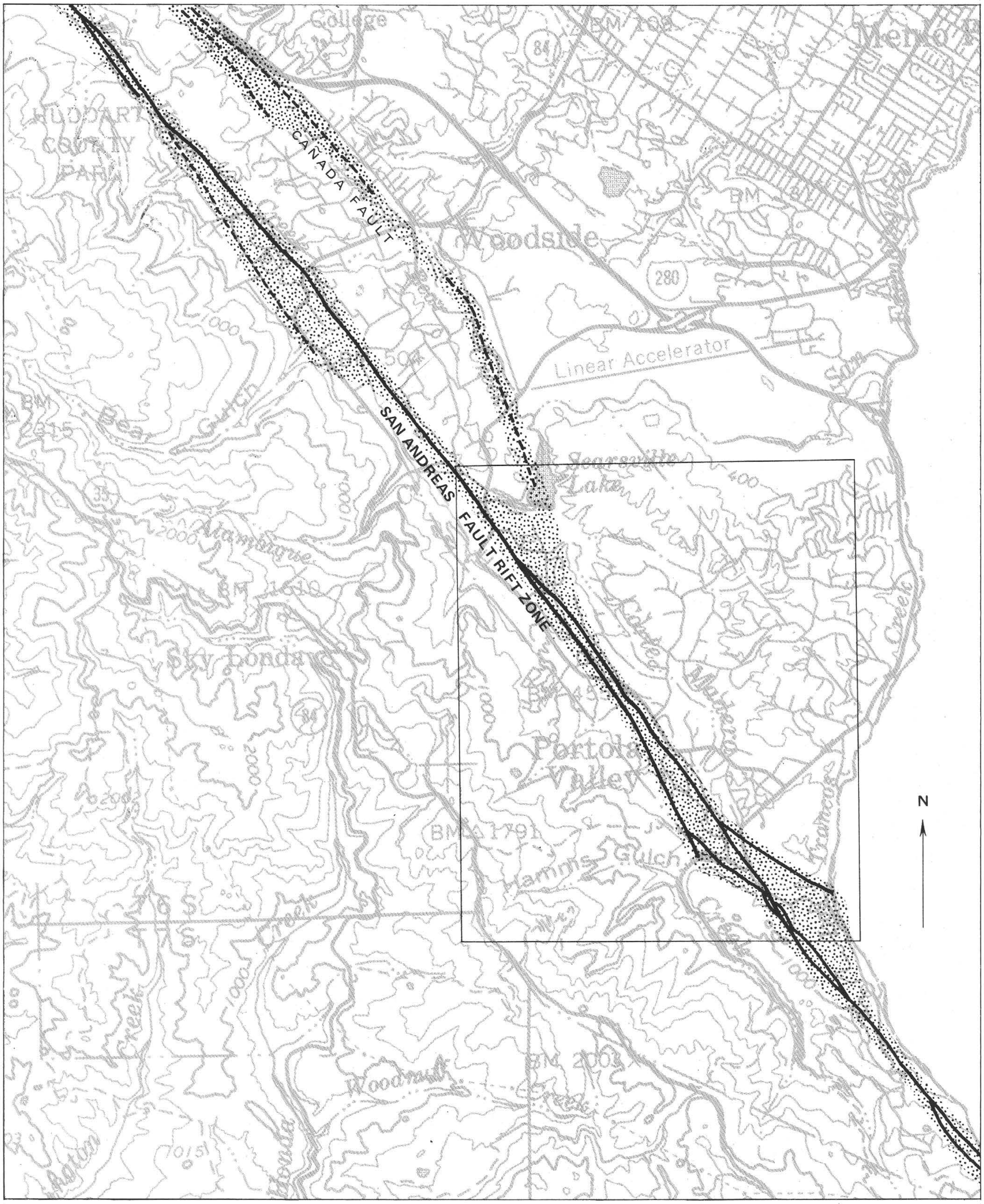


FIGURE 31. —Active and probably active faults and fractures and fracture zones for a portion of San Mateo County, Calif. at a scale of 1:62,500 (Brown, 1972). The rectangle outlined is shown at larger scale in figure 32.

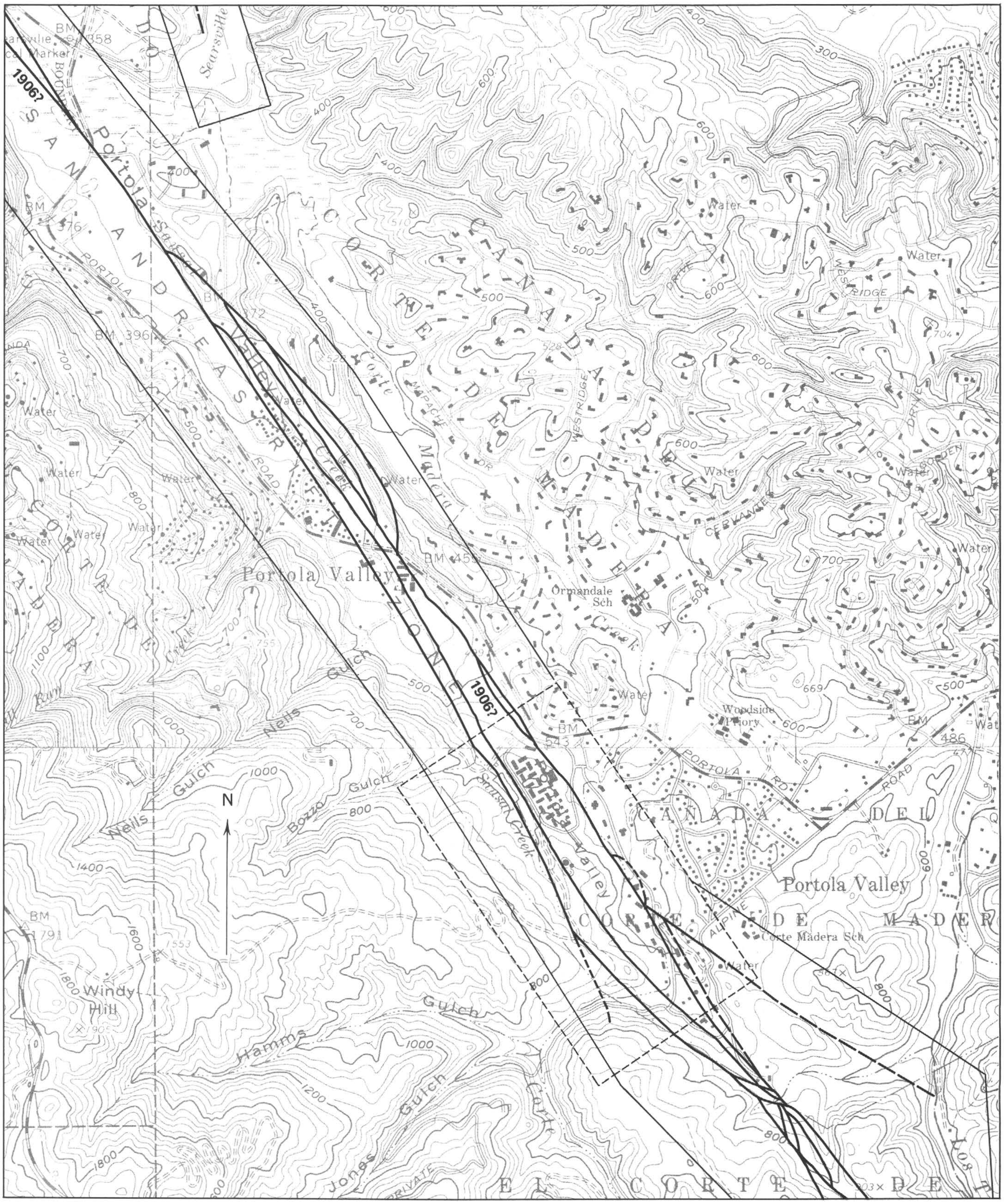


FIGURE 32.—Special Studies Zones for a part of San Mateo County, Calif., at a scale of 1:24,000. The area outlined is shown at larger scale in figure 33.

than that subject to the setback regulations of the town. Specific geologic investigation often narrows the area of potential surface rupture, but where site investigations produce uncertain or unforeseen results, a wider zone of potential surface rupture may be included.

Fault maps used for planning should be systematically updated as new geologic and seismic information becomes available. Excavations for road cuts or construction projects, geologic and geophysical site studies, and wells drilled near a known or suspected fault may provide new evidence of subsurface faulting. Where the public interest is affected, geologic investigations to locate fault traces more exactly may appropriately become the responsibility of the public agency. All information pertaining to fault location at a given site should become part of the title record for the parcel.

SURFACE RUPTURE—DEVELOPED AREAS

Where an active or potentially active fault passes through urban or urbanizing areas, the basic planning problem is how to prevent new construction and how to remove existing structures from on or near an active fault trace with equity and a minimum economic impact on the community. Some local jurisdictions decide that the effort simply is not worth the economic and social costs, and the risk is accepted.

At the least, agencies faced with this risk should prepare a plan to prevent rebuilding after an earthquake in areas subject to surface rupture. Such a plan can be similar to a redevelopment plan, that is, specific enough to assure relocation of structures away from areas of potential surface rupture, but general enough to allow flexibility in responding to conditions existing after the earthquake.

During redevelopment under various Federal, State, or private programs, structures can be removed from an active fault trace. Such removal is appropriate in older areas where there is structural deterioration. The redevelopment area needs to be large enough to retain the fault zone as open space and still provide enough buildable space to make a project economically feasible.

Although high-occupancy or critical facilities in active fault zones should be removed, public investment in such facilities may be so high as to make such action uneconomic.

The Hayward fault runs through a highly urbanized and rapidly growing part of the East Bay (fig. 34). Many schools, public facilities, commercial, industrial, and residential buildings are located on or near the fault. Although no major earthquake has occurred on this fault in more than 100 years, tectonic creep makes continuing maintenance and repair necessary. The fault is active and is considered capable of producing an earthquake of magnitude 7.0–7.5 accompanied by surface rupture.

The City of Hayward, crossed by the fault, adopted a seismic safety element in 1972. In it fault traces were

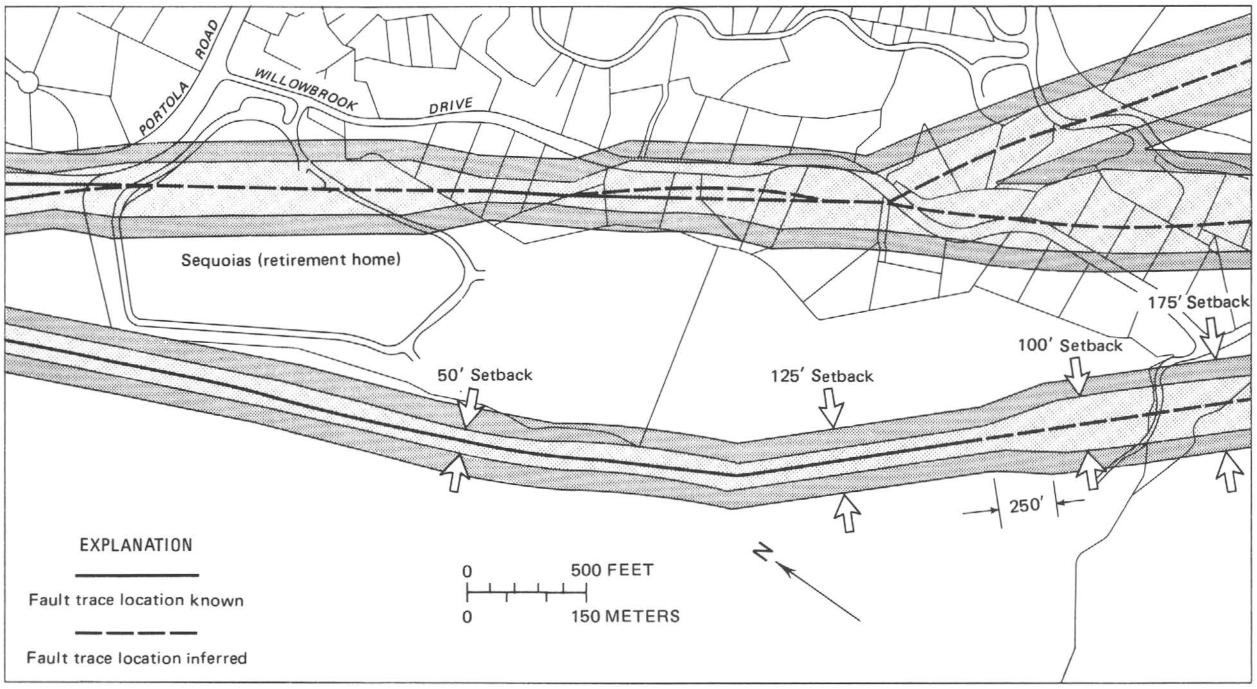


FIGURE 33.—Known and inferred fault trace locations and setback lines, Portola Valley, Calif., at a scale of 1:6,000 (Dickinson, 1970).

mapped at a scale of 1:12,000, and a "fault corridor" was defined including the mapped fault traces and 15 m (50 ft) on either side. This corridor was declared an area of high seismic risk, and creation of a zoning combining district applying to the corridor was recommended.

This seismic safety element further recommended that existing structures or portions of structures identified as hazardous be declared public nuisances and, as such, subject to repair, rehabilitation, or removal. Structures within the fault corridor would be subject to the nonconforming use provisions of the zoning ordinance upon adoption of the earthquake-fault combining district.

In accord with these recommendations, the Hayward City Council considered designating an Earthquake-Fault Combining District within which construction of the following types of structures over an active fault trace would be prohibited: residences, facilities required for emergency response, structures over 23 m (75 ft) in height, or high-occupancy buildings such as schools, churches, and theaters. Seismic, soils, and geologic reports would be required for new structures and additions to existing structures intended for human occupancy. Before the Council adopted the combining district, the Alquist-Priolo Act, with similar provisions, was passed by the State legislature, and so the city dropped the matter.

The Hayward fault corridor runs through the middle of the older downtown section of the city. The city hall and police station, formerly located astride the fault, have been relocated to a new city-center complex a few blocks from the fault (fig. 35). Concern over economic decline of the downtown area led to a revitalization plan (Hayward, 1975a). The plan envisions an L-shaped downtown area linking the BART (Bay Area Rapid Transit) station and the new city center. An increase in development was recommended in the area bounded by Foothill Boulevard, C Street, Main Street and Hazel Avenue (fig. 35). Because this area is in the Special Studies Zone, no new development or substantial redevelopment could be approved without a geologic investigation. The city contracted with a consulting firm to conduct geological and geophysical investigations, including trenching, in this part of the proposed redevelopment area. The study concluded that no fault traces were present in the area (Burkland and Associates, 1975).

The consultant's report provided the basis for a request by the city to the CDMG (California Division of Mines and Geology) that the area be removed from the Alquist-Priolo Special Studies Zone. The study, if approved by CDMG, will meet the requirements of the act for geologic investigations, and development may be permitted in the area. This is one of the few examples of a public agency assuming the responsibility and cost (in this case $18,000) of conducting the geologic investigations required by the State law. In most instances, the burden falls on the individual property owner.

FIGURE 34.—Hayward fault traces in urban and urbanizing area (from Nichols and Buchanan-Banks, 1974).

Four blocks of the redevelopment area between Main Street and Mission Boulevard are crossed by the Hayward fault. Consequently, the plan calls for meeting the needs for additional downtown parking by expanding parking lots in this area as parcels become available. The city proposes to use tax increment financing permitted under the California Community Redevelopment Law (California State Legislature, 1963), HUD Community Development Block Grant funds, parking revenues, and other available funds for public improvements in the redevelopment area.

The official redevelopment plan (Hayward, 1975b) does not directly address the risk from surface rupture in the fault zone. However, implementing the plan could significantly reduce risk from surface faulting. If carried out in accordance with State law and the adopted policies of the *Hayward Earthquake Study* (Hayward, 1972), the plan will meet seismic safety objectives as well as its stated objectives of revitalizing the downtown area and increasing the space available for parking.

PLANNING TO REDUCE RISK FROM FLOODING

Tsunamis and failures of dams or dikes are the major source of earthquake-induced flooding. Reducing the flood hazard can be accomplished by regulating construction in flood-prone area, by the use of warning systems, by planning for evacuation, and by building various structures to confine or control flooding.

TSUNAMIS

Because damaging tsunamis are infrequent in United States coastal areas, few coastal communities have tsunami-preparedness plans. A tsunami warning system in the Pacific basin, directed by the National Oceanic and Atmospheric Administration, is the major attempt to reduce risk. Sea walls, breakwaters, or other structures designed to protect coastal areas from storm surges may also prevent damage from small tsunamis; but the cost of protecting communities from the largest foreseeable tsunami by engineering works is unacceptably high (Ayre, 1975, p. 106).

Planning to reduce tsunami risk may be stimulated by the Federal Coastal Zone Management Act of 1972 (U.S. Congress Public Law 92–583); this act authorizes Federal grants to coastal states to prepare management programs for coastal zones. These programs must identify and list "areas of significant hazard if developed due to storms, slides, floods, erosion, settlement, etc." (U.S. National Oceanic and Atmospheric Administration, 1975, p. 1687).

Potential tsunami runup areas are also included in "coastal high hazard areas" and subject to the requirements of the National Flood Insurance Program outlines in Section II.

Because of Federal and State requirements, the land-use plans of coastal cities and counties are now more likely to include risk from tsunamis than in the past. The Seismic Safety Element for Monterey County is one of the few that contains policy directly relating to tsunami risk. The following policies (Monterey County, 1975, p. 34), based on very general mapping of areas of historic tsunami runup, were adopted by the county:

1. In general, known tsunami runup areas should be avoided by new development except marine installations requiring location in proximity to water.
2. Where development presently exists an adequate warning and evacuation system is essential.
3. All reasonable measures will be taken by this jurisdiction to reduce potential damage. Such measures will include establishing and enforcing standards of construction for structures within harbors and known runup areas, and formulating post-disaster plans for debris clearance and emergency repairs to essential facilities.

More precise delineation of potential runup areas and estimates of probable frequency of occurrence would make it possible to implement plan policies in tsunami runup areas by zoning for low-intensity or marine-oriented uses, establishing setback or elevation requirements for proposed structures or imposing design and construction standards.

DAM AND DIKE FAILURE

Reducing risk from dam or dike failure is particularly critical in seismically active areas because of the enormous potential for loss of life and destruction of property. Preliminary estimates of property damage from the recent failure of the Teton Dam in Idaho in a sparsely populated area are around $1 billion. Dam or dike safety is chiefly the responsibility of the engineer, builder, and operator, and, in the past, little effort has been made to control downstream land use as a means of reducing the change of catastrophic losses. In the future, risk of dam failure may be considered in land-use planning by placing restrictions on development of lands below the dams.

Dike failure is of particular concern to communities along the edge of San Francisco Bay. Many dikes rest on unstable bay mud and are composed of materials unlikely to withstand severe ground shaking. The area subject to flooding from dike failure depends on the tide level and elevation of the land. The Alviso area of San Jose, situated about 2½ m (8 ft) below sea level, is particularly vulnerable to severe flooding as well as other environmental hazards.

In recognition of this, the comprehensive plan of the City of San Jose recommends that land uses in close proximity to water retention levees or dams with moderate or high potential for seismic failure shall be carefully regulated (San Jose, 1976, p. 19). No residential or employment growth or land-use change through 1990 is projected for the Alviso area. This decision was reached after two basic alternatives for the future of the area were explored: (1) Build flood control levees and maintain and upgrade the existing community, or (2) relocate Alviso residents to other parts of San Jose (San Jose, 1976, p. 35). Based on an analysis of comparative costs and existing public investment in Alviso, the planers concluded that Alviso should remain where it is, and flood-protection levees should be provided. Long-term development options for the area are contingent upon a structural solution to the flood hazard.

Planning for the Alviso area is a good example of the complex considerations involved in land-use decisions. The result is not optimum from the point of view of reducing seismic risk, but it represents a balancing or risk with other important economic and social factors and objectives.

PUTTING IT ALL TOGETHER

The effects of an earthquake are varied, and the ability to predict and evaluate the potential severity and

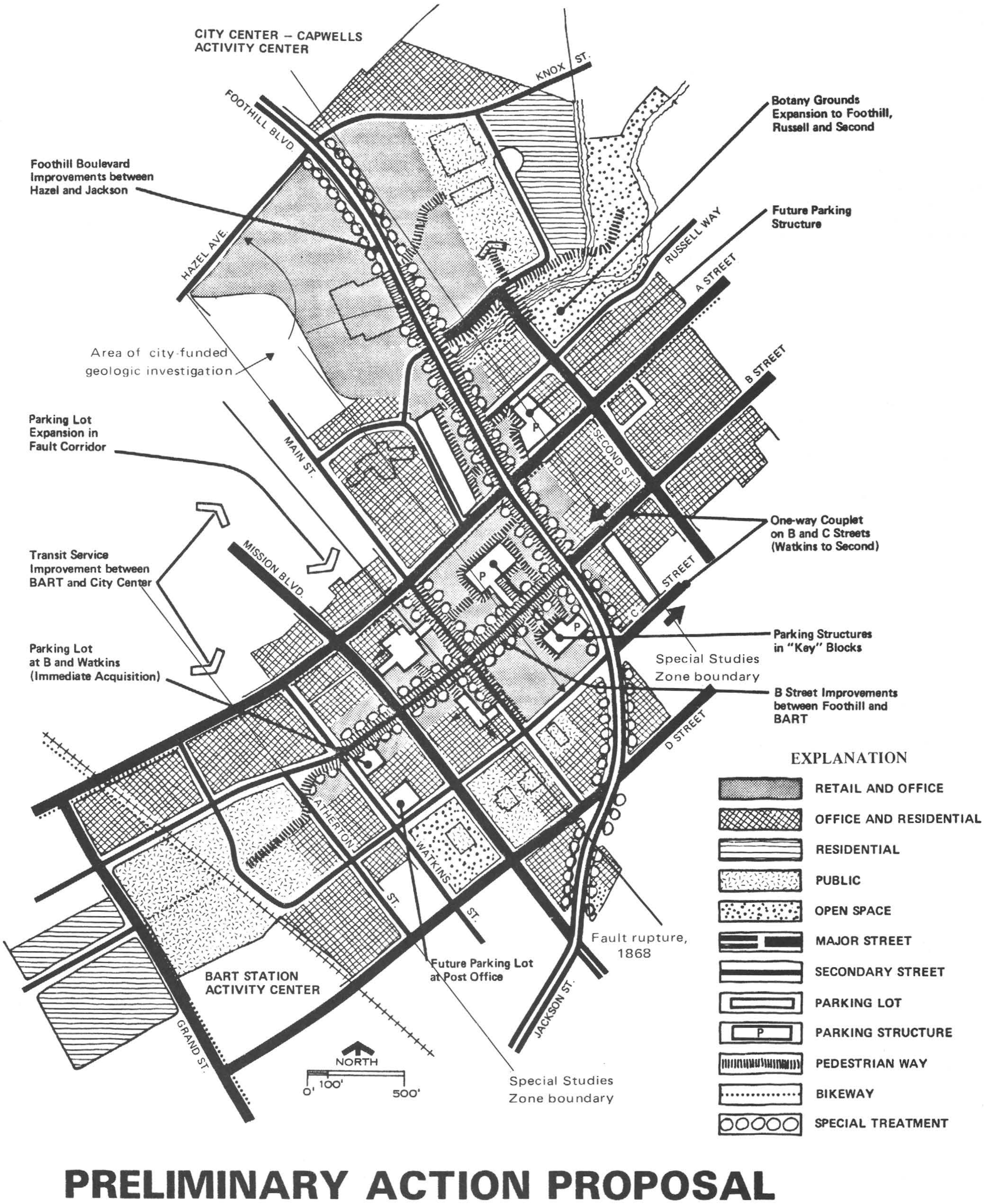


FIGURE 35.—Hayward redevelopment plan.

location of each effect differs, therefore, it is often necessary and desirable to respond to risk from each seismic hazard separately. A land-use plan, however, reflects the desires of a community for the future and is based on a multitude of often conflicting objectives and priorities. Reducing seismic risk requires integrating all the related seismic concerns into an overall plan for community development. Three methods are used to achieve this end: land-capability analysis, systematic consideration of seismic risk in land-use policy and regulation, and project review requirements within a general policy framework. These methods are complementary, not mutually exclusive. Each method relates to a particular phase of the planning process. A land-capability study is a way of interpreting data for direct application in plan formulation. Designating land uses involves formulating a plan and regulating land use. Project review is largely reactive, dealing with development proposals as they come rather than prescribing specific uses ahead of time; it emphasizes plan implementation. Each method is discussed below.

LAND-CAPABILITY ANALYSIS

In any area, the existing natural features and processes present a range of constraints and opportunities for different uses of land. Land-capability studies systematically record judgments concerning the effects of these factors on the value of the land for selected uses. The factors considered usually include topography, hydrology, geology, soils, vegetation, and climate.

Methods of evaluating land capability differ. A study may be largely descriptive, pulling together in narrative form information concerning the natural features and processes relevant to a particular land use; or a study may involve a fairly sophisticated effort to quantify, weight, and aggregate the factors relevant to specific uses for all lands within a planning area. In any case, judgment is needed, and the studies should be carried out by planners with the assistance of experienced earth scientists. Land-capability analysis involves four basic steps:

1. Defining the scope of the study and the land use or uses to be considered.
2. Determining the factors affecting capability for the use or uses selected.
3. Gathering, analyzing, and presenting the pertinent information.
4. Evaluating the relative capability of the land units to support the selected use or uses.

The relative importance of each factor, as well as the range of conditions within each, can be expressed numerically. The main advantage of numerical analysis is the greater ease in combining many judgments into an overall rating of land capability. Such analyses vary greatly in precision, however, depending on the quality of data, the qualifications of the analysts, and the method used.

Land capability studies vary in focus as well as in method. A common variation is an analysis which rates land within a study area in terms of relative risk from selected natural hazards. A study may be very detailed, dividing an area into small units which are evaluated for a specific use such as a sanitary landfill; or it may be general, dividing an area into large units which are evaluated for a broad category such as urban development.

The Seismic Safety Element of Santa Barbara County uses techniques of land-capability analysis to rank areas, on a grid system, in terms of relative seismic and geologic hazards. The following hazards were evaluated: ground shaking, tsunamis and seiches, liquefaction, slope stability, expansive soils, soil creep, compressible/collapsible soils, and high ground water. Surface rupture was considered separately because, as an essentially linear phenomenon, it is difficult to incorporate into a grid analysis.

Each grid cell was rated 1–3 for each hazard based on the following system: 1 equals none or low hazard; 2 equals moderate hazard; and 3 equals high hazard. Each hazard was given a weight representing its importance relative to the other hazards. The weight was based on three considerations: consequences severe or moderate consequences (such as loss of life or property damage), frequency of occurrence, and difficulty of prevention or mitigation. The hazards were then assigned the following weights:

Seismic severity (ground shaking)	18
Tsumani-seiches	19
Liquefaction	15
Slope stability	23
Expansive soils	7
Soil creep	4
Compressible/collapsible soils	11
High groundwater	3
Total	100

(100 is the lowest possible score assuming a rating of 1 for all hazards)

For each grid cell, a weighted rating for each hazard was obtained by multiplying the weight by the rating. The weighted ratings for all hazards are then totalled for each grid cell. This total is called the GPI (geologic problem index). The GPI was calculated for each 90-acre grid cell county-wide and for each 5-acre grid cell in four urban areas. The range of GPI's was 100–236 (300 max.). No cell received a maximum GPI because some problems are confined to flatlands or hillsides, and no one cell had a high rating for all hazards. For convenience, GPI's were grouped into five categories;

GPI range	*Category*	*Severity*
100–125	I	low
126–145	II	low-moderate
146–180	III	moderate
181–210	IV	moderate-severe
210–up	V	severe

Computer mapping of the five categories was used to show the relative severity of geologic hazards throughout the county and in the four urban areas in greater detail. The system employed in Santa Barbara County includes a "variability number" to indicate differences in reliability of the hazard ratings for particular grid cells resulting from potential local variations, quality of data, and other factors. Areas with the same GPI rating or in the same severity category may have different variability numbers which can affect planning recommendations.

The Santa Barbara study is a good example of the incorporation of seismic considerations into a land capability analysis. Although the hazard ratings were not related to particular land uses, the GPI does provide an overview of relative seismic and geologic hazards throughout the county. The ratings can be related to levels of acceptable risk for different categories of use, thus providing a guide for land-use planning.

Based on the GPI, the seismic safety element recommends that the county:

1. Consider areas in category V for open space, recreational or agricultural use, or possible low-density use, because cost of safe development may be high.
2. Consider areas in category IV for low-density use or nondevelopment.

The relative costs of measures needed to mitigate adverse natural conditions affect the values assigned in a land-capability study. In a pilot study of a part of the Santa Clara Valley, the Association of Bay Area Governments (Laird and others, 1979), expressed land capability in terms of the dollar costs required to mitigate hazards or to compensate for property damage and loss of natural resources.

The ABAG study included such geologic and hydrologic hazards as ground shaking, surface rupture, flooding, bearing-materials problems (potential for shrink/swell, settlement, liquefaction, and subsidence), slope stability, erosion/sedimentation, and septic-tank limitations. The study also included an evaluation of natural resources. Lands in the study area were evaluated for a range of uses: agricultural or rural, semi-rural residential, single-family residential, multi-family residential, regional commercial, downtown commercial, industrial manufacturing, and freeway.

The total cost associated with each natural constraint and resource for each land use was estimated. Table 18 lists for each land use the estimated costs associated with different intensities of ground shaking. Estimated costs per acre are obtained by multiplying the value of buildings, personal property, and utilities by the percent damage expected by the annual frequency of occurrence, and dividing by a discount rate to reduce future values to present levels. In this case costs were based on an anticipated damage level associated with each land use.

Cost information for the identified natural resources and hazards for each 24.9-acre grid cell was aggregated for each land use. The resulting number indicates for each cell the estimated dollar cost per acre of developing that cell with that land use. The range of total costs was divided into six capability levels and a land-capability map for each use was printed by computer. Figure 36, a land-capability map for a part of the Santa Clara Valley study area, is derived from table 19, which shows the costs associated with all the hazards, constraints and resources for multi-family residential use.

Analysis of land capability provides only part of the information needed for land-use decisions. Economic, social, political, and esthetic considerations are also important. The physical capability of a parcel of land to support an intensive use may be poor, but other factors, such as location and accessibility, land cost, absence of alternative lands, or overriding public need, may well indicate that the parcel should be intensively developed.

A study which systematically evaluates economic, social, and political factors, in addition to physical capability, is often called a "land-suitability study". A land-capability study can be undertaken as part of a broader land-suitability study. However, on occasion, capability is, or should be, the determining factor. Areas with very low capability for sustaining a par-

TABLE 18.—*Costs associated with ground shaking resulting from events on the San Andreas, Hayward, or Calaveras faults*

[Laird and others, 1979]

	Cost per acre (in dollars)				
	San Francisco Intensity Scale				
Land use	A	B	C	D	E
Rural or agricultural	40	30	10	5	1
Semi-rural residential	300	300	100	40	4
Single-family residential	4,000	3,000	1,000	500	50
Multi-family residential	20,000	20,000	5,000	2,000	200
Regional shopping centers	50,000	40,000	10,000	4,000	800
Downtown commercial	70,000	50,000	20,000	5,000	1,000
Industrial	40,000	30,000	10,000	3,000	700
Freeways	10,000	10,000	10,000	0	0

TABLE 19.—*Summary of costs for multifamily residential use*

[Laird and others, 1979]

Hazard, constraint, or resource	Costs for map categories (in dollars per acre) (scale from severe to slight) Severe				Slight
Surface rupture	800	800	0	----	----
Ground shaking, San Andreas, Hayward	20,000	20,000	5,000	2,000	200
Ground shaking, Southern Hayward	2,000	2,000	500	200	20
Ground shaking, Calaveras	20,000	5,000	2,000	200	----
Stream flooding	40,000	0	----	----	----
Dam failure	0	----	----	----	----
Dike failure	80,000	0	----	----	----
Shrink/swell soils	20,000	7,000	0	0	----
Settlement	30,000	30,000	20,000	2,000	----
Liquefaction	4,000	3,000	300	20	0
Subsidence	0	----	----	----	----
Landslides	200,000	100,000	50,000	9,000	0
Soil creep	40,000	40,000	0	0	----
Erosion and sedimentation	200	30	10	0	----
Septic tanks	0	----	----	----	----
Sand and gravel	20,000	0	----	----	----
Mercury	0	----	----	----	----
Agricultural land	5,000	0	----	----	----

ticular use can sometimes be eliminated from further consideration, allowing the planner to focus attention on more realistic options.

Land-capability studies are becoming increasingly important to land-use planners at all governmental levels. They assure that physical characteristics of the land will be systematically considered in land-use planning. The earth-science information requirements for such studies vary with the total land area and the specific use to be studied. For example, fairly general data may be appropriate for an initial analysis of land capability for regional open space. On the other hand, a study undertaken, at any governmental level, to locate specific sites with good capability for sanitary landfill will require detailed information.

Land-capability analysis allows seismic-risk constraints to be considered along with other natural characteristics in making land-use decisions. The hazard information developed in the process of seismic zonation is combined with other natural characteristics and given a numerical weight. Capability analysis relates seismic and other hazards directly to potential land uses. Land-capability studies may usefully serve as an intermediate step in identifying areas where hazards are present and where detailed consideration of risk is needed in deciding land uses, structural design, and occupancy.

LAND-USE POLICY AND REGULATION

Many cities and counties in California have completed the seismic safety elements of their general plans. For many of these jurisdictions, the preparation of these elements was their first experience in using geologic information systematically in a planning task. The typical seismic safety element is a preliminary step toward developing a comprehensive program to reduce seismic risk. Because of limited experience in using existing geologic data, most seismic safety elements emphasize the need for more data. If detailed data were available and the planning staff was experienced, more specific recommendations for immediate action resulted. While most seismic safety elements contain recommendations for land-use policy, few jurisdictions have yet integrated seismic safety policies and programs into their comprehensive plans. This kind of planning will come about when more cities and counties combine the various required general plan elements into a comprehensive document.

The recently adopted General Plan 1975 for the City of San Jose is one of the first to consider seismic risk as an integral part of a comprehensive plan. The land-use pattern of San Jose is a classic example of urban sprawl resulting from very rapid development following World War II. An aggressive annexation policy and a growth-oriented political climate led to more than a fivefold increase in city population from 1950 to 1975—from just under 100,000 to 547,500. During the five-year period 1969–1974, an average of 769 hectares (1,900 acres) was converted to urban uses each year (San Jose, 1976, p. 7). Increasingly, land with development constraints was being pressed into urban use.

The San Jose **General Plan 1975** is a guide for managing growth to match the city's ability to extend urban services, avoid development of unsuitable lands, and achieve a more efficient urban form and a better balance of land uses. The first step was the adoption in 1970 of a set of urban development policies. These policies are now incorporated into the **General Plan**

FIGURE 36.—Land-capability map for multi-family residential use (Laird and others, 1979, p. 75).

1975. Future development is to be limited to a designated urban service area for the 15-year time span of the plan. Within the urban service area approximately 8,134 hectares (20,100 acres) were undeveloped in 1975. Of these, 1,052 hectares (2,600 acres) were already approved for private development; 425 hectares (1,050 acres) committed to public uses; 399 hectares (985 acres) under Williamson Act Contract[1], 301 hectares (745 acres) programmed for public acquisition; and 770 hectares (1,920 acres) considered ill-suited for development because of size, shape, slope, soil subsidence flooding, or location in an airport safety zone (San Jose, 1976, p. 7).

The plan contains specific policies related to lands considered unsuitable for urban development within the urban service area as well as throughout the area. Based on a goal of striving to minimize risk from natural hazards, the plan (San Jose, 1976, p. 19) contains the following general policies:

1. The City shall not permit urban development in those areas where such development would constitute a significant potential danger to the health, safety, and welfare of the residents.
2. Low levels of 'acceptable exposure to risk' shall be established for land uses and structures in which failure would be catastrophic, which are required during emergencies, or which involve involuntary or high human occupancy.
3. Risks from natural hazards shall be reduced as much as possible in areas where human activity is necessary or already exists, and where the natural and man-made environment can be safely integrated.
4. Preventative measures for known natural hazards shall be taken simultaneously with new development.
5. Site-specific information on natural hazards shall be required for proposed new development and where identified hazards preclude safe human interaction, development shall yield to natural processes.
6. Provision shall be made for the continuation of essential public services during natural catastrophes.
7. The City shall promote an awareness and caution among San Jose residents regarding possible natural hazards including soils conditions, earthquakes, flooding, and fire hazards.

Specific policies regarding seismic safety call for rehabilitating or removing structural hazards "without creating undue hardship or relocation policy problems" (San Jose, 1976, p. 19); restricting construction near creek channels where liquefaction is a hazard; requiring geotechnical studies to determine the extent of seismic hazards prior to approval of development proposals; regulating land uses in areas prone to flooding from dike or dam failure; and requiring detailed dynamic ground motion analysis and suitable structural design for critical facilities (San Jose, 1976, p. 19).

These and other policies apply to areas designated as hazardous on maps which are part of the Geotechnical Report prepared by Cooper, Clark, and Associates (1974) as background for the Seismic Safety Element. A generalized natural hazards map (fig. 37) is incorporated in the **General Plan 1975.**

The importance of avoiding development in hazardous areas is reflected in the land-use policies and land-use diagram. For example, the following policies of the General Plan 1975 (San Jose, 1976, p. 21, 25) are related to specific land uses:

Solid waste disposal land fill sites shall be discouraged on lands which are susceptible to landslides, seismically induced ground failure, ***dam inundation***. Residential development shall not be allowed to occur in areas where such development might be hazardous to human habitation***Densities permitted by the General Plan on

[1]The California Land Conservation Act of 1965 (California Government Code, 1965), also called the Williamson Act, permits landowners to enter into contracts with cities and counties in which the landowners agree to maintain land in agricultural use in exchange for tax assessments based on the economic return from agricultural use of land.

EXPLANATION

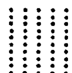
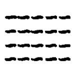
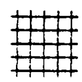
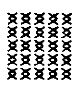
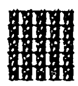
Level	Symbol	Total Cost Range (in dollars per acre)		No. Of Cells In Level
1		0.01	10.00	0
2		10.01	100.00	0
3		100.01	1000.00	0
4		1000.01	10000.00	16
5		10000.01	100000.00	4644
6		100000.01	1000000.00	2877

FIGURE 36.—Continued.

slopes greater that 15 percent may be allowed to be transferred***.

The land-use diagram shows the area underlain by bay mud as open space, agriculture, and light industry. Areas adjacent to major creeks which may be subject to ground failure are shown as open space. Hillside areas to the northeast and southwest of the valley floor are designated for nonurban uses. In these areas, slope failure and surface rupture during an earthquake are potential hazards.

To implement the plan, new zoning districts limiting the density of residential development in hillside and other outlying areas are to be prepared. Geologic hazards are to be systematically considered in the review of development proposals. Where warranted by geologic investigation, designated land uses can be altered because the geologic hazards may be overriding.

The 1975 plan evaluates the full range of factors affecting the future development of the San Jose area. Conflicts among economic, social, and environmental objectives are recognized and resolved into a plan and an implementing program that explicitly incorporates seismic safety concerns into the decisionmaking process.

PROJECT REVIEW

Another means of integrating seismic risk and land-use planning is to develop, within a general policy framework, project review requirements and procedures. Such requirements and procedures are appropriate when detailed data on seismic hazards are not available. Generalized data can be used to alert planners and decisionmakers to potential problems. Such a system generally identifies areas where seismic, geologic, or soils investigations are required before development proposals are approved. Specific report requirements, procedures for evaluating reports and requiring hazard mitigation, and criteria for determining the acceptability of proposed projects can be developed to incorporate seismic safety concerns.

Project review can be very effective if it assures that seismic risk is considered in site selection, structural design,a nd occupancy of major development proposals. Although the developer has the responsibility for collecting data, the public agency must have sufficient information and geologic expertise to evaluate the geologic and seismic reports submitted with the proposals.

Santa Clara County emphasizes project review. The **Seismic Safety Plan (1975)** describes the seismic and geologic hazards in the county and general policies to mitigate or avert undue seismic risk in existing or future development. The essence of the plan, however, is contained in the recommendations for geotechnical site investigations (Santa Clara County, 1975, p. 19–20):

In order to maximize public safety and minimize seismic hazards, additional local geotechnical studies should be performed prior to further development in many areas of the County. These studies should consider the data in this report as general background and regional material and should determine the extent of particular seismic hazards on each site in relation to the specific intended use.

These geotechnical investigations should be multidisciplinary, including component studies of seismology, engineering geology, planning, hydrology, architecture, design engineering, structural engineering, and soil engineering. These interrelated components should be coordinated so that all pertinent factors are considered.

To review and approve these geotechnical investigations, it is recommended that the County should develop an adequately trained and funded staff team including the various disciplines mentioned above.

To help decide if a geologic or geotechnical investigation should be required, the county uses a Relative Seismic Stability Map prepared by the California Division of Mines and Geology at a scale of 1:62,500. Figure 38 is a part of the reduced version of this map which is included in the *Seismic Safety Plan.* The original map is incorporated, by reference, in a county ordinance setting forth soils and geologic report requirements (Santa Clara County Board of Supervisors Ordinance No. NS–1203.31, December 1974). Soils and geologic reports may be required when applications are submitted for subdivisions, building site review, grading permits, and building permits.

Soils reports are to be prepared by a civil engineer registered by the State and geologic reports by an engineering geologist certified by the State. The county staff includes an engineering geologist and other experts competent to evaluate the reports and the mitigating measures proposed. The report requirements and evaluated procedures are part of the total review process, and they ensure that geologic and seismic hazards are considered adequately in land-use decisions and land-development practices.

POSTEARTHQUAKE RECONSTRUCTION

After a damaging earthquake, economic, social, psychological, and political pressures coalesce to hasten rebuilding. Often this leads to restoring area, buildings, and services to their previous condition without regard for site or structural hazards revealed by the earthquake, or hazards previously identified, but not heeded. If properly planned and carried out, reconstruction following an earthquake can greatly reduce risk from future events.

The San Francisco Community Safety Plan (San Francisco Department of City Planning, 1975) stresses the opportunities presented during reconstruction to carry out the objectives of the comprehensive plan. The plan (p. 38) recommends that the city:

Adopt contingency legislation to provide for anticipated needs following a disaster and to reduce pressures for unnecessarily rapid reconstruction.

Create a reconstruction planning committee to insure that development following a major disaster takes place in a timely fashion according to established objectives and policies.

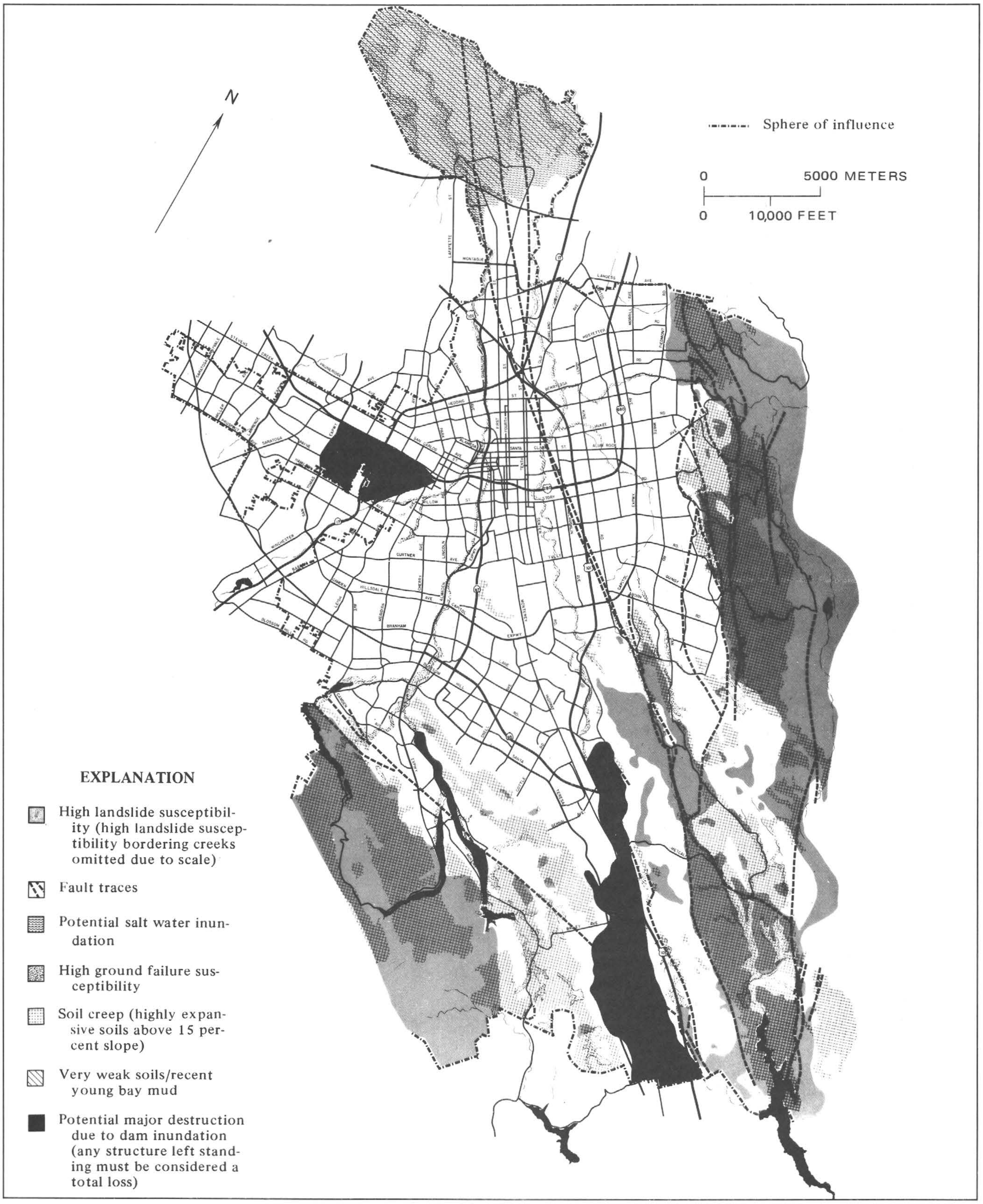


FIGURE 37.—Natural hazards map, City of San Jose.

The proposed Reconstruction Planning Committee would have the following duties (San Francisco Department of City Planning, 1974, p. 63–64):

1. Insure that postearthquake building code and design standards are as advanced in terms of seismic safety as possible.
2. Implement objectives, policies, and criteria of the Comprehensive Plan.
3. Recommend contingency legislation to be enacted now, but taking effect after an earthquake to authorize such actions as provision of temporary housing.
4. Determine priorities for allocating resources, particularly building materials.
5. Seek joint agreements with lending institutions, insurance companies, and Federal disaster assistance agencies to require a valid building permit before money for new construction is released.
6. Develop an information booklet setting forth all requirements pertinent to reconstruction and sources of financial assistance.

EARTHQUAKE PREDICTION

Current research in earthquake prediction appears quite promising and has attracted considerable public attention. Although the science of prediction is still in its infancy, many seismologists in the United States believe that within the next decade or two, they will be able to predict at least some earthquakes. However, predictions that specify the location, magnitude, and time of damaging earthquakes with accuracy and enough lead time to take measures to reduce risk are probably a long way off.

Credible earthquake prediction may have short-term adverse economic and social impacts, but the possibilities for reducing loss of life, injury, and substantial property damage make prediction a worthwhile research objective. The value of such predictions is well stated in a recent article by Frank Press (1975, p. 14–15):

> Preliminary results of current investigations indicate that predictions of strong earthquakes could be made many years in advance. It also appears likely that a method for making short-term predictions, as short as weeks or even days, will be developed. With this dual capability it should become possible to devise a remedial strategy that could greatly reduce casualties and lower property damage. For example, the long-range prediction of a specific event could greatly reduce casualties and lower property damage. For example, the long-range prediction of a specific event could spur the strengthening of existing structures in the threatened area and motivate authorities there to enforce current building and land-use regulations and to revise such codes for new construction. A public-education campaign on safety procedures could also be instituted.
>
> Short-term prediction could mobilize disaster-relief operations and set in motion procedures for the evacuation of weak structures or particularly flammable or otherwise hazardous areas. The shutdown of special facilities, such as nuclear power plants and gas pipelines, and the evacuation of low-lying coastal areas subject to tsunamis, or "tidal waves," could also follow a short-term forecast.

In brief, long-term earthquake prediction could spur public agencies to take those actions which are recommended in seismic safety and emergency preparedness plans. High priorities could be assigned to such measures if an earthquake were predicted, thus substantially reducing the risks. Short-term predictions could avert little property damage but could reduce dramatically the risk of death or injury.

Planning responses to seismic risk are just as, or even more, relevant if accurate prediction becomes possible. The jurisdiction with a development pattern which avoids intensive use of hazardous areas and which provides for sound structural design and construction and carefully located and designed emergency response facilities will be well prepared for that inevitable earthquake whether or not it is predicted.

CONCLUSIONS

Over the past decade, remarkable progress has been made in understanding the nature, cause, and effects of earthquakes. Planners are still developing methods and procedures to make effective use of the data. Methods which more fully integrate safety concerns in land-use planning and decisionmaking can be expected to emerge.

Success in seismic safety planning requires public awareness of the nature of seismic risk and the potential for reducing it. Historically, safety has not been an important factor in locating urban settlements, and overcoming apathy toward seismic risk is a formidable task. Typically, the spurt of public interest following each damaging earthquake gradually dwindles away. Recent California seismic safety planning has occurred because of the State law adopted after the San Fernando earthquake of 1971. It is to be hoped that these planning efforts will continue and ultimately will result in significant reduction of losses in future earthquakes.

Success in reducing seismic risk requires a comprehensive program including preparing for disaster response, establishing and enforcing structural design standards, and planning for safe land and building uses. The land-use planning component of the program is particularly important because if seismic hazards are properly recognized in the land-use patterns, disaster response and structural design requirements can be correspondingly reduced. Reducing risk through land-use planning requires an interdisciplinary effort involving earth scientists, engineers, and planners.

A land-use plan provides the framework for many public actions including land-use and development regulations, building code provisions, and project review

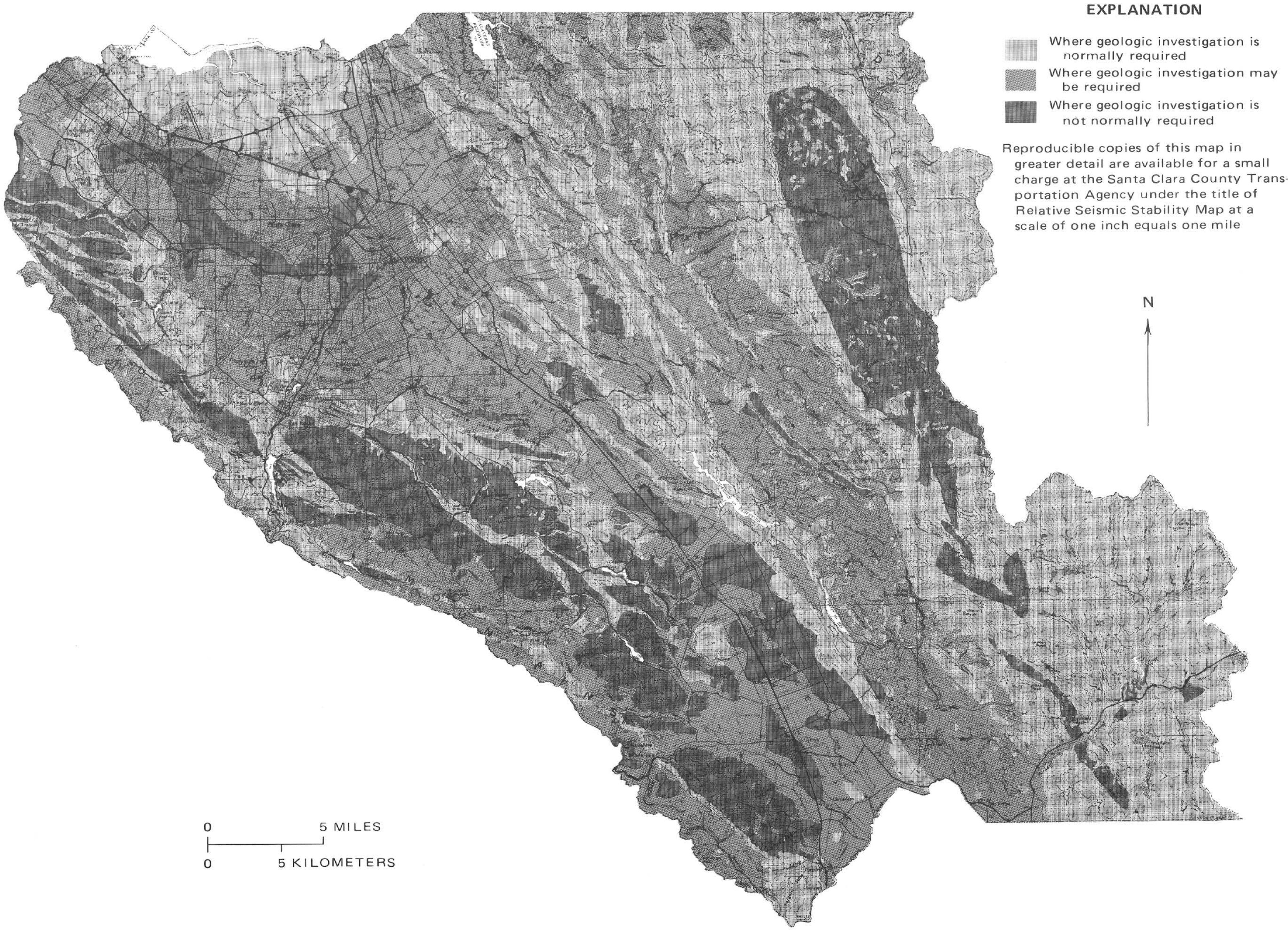


FIGURE 38.—Seismic safety zones, Santa Clara County.

procedures and criteria. The basic objective of land-use planning for seismic safety is to reduce exposure to seismic hazards by relating land uses to degrees of seismic hazards. In formulating a land-use plan, the social and economic benefits of particular locations for particular uses must be weighed against the costs for structural measures needed to reduce risk to acceptable levels. In developed areas, the value of existing buildings and infrastructure must be weighed against costs of damage and injuries from earthquakes.

In the future, more effective land-use planning to reduce seismic risk will be possible as more accurate and detailed information becomes available and planners become more experienced in its application. Maps showing where ground shaking, slope instability, and liquefaction may occur will be particularly useful to land-use planners. Further research in structural response to seismic forces is needed to develop more realistic building code requirements.

The relative costs of applying various risk reduction measures are usually unknown but are greatly needed. In addition, the public and private costs associated with various land uses and structural types in hazardous areas need to be studied. Legal mechanisms and funds are required to help reduce existing structural hazards. If these additional tools are provided, local public agencies in cooperation with knowledgeable citizens and decisionmakers will be well equipped to plan for seismic safety.

REFERENCES

Alfors, J. T., Burnett, J. L., and Gay, T. E., Jr., 1973, Urban geology master plan for California: California Div. Mines and Geology, Bull. 198, 112 p.

Algermissen, S. T., 1969, Seismic risk studies in the United States *in* Proceedings of the fourth world conference on earthquake engineering: Santiago, Chile, v. 1, p. 19–27.

———(principal investigator), 1972, A study of earthquake losses in the San Francisco Bay area: Natl. Oceanic Atmospheric Admin., U.S. Dept. Commerce, 220 p.

Armstrong, Dean, 1973, The seismic safety study for the general plan: Sacramento, Calif., California Council on Intergovernmental Relations, 199 p.

Association of Bay Area Governments, 1973 Procedures for regional clearinghouse review of environmental impact statements—Phase two: Assoc. Bay Area Govts., Berkeley, Calif., 225 p.

———1975a, Areas of critical environmental concern. Review draft: Assoc. Bay Area Govts., Berkeley, Calif., 83 p.

———1975b, Hazards evaluation for disaster preparedness planning: Assoc. Bay Area Govts., Berkeley, Calif., 37 p.

———1976, Earthquake preparedness—ideas for action: Assoc. Bay Area Govts., Berkeley, Calif. unpaged.

Association of Engineering Geologists, 1973, Geology, seismicity, and environmental impact: Special Publication, Los Angeles, University Publishers, 446 p.

Ayre, R. S., 1975, Earthquake and tsunami hazards in the United States—A research assessment: Natl. Sci. Found.–RA–E–75–005, Univ. Colorado, Boulder, 149 p.

Baker, L. C., Jr., 1971, Availability and desirability of earthquake insurance in earthquake risk: Conference proceedings Sept. 22–24, 1971, sponsored by the Joint Committee on Seismic Safety to the California Legislature, report of the Special Subcommittee to the Joint Committee on the San Fernando Earthquake Study, p. 31–33.

Borcherdt, R. D., ed., 1975, Studies for seismic zonation of the San Francisco Bay region—Basis for reduction of earthquake hazards, San Francisco Bay region, California: U.S. Geol. Survey Prof. Paper 941–A, 102 p.

Borcherdt, R. D., Gibbs, J. F., and Lajoie, K. R., 1975, Maps showing maximum earthquake intensity predicted in the southern San Francisco Bay region, California, for large earthquakes on the San Andreas and Hayward faults: U.S. Geol. Survey Misc. Field Studies Map MF–709, 3 sheets, scale 1:125,000.

Brown, R. D., Jr., 1972, Active faults, probable active faults, and associated fracture zones, San Mateo County, California: U.S. Geol. Survey Misc. Field Studies Map MF–355, scale 1:62,500.

Burkland and Associates, 1975, Geological and geophysical investigation in downtown Hayward: Burkland and Assoc., Mountain View, Calif., 22 p. and appendix.

California Council on Intergovernmental Relations, 1973, Guidelines for local general plans, Sacramento: Calif. Council on Intergovernmental Relations, Sacramento, 106 p.

California Division of Highways, 1971, The effect on state highways of the San Fernando earthquake February 9, 1971: Calif. Div. Highways, Sacramento, Calif., 62 p. and appendixes.

———1975, Highway design manual of instructions: Calif. Div. Highways, Sacramento, Calif., Section 7–110.

California Division of Mines and Geology, State Mining and Geology Board, 1975, Policies and criteria of the State Mining and Geology Board with reference to the Alquist-Priolo Special Studies Zones Act, 3 p.

California Education Code, 1933, secs. 15451–15465.

———1967, sec. 15002, Field Act.

California Government Code, 1965, California Land Conservation Act of 1965 (Williamson Act): California Govt. Code, secs. 51,200–51,295.

———1970, sec. 65302, Emergency Services Act.

———1973, sec. 8589–5, Alquist Dam Safety Act.

———1974, secs. 8890–8899, Seismic Safety Commission Act.

California Governor's Earthquake Council, 1972, First report of the Governor's earthquake council: Sacramento, Calif., 65 p.

California Office of Planning and Research, 1973, Summary report—Environmental goals and policy: Sacramento, Calif., 29 p.

California Public Resources Code, 1972, secs. 2621–2625, Alquist/Priolo Special Studies Zones Act.

———1976, California Coastal Act: secs. 30000 to 30900.

California Resources Agency, 1974, Amendments to guidelines for implementation of the California Environmental Quality Act, December 1974, secs. 15001–15163, 23 p.

California State Legislature, 1963, California Health and Safety Code, California Community Redevelopment Act, secs. 33000–33738.

———Joint Committee on Seismic Safety, Gates, George O., ed. 1972, The San Fernando earthquake of February 9, 1971 and public policy: Calif. Joint Comm. on Seismic Safety, Sacramento, Calif., 127 p.

California State Legislature, Joint Committee on Seismic Safety, 1974, Meeting the earthquake challenge, final report to the Legislature, January 1974: Calif. Div. Mines and Geology, Special Publication 45, 223 p.

California State Senate, 1969, Concurrent resolution no. 128 of 1969.

Chinnery, M. A., and North, R. G., 1975, The frequency of very large earthquakes: Science, v. 190, no. 4220, p. 1197–1198.

Cooper, Clark, and Associates, 1974, Technical report, geotechnical investigation, city of San Jose's sphere of influence for the city of San Jose: Cooper, Clark, and Associates, San Jose, Calif., 233 p. and appendix.

Council on Environmental Quality, 1973, Preparation of environmental impact statements—guidelines: 38 Fed. Reg., August 1, 1973, p. 20562.

Dewey, J. F., 1972, Plate tectonics: Scientific American, v. 226, no. 5, p. 56–66.

Dickinson, W. R., 1970, Commentary and reconnaissance photogeologic map, San Andreas rift belt, Portola Valley, California: Town of Portola Valley, Calif., public document, 51 p.

Duncan & Jones, 1974, Seismic safety element, San Jose, California: Duncan and Jones, Berkeley, Calif., 48 p.

Elders, W. A., 1974, "Is there an earthquake in your future?", Cry California, Jour. of California Tomorrow, v. 9, no. 2, p. 20–25.

Hayward, 1972, Hayward earthquake study: Planning Commission Subcommittee on Land Use and Development Regulations, Hayward, Calif., 50 p.

———1975a, Redevelopment plan, Downtown Hayward redevelopment project: Redevelopment Agency of the City, Hayward, Calif., 24 p.

———1975b, Preliminary action proposal for downtown revitalization: Executive Comm. of the Downtown Planning Team, Hayward, Calif., 30 p.

International Conference of Building Officials, 1976, Uniform building code: Whittier, Calif., Internat. Conf. Bldg. Officials, 728 p.

Interprofessional Council of Environmental Design, 1974, Guide to interprofessional collaboration in environmental design.

Jennings, C. W., 1975, Fault map of California with locations of volcanoes, thermal springs and thermal wells: California Div. Mines and Geology, Geologic Data Map No. 1, scale 1:750,000.

Laird, R. T., Perkins, J. B., Bainbridge, D. A., Baker, J. B., Boyd, R. T., Huntsman, Daniel, Zucker, M. B., and Staub, Paul, 1979 Quantitative Land Capability Analysis, U.S. Geol. Survey Prof. Paper 945, 115 p.

Lakshmanan, T. R., 1972, Integration of physical and economic planning: Prepared for United Nations Centre for Housing Building and Planning, New York, N. Y., 48 p.

Livingston and Blayney, 1974, Santa Barbara County Comprehensive Plan, seismic safety element: Livingston and Blayney, City and Regional Planners, San Francisco, Calif., 93 p.

Mader, G. G., 1974, "Earthquakes, landslides and public planning", Cry California, Jour. of California Tomorrow, v. 9, no. 3, p. 16–22.

Metropolitan Transportation Commission, 1974, Regional transportation plan: Metropolitan Transp. Comm., Berkeley, Calif., 126 p. and appendix.

Monterey County, 1975, County-wide seismic safety element for the General Plans of the county of Monterey and participating municipalities: Prepared by William Spangle and Associates, Monterey County, Monterey, Calif., 50 p.

Nichols, D. R., and Buchanan-Banks, J. M., 1974, Seismic hazards and land-use planning: U.S. Geol. Survey Circ. 690, 33 p.

Nilsen, Tor, and Wright, R. H., 1979, Relative slope stability and land-use planning: selected examples from San Francisco Bay region, California: U.S. Geol. Survey Prof. Paper 944, 96 p.

Palo Alto, City of, 1976, Palo Alto comprehensive plan: Palo Alto, Calif., 62 p. (in press).

Planning Policy Committee of Santa Clara County, 1972, A policy plan for the baylands of Santa Clara County: County of Santa Clara Planning Dept., San Jose, Calif., 76 p.

Press, Frank, 1975, Earthquake prediction: Scientific American, May 1975, v. 232, no. 5, p. 14–23.

Ritter, J. R., and Dupre, W. R., 1972, Maps showing areas of potential inundation from tsunamis in the San Francisco Bay Region: U.S. Geol. Survey Misc. Field Studies Map MF–480.

San Diego County, 1975, Seismic safety element, San Diego County general plan: San Diego, Calif., 13 p. and appendixes.

San Francisco Bay Conservation and Development Commission, 1969, San Francisco Bay plan: San Francisco Bay Conserv. and Devel. Comm., San Francisco, Calif., 43 p. and appendix.

———1974a, Bay plan evaluation project, safety of fills: San Francisco Bay Conserv. and Devel. Comm., San Francisco, Calif., 23 p.

———1974b, Bay plan evaluation project, final report—Guidelines for Bay plan revision: San Francisco Bay Conserv. and Devel. Comm., San Francisco, Calif., 24 p.

San Francisco Department of City Planning, July 1974, A proposal for citizen review, community safety, the comprehensive plan of San Francisco, Dept. of City Planning, San Francisco, Calif. 69 p.

San Jose, City of, 1976, The general plan 1975: San Jose, Calif., 57 p. and land use/transportation diagram.

San Mateo County, 1975, City-county planning task force, seismic and safety elements of the General Plan, v. 1, Redwood City, Calif., 95 p.

Santa Clara County, 1975, Seismic safety plan, An element of the general plan: San Jose, Calif., 75 p. and appendixes.

Santa Clara County Board of Supervisors, 1974, San Jose, Calif., Ordinance No. NS–1203.31, 11 p.

Santa Clara County Planning Policy Committee, 1972, A policy plan for the baylands of Santa Clara County: Santa Clara Co. Planning Dept., San Jose, Calif., 76 p.

Scott, Nina H., 1973, Felt area and intensity of San Fernando earthquake *in* San Fernando, California, Earthquake of February 9, 1971, v. III, Geological and Geophysical Studies: Natl. Oceanic and Atmospheric Ad., U.S. Dept. Commerce, p. 23–48.

Spangle, William and Associates and F. Beach Leighton and Associates, and Baxter, McDonald and Smart, Inc., Feb. 22, 1974, Application of earth science information in urban land-use planning, state-of-the-art review and analysis: Natl. Tech. Inf. Service, U.S. Dept. Commerce, Springfield, Va. (NTIS PB 238–081/AS), 330 p.

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

Strahler, A. N., 1971, The earth sciences: New York, Harper and Row, 824 p.

U.S. Civil Defense Preparedness Agency, 1974, Assumptions, precepts, and objectives, program paper: Civil Defense Preparedness Agency, v. 1, 32 p.

U.S. Congress, 1968, Intergovernmental cooperation act of 1968: Public Law 90–577.

———1970, National environmental policy act of 1969: Public Law 91–190, 5 p.

———1972, Federal coastal zone management act of 1972: Public law 92–583.

———1973, Flood disaster protection act of 1973: Public Law 93–234, 9 p.

———1974, Disaster relief act of 1974, Public Law 93–288, 22 p.

U.S. Department of Housing and Urban Development, 1973, Minimum property standards for multifamily housing: Washington, D.C., v. 2, unpaged.

———1975a, Comprehensive planning assistance; General applicability: Fed. Reg., v. 40, no. 164, p. 36856–36865.

———1975b, Environmental review procedures for community development block grant program: Fed. Reg., v. 40, no. 4, Part II, January 7, 1975, Washington, D.C., p. 1392–1399.

U.S. Federal Insurance Administration, 1975, National flood insurance program, proposed criteria, Part II: Washington, D.C., Federal Register, March 26, 1975, v. 40, no. 59, p. 13420–13433.

U.S. Geological Survey, 1971, Earthquakes: Washington, D.C., U.S. Govt. Printing Office, 19 p.

U.S. Geological Survey and U.S. National Oceanic and Atmospheric Administration, 1971, The San Fernando, California, earthquake of February 9, 1971: U.S. Geol. Survey Prof. Paper 733, 254 p.

U.S. National Oceanic and Atmospheric Administration, 1975, Coastal zone management program administrative grants, Notice of final rulemaking: Fed. Reg., v. 40, no. 6, part I, p. 1687.

U.S. Office of Emergency Preparedness, 1971, X-day + 100, the Federal response to the California earthquake of February 9, 1971, an interim report as of May 20, 1971, in Governmental response to the California earthquake disaster of February 1971, Hearings before the Senate Committee on Public Works: U.S. 92d Cong., Calif., Serial No. 92–H22, 21 p.

———1972, Disaster preparedness, report to Congress: U.S. Govt. Printing Office 4102–0006, 3 vols. 353 p.

U.S. Office of the Federal Register, 1973, United States Government Manual 1973/74: U.S. Govt. Printing office, 794 p.

U.S. Office of Management and Budget, 1973, Evaluation, review, and coordination of Federal and Federally assisted programs and projects: Washington, D.C., Govt. Printing Office, Circ. A–95 (rev.), Federal Register, V. 38, no. 228, p. 32874–32881.

U.S. Office of Science and Technology, 1970, Earthquake hazard reduction, Report of the task force on earthquake hazard reduction: U.S. Govt. Printing Office, 54 p.

U.S. Senate, 1971, Hearings before the Committee on Public Works, Governmental response to the California earthquake disaster of February 1971: U.S. Govt. Printing Office, 985 p.

Wallace, R. E., 1970, Earthquake recurrence intervals on the San Andreas Fault, Geol. Soc. Am. Bull., v. 81, no. 10, p. 2875–2890.

Wood, H. O., 1908, Distribution of apparent intensity in San Francisco, *in* The California earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission: Carnegie Inst. Washington Pub. 87, p. 220–245.

Yanev, Peter, 1974, Peace of mind in earthquake country: San Francisco, Chronicle Books, 304 p.

Youd, T. L., Nichols, D. R., Helley, E. J., and Lajoie, K. R., 1975, Liquefaction potential, *in* Studies for seismic zonation of the San Francisco Bay region, California: U.S. Geol. Survey Prof. Paper 941–A, p. A68–A74.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MARCH 3, 1849
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