GEOLOGICAL SURVEY CIRCULAR 816

Program and Plans of the U.S. Geological Survey for Producing Information Needed in National Seismic Hazards and Risk Assessment, Fiscal Years 1980–84

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1979

United States Department of the Interior
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Geological Survey
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Free on application to Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202

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ABSTRACT

In accordance with the provisions of the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124), the U.S. Geological Survey has developed comprehensive plans for producing information needed to assess seismic hazards and risk on a national scale in fiscal years 1980-84. These plans are based on a review of the needs of Federal Government agencies, State and local government agencies, engineers and scientists engaged in consulting and research, professional organizations and societies, model code groups, and others.

The Earthquake Hazards Reduction Act provided an unprecedented opportunity for participation in a national program by representatives of State and local governments, business and industry, the design professions, and the research community. The USGS and the NSF (National Science Foundation) have major roles in the national program. The ultimate goal of the program is to reduce losses from earthquakes. Implementation of USGS research in the Earthquake Hazards Reduction Program requires close coordination of responsibility between Federal, State and local governments.

The projected research plan in national seismic hazards and risk for fiscal years 1980-84 will be accomplished by USGS and non-USGS scientists and engineers. The latter group will participate through grants and contracts. The research plan calls for (1) national maps based on existing methods, (2) improved definition of earthquake source zones nationwide, (3) development of improved methodology, (4) regional maps based on the improved methodology, and (5) post-earthquake investigations. Maps and reports designed to meet the needs, priorities, concerns, and recommendations of various user groups will be the products of this research and provide the technical basis for improved implementation.

INTRODUCTION

Purpose

This report describes the program and plans of the USGS (U.S. Geological Survey) for producing information needed to assess seismic hazards and risk on a national scale. The needs of users representing Federal Government agencies, State and local government agencies, engineers and scientists engaged in consulting and research, professional organizations and societies, model code groups, and others have been reviewed. This review was begun in 1978, primarily as a consequence of the enactment of the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124), which directed the President "to establish and maintain an effective earthquake hazards reduction program" and to develop an implementation plan which "sets year-by-year targets through at least 1980."

There can be no "final" determination of the priorities and requirements of various users for certain types of information to use in assessments of seismic hazards and risk. Needs for specific types of information change in response to diverse and complexly related political, legal, economic, and technological factors. Consequently, the program and plans defined in this report reflect the USGS perception of the current needs of various users for information. Their actual needs and our perceptions may change substantially in the next several years; therefore, an effective communication process between the USGS and all who use our products is necessary.

Definition of seismic hazards and risk

Used in the broad sense intended in this report, the term "seismic hazards" includes ground shaking, ground failure, surface faulting, tectonic deformation, and inundation. Geologic phenomena accompanying earthquakes, such as landslides, slumping, and liquefaction, occur primarily because of certain physical properties of the material at the site, but they can all be triggered by the ground shaking.

The term "seismic risk" has several connotations. Its primary use refers to possible damage and losses (economic and life) from earthquakes. In this report, the term "assessments of seismic risk" refers to the procedures or decision-making processes followed to evaluate the possibility of damage and losses from earthquakes. Seismic hazard maps depict the geographic variation of some parameter (for example, peak ground-acceleration level) in probabilistic terms and denote the probability that the parameter will equal or exceed a specified value at a site during a specified exposure time. Seismic risk maps depict the probability that social or economic consequences of an earthquake will equal or exceed specified social or economic values at a site during a specified exposure time. Appendix A contains a list of terms that are used frequently in discussions of seismic hazards and risk and gives a common usage.

Why assessments of seismic hazards and risk are needed

The question of why seismic hazard and risk assessments are needed is illustrated schematically in terms of a typical community in figure 1. This community not only has many existing physical systems exposed to the various earthquake hazards, but also may be considering many new construction projects. These projects might include siting and design of nuclear power plants, hospitals, dams, schools, high-rise buildings, oil pipeline systems, waste storage facilities, military facilities, and community lifeline systems. Each project may require an evaluation of the seismic risk by Federal, State, and local government officials and others in the private sector; it may also involve consideration of environmental impact, land-use planning, disaster planning, and insurance requirements for indemnification of losses. For existing and new construction, all of the political, legal, economic, and technological factors must be satisfactorily resolved and balanced. In each case, the objective is to make a precise assessment of the seismic risk, consistent with the present state of knowledge, and to develop an earthquake-resistant design appropriate for the region and specific site. The ultimate decisions are based on assessments of seismic risk on national, regional, and local scales; each change in scale sharpens the precision of the earthquake-resistant design for the specific construction under consideration.

In the United States, the total value of construction exposed to the earthquake threat in 1980 is estimated to be about $2.3 trillion (Office of Science and Technology Policy, 1978). In addition to the buildings, the contents and functions housed in these buildings must be considered in the assessment of seismic risk.

The Federal Government has a large inventory of existing structures, including buildings, hospitals, dams, highway structures, and military facilities, that are exposed to the earthquake threat. In addition, some 35 agencies are directly or indirectly involved in and have a need to assess the seismic risk. Also, the Federal Government has a regulatory role in construction throughout the country, which sometimes requires an evaluation of the seismic risk by law.

In every State, many old buildings are in use that do not conform to the current seismic design provisions of the Uniform Building Code. For example, in Los Angeles, Calif., alone, which has required earthquake-resistant design since 1933, it has been estimated that 20,000 to 50,000 buildings fail to meet present-day standards for earthquake resistance. For other cities in other States, the problem is larger. On a national scale, the potential cumulative loss from old buildings in earthquakes is unknown, but considered to be enormous.

Vital facilities and lifelines exist in every community throughout the United States. Experience from past earthquakes has shown that facilities such as hospitals, fire and police departments, communications and administration centers, and major repair and storage facilities must remain operational following an earthquake to insure rapid recovery. In the past, many of these facilities, as well as the energy, water, transportation, and communication lifeline systems, have been located and constructed with little regard for seismic risk. As a consequence, people in these communities have suffered following an earthquake.

Siting and design of critical facilities such as nuclear power plants, major dams, and nuclear-waste and liquid-natural-gas storage facilities receive a great deal of attention with regard to evaluation of seismic risk. The process is long, involved, and fairly well defined at this time. Because the cost of each facility can approach hundreds of millions of dollars and because emotional and political issues are usually involved, the requirement for evaluating the seismic risk for each facility is likely to become even more stringent in the future.

Building codes are the only technical and legal requirement governing the construction of certain classes of private and public buildings in States and local jurisdictions. A building code imposes a general consideration of seismic risk. The problem, however, is that adoption of seismic-design requirements at the State and local level varies widely; more than half of the States do not have any type of Statewide building code-authority. Another shortcoming is that building codes are generally considered to lag behind the current state-of-the-art in earthquake-resistant design. Modifications to building codes are usually motivated by the

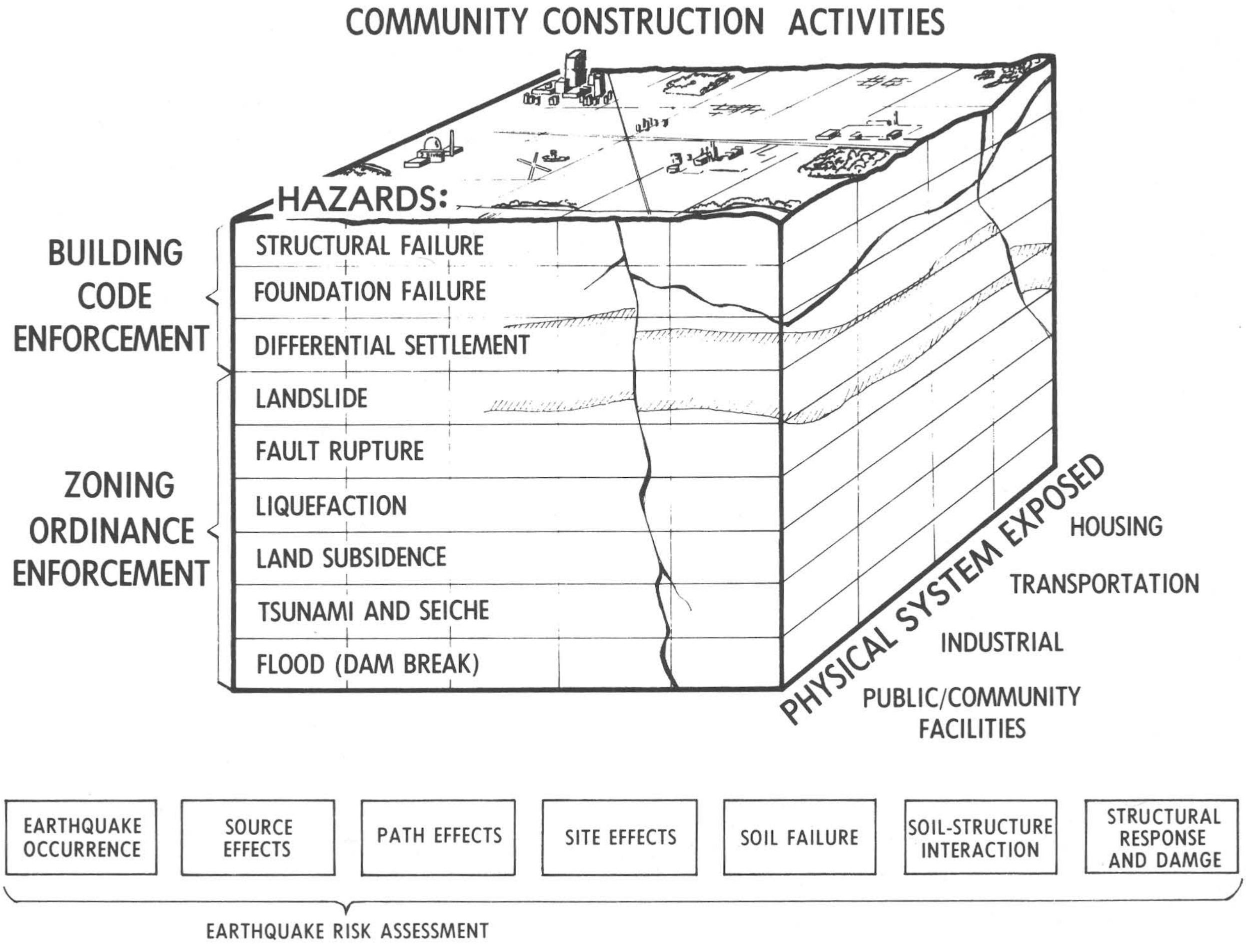

Figure 1.--Schematic illustration of a typical community with needs for assessing seismic risk.

occurrence of a damaging earthquake rather than by scientific advances.

The earthquake threat

Earthquakes are one of nature's severest hazards. Although earthquakes have caused considerably less damage than hurricanes, tornadoes, and floods, they pose the largest single-event natural hazard faced by the nation's population (table 1). Earthquakes can affect areas of hundreds of thousands of square kilometers (fig. 2), can cause great damage (figs. 3 and 4) to single-family dwellings and other structures collectively valued in billions of dollars, can cause loss of life and injury to tens of thousands, and can significantly alter the social and economic functions of communities.

Although the zone of greatest seismicity in the United States occurs along the Pacific coast, in Alaska, and in California, the central and eastern portions of the United States have also experienced seismic activity (fig. 5). Damaging earthquakes occurred in the St. Lawrence River region on many occasions from 1650 to 1928, in the Boston vicinity in 1755, in the central Mississippi Valley near New Madrid, Mo., in 1811-1812; near Charleston, S.C., in 1886; and at Hegben Lake, Mont., in 1959.

Table 1.--Estimates of annual and sudden loss potential from natural hazards in the United States

[From Wiggins, 1973.]

Natural hazard	Annual loss (in $ billions)	Sudden loss potential (in $ billions)
Earthquakes----	0.2	50
Tsunami--------		
Floods---------	2.5	3.5
Hurricanes-----		
Tornados-------	.5	2.0
Local winds----		
Landslides-----	.1	.3

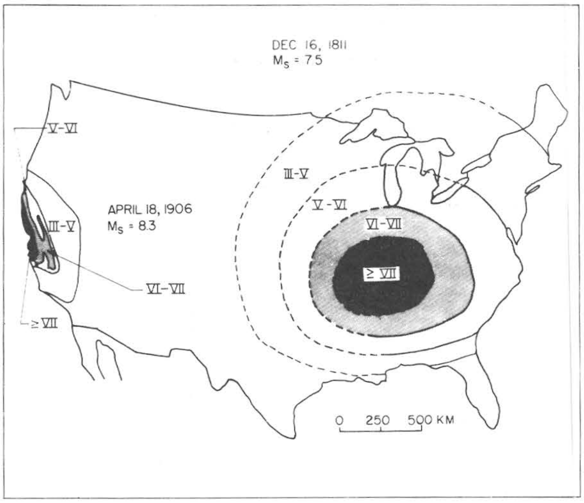

Figure 2.--Comparison of isoseismal maps of 1811-1812 New Madrid, Mo., and 1906 San Francisco, Calif., earthquakes. M_s denotes surface wave magnitude and roman numerals denote Modified Mercalli intensity. Dashed lines depict inferred isoseismal values.

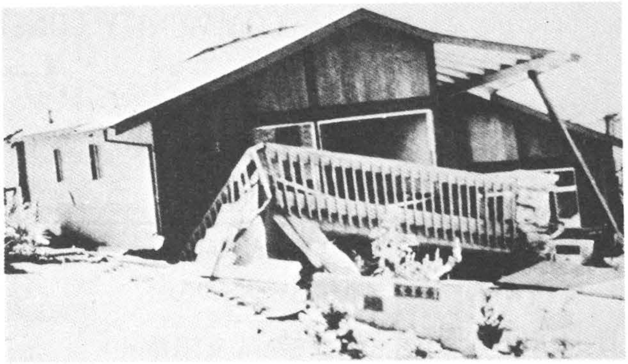

Figure 4.--Damage to a single-family dwelling, 1971 San Fernando, Calif., earthquake photograph courtesy of H. S. Lew, E. V. Leyendecker, and R. D. Dikkers, National Bureau of Standards.

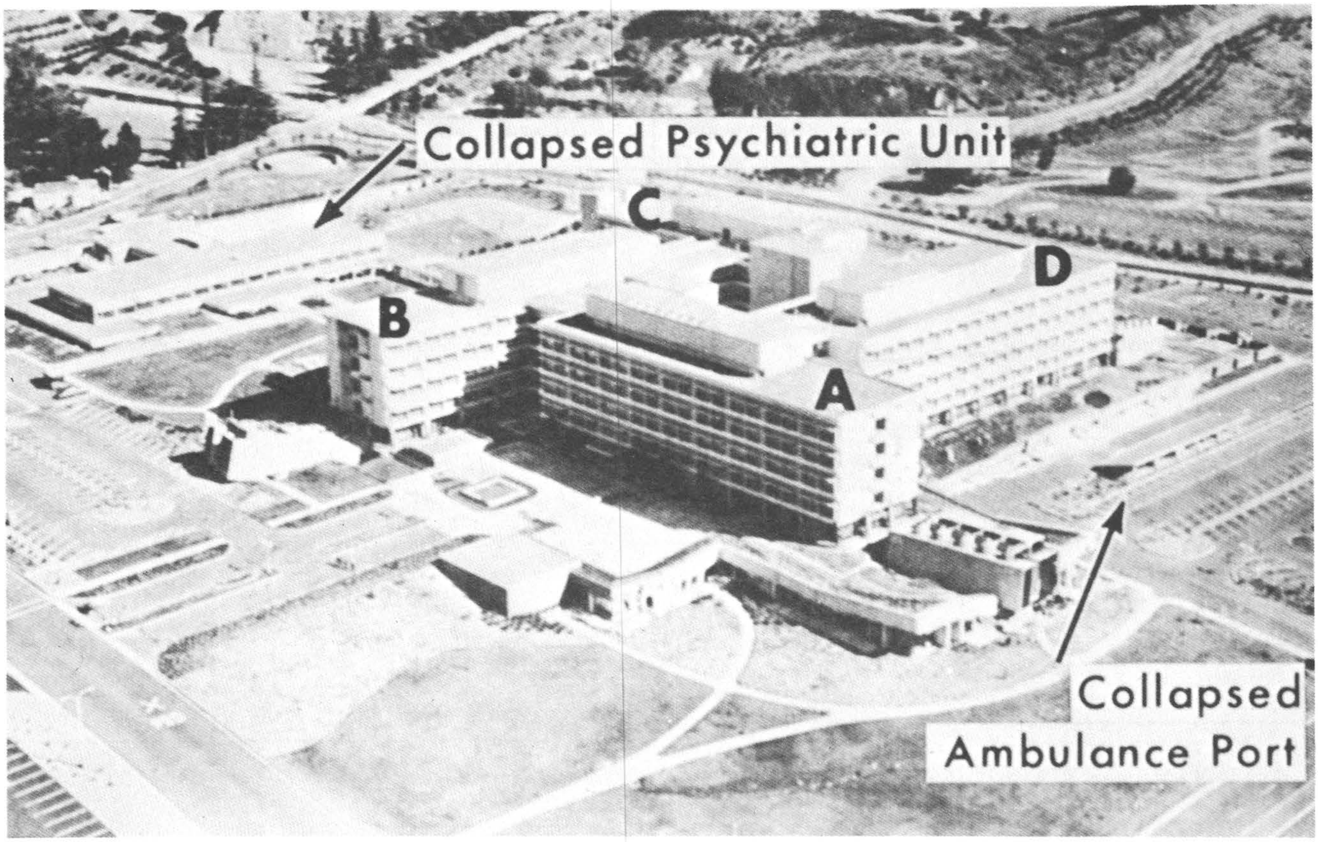

Figure 3.--Damage at Olive View Hospital, 1971, San Fernando, Calif., earthquake. A, B, C, and D denote the four wings of the 6-story main building. Wing D is approximately 240 ft (72 m) long and 65 ft (20 m) wide. Photograph courtesy of H. S. Lew, E. V. Leyendecker, and R. D. Dikkers, National Bureau of Standards.

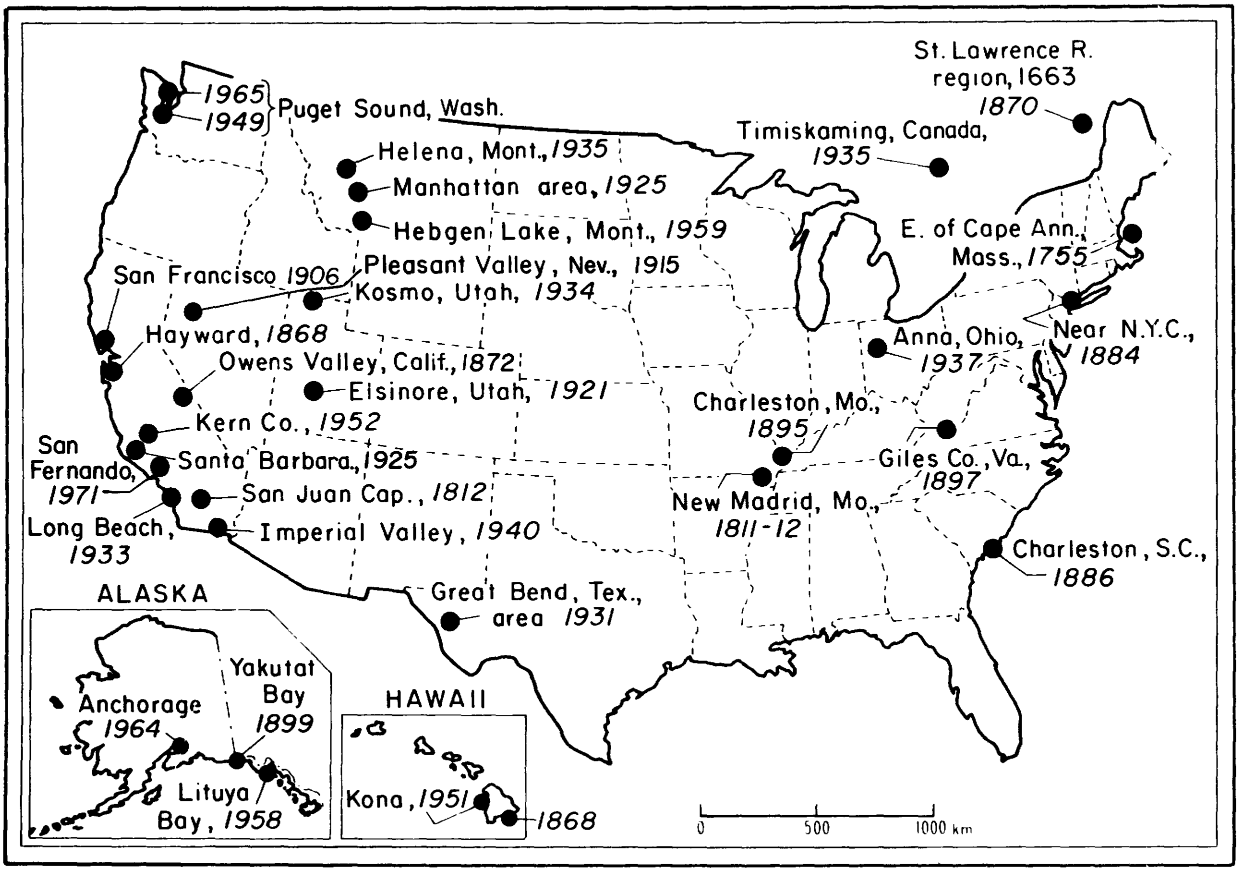

Figure 5.--Map showing locations of damaging earthquakes in the United States.

Historical earthquakes in the United States that have caused damage and loss of life are listed in table 2. Property damage in the United States due to earthquakes occurring since 1865 approaches $2 billion. However, a repeat of the 1906 San Francisco, Calif., earthquake would cause losses in the tens of billions of dollars. The loss of life in the United States has fortuitously been relatively light considering the number of destructive earthquakes and the continually increasing population density in the earthquake-prone areas. Enormous loss of life has occurred in other countries, however. For example, the death toll was reportedly at 600,000 in the July 28, 1976, Chinese earthquake (Hamilton, 1978). Some 23,000 people died in the February 4, 1976, Guatemalan earthquake. The Romanian earthquake of February 1977 killed 1,500 people. Nineteen hundred seventy-six was the worst year for loss of life from earthquakes in the world since 1556.

Seismicity and faults

The seismic activity of the western and eastern parts of the conterminous United States is quite different. In the Western United States, the activity is very high. More large and moderate earthquakes have occurred in California and Nevada than in all the remaining conterminous United States.

The high rate of seismic activity in the Western United States is largely the result of movement along the boundary between the Pacific and North American plates, two of the major plates of the Earth's crust. The relative movement between these two plates is accommodated by slippage along the 1000-km-long San Andreas Fault system (fig. 6) in California and, to a lesser degree, along subsidiary faults in California and Nevada. The destructive 1906 San Francisco, Calif., earthquake was produced by rupture along this fault system. Nevertheless, many structures, including hospitals and single-family dwellings, are located along the fault trace today and may be damaged if another large earthquake occurred. Also, some of the San Francisco Bay area communities have been developed on artificial fill in tidal flats. Some of these areas may be susceptible to liquefaction (a temporary transformation of soil into a fluid mass) and enhanced levels of ground shaking in an earthquake.

Surface faulting related to historic earthquakes is common in the Western United States,

Table 2.--Property damage and lives lost in notable U.S. earthquakes

[Taken from Report to the Congress on disaster preparedness, Office of Emergency Preparedness.]

Year	Locality	Magnitude	Damage (million dol.)	Lives lost
1811-12	New Madrid, Mo.----------	7.1-7.2(m_b)	---	---
1865	San Francisco, Calif.----	8.3 (est.)	.4	---
1868	Hayward, Calif.----------	---	.4	30
1872	Owens Valley, Calif.-----	8.3 (est.)	.3	27
1886	Charleston, S.C.---------	---	23.0	60
1892	Vacaville, Calif.--------	---	.2	---
1898	Mare Island, Calif.------	---	1.4	---
1906	San Francisco, Calif.----	8.3 (est.)	500.0	700
1915	Imperial Valley, Calif.--	---	6.0	6
1925	Santa Barbara, Calif.----	---	8.0	13
1933	Long Beach, Calif.-------	6.3	40.0	115
1935	Helena, Mont.------------	6.0	4.0	4
1940	Imperial Valley, Calif.--	7.0	6.0	9
1946	Hawaii (tsunami)---------	---	25.0	173
1949	Puget Sound, Wash.-------	7.1	25.0	8
1952	Kern County, Calif.------	7.7	60.0	8
1954	Eureka, Calif.-----------	---	2.1	1
1954	Wilkes-Barre, Pa.--------	---	1.0	---
1955	Oakland, Calif.----------	---	1.0	1
1957	Hawaii (tsunami)---------	---	3.0	---
1957	San Francisco, Calif.----	5.3	1.0	---
1958	Khantaak Island and Lituya Bay, Alaska-----	7.5	---	5
1959	Hebgen Lake, Mont.-------	7.5	11.0	28
1960	Hilo, Hawaii (tsunami)---	---	25.0	61
1964	Prince William Sound,---- Alaska	8.4	500.0	131
1965	Puget Sound, Wash.-------	6.5	12.5	7
1971	San Fernando, Calif.-----	6.6	553.0	65

particularly in California and Nevada. In some States, such as Utah, young prehistoric fault scarps have been recognized. These faults may have the potential for generating damaging earthquakes in the future that would affect a large percentage of Utah's population.

Surface faulting has not been associated with all historic earthquakes in the United States. In fact in the Eastern United States, surface faulting has not yet been recognized for any historic earthquake.

The USGS Earthquake Hazards Reduction Program

The USGS and the NSF (National Science Foundation) have major roles in the comprehensive Earthquake Hazards Reduction Program enacted by the Earthquake Hazards Reduction Act of 1977. The USGS program is conducted by both USGS and non-USGS scientists, the latter group participating through grants and contracts. The USGS and NSF programs (NFS and USGS, 1976) are complementary and represent a balance of six elements: (1) fundamental earthquake studies, (2) earthquake prediction, (3) induced seismicity, (4) earthquake hazards assessment, (5) engineering, and (6) research for utilization. The funding level for each element is shown in table 3 for FY 78-80.

Some 37 percent of USGS funding is allocated toward earthquake hazards assessment. The distribution of funding for this activity in FY 78 and FY 79 is shown in table 4.

A list of projects in seismic risk funded by the USGS in FY 79 is shown in table 5. These projects involve both USGS and non-USGS scientists. A list of all the earthquake hazards projects funded in FY 79 in the USGS program is shown in appendix B. The projects funded in FY 78 are listed in Hamilton (1978) and described in MacCabe (1979).

USGS hazard assessment studies are currently grouped in the following categories:

1. National studies--broad-scale investigations of geographic studies to determine the history and likelihood of earthquake

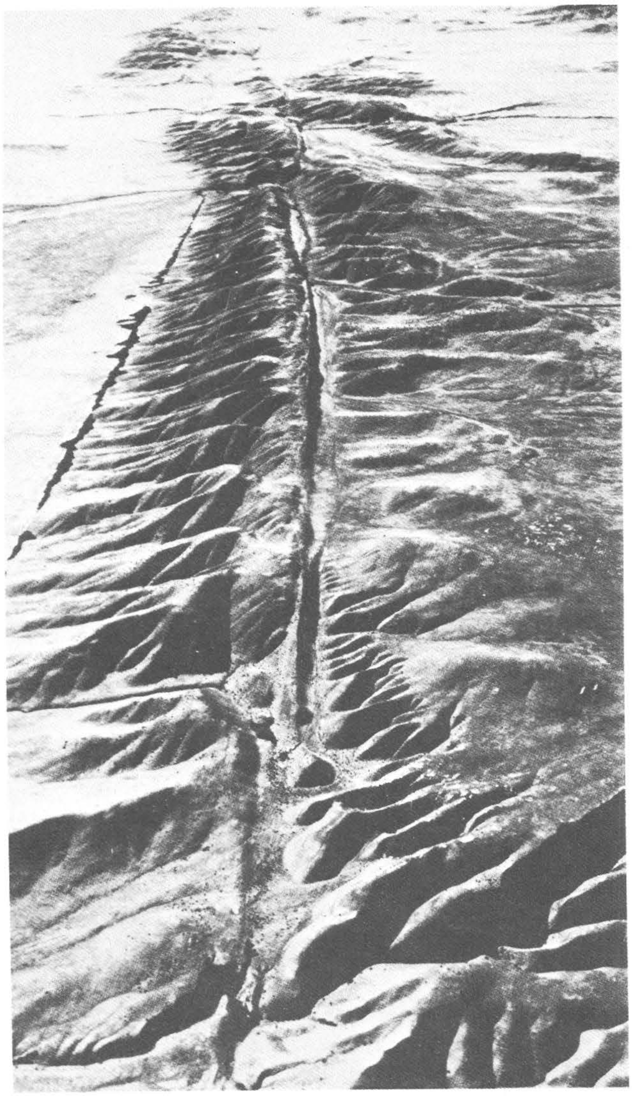

Figure 6.--Surface trace of San Andreas fault near Carrizo Plain, Calif. Photograph courtesy of R. E. Wallace, U.S. Geological Survey.

occurrence, degree of ground shaking, severity of geologic effects, and earthquake losses for the entire nation at a national scale (for example, map scale of 1:5,000,000).

2. Regional studies--investigations of the temporal and spatial characteristics of earthquake hazards (for example, seismicity, faulting, unstable ground, and so forth) and assessment of risk for regions of the country at high seismic risk at a regional scale (for example, map scale of 1:250,000 or larger).
3. Topical studies--investigations into the cause and nature of geologic earthquake hazards and into improved methods for quantitatively assessing earthquake hazards and risk.
4. Earthquake data services--collection and dissemination of data on earthquake occurrences and effects.

The core of the USGS mission in the Earthquake Hazards Reduction Program is research. The USGS carries out and sponsors scientific and engineering studies that will contribute to an improved understanding of earthquake hazards, then communicates the results of these studies to various users. Associated with this basic mission is a variety of other functions related to the USGS role as the Federal Government's expert on earthquake hazards. For example, the USGS frequently serves as a reviewer and consultant for other Federal Government agencies that are faced with decisions involving technical issues related to earthquake hazards, such as in the siting of nuclear power plants, hospitals, dams, and oil pipelines and in the preparation of disaster plans. USGS personnel often serve on advisory committees for other Federal agencies (for example, National Aeronautics and Space Administration (NASA), Department of Energy (DOE), Department of Defense (DOD), State agencies (for example, Utah Seismic Safety Advisory Council, California Strong Motion Instrumentation Program), and other types of organizations (American Nuclear Society Standards Committee, American Society of Civil Engineers Nuclear Materials and Structures Committee, Earthquake Engineering Research Institute). In addition, the USGS sometimes represents the United States in assisting foreign countries in dealing with their technical earthquake-related problems.

Sharing of responsibility between Federal, State, and local governments, and others

The Earthquake Hazards Reduction Act provided an opportunity for participation in a national program by representatives of State and local governments, business and industry, the design professions, and the research community. The ultimate goal of the USGS Earthquake Hazards Reduction Program is to reduce losses from earthquakes. These mitigation actions are taken by Federal agencies; by local, regional, and State levels of government; and by the private sector. The USGS is usually not directly responsible for implementation, but is often involved as an intermediary or as an informal consultant to those who are.

The division of responsibility between the Federal, State, and local governments is shown in table 6. Many of the USGS scientific studies are such that additional studies are needed to make them applicable on a site-specific basis. For example, the regional hazards mapping performed by the USGS may be at a scale of from 1:250,000 to 1:63,360, whereas land-use planning decisions require maps on a much larger scale. The link between the national and regional research products of the USGS and specific

Table 3.--Summary of funding levels of earthquake program (in millions of dollars)

Subelement	FY 78	FY 79	FY 80 Request
Fundamental earthquake studies (NSF and USGS)	7.9	9.1	10.2
Prediction (USGS)	16.0	15.9	15.5
Induced seismicity (USGS)	1.2	1.2	1.2
Hazards assessment (USGS)	10.8	11.1	11.3
Engineering (NSF)	18.1	17.4	18.3
Research for utilization (NSF)	2.0	.8	5.0
USGS total	30.7	31.2	31.7
NSF	25.8	32.4	38.9

Table 4.--Summary of funding of hazards assessment element (in percent)

	FY 78	FY 79
National studies	7	7
Regional studies	59	59
California	26	26
Western	16	16
Eastern	17	17
Topical studies	32	32
Earthquake potential	7	7
Ground motion	13	13
Ground failure	7	7
Risk	3	3
Post-earthquake investigations	2	2
Program management	2	2

implementation actions is appropriately performed by intermediaries. The intermediaries include private consultants and consulting companies in the scientific, engineering, and planning fields; professional organizations; government agencies at all levels of government; public interest groups; and others.

The total process of reducing earthquake hazards involves three basic groups of people: (1) researchers, who generate new knowledge; (2) intermediaries, who translate and synthesize this knowledge into material that provides a basis for decisions; and (3) implementors or decisionmakers, who effect the mitigation actions needed at the community level. Success depends on how well these three groups interact and cooperate throughout the period of time needed to accomplish the goal.

Determining the needs and priorities of users

Over the years, the USGS has developed a number of procedures for determining the needs and priorities of users for USGS products. During the past 2 years, special attention has been given to finding effective ways of defining needs for products to be used in assessing seismic hazards and risk. The most effective contact procedures have proven to be (1) workshops (such as that convened in Vail in October 1978), which bring together leading authorities in the fields of geology, seismology, and earthquake engineering and users such as decisionmakers in Federal, State, and local governments, members of professional societies, model code groups, and the Interagency Committee on Seismic Safety in Construction; (2) "cluster" meetings with State Geologists and other State and local officials concerned with evaluation of seismic hazards and risk; (3) questionnaires; and (4) frequent correspondence. By implementing these and other communication procedures, the USGS has succeeded in developing a critical perception of the needs and priorities of the various users who have responsibility for the assessment of seismic hazards and risk. These needs will be described in the following section.

EXAMPLES OF THE NEEDS OF VARIOUS USERS

Summary of needs

The process of developing the implementation plan required by the 1977 Earthquake Hazards Reduction Act has uncovered a large and diverse group of users who have responsibilities for assessments of seismic hazards and risk. Some of these users are shown schematically in figure 7. Their needs are numerous and varied:

1. <u>Evaluation on a national scale</u>--these applications primarily require maps that show relative geographic variations in earthquake hazards, including young

Table 5.--Projects in seismic risk and risk-related mapping funded by USGS in FY 79

Project	Principal investigator
Seismogenic zones of the United States.	J. I. Ziony, USGS.
Regional and national seismic hazard and risk.	S. T. Algermissen, USGS.
A new attempt at seismic zoning maps for southern California.	C. R. Allen, California Institute of Technology.
Microzonation of the Memphis, Tenn., area.	W. D. Kovacs, Purdue Univ.
Methods of probabilistic seismic----- hazard assessment.	R. K. McGuire, USGS.
Probabilistic seismic hazard of the Outer Continental Shelf.	D. M. Perkins, USGS.
Experimental mapping of liquefaction potential.	T. L. Youd, USGS.
Preliminary assessment of liquefaction potential in and near San Juan, Puerto Rico.	T. L. Youd, USGS.
Development of data bases, parameters, and methods for converting ground motion to expected dollar loss for high-rise buildings.	R. E. Scholl, URS/ John A. Blume and Associates.
Development of an exposure model for the United States building wealth and annual economic loss consequence of the various seismic risk maps.	J. H. Wiggins, J. H. Wiggins Co.
A stochastic and Bayesian model for----- hazard mapping and for estimating earthquake losses.	H. C. Shah, Stanford Univ.
An alternating Markovian process for---- earthquake occurrences.	H. C. Shah, Stanford Univ.

faults, potential or historic ground motion, and ground failure. The maps are used to identify high risk areas for insurance indemnification and earthquake zoning and to establish program priorities, design criteria, and public policy.

2. Evaluation on a regional scale--these applications primarily require maps and publications that describe the relative geographic distribution and nature of earthquake hazards. The maps and publications are needed for actions that include land-use zoning, building code development, community development, siting of critical facilities, disaster-preparedness planning, and public policy.

3. Evaluation of the potential for strong ground motion and ground failure at specific sites--these applications require reports, maps, and guidelines that synthesize information to develop methods, to provide a basis for determining design criteria, and to define public policy.

4. Information on seismicity and earthquake effects--these needs require data, maps, and interpretative reports showing current and historic earthquake locations and earthquake effects. Uses include post-earthquake relief operations, engineering-scientific-sociological investigations following an earthquake, deci-

Table 6.--Division of responsibility for the Earthquake Hazards Reduction Program

Aspect of program	Level of government responsibility
Development of new techniques.	Federal.
Demonstration projects.	--------Do.-------
National hazards assessment.	--------Do.-------
Regional hazards assessment.	Federal, State, regional, and local.
Local hazards assessment.	State, regional, and local.
Land use planning.	--------Do.-------
Standards, codes, regulations.	--------Do.-------

sionmaking on both individual and group levels, and various research activities carried out by universities, professional societies, and others.

Federal Government agencies

As indicated earlier, some 35 Federal Government agencies have responsibility either for construction or construction-related activities. These agencies are involved in assessments of seismic hazards and risk for facilities such as nuclear power plants, hospitals, dams, military facilities, nuclear-waste-storage repositories, highway structures, and housing. Some examples of the needs of Federal agencies, as defined in the communication process described above, are generalized and summarized below. These statements represent USGS perceptions of their needs.

Department of the Army

In the Army's military programs, implemented by the Corps of Engineers, the primary needs are for (1) refinement of methods to

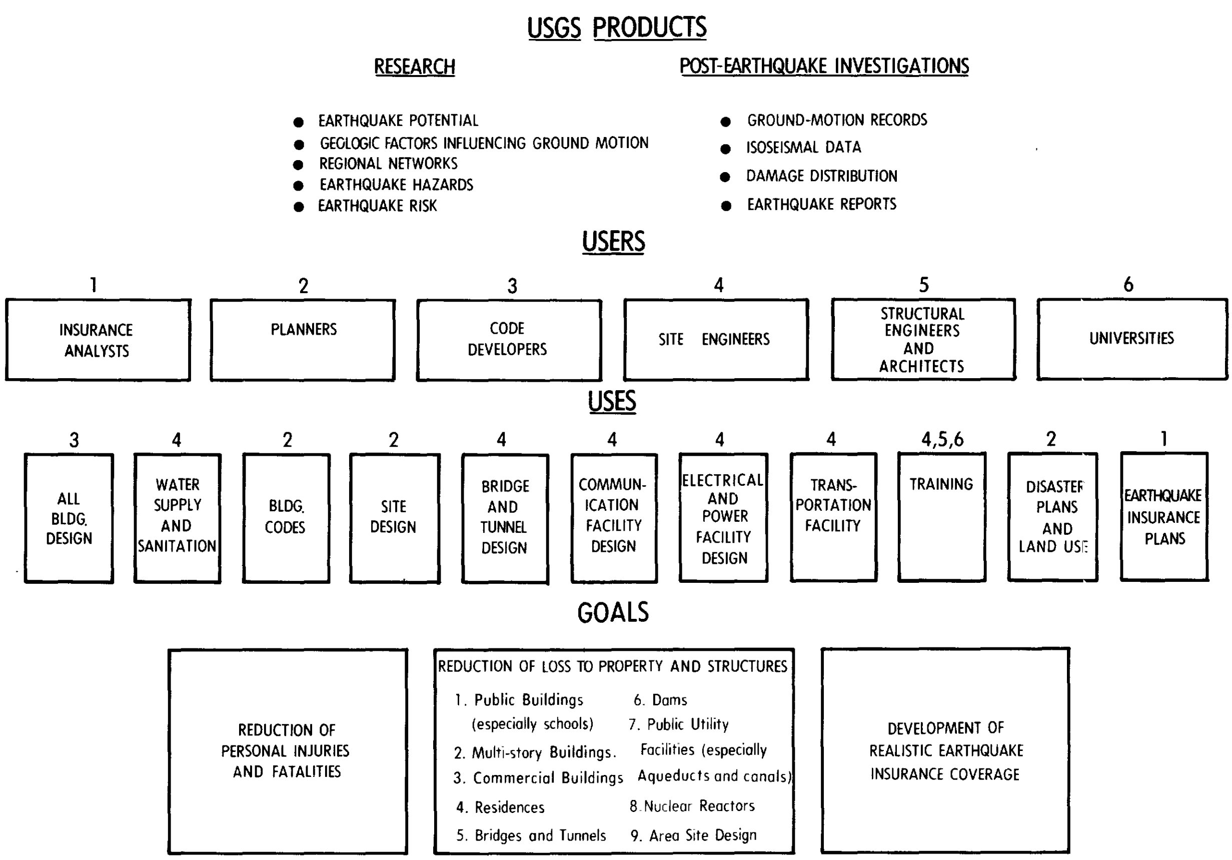

Figure 7.--Schematic illustration of USGS seismic hazards and risk assessment products and their uses.

determine design earthquakes for use in the design of hospitals and dams located in various regions in the United States; (2) update of seismic zone maps (Algermissen and Perkins, 1969, 1976; Applied Technology Council, 1976) for the United States and territories, currently used in the Uniform Building Code and the Tri-Service Seismic Design Manual (Depts. of Army, Navy, and Air Force, 1973); (3) establishment of the best relations between the values of peak ground acceleration and velocity and the seismic risk zones, and (4) development of guidelines for determining design earthquakes for vital and (or) critical facilities in terms of seismic risk and exposure time.

Bureau of Reclamation (BUREC)

For siting of dams and other hydraulic structures, BUREC needs maps showing the probability of future ground-shaking levels and fault rupture on both national and regional scales. The relations between ground motion and faulting mechanisms need to be established, especially close to the fault. Assessments of seismic hazards and risk need to be based on standardized guidelines and an information base containing information about induced seismicity, seismogenic zones, earthquake-source strength (magnitude), and faults.

Department of Transportation (DOT)

DOT owns more than 12,000 facilities throughout the United States which consist of over 34,000,000 ft^2 of space located on 193,000 acres of land. The Coast Guard, Federal Aviation Administration, Alaska Railroad, St. Lawrence Seaway Development Corporation, and Transportation Systems Center all own or operate facilities within high seismic risk zones. To fulfill its requirements for seismic hazards and risk assessment, the following products are needed: (1) regional- and national-scale maps showing the intensity of ground shaking for various probabilities of earthquake occurrence that can be used in the siting of highway, railroad, and airport structures; (2) maps of coastal areas that depict the intensity of ground shaking, tsunami inundation, and liquefaction potential for various probabilities of earthquake occurrence, to apply to port facility design; (3) maps showing active faults that can be used in conjunction with maps of ground shaking for design, construction, and retrofit of pipeline structures; and (4) maps showing areas of potential seismically induced land/rock slides that can be used for land-use planning of transportation structures.

Bureau of Land Management (BLM)

BLM needs maps showing the location, frequency of occurrence, and intensity of shaking of earthquakes for land use planning, environmental statements, dam construction, and other activities. Evaluation of seismic hazards and risk on undeveloped public lands is needed if temporary relocation is adopted as a viable earthquake mitigation measure.

Federal Disaster Assistance Administration (FDAA)

FDAA (now part of the Federal Emergency Management Agency) is responsible for the preparation of earthquake damage studies for selected urban areas in high seismic risk zones. Studies of four areas--San Francisco, Calif.; Los Angeles, Calif.; Puget Sound, Wash.; and Salt Lake City, Utah--have been completed with assistance from the USGS. Similar studies are currently planned by FDAA for Anchorage, Alaska, and for Hawaii and may also require USGS assistance.

Veterans Administration (VA)

The VA needs to quantify which States, geographic areas, and population centers are vulnerable to the earthquake threat, both for existing and new hospitals. National and regional seismicity maps are needed, as well as maps depicting the variation of ground-shaking parameters and ground failure in terms of the frequency of earthquake occurrence. These maps should be continually updated to incorporate the best available geologic information and to assist the VA to continually update its design standards (VA, 1973).

National Bureau of Standards (NBS)

NBS has responsibility for development of seismic design and construction standards, for consideration and subsequent application in Federal construction, and for encouraging the adoption of improved seismic provisions in State and local building codes. To fulfill this responsibility, national and regional maps are needed that show earthquake ground shaking effects (acceleration, velocity, and duration) in probabilistic terms, suitable for estimating loads on buildings and for regional zoning. Multiple maps for a single effect (for example, acceleration for several probabilities of exceedance) are more useful than a single map for one probability of exceedance.

Department of Energy (DOE)

In its Waste Isolation Safety Program, DOE needs a long-term (thousands of years) predictive capability for evaluating seismic hazards and risk. The goal is to be able to predict with a high confidence that future earthquakes will not cause significant faulting or other seismic hazards in the geologic environment where a waste repository is located. National and regional maps showing faults, seismicity, and regional tectonic movement and their interrelations are needed. DOE is also responsible for assessing the hazards and risk for nuclear reactor sites.

Federal Housing Administration (FHA)

At the present time, FHA has a relatively limited role in enforcing rules, standards, regulations, and seismic requirements. However, agency policies and standards, such as the Minimum Property Standards, do have significant impact upon design and construction of residential buildings throughout the country. At the present time, FHA has adopted the 1973 edition of the Uniform Building Code for seismic design of new construction, but has adopted the policy of less than 100 percent compliance with 1973 code requirements for existing buildings. The primary and continuing need of FHA is for information that will help to establish criteria for better housing, taking into account state-of-the-art seismic requirements and their cost impact. The priority need is for maps that depict seismic hazards and risk, especially in the Eastern United States, in terms of the probability of earthquake occurrence. Damage-estimation studies are also needed to develop the capability for estimating damage from ground shaking and ground failure to (1) masonry one- to four-family homes, (2) wood frame one- to four-family homes, (3) high-rise commercial and industrial structures, and (4) nonresidential structures. FHA wants to upgrade its "Methodology for seismic design and construction of single-family dwellings" (Dept. of Housing and Urban Development, 1976).

General Services Administration (GSA)

In executing its responsibility for the design and construction of Federal buildings, GSA uses the seismic design criteria contained in its 1978 publication, "Design Guidelines." In its assessment of seismic hazards and risk, GSA needs national and regional-scale maps showing (1) active faults, (2) ground failure, (3) potential tsunamis or seiches, (4) dam-failure inundation, (5) local ground conditions that might enhance ground shaking, and (6) ground-motion characterizations. The most urgent need is for much more data showing actual building performance and soil-structure interaction during an earthquake for buildings of varying sizes, construction materials, and design concepts.

Defense Civil Preparedness Agency (DCPA)

DCPA (now part of the Federal Emergency Management Agency) is not directly involved in building design and construction programs. However, agency personnel advise State and local civil defense organizations on the current assessment of seismic hazards and risk in their area for emergency preparedness purposes, and provide "Summer Institutes." To carry out these responsibilities, DCPA needs a series of maps that depict the variation of ground shaking and other seismic hazards in terms of frequency of earthquake occurrence in a given exposure time for States, regions, and the entire United States.

Nuclear Regulatory Commission (NRC)

NRC is responsible for a variety of research and regulatory activities connected with the siting of nuclear power plants. The emphasis in current research is placed on (1) regional and tectonic evaluations in the Eastern United States; (2) evaluation of engineering methods and practices that are used to mitigate the effects of earthquakes; and (3) quantification of the levels of conservatism that are currently incorporated into seismic design. NRC's program is coordinated closely with the activities of other agencies, including the USGS, NSF, COE, and many State agencies. The overall objectives of the NRC research program are similar to many of those in the USGS Earthquake Hazards Reduction Program, except that priority emphasis is placed on the Eastern United States and the objective level of hazard mitigation required for nuclear power plants is much higher than that for conventional civil structures. NRC needs almost every research product in seismic hazards and risk that the USGS is currently working on. In particular NRC needs empirical data about ground-motion characteristics close to the fault. In the Eastern United States, one of the primary needs is to develop a systematic procedure for defining earthquake source limits. Probabilistic maps of ground shaking having return periods as long as 10^4 years are needed.

Federal Home Loan Bank Board

As a Federal financial regulatory agency, needs for seismic hazard and risk assessment products are limited to those potentially useful for protecting the viability of the Federal Savings and Loan Insurance Corporation. The most needed products are maps delineating moderate- and high-risk areas accompanied by tables showing pertinent factors, such as (1) percentage probability of various levels of earthquake ground shaking within the next 25, 50, or 100 years; (2) valuation of residential and commercial properties at risk; (3) population; (4) estimated loss in terms of lives and property at various levels of ground shaking; and (5) estimated capability of community public services to survive and to respond to a severe earthquake.

Interagency Committee on Seismic Safety in Construction

The newly created Interagency Committee on Seismic Safety in Construction is an example of a group that will use USGS research products and exert considerable influence on many agencies of the Federal Government and various other user groups in the next several years. This committee is composed of representatives of all Federal agencies that are significantly engaged in construction, the financing of construction, or various construction-related activities. This committee is organized into 10 subcommittees that are dealing with (1) format and notation; (2) standards for buildings; (3) existing buildings; (4) lifelines; (5) risk analysis; (6) grant, lease, and regulatory programs; (7) evaluation of site hazards; (8) tsunamis and flood waters; (9) post-earthquake serviceability; and (10) critical facilities. The goal of the Committee is to develop a common set of standards, codes, and practices with regard to all Federally funded, assisted, and regulated construction. This committee will play an important role in standardization of terminology and procedures within the Federal sector.

State and local government agencies

Within each State, numerous government agencies and groups are concerned with seismic hazards and risk. These groups include (1) State geological surveys; (2) State seismic safety advisory groups; (3) regional governmental bodies; (4) emergency preparedness groups; and (5) city planners. These agencies and groups have differing responsibilities with respect to evaluation of seismic hazards and risk, but all need USGS products to augment their capability for making assessments of seismic hazards and risk on a State and local scale.

Each State geological survey, depending on the State, its individual resources, and legislative mandates, is involved in some way with the assessment of seismic hazards and risk. In California, for example, the California Division of Mines and Geology has a staff which performs many functions, including (1) research; (2) post-earthquake investigation; (3) fault mapping; (4) strong-motion instrumentation; and (5) monitoring of the Alquist-Prioli special fault study zones. On the other hand, in Wisconsin, which has a low level of seismicity, the staff of the State Survey is smaller; its functions in seismic hazards and risk assessment are largely advisory and primarily concern issues such as earthquake potential and active faults arising in regard to siting of important facilities.

The continuing record of cooperation between the USGS and the State surveys in the Earthquake Hazards Reduction Program is good. The State surveys have an opportunity for participation in the planning of each USGS research project and in the grants and contracts program. Reports, maps, and other information developed in the program are transmitted to each concerned State, often prior to publication for review and always as they are published.

At the present time, four States have seismic safety advisory groups: California, Utah, Montana, and Nevada. California's Seismic Safety Commission, formed in 1973, has the longest record of experience in the development of public policy with respect to seismic safety. The general responsibilities of these advisory groups vary within the four States, but they collectively include:

1. providing advice to the governor and legislature on earthquake safety matters;
2. recommending a consistent policy framework for seismic safety within the State;
3. suggesting goals and priorities for earthquake hazards reduction;
4. recommending Statewide and local programs to reduce earthquake hazards;
5. recommending methods for improving building standards and construction compliance with the standards; improving siting and design of critical facilities, hospitals, and schools; and delineating fault zones that require special investigations, regulation, and reporting procedures;
6. educating the public and private sectors on seismic safety;
7. recommending training for specialized enforcement and technical personnel; and
8. reviewing proposed earthquake-related legislation and proposing needed legislation.

To carry out these responsibilities, seismic safety advisory groups need information about seismic hazards and risk that can be applied on the community (or city-planning) scale. Land-use practices determine where buildings and development occur relative to seismically hazardous zones. It is in the city-planning process that decisions are made regarding the siting of most buildings, critical facilities, and lifelines. Planning professionals need to know:

1. the location and nature of earthquake hazards,
2. the potential effect of the hazard to public safety and welfare,
3. the regulatory tools that are available to provide equal treatment for equal problems on a standardized basis,

4. the mitigation procedures that can be implemented by nonprofessionals, and

5. the availability of technical expertise to evaluate the exceptions from routine regulations.

The experience of the Utah Seismic Safety Advisory Council, formed in 1977, is probably typical of the implementation process that might be expected in many States. Utah has experienced only a few damaging earthquakes having Modified Mercalli intensity ranging from VII to IX since 1850. Although large earthquakes have not occurred in historic time, the geologic record contains clear evidence that the Wasatch fault zone has been active for millions of years and that the faults within this extensive zone may have the potential for generating a large (magnitude (M_S) 7.5) earthquake. Thus, many public policy issues need resolution, including (1) building codes and construction standards; (2) land-use-planning practices; (3) hazards and risk mapping; (4) strong-motion instrumentation; and (5) vital facilities such as schools, hospitals, police stations, fire stations, lifelines, and dams. Recommendations to correct possible deficiencies in seismic safety require time for considerable study and assessment before legislation can be proposed. To be successful, each proposed earthquake-hazard-mitigation measure must be accomplished through programs that are specifically tailored to the local seismic risk and fitted to existing procedures of government. Progress in earthquake hazard reduction in any State requires time and a balance of private sector-State-Federal support.

Regional government bodies can play an important role in the assessment of seismic hazards and risk on a local scale. Two groups with contrasting, but representative, experiences are (1) Association of Bay Area Governments (ABAG), in northern California; and (2) Mississippi-Arkansas-Tennessee Council of Governments (MATCOG), in the metropolitan Memphis, Tenn., area.

ABAG is a regional planning agency operated by the local governments of the San Francisco Bay Area. It was established in 1961 to meet regional problems through cooperative action of its member cities and counties and to perform three main planning and coordinating functions (1) reviewing plans and projects of local governments; (2) assisting local governments in obtaining earth sciences information from USGS, California Division of Mines and Geology, and other groups; and (3) providing advocacy for regional concerns at both the State and Federal levels. ABAG's contributions in the HUD/USGS San Francisco Bay Region Environmental and Resources Planning Study and in the development of seismic safety elements are a model for other regional governments to follow (Perkins, 1978).

MATCOG, a regional planning agency for metropolitan Memphis, Tenn., was responsible in 1972 for developing a long-range plan to improve the seismic safety in the region. The HUD-funded study considered (1) improvements in earthquake-resistant design; (2) lifeline systems; (3) planning regulations; and (4) disaster recovery plans. Mann (1978) noted that although Memphis is not far from the revised location of the epicenter of the 1811-12 New Madrid earthquakes, no seismic design requirements and a low level of seismic awareness presently exist within the community, and official reaction was varied and nonproductive to the finding of the 1972 MATCOG study showing that the risk of damage from an earthquake is higher than previously thought. Mann (1978) concluded that it is difficult to motivate and educate decisionmakers and various public interest groups in the Central United States to be earthquake-conscious because of the lack of recent "triggering" events, and that people seem to respond best to the earthquake hazard if they are given earthquake-loss information that can be compared easily with loss data from more familiar natural hazards (for example, flood, tornado).

Within every State and local government, various agencies and groups have responsibility for preparedness and response in the event of an earthquake or other disaster. They work closely with Federal agencies (for example, FDAA) and other local groups (for example, hospitals and hospital associations or councils; natural gas, electric, and telephone utilities; and American Red Cross). These agencies and groups need a complexly integrated balance of earth-science, management-science, economic, political-science, and sociological data to execute their responsibility (Buck, 1978). The four earthquake-damage studies performed jointly by FDAA and the USGS for San Francisco, Calif. (Algermissen and others, 1972), Los Angeles, Calif. (Algermissen and others, 1973); Puget Sound, Wash. (Hopper and others, 1975); and Salt Lake City, Utah (Rogers and others, 1976), represent the current extent of the USGS involvement in this type of seismic hazard and risk assessment. Additional studies of this type are planned in the future by FDAA for other urban areas in the United States and may require USGS assistance.

Land use planners

Land-use planning encompasses all the decisions affecting the locations of physical improvements in a locale or community. Examples of the varied aspects of land-use planning include (1) policies at a Federal level for interstate-freeway locations; (2) policies at a State level for dam safety; (3) policies of lending institutions for good lending risks; and (4) policies of cities and counties for subdivision design and zoning ordinances.

Land-use planning at the local level calls for establishment of goals, conducting research, and assessing seismic hazards and risk. It involves six areas of activity:

1. preparation and maintenance of general plans,
2. zoning of land,
3. regulation of subdivisions,
4. regulation of building and grading (shared with building officials),
5. urban-renewal planning, and
6. planning for public buildings and other structures.

In most communities throughout the country, these activities have been performed in the past with little regard for seismic safety. Only California has developed the concept of a seismic safety element; however, other States are now considering it.

In California following the 1971 San Fernando earthquake, the State Planning Law was amended to require that each city and county in the State prepare and adopt a Seismic Safety Element (SSE) as part of its general plan. The preparation of a SSE required the following:

1. recognition of seismic hazards and their possible effect on the community,
2. identification of general goals for reducing seismic risk,
3. specification of the level or nature of acceptable risk to life and property,
4. specification of seismic-safety objectives for land use, and
5. specification of objectives for reducing the seismic hazards to existing and new structures.

In many cases, USGS results were used substantially in the preparation of the SSE (Young, 1978; Kockelman, 1978). However, no State requirement exists at present to force local jurisdictions to complete their general plans and, of the 412 cities and 58 counties in California, 81 cities and 19 counties still did not have an SSE in January 1977 (Olson, 1978).

Engineers and scientists

Many engineers and scientists in the private sector and in universities throughout the United States are engaged in a wide variety of activities requiring knowledge of seismic hazards and risk. These activities include earthquake-resistant design, consultation, and research and development. Only the broad scope of needs of this diverse group of users can be summarized. Discussions at three USGS-sponsored workshops, held in 1975, 1977, and 1978, have established that engineers and scientists want to know the answers to questions such as the following:

1. Where have the earthquakes occurred in the past?
2. Where are the earthquakes occurring now?
3. What are the source parameters (magnitude, seismic moment, stress drop) of these earthquakes?
4. What are the characteristics of the ground motion close to the fault?
5. What are the characteristics of the seismic waves as they attenuate from the source?
6. What kinds of geologic effects (surface faulting, ground failure, tectonic deformation, inundation) occurred during each earthquake?
7. What was the distribution of damage in each earthquake?
8. Did local ground conditions enhance the level of ground shaking, and, if so, what was the horizontal and vertical spatial variation?
9. On the basis of the best available data, what characteristics of ground shaking and ground failure are expected at the proposed construction site in the next 25, 50, 100, 200 years?

The structural engineer has the ultimate responsibility for developing earthquake-resistant design. He is the one who must integrate the technical answers to questions such as those listed above with the legal, political, economic, and technological constraints to effect the appropriate seismic design. Because the vast majority of structures do not have and cannot justify an individual assessment of seismic hazards and risk, the level of seismic design is commonly set by the building code adopted by the State and (or) local community in which the construction is located.

Architects

An architect's responsibility in the design of a building includes functional planning (space layout), but may or may not include site selection. The architect is legally accountable for meeting certain minimum safety and health requirements, as prescribed by applicable codes and standards, and is professionally accountable for creating a serviceable facility within the legal, political, economic, and technological constraints. If earthquake-resistant design is the goal, the architect needs to know the following:

1. the primary and secondary earthquake hazards for the site,

2. the potential damage mechanisms for that type of building which have been observed during past earthquakes,

3. the seismic forces associated with these potential damage mechanisms,

4. alternative design arrangements and assemblies that will accommodate the potential seismic forces, and

5. the expected limits of the alternative techniques to resist the potential seismic forces.

The priority needs of the architect are for hazards and risk assessment products that correlate directly with building design criteria. If the criteria differ for various building types and occupancy levels, then the specificity of the hazards and risk assessment products must also differ. If microzonation eventually replaces regionwide seismic risk zones, then larger scale hazard and risk maps will be required. It should be emphasized, however, that the vast majority of buildings constructed in the United States are one- to five-story structures, not large complexes or high-rise structures, and they do not routinely receive rigorous site and engineering analysis because of economic constraints. In this case, the need is for seismic-design values rather than methodologies.

Code-development groups

The International Conference of Building Officials (ICBO) is a representative example of a group involved in the development of building codes that incorporate seismic-design provisions. Development of these provisions is a continuously evolving process which is directly related to the changing state-of-the-art. Building codes have to satisfy many segments of society and to balance legal, political, economic, and technological constraints. The goal is to develop a concept of seismic risk zoning which allows everyone throughout the United States to adopt mitigative measures that are reasonable and equitable in terms of the local seismic hazards.

To evolve seismic-design provisions for use in building codes, code-development groups require national-scale maps that delineate the variation of the maximum ground motion and incorporate frequency of earthquake occurrence and exposure times. These maps must depict a ground-motion parameter (for example, peak acceleration) that can be directly translated into a building-design parameter contained in the code formulation.

The USGS has participated in the evolution of building codes that consider seismic-design provisions since 1969 (Algermissen, 1978). The primary ways currently used by the USGS to introduce seismic-hazards and risk information into the code-development process are illustrated in figure 8.

Financial sector

Whether or not earthquake risk is carried by a financial institution or transferred to an insuror, each group has a similar requirement for information. Each must make judgments that will enable it to achieve its goals of (1) pricing, so that cost of insurance is at least equal to earthquake loss; and (2) husbanding capital, so that maximum probable loss situations are met. To achieve these goals, the financial sector needs the following information:

1. the areal extent of ground shaking, ground failure, and inundation for upper-bound events on various faults and tectonic structures throughout the United States;

2. the geographical variation of these effects within each potentially affected area; and

3. the recurrence times or return periods of these effects for various levels of ground shaking.

The first item will permit the establishment of a maximum probable loss expectancy which, in turn, will permit management of dollar-loss exposure to the extent that it can be accommodated within the financial institution or shared with others. The second item will reflect the expected damage in individual structures at risk in the area. The second and third items in combination will provide a basis for pricing of insurance that adequately reflects "how bad and how often."

Each of the user groups described above has concerns about the information that the USGS provides or will provide to them for assessing seismic hazards and risk. These concerns are discussed in the following section.

USER CONCERNS AND RECOMMENDATIONS RELATED TO NATIONAL SEISMIC HAZARDS AND RISK PRODUCTS

Overview of concerns

Past workshops and other communications have shown that a broad range of perspectives are represented in each user group and that each

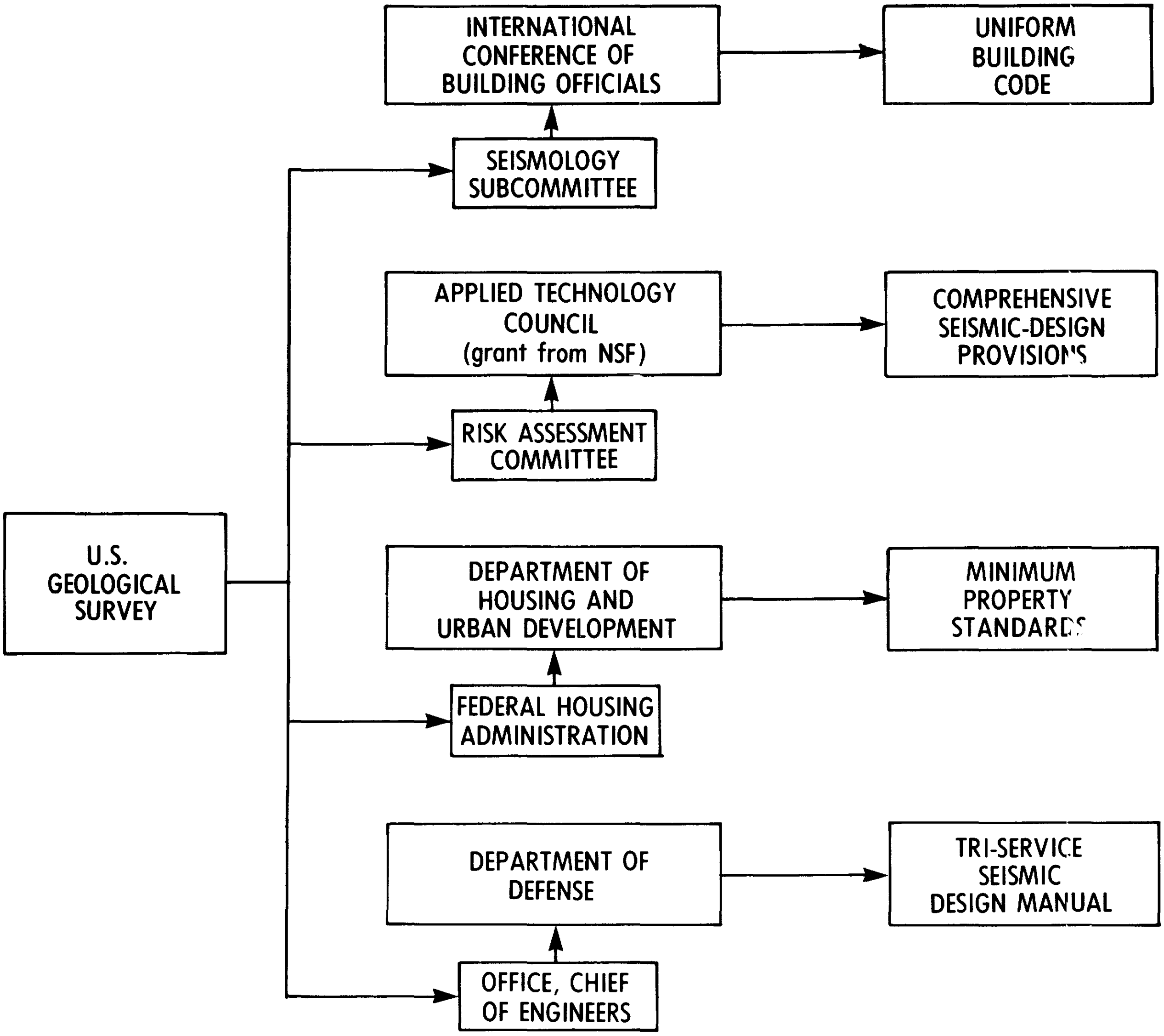

Figure 8.--Schematic illustration of ways that USGS probabilistic ground-shaking maps are introduced into the code-development process.

group has particular concerns. Some of these concerns cut across all of the user-group boundaries. They include (1) what parameters should be mapped; (2) the usefulness of the map products; (3) how to depict uncertainty; (4) how to minimize conservative tendencies; and (5) how to disseminate the information effectively. Each of these concerns will be discussed and followed by some general recommendations.

Mapping parameters

This concern is discussed frequently because there is general agreement that a map of a single ground-motion parameter (for example, peak acceleration) is a simplistic approximation of the ultimate product needed by the user community. The engineer argues that he needs data on ground motion, not just on peak acceleration, and that peak acceleration may not always be the best way to characterize ground shaking. Some of the limitations on peak acceleration are the following: (1) it seems to be weakly dependent on magnitude; (2) its effect on short- and long-period buildings is not well understood; (3) it does not correlate well with Modified Mercalli intensity or with all aspects of damage; and (4) its large values, as defined by recent instrumental records obtained near the source, are not always practically important and may need to be reformulated as an "effective peak acceleration" (Whitman, 1978). The compelling counterargument for using peak acceleration is that it is a fundamental ground-motion parameter directly available from the strong-motion accelerogram without interpretation or derivation.

Other ground-motion parameters that might be mapped include (1) peak and "effective peak velocity;" (2) peak displacements; (3) Modified Mercalli intensity; (4) duration of shaking; and (5) spectral velocity for several period bands. The ultimate map is one that depicts the time history of ground shaking at a site, but such a map is beyond the current state-of-the-art.

Probabilistic maps of faulting and ground failure can also be constructed. However, with the exception of liquefaction opportunity maps (Youd and Perkins, 1978), none of these maps have been produced yet.

Usefulness

How USGS seismic hazard and risk assessment products will meet the needs of various user groups, individually and collectively, is the key question. As noted previously, the needs for specific products vary between user groups and as a function of time. Triggering events can also change the priority of a user's needs. For example, the 1971 San Fernando earthquake resulted in reevaluation and modification of the criteria for siting and design of hospitals and other critical facilities. One way the USGS might enhance the usefulness of its seismic hazards and risk assessment products is to focus first on the development of those products that are relatively simple, based on fundamental (not derived) data, and free as possible from controversial or unproven interpretations and analyses.

Uncertainty

The question that characterizes this user concern is, "How does one depict on a seismic hazard or risk map the uncertainty in the values of the mapped parameter that arises from uncertainties in the data used to derive the map?" The best current example of the problem is depicting what we know and do not know about earthquake hazards in the Eastern United States.

Conservatism

In most cases, the evaluation of seismic hazards and risk is a controversial process. The controversy is caused, in part, by debate about whether the available geologic, geophysical, seismological, and geotechnical data are adequate to specify the hazards and risk precisely and whether conservatism introduced into the earthquake-resistant design specification is reasonable in view of the uncertainties in the data. For example, six empirical procedures are currently used to introduce conservatism into the design spectrum for a nuclear power plant (Hays, 1979a). They are (1) selecting a low-probability, extreme seismic event and moving it to the closest epicentral distance to the site; (2) using smooth, broadband, mean-plus-one-standard-deviation design spectra which are derived to be independent of the epicentral distance from the site; (3) using a mean-plus-one-standard-deviation regional seismic-attenuation function; (4) requiring that the design time histories produce response spectra that envelop the design spectra; (5) requiring that the two horizontal-component design time histories have equal values of peak ground acceleration and that the vertical component has a peak value that is two-thirds or more of the peak horizontal-ground acceleration; and (6) modifying the smooth design spectrum to account for local ground response.

The question that characterizes this user concern is "Who will introduce the conservatism?" The position of most users is that the hazards and risk assessment products of the Survey should be based on the best available "hard" data and that all data and methodology should be well described in reports that accompany every map.

Information dissemination

The basic question is "How does a user obtain a Survey seismic hazard or seismic risk map when he needs it, even though the map may be preliminary?" This question has no easy answer, but it appears that one solution is to publish dated, well-documented, preliminary maps through professional journals and USGS open-file reports to provide information on a timely basis and then to publish "final" maps in formal USGS publications.

Recommendations

The following recommendations are a summary of those made by participants in the October 1978 USGS-sponsored workshop on seismic hazards and risk (Hays, 1979b). They touch on the subjects of (1) data, (2) basic research, (3) products, and (4) communication. Each recommendation should be integrated with the above statements of user concerns and viewed in terms of the current scope and balance of the USGS Earthquake Hazards Reduction Program. (See "Introduction" and appendix B).

Data

The USGS should use its resources to acquire important information now lacking about ground-motion effects. Examples include (1) ground motion for magnitude (M_S)-6 to -8 earthquakes close to the source, and (2) data to define the horizontal and vertical spatial variation of ground motion. These data should be disseminated to the earthquake engineering community and incorporated in seismic hazards and risk assessment products.

Post-earthquake investigations should be carried out following each important earthquake in order to take advantage of unique opportunities to acquire badly needed data about ground motion and ground failure effects.

The USGS should be a national resource for the "hard" data on seismicity, ground motion, and ground failure.

The USGS should take the lead in establishing a national seismic network capable of detecting and locating earthquakes of magnitude 4 (M_L) and greater and in disseminating the data to the concerned community of users.

Basic research

The USGS should keep emphasizing fundamental research on topics such as seismogenic zones, capability of faults, seismicity (including reservoir-induced seismicity), ground-motion characterization, and geologic effects.

The USGS should utilize data from earthquakes occurring worldwide to refine models of ground motion, ground failure, and seismic risk assessment.

The USGS should quantify the uncertainty in all empirical relations derived for hazards and risk assessments.

The USGS should consider research on decisionmaking using limited data, utilizing knowledge and concepts now available in many business schools.

Products

The USGS should develop the seismic hazards and risk assessment products that are simplest first, as well as publishing intermediate products and dated maps.

The USGS should develop "guidelines" along with the research report to suggest ways that the research results might be implemented.

The USGS should use its resources to prepare suites of probabilistic ground motion maps to show the parametric sensitivity and the consequence of different tectonic models. These maps should be properly identified as research products, dated, and accompanied by a report that identifies the data base, methodology, assumptions, and so forth.

The USGS should participate in multidisciplinary committees (such as the Interagency Committee on Seismic Safety in Construction) to define user needs and the interfaces between disciplines.

The USGS should construct maps for specific uses in addition to those for a "general purpose" use.

Communication

The USGS should make greater use of open-file reports and journal articles to publish "preliminary" seismic hazards and risk assessment products and use Professional Papers and other formal USGS publications for "final" products.

The Survey should help in the education of public officials and the various users of seismic hazards and risk assessment products.

The Survey should develop a process for introducing change in a seismic hazards or risk assessment map and implement it, involving the entire scientific and engineering community.

The following section discusses USGS products that are used in the assessment of seismic hazards and risk.

EXAMPLES OF CURRENT USGS PRODUCTS USED TO ASSESS SEISMIC HAZARDS AND RISK

Summary of current products

To meet the needs of user groups for USGS research products to use in their assessments of seismic hazards and risk, the USGS is presently producing products such as the following:

Type	Example
National probabilistic map of peak ground acceleration.	Algermissen and Perkins, 1976.
National maps showing young faults.	Howard and others, 1977.
Maps and catalogs of earthquake epicenters and improved earthquake locations.	National Earthquake Information Service's "Preliminary Determination of Epicenters;" Stover, 1977; Dewey, 1979.
Seismotectonic maps.	Hadley and Devine, 1975; Heyl and McKeown, 1978.

Studies of recurrence intervals of faulting on specific faults.	Bucknam and Anderson, 1979.
Disaster preparedness studies.	Algermissen and others, 1972; Algermissen and others, 1973; Hopper and others, 1975; Rogers and others, 1976.
Post-earthquake investigation.	U.S. Geological Survey and National Oceanic and Atmospheric Administration, 1971; Espinosa, 1976; Rankin, 1977.
Analysis of earthquake hazards.	Borcherdt, 1975.
Estimation of economic and life loss.	Rinehart and others; 1976; Algermissen, McGrath, and Hanson, 1978; Algermissen, Steinbrugge, and Lagorio, 1978.

Probabilistic ground-shaking maps

The national probabilistic map of peak ground acceleration (fig. 9) is a good example of a USGS product that is widely used. A brief discussion will enable the reader to have a broad perspective about (1) what probabilistic maps depict; (2) the technical data needed to construct a probabilistic map; and (3) how a probabilistic map can be extended and improved. The reader who is interested in more detail should refer to the publications by Cornell (1968), Algermissen (1973), Hays and others (1975), Algermissen and Perkins (1976), and Karnik and Algermissen (1978).

What probabilistic maps depict

The map shown in figure 9 was prepared by Algermissen and Perkins (1976) and used in the definition of seismic zones in the Applied Technology Council's model code. Unlike earlier seismic zoning maps (fig. 10), which were based on Modified Mercalli intensity without regard for frequency of occurrence, this map depicts the variation of a ground-shaking parameter in terms of probabilities that a certain level of ground motion will occur at a specific location in a given interval of time. The map represents the ground-shaking hazard across the United States in a uniform manner, taking into account the differences in seismicity in the Eastern and Western United States and the geologic characteristics of seismic source zones. The hazard is depicted in terms of contoured values of the peak ground acceleration expected in a 50-year period at the 90 percent probability level at sites underlain by rock. Another way to state the probability is that there is a 10 percent probability of exceeding the value of peak acceleration shown on the map in a 50-year interval at rock sites.

The term "return period" is frequently used in the discussion of seismic hazards and risk. Return period differs from exposure time, the interval of time (for example, 50 years) a structure is exposed to the earthquake threat. Return period is the time that is required (on the average) to experience the recurrence of a certain level of ground acceleration. It is defined in terms of the ratio of the average number of earthquakes it takes to experience an acceleration exceeding "a" to the number of earthquakes expected each year. The return period is 475 years for peak accelerations having an exceedance probability of 10 percent in a 50-year period; it is 1 million years for peak accelerations having an exceedance probability of 0.5-percent in a 50-year period. The corresponding risks are 0.002 and 0.000001/year.

Data requirements for probabilistic maps

Construction of a probabilistic ground-shaking map, such as that shown in figure 9, requires the best available data on (1) seismicity, (2) seismic source zones, and (3) attenuation. The elements involved in preparing a map are illustrated schematically in figure 11 and are discussed below.

The first step is to assemble seismicity data and to decide upon the spatial and temporal distribution of the earthquakes in discrete seismic source zones. In defining the seismic source zones, all available information about the correlations between earthquakes occurrence and other geologic processes and structures, are used, including:

1. location of the boundaries of crustal blocks undergoing contrasting displacements,

2. history of vertical and horizontal regional tectonic movements,

3. location and history of active faults, and

4. tectonic stress.

The seismic source zone is chosen so that it encloses an area of seismic activity and, to the extent possible, an area of related tectonic elements. Earthquakes are assumed to be equally

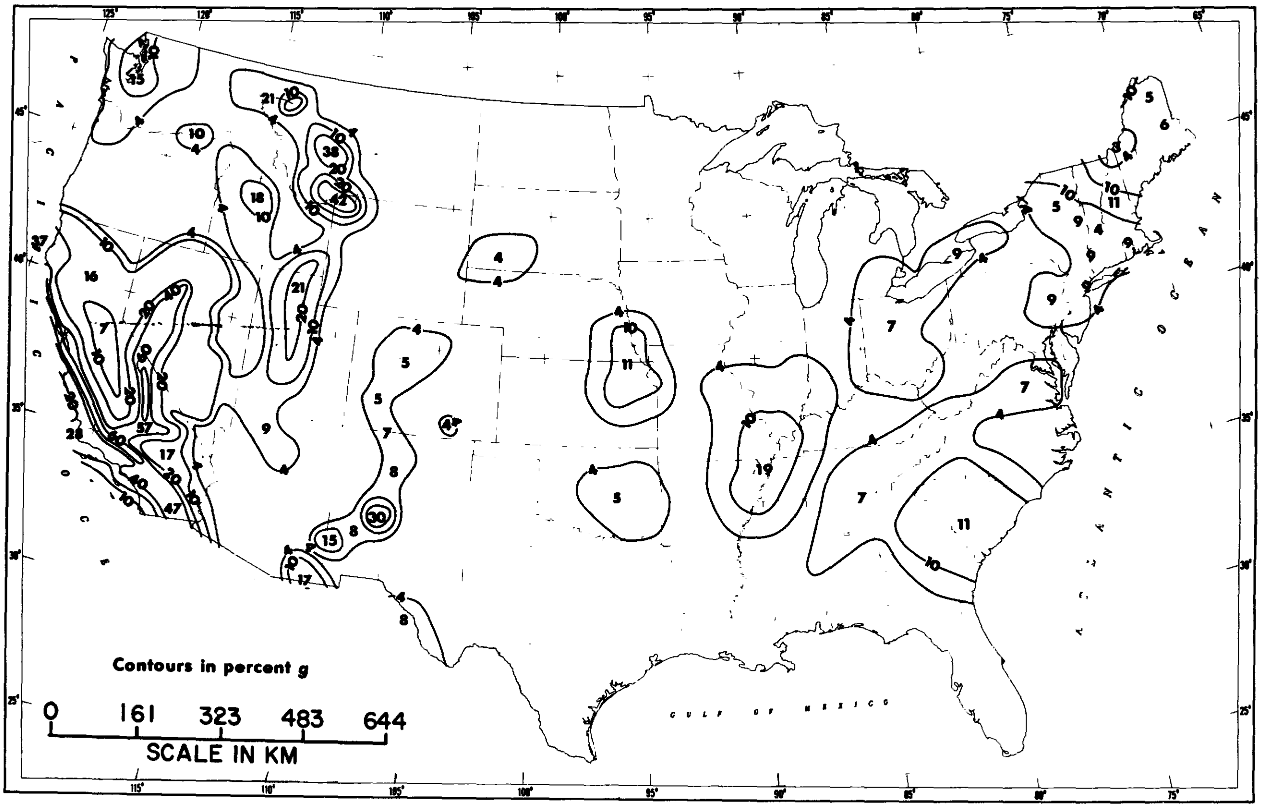

Figure 9.--Map of peak acceleration in rock in the conterminous United States (Algermissen and Perkins, 1976). A 10-percent probability exists that the specified level of ground-shaking will be exceeded in 50 years.

likely anywhere in the source zone, to have an average rate of occurrence that is constant in time, and to follow a Poisson distribution of recurrences. For each source zone the recurrence relation is based on the statistical parameters of the log N versus intensity (or magnitude) curve derived from the seismicity data. For the map of Algermissen and Perkins (1976) seventy-one seismic source zones were defined for the United States (fig. 12). The seismic source zones are larger in the Eastern United States than in the Western United States, reflecting comparative levels of lack of knowledge.

A key step involves the calculation of the severity of ground shaking on rock at every location of interest or in the "affected area." The affected area in figure 11 consists of a large rectangle that is subdivided into subrectangles of constant latitude and longitude (inset A). The grid points at which the calculations are made are located at the centers of these subrectangles. The seismicity (inset B) is apportioned among the grid points in accordance with the location of the seismic source zones. The calculation sums the effects of each level of seismicity of each seismic source zone at each of the grid points of the affected area. The end result is a ground-shaking parameter (for example, peak acceleration) determined at each grid point of the affected area. A set of attenuation curves (inset B)(for example, Schnabel and Seed, 1973) that specifies how the ground motion parameter decreases with distance from the source for a given epicentral intensity or magnitude is essential for this determination.

The probability distribution function (inset C) of the ground-shaking parameter is calculated at each grid point. This distribution function allows one to determine (1) the number of times that a particular level of ground acceleration is likely to occur in a given period of years at a given site, and (2) the maximum level of acceleration for any level of probability. Contour maps can then be prepared to show the variation of peak ground acceleration in terms of exposure times and probability levels (inset D).

Analogous procedures are involved when preparing probabilistic maps of other ground-shaking parameters (for example, peak velocity, peak displacement, spectral velocity at discrete periods, duration).

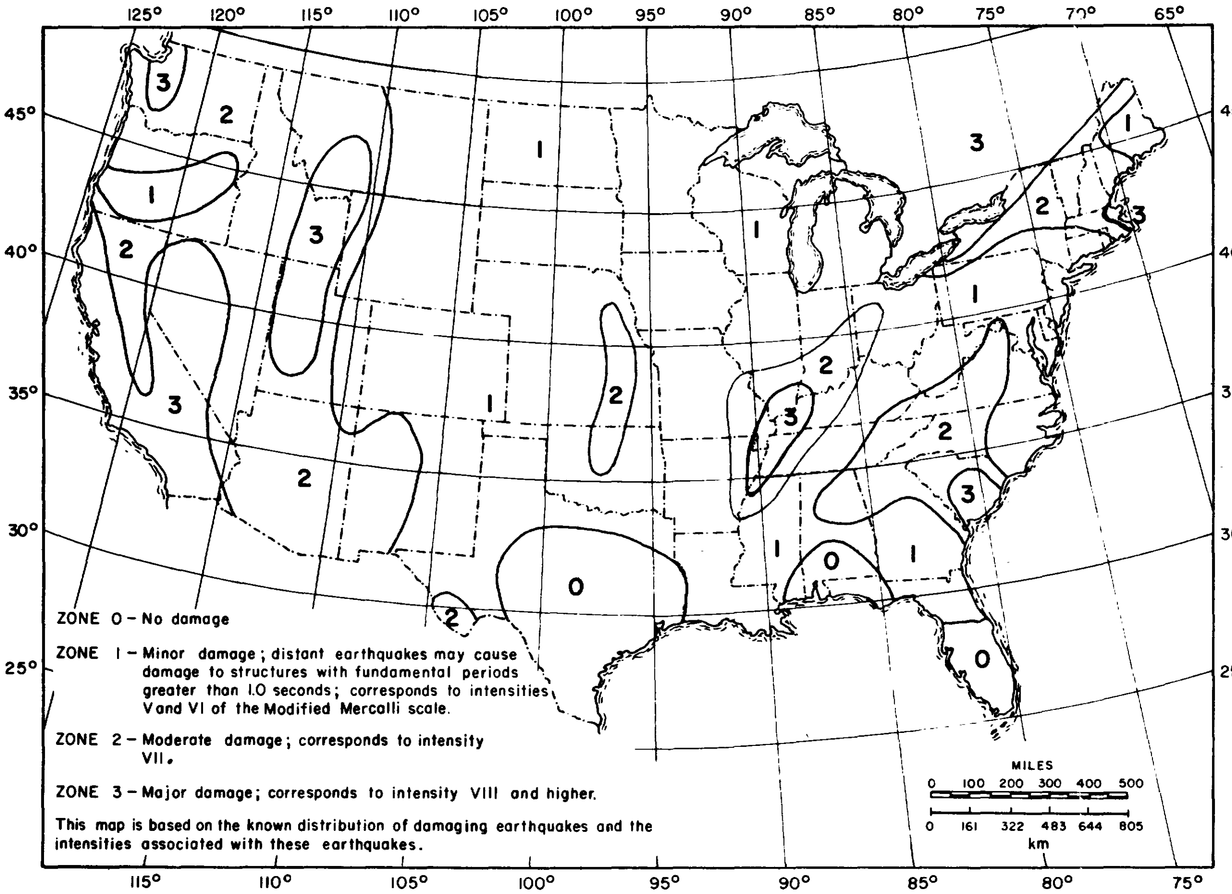

Figure 10.--Seismic zoning map of the United States, 1969 (Algermissen, 1969). This map, with modifications, is incorporated in the 1979 edition of the Uniform Building Code.

How probabilistic maps can be extended and improved

The key to extending and improving probabilistic ground-shaking maps is to improve the definition of each of the three primary components required to construct the map; namely, seismicity, seismic source zones, and regional attenuation functions. The ground motion produced by an earthquake is a complex function of the tectonic province in which the earthquake occurs, the earthquake source mechanism, and the geology between the source and the site. The most important parameters are summarized in table 7 along with information about the effect of each parameter on ground motion and the uncertainty in some of the empirical relations. The statistical distribution of many of these parameters is lacking or poorly defined at this time because of limited data, especially in the Eastern United States.

The seismicity record in the United States is quite variable regionally and encompasses about 100-400 years. It is impossible to specify the exact location and magnitude of the upper-bound earthquake that will occur in a tectonic province containing a construction site on the basis of the seismicity alone, for geologic studies are the most definitive method for defining upper-bound magnitude and recurrence. Additional seismicity networks may be needed in some areas. Analysis of the 2,000-year seismicity record of China (McGuire, 1979) has shown that detailed, long-term knowledge of the seismicity is required to define precise recurrence relations needed for evaluating seismic hazards and risk on a national scale. Construction of regional-scale maps and maps for very low probabilities of exceedance or very long exposure times also requires long-term knowledge of the seismicity.

Most researchers argue that the greatest hope for extending and improving the current probabilistic map of ground acceleration is to improve the definition of seismic source zones, especially in the Eastern United States. This work is underway, and current results in South Carolina (Rankin, 1977) seem to indicate that the greatest advances are made through multidisciplinary geologic and geophysical studies.

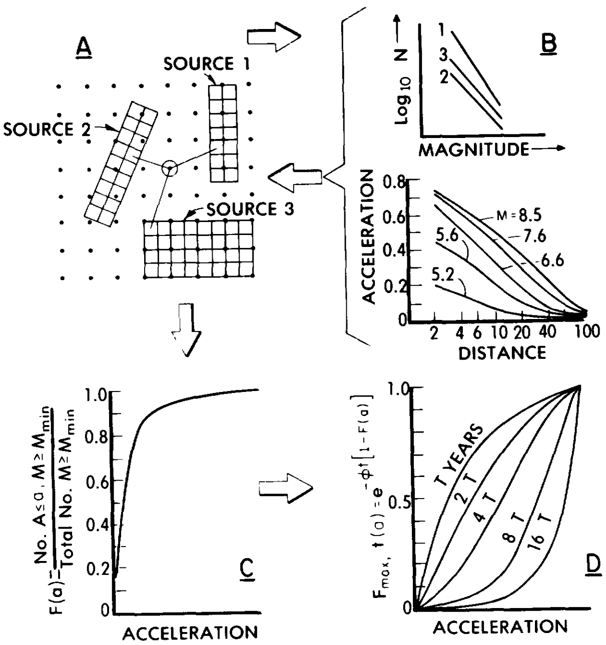

Figure 11.--Schematic illustration of the elements involved in constructing probabilistic maps of ground shaking. A shows three typical seismic source zone configurations and the grid of points at which the ground acceleration hazard is calculated. B shows typical statistical representations of seismicity for the three source zones and acceleration attenuation curves for the region. C depicts a typical cumulative probability distribution F(a) of ground acceleration at site. D shows the extreme probability $F_{max,t(a)}$ for various ground acceleration levels and exposure times T at a site. Acceleration values obtained in D for every site form the basis of a contour map such as figure 9.

Characterization of the ground motion close to the fault is one of the most difficult parts of the scientific problem. In the near-field (that is, distances of a few fault widths from the earthquake energy source), the ground motion is strongly influenced by the dynamics of the fault rupture. In this region, the dynamic stress drop primarily determines the high-frequency characteristics of the seismic waves (and consequently the peak ground acceleration), and the permanent static displacement determines the low-frequency characteristics. At this time, only a few accelerograms, such as that recorded at Pacoima Dam during the 1971 San Fernando earthquake, are available to define the amplitude level and spectral characteristics of near-field ground motion. Substantial improvement in probabilistic ground shaking maps will come only as this gap in knowledge is closed, perhaps as the recommendations made at the May 1978 NSF-sponsored workshop on "Strong motion earthquake instrument arrays" (Iwan, 1978) are implemented to acquire near-source ground-motion records throughout the world in high seismicity areas.

At the present time, insufficient data are available to define precise attenuation functions for various regions of the United States. The few attenuation functions that are widely used (for example, Schnabel and Seed, 1973; Donovan, 1973) are acknowledged to have limitations, especially close to faults and outside California. The ideal case would be to "calibrate" the frequency-dependent attenuation characteristics of various regions of the United States by obtaining a set of records for the whole range of variables (distance, focal depth, magnitude, region) and a reference ground condition.

The probabilistic method of constructing ground-shaking maps has advantages that the deterministic methods do not have. A ground-shaking map derived deterministically cannot reflect the statistical distribution of physical parameters that affect ground motion. Probabilistic maps are based on deterministic methods, but they reflect parameter uncertainty.

Probabilistic methods are also being used to produce maps of liquefaction opportunity (Youd and Perkins, 1978). The approach is similar, so these maps will not be discussed here.

THE USGS PROGRAM IN NATIONAL SEISMIC HAZARDS AND RISK, FY 80-84

Scope and objectives

During the next five years (FY 80--FY 84), the USGS plans to continue its research program in national seismic hazards and risk at about the current level of funding. The objectives will continue to be the same; namely, (1) to use existing methods for making maps; (2) to develop improved methods for more precise delineation of these effects; and (3) to assess the risk. This research program will continue as a subelement of the "Hazards assessment element" (see tables 3, 4) one of the six elements constituting the NSF-USGS Earthquake Hazards Reduction Program; therefore, the program is dependent on the technical progress made in the individual research projects within that element. As noted in the preceding section, the capability to construct a map that accurately depicts the variation of ground shaking nationwide requires improved technical knowledge from ongoing research activities:

1. improvement in the location, accuracy, and completeness of historic earthquake data, including a remapping of poorly located earthquakes and redefinition of critical parameters in the data base;

Table 7.--The uncertainty in physical parameters that affect ground motion

Physical parameter	Effect on ground motion	Uncertainty
Seismicity parameters:		
Seismic source zone----	Controls location of earthquakes.	Not known; function of seismicity record and geologic and tectonic history.
Recurrence rate (b)----	Defines frequency of occurrences.	$\bar{b}$=0.45 in Eastern United States where Log N=a-bI; σ=f(N).
Upper bound magnitude--	Establishes ground-motion design levels.	Not known; function of seismicity record and fault rupture.
Source parameters:		
Epicenter--------------	Establishes location of design earthquake.	Best location accuracy is 1 km; worst is 50 km.
Focal depth------------	Affects partition of body/surface waves.	Best location accuracy is 2 km; worst is 50 km.
Magnitude (m_b, M_L, M_s)	Affects low frequencies; ground-motion scaling.	Best accuracy is 0.1 unit; worst is >1 unit.
Seismic moment (M_o)---	Affects low frequencies--	Log M_o ~3/2 M_s until $M_o \geq 10^{28}$ dyne-cm. M_o=21.9+3 log L with 1$\sigma \cong$2.
Stress drop ($\Delta\sigma$) and effective stress.	Affects high frequencies; peak acceleration.	Earthquakes exhibit a constant average stress drop of about 10 bars with 2$\sigma \cong$10.
Fault length (L)-------	Affects magnitude and moment.	M_L=1.235+1.243 Log L; σ=0.93.
Epicentral intensity (I_o)	Affects site acceleration (a_H and a_V).	Log a_H=0.24 I_{MM}+0.26; 1σ=2.19 WORLDWIDE Log a_V=0.28 I_{MM}-0.40; 1σ=2.53 DATA
Path parameters:		
Attenuation of seismic energy with distance.	Establishes peak ground-motion values at site.	Not well defined; 1σ for peak acceleration vs. distance is 2.01 for worldwide data. 1σ for frequency-dependent attenuation of spectral velocity ranges from 1.61 to 2.22. The statistical distribution for Modified Mercalli intensity attenuation is not known.
Local site parameters:		
Soil-rock acoustic impedance ($\rho\beta$) contrast.	Affects amplitude level of ground motion.	Not well defined.
Soil thickness and geometry.	Affects dominant frequency, duration.	Not well defined.
Strain level--------------	Determines if ground response is linear.	Not well defined because of limitations of the ground-motion data sample.
Transfer function---------	Determines relative response between sites.	Repeatable with 1σ=1.30 for nuclear explosions and 1.50 for earthquake aftershocks.

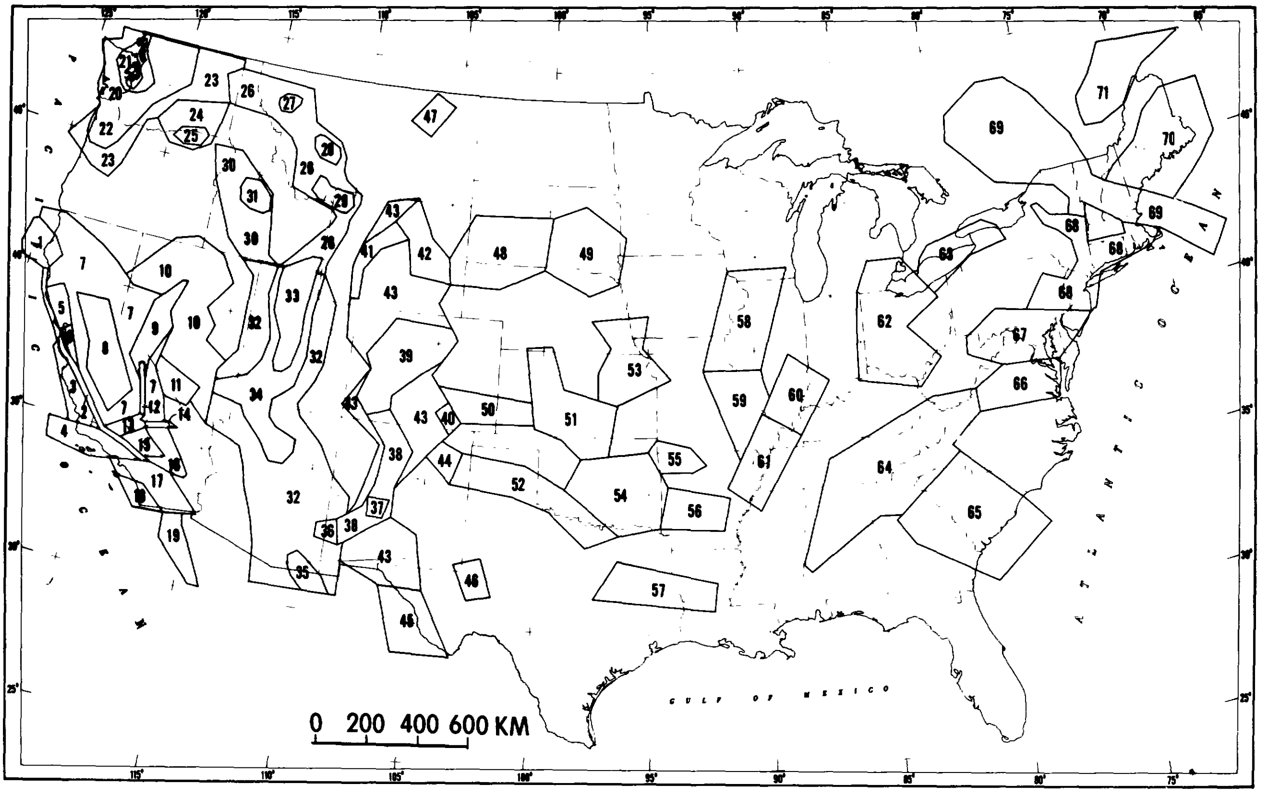

Figure 12.--Map showing seismic source zones in the conterminous United States (Algermissen and Perkins, 1976).

2. identification of seismically active faults;

3. definition of earthquake recurrence intervals from analysis of the Quaternary history of individual faults;

4. delineation of seismic source zones on the basis of seismic, geologic, and geophysical characteristics;

5. specification of seismic attenuation functions for various regions of the United States; and

6. post-earthquake investigations.

Who will do the research

The research in the national seismic hazards and risk program will be accomplished by USGS scientists, with management responsibility being assigned primarily to the Branch of Earthquake Tectonics and Risk (fig. 13), and by non-USGS scientists and engineers through grants and contracts. Viewed as a whole, the research will be multidisciplinary and involve geologists, geophysicists, and engineers.

Research plan

The projected research plan in national seismic hazards and risk for FY 80-84 is described below. This plan is based on a consideration of (1) the needs, priorities, concerns, and recommendations of various user groups; and (2) the resources currently available within the USGS to perform the research. The research plan does not identify specific research tasks that might be performed by non-USGS scientists and engineers because of the constraints of the procurement procedure. However, it is anticipated that considerable research on component parts of the national seismic hazards and risk program will be conducted through grants and contracts.

National maps based on existing methods

A number of probabilistic maps of ground shaking on a national (1:7,500,000) scale will be developed during the period FY 80-84. The various maps and other products that will receive priority attention are listed below. However, circumstances beyond our control (for example, studying the effects of a destructive earthquake in the United States) would take priority over some ongoing studies and might cause a delay in publication.

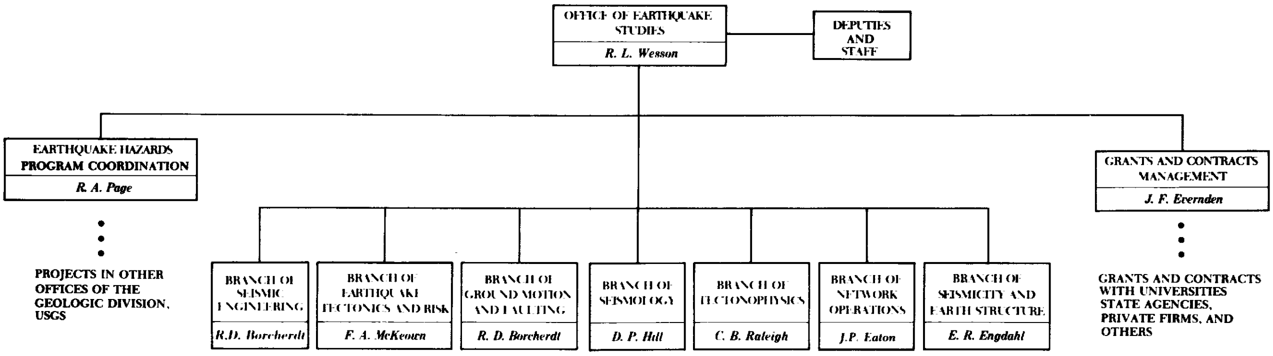

Figure 13.--Organization of Office of Earthquake Studies, USGS.

Map

1. National map showing the annual probability of acceleration of 0.10 g.

2. National map of historical maximum Modified Mercalli intensity.

3. National-scale maps of acceleration and velocity for rock sites in the Outer Continental Shelf.

4. National probabilistic maps of maximum Modified Mercalli intensity.

5. National probabilistic maps of acceleration and velocity for rock sites.

Definition of earthquake source zones

An effort is currently underway to delineate earthquake source zones nationwide using existing methods and geologic and geophysical data. The objective is to refine the current characterization of earthquake source zones and the existing data bases so that improved national and regional-scale probabilistic maps of ground shaking can be developed. The map and accompanying text of the report that is expected from this research is listed below. The list does not contain maps and reports that will be produced through grants or contracts.

Map or report

1. Map of earthquake source zones for coastal Alaska (1:7,500,000).

2. Map of earthquake source zones for coastal California (1:7,500,000).

3. Map of earthquake source zones for coastal southeast United States (1:7,500,000).

4. Map of earthquake source zones for coastal northeast United States (1:7,500,000).

5. Map of earthquake source zones for coastal northwest United States (1:7,500,000).

6. Map of focal mechanisms for North America (1:11,000,000).

7. Map of late Quaternary faults in Utah categorized according to estimated age of last movement (1:250,000 and 1:500,000).

8. Map of stress determinations for North America (1:2,500,000).

9. Report on geologic and seismologic studies in the upper Mississippi Embayment area.

10. National map of earthquake source zones.

11. Revised seismicity catalog for the United States.

12. Report on geologic and seismologic studies in the upper Mississippi Embayment area.

13. Seismicity map of the United States (1:5,000,000).

14. State seismicity maps (1:1,000,000).

Development of improved methods

Concurrent with the mapping effort, a research effort is also underway to develop improved methods for making probabilistic maps of ground shaking and ground failure. This effort is summarized below with identification of the map or report being prepared.

Map or report

1. Redetermination of epicenters of instrumentally recorded earthquakes in the Eastern United States.

2. Methods for estimating ground-motion characteristics close to a fault.

3. Methods for incorporating variability in ground-motion parameters.

4. Methods for assessing liquefaction potential, taking account of duration of shaking and number of stress cycles.

5. Regional attenuation functions for peak acceleration and velocity.

6. Catalog of observed Modified Mercalli intensities in the United States.

7. Regional attenuation functions for Modified Mercalli intensity.

8. Recommended revision to Modified Mercalli intensity scale.

9. Methodology for assessing source regions for long return periods.

10. Frequency-dependent attenuation relations.

Regional maps based on improved methods

The current plan is to develop a series of maps of ground shaking and possibly ground failure on a regional scale (1:250,000 or larger). These maps will be based on improved methods and data and will incorporate the best available information about seismic source zones. They will be a useful extension of the national-scale maps. It is anticipated that they will include information such as (1) age dating of faults, especially in California, Nevada, and Utah; (2) understanding of the characteristics of intraplate earthquakes, especially in the Eastern United States; and (3) understanding of the physical correlations between earthquake occurrence, regional tectonics, and basement features (for example, volcanic intrusives, rift zones), especially in the Eastern United States. The maps will be developed first for those urban areas of the United States where sufficient advances in understanding of earthquake source zones have occurred to warrant refining the national-scale maps and will require interaction with the States. The map or report being prepared is listed below.

Map or report

1. Map of probabilistic liquefaction potential, San Juan, Puerto Rico.

2. Probabilistic maps of economic loss for the San Francisco Bay region.

3. Maps of probabilistic ground shaking for the Wasatch Front area, Utah.

4. Map of probabilistic liquefaction potential, southern California.

5. Probabilistic maps of economic loss for Wasatch Front area, Utah.

6. Probabilistic maps of economic loss for the Mississippi Embayment area.

7. Maps of probabilistic ground shaking for the Mississippi Embayment area.

8. Maps of probabilistic ground shaking for the Charleston, S.C., area.

9. Probabilistic maps of economic loss for the Charleston, S.C., area.

Post-earthquake investigations

The USGS will coordinate with other groups in sending a team to investigate each important damaging earthquake throughout the world and in publishing the data and results. Damaging earthquakes provide a unique opportunity to improve the level of scientific knowledge about earthquake source zones, geologic effects, and the nature and distribution of earthquake-related losses. The types of seismological, engineering, economic, and sociological data available after a damaging earthquake include the following:

1. identification of the direction of faulting,

2. identification of active tectonic elements,

3. ground-motion records and improved correlation of ground motion with damage,

4. understanding of the mechanism of occurrence of faulting and ground failure,

5. test of building performance and earthquake-resistant design and construction practice,

6. primary and secondary economic effects, and

7. sociological changes caused by the event.

All of these data are critically important to nearly all phases of earthquake hazard and risk evaluation and contribute, eventually, to improved earthquake-resistant design.

Earthquakes in foreign countries as well as in the United States are important sources of information. Although construction practices may differ, earthquake-resistant design is becoming increasingly common throughout the world, and many buildings are designed on the basis of principles used in the United States. Thus, important damaging earthquakes should be investigated regardless of their location in the world.

The communication process

The ultimate aim of the USGS seismic hazards and risk program is effective utilization of all of its research products by the various user groups. Publication of a map follows years of research and data gathering, but it is not an end in itself. Both during and following the research and data-gathering phase, extensive communication must take place between the researchers and potential users to insure maximum benefit in earthquake hazard reduction.

The USGS plans to continue to seek ways to improve communication between producers and users of seismic-hazards and risk-assessment information. Communication methods, such as workshops and cluster meetings, that have worked well in the past will be continued and strengthened. Methods that have proven ineffective (such as simply transmitting a map or report) will be replaced with more workable methods. The emphasis will be placed on improving communications in what may be the two most critical periods of time: (1) the planning period before the research starts, and (2) the period of time immediately following the distribution of a research product. Emphasis will also be placed on developing a procedure to introduce change. The goal of implementing USGS research products at all levels requires timely and effective communication.

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Appendix A--Glossary

These terms are intended to denote common usage, but the definitions do not represent a consensus.

Accelerogram. The record from an accelerometer showing acceleration as a function of time.

Acceptable risk. A specification of the acceptable number of fatalities due to the earthquake threat, or an equivalent statement in terms of buildings. Residual risk is a preferable term.

Active fault. A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. This active state exists independently of the geologists' ability to recognize it. Geologists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geologically recent displacement inferred from topography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behavior of faults to assure identification of all active faults by such characteristics. Selection of the criteria used to identify active faults for a particular purpose must be influenced by the consequences of fault movement on the engineering structures involved.

Attenuation. (1) A decrease of signal amplitude during transmission; (2) a reduction in amplitude or energy with or without change of waveform; or (3) a decrease in seismic signal strength with distance, which depends not only on geometrical spreading but also may be related to those physical characteristics of the transmitting medium that cause absorption and scattering.

Base shear. A seismic-design parameter in the Uniform Building Code that is a horizontal load on a structure and is determined by a product of a seismic coefficient, an exposure factor, and the weight of the structure.

Body waves. Waves propagated in the interior of a body; that is, compression and shear waves, the P and S waves of seismology.

Capable fault. A fault along which future surface displacement is possible, especially during the lifetime of the project under consideration.

Design earthquake. The largest earthquake that has such a high probability of occurrence based on studies of historic seismicity and structural geology that it is appropriate to design a structure to withstand it. Ground shaking of the design earthquake might be exceeded, but the probability of this happening is considered to be small.

Design spectra. Spectra appropriate for earthquake-resistant design purposes. Design spectra are typically smooth curves that have been modified from a family of spectra of historic earthquakes to take account of features peculiar to a geographic region and a particular site. Design spectra do not include the effect of soil-structure interaction.

Design time history. One of a family of time histories which produces a response spectrum that envelopes the smooth design spectrum, for a selected value of damping, at all periods.

Earthquake hazards. The probability that natural events accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation, which may cause damage and loss of life, will occur at a site during a specified exposure time. See Earthquake risk.

Earthquake risk. The probability that social or economic consequences of earthquakes, expressed in dollars or casualties, will equal or exceed specified values at a site during a specified exposure time.

Earthquake waves. Elastic waves propagating in the earth, set in motion by a sudden change such as faulting of a portion of the earth.

Effective peak acceleration. The peak ground acceleration after the ground-motion record has been filtered to remove the very high frequencies that have little influence upon structural response.

Effective peak velocity. The peak ground velocity after the ground-motion record has been filtered to remove high frequencies.

Epicenter. The point on the Earth's surface vertically above the point where the first rupture and the first earthquake motion occur.

Exceedance probability. The probability (for example, 10 percent) over some period of time that an event will generate a level of ground shaking greater than some specified level.

Exposure time. The period of time (for example, 50 years) that a structure is exposed to the earthquake threat. The exposure time is sometimes chosen to be equal to the design lifetime of the structure.

Fault. A fracture or fracture zone in the earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. See Active, Capable, Normal, Thrust, and Strike-slip faults.

Focal depth. The vertical distance between the hypocenter and the Earth's surface in an earthquake.

Ground response, motion, or seismic response. A general term, including all aspects of motion; for example, particle acceleration, velocity, or displacement; stress and strain from a nuclear explosion, an earthquake, or another energy source.

Intensity. A numerical index describing the effects of an earthquake on the Earth's surface, on man, and on structures built by him. The scale in common use in the United States today is the Modified Mercalli scale of 1931 with intensity values indicated by Roman numerals from I to XII. The narrative descriptions of each intensity value are summarized below.

I. Not felt--or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes, birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most; outdoors direction estimated. Awakened many, or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: Threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-build bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earth completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

<u>Liquefaction.</u> Temporary transformation of unconsolidated materials into a fluid mass.

<u>Magnitude.</u> A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. Professor C. F. Richter devised the logarithmic scale for local magnitude (M_L) in 1935. Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicenter of an earthquake. Several other magnitude scales in addition to M_L are in use; for example, body-wave magnitude (m_b) and surface-wave magnitude (M_s), which utilize body waves and surface waves, and local magnitude (M_L). The scale is open ended, but the largest known earthquake to have occurred had M_s magnitudes near 8.9.

<u>Model.</u> A concept from which one can deduce effects that can then be compared to observation, which assists in developing an understanding of the significance of the observations. The model may be conceptual, physical, or mathematical.

<u>Moment.</u> The seismic moment $M_o = \mu \bar{u} A$ contains information on the rigidity (μ) of the elastic medium in the source region, average dislocation ($\bar{u}$), and area (A) of faulting. It determines the amplitude of the long-period level of the spectrum of ground motion.

<u>Normal fault.</u> A fault in which the hanging wall has gone down relative to the footwall.

<u>Probability of occurrence.</u> The annual rate of occurrence of a hazard.

<u>Region.</u> A geographical area surrounding and including the site sufficiently large to contain all the features related to a particular earthquake hazard.

<u>Response spectrum.</u> The peak response of a series of simple harmonic oscillators of different natural period when subjected

mathematically to a particular earthquake ground motion. The response spectrum may be plotted as a curve on tripartite logarithmic graph paper showing the variations of the peak spectral acceleration, displacement, and velocity of the oscillators as a function of vibration period and damping.

Return period. The average period of time or recurrence interval between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be exceeded once in 475 years.

Risk. See Earthquake risk.

Rock. Any solid rock either at the surface or underlying soil having a shear-wave velocity >2,500 ft/s (765 m/s) at small (0.0001 percent) strains.

Seismic source zones. Areas of spatially homogeneous earthquake activity.

Seismotectonic province. A geographic area characterized by similarity of geological structure and earthquake characteristics.

Standard deviation. A measure of the scatter of n measurements of a quantity X_i, with respect to the mean, $\bar{X}$.

Stress drop. $\Delta\sigma=\sigma_0-\sigma_1$, where σ_0 is the initial stress before the earthquake and σ_1 is the stress after the earthquake. For the 1971 San Fernando, Calif., earthquake, the average initial stress is estimated to have been about 100 bars and the stress drop to have been about 60 bars. Stress drop is believed to control the high-frequency spectral content of earthquake ground motions, whereas seismic moment controls the low frequencies.

Stress (effective). In modeling an earthquake, the effective stress is defined as $\sigma=\sigma_0-\sigma_f$, where σ_0 is the stress before the earthquake and σ_f is the frictional stress acting to resist the fault slip.

Strike-slip fault. A fault in which movement is principally horizontal. The San Andreas fault is strike-slip.

Strong motion. Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes.

Surface waves. Seismic energy that travels along or near the surface; includes Rayleigh and Love waves.

Thrust fault. An inclined fracture along which the rocks above the fracture have apparently moved up with respect to those beneath. The 1964 Alaska and 1971 San Fernando earthquakes occurred on thrust faults.

Upper-bound earthquake. The hypothetical earthquake that is considered to be the most severe reasonably possible on the basis of comprehensive studies of historic seismicity and structural geology.

Appendix B

PROJECTS, GRANTS, AND CONTRACTS FUNDED IN FY 79 EARTHQUAKE HAZARDS REDUCTION PROGRAM, U.S. GEOLOGICAL SURVEY

This list includes commitments made prior to 17 November 1978.

I. EARTHQUAKE HAZARDS STUDIES

I.A. EARTHQUAKE POTENTIAL

I.A.1. Tectonic framework, Quaternary geology, and active faults

I.A.1. California

VERTICAL CRUSTAL DEFORMATION IN SOUTHERN CALIFORNIA AND THE PACIFIC STATES, R. O. Castle, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2482.

COASTAL TECTONICS OF CALIFORNIA, OREGON, AND WASHINGTON, K. R. Lajoie, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2642.

Southern California

EARTHQUAKE HAZARDS GEOLOGIC MAPPING OF THE SAN ANDREAS FAULT ZONE, LOS ANGELES COUNTY, CALIFORNIA, A. G. Barrows, State of California, Division of Mines and Geology, 107 South Broadway, Room 1065, Los Angeles, California 90012.

SURFACE FAULT TRACES AND HISTORIC EARTHQUAKE EFFECTS NEAR LOS ALAMOS VALLEY, SANTA BARBARA COUNTY, CALIFORNIA, G. E. Brogan, Woodward-Clyde Consultants, P.O. Box 1149, Orange, California 92668, (714) 799-2011.

SURFICIAL QUATERNARY DEPOSITS AND TECTONICS OF THE WESTERN MOJAVE DESERT REGION, D. B. Burke, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2048.

ACTIVE FAULTS AND RECENT TECTONIC DEFORMATION, SOUTHERN CALIFORNIA, M. M. Clark, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2591.

GEOMORPHIC STUDIES OF POST-PLEISTOCENE DEFORMATION ALONG THE SAN ANDREAS FAULT, WEST-CENTRAL TRANSVERSE RANGES, CALIFORNIA, J. C. Crowell, University of California, Department of Geological Sciences, Santa Barbara, California 93106, (805) 961-3224.

GEOLOGIC INVESTIGATION OF THE SAN MIGUEL FAULT ZONE, BAJA, CALIFORNIA, R. G. Gastil, San Diego State University, Department of Geological Sciences, San Diego, California 92182, (714) 286-6211.

QUATERNARY TECTONICS, OFFSHORE LOS ANGELES-SAN DIEGO AREA, H. G. Greene, U.S. Geological Survey, Branch of Pacific-Arctic Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 7047.

AEROMAGNETIC INTERPRETATION OF THE WESTERN TRANSVERSE RANGES, CALIFORNIA, Andrew Griscom, U.S. Geological Survey, Branch of Regional Geophysics, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2268.

EARTHQUAKE HAZARDS ASSOCIATED WITH THE VERDUGO-EAGLE ROCK AND BENEDICT CANYON FAULT ZONES, LOS ANGELES COUNTY, CALIFORNIA, R. L. Hill, State of California, Division of Mines and Geology, 107 South Broadway, Room 1065, Los Angeles, California 90012.

TECTONIC GEOMORPHOLOGY AND POSSIBLE FUTURE SEISMIC ACTIVITY OF THE CENTRAL VENTURA BASIN, CALIFORNIA, E. A. Keller, University of California, Department of Geological Sciences, Santa Barbara, California 93106.

RECENCY AND CHARACTER OF FAULTING OFFSHORE FROM METROPOLITAN SAN DIEGO, CALIFORNIA, M. P. Kennedy, State of California, Division of Mines and Geology, 107 South Broadway, Room 1065, Los Angeles, California 90012, (714) 452-2751.

TECTONICS OF THE EASTERN TRANSVERSE RANGES AND QUATERNARY GEOLOGY OF THE UPPER SANTA ANA VALLEY, CALIFORNIA, D. M. Morton, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2353.

SEISMIC HAZARD STUDY OF THE WESTERN PORTION OF THE GARLOCK FAULT, SOUTHERN CALIFORNIA, C. M. Payne, Fugro, Inc., 3777 Long Beach Blvd., Long Beach, California 90807, (213) 595-6611.

BASEMENT ROCKS ALONG THE SAN ANDREAS FAULT SYSTEM, D. C. Ross, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2341.

TECTONICS OF THE SALTON TROUGH AND VICINITY, R. V. Sharp, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2596.

STUDIES OF LATE HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT SYSTEM--SAN JUAN BAUTISTA TO THE SALTON SEA, K. E. Sieh, California Institute of Technology, Division of Geological and Planetary Sciences, Pasadena, California 91125, (213) 795-6811, ext. 2108.

CLASSIFICATION AND MAPPING OF QUATERNARY SEDIMENTARY DEPOSITS FOR PURPOSES OF SEISMIC ZONATION, SOUTH COASTAL LOS ANGELES BASIN, ORANGE COUNTY, E. C. Sprotte, State of California, Division of Mines and Geology, Department of Conservation, 107 South Broadway, Room 1065, Los Angeles, California 90012.

QUATERNARY GEOLOGY OF THE LOS ANGELES BASIN, J. C. Tinsley, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2037.

GEOLOGIC INVESTIGATION OF THE MARINE TERRACES OF THE SAN SIMEON REGION AND PLEISTOCENE ACTIVITY ON THE SAN SIMEON FAULT ZONE, CALIFORNIA, G. E. Weber, Weber and Associates, 127 Pryce Street, Santa Cruz, California 95060.

SUBSURFACE GEOLOGY OF THE SAN GABRIEL, HOLSER, AND SIMI-SANTA ROSA FAULTS, TRANSVERSE RANGES, CALIFORNIA, R. S. Yeats, Oregon State University, Department of Geology, Corvallis, Oregon 97330, (502) 754-2484.

SUBSURFACE GEOLOGY OF POTENTIALLY ACTIVE FAULTS IN THE COASTAL REGION BETWEEN GOLETA AND VENTURA, CALIFORNIA, R. S. Yeats, Oregon State University, Department of Geology, Corvallis, Oregon 97330, (502) 754-2484.

TECTONICS OF THE WESTERN TRANSVERSE RANGES, R. F. Yerkes, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2350.

Northern California

TECTONIC FRAMEWORK AND SEISMIC ZONATION OF THE SAN FRANCISCO BAY REGION, E. E. Brabb, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2203.

HOLOCENE BEHAVIOR OF THE SAN ANDREAS FAULT--SAN JUAN BAUTISTA TO POINT ARENA, CALIFORNIA, W. R.

Cotton, Foothill-DeAnza Community College District, 12345 El Monte Road, Los Altos Hills, California 94022, (415) 948-8590.

GEOPHYSICS OF THE SAN FRANCISCO BAY REGION, Andrew Griscom, U.S. Geological Survey, Branch of Regional Geophysics, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2268.

NEOTECTONICS OF THE SAN FRANCISCO BAY REGION, D. G. Herd, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2870.

RELATION OF SEISMICITY TO REGIONAL GEOLOGY IN NORTHERN CALIFORNIA, W. P. Irwin, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2065.

MOVEMENT AND DEFORMATION ON THE SOUTHERN FOOTHILLS FAULT SYSTEM, CALIFORNIA, Richard Schweickert, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964.

I.A.1.b. Western United States (excluding California)

LATE QUATERNARY FAULTING AND LATE CENOZOIC TECTONICS IN SOUTHWESTERN UTAH, R. E. Anderson, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5109.

LATE QUATERNARY FAULTING IN NORTHWESTERN UTAH, R. C. Bucknam, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5089.

REGIONAL GEOLOGICAL STRUCTURE OF THE PUGET SOUND BASIN, H. D. Gower, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2352.

SURFICIAL GEOLOGY OF THE SALT LAKE VALLEY, R. D. Miller, U.S. Geological Survey, Branch of Engineering Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-2960.

STRATIGRAPHY OF PRE-VASHON QUATERNARY SEDIMENTS APPLIED TO THE EVALUATION OF A PROPOSED MAJOR TECTONIC STRUCTURE IN ISLAND COUNTY, WASHINGTON, Pamela Palmer, State of Washington, Department of Natural Resources, P.O. Box 168, Olympia, Washington 98501.

GEOCHEMICAL CRITERIA TO AID IN MAPPING THE MARINE LIMIT IN THE PUGET LOWLAND, D. R. Pevear, U.S. Geological Survey, Branch of Western Environmental Geology, Western Washington University, Department of Geology, Bellingham, Washington 98225, (206) 733-1848 or 676-3590.

SOUTHERN ALASKA SEISMOTECTONICS, George Plafker, U.S. Geological Survey, Branch of Alaskan Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2201.

QUATERNARY GEOLOGY OF THE WASATCH FRONT, W. E. Scott, U.S. Geological Survey, Branch of Central Environmental Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-5215.

GEOLOGIC MAPPING OF THE VISTA AND STEAMBOAT 7 1/2-MINUTE QUADRANGLES, NEVADA, D. Trexler, State of Nevada, Nevada Bureau of Mines, Mackay School of Mines, University of Nevada, Reno, Nevada 89507, (702) 784-6691.

I.A.1.c. Eastern United States

LATE TERTIARY AND QUATERNARY TECTONIC DEFORMATION OF SHORELINES IN THE SOUTHEASTERN UNITED STATES, B. W. Blackwelder, U.S. Geological Survey, Branch of Paleontology and Stratigraphy, Room 501, National Museum, Washington, D.C. 20244, (202) 343-5488.

SEISMOTECTONICS OF THE NORTHEASTERN UNITED STATES, W. H. Diment, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-6520.

TECTONIC HISTORY OF EASTERN OZARK UPLIFT, E. E. Glick, U.S. Geological Survey, Branch of Central Environmental Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-3353.

TECTONIC ORIGIN OF EASTERN UNITED STATES SEISMICITY, R. M. Hamilton, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-7684.

GEOPHYSICS OF THE NEW MADRID SEISMIC ZONE, T. G. Hildenbrand, U.S. Geological Survey, Branch of Regional Geophysics, Denver Federal Center, Denver, Colorado 80225, (303) 234-5464.

ENGINEERING GEOLOGY OF METROPOLITAN BOSTON, C. A. Kaye, U.S. Geological Survey, Branch of Engineering Geology, 150 Causeway Street, Room 1304, Boston, Massachusetts 02110, (617) 223-7200.

QUATERNARY STRATIGRAPHY AND BEDROCK STRUCTURAL FRAMEWORK, GILES COUNTY, VIRGINIA, W. L. Newell, U.S. Geological Survey, Branch of Eastern Environmental Geology, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-6420.

RELATION OF SEISMICITY TO GEOLOGIC STRUCTURES IN NORTHEASTERN UNITED STATES AND GEOLOGIC STUDIES OF THE RAMAPO FAULT ZONE, NEW YORK, N. M. Ratcliffe, U.S. Geological Survey, Branch of Eastern Environmental Geology, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-6404.

MISSISSIPPI VALLEY SEISMOTECTONICS, D. P. Russ, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5065.

GEOPHYSICS OF THE NORTHEASTERN UNITED STATES FOR EARTHQUAKE STUDIES, Robert Simpson, U.S. Geological Survey, Branch of Regional Geophysics, Denver Federal Center, Denver, Colorado 80225, (303) 234-2623.

NORUMBEGA FAULT ZONE, EASTERN MAINE, D. R. Wones, U.S. Geological Survey, Branch of Eastern Environmental Geology, 4044 Derring Hall, Virginia Polytechnical Institute, Blacksburg, Virginia 24061, (703) 951-5980.

I.A.1.d. National

NEOTECTONIC SYNTHESIS OF THE UNITED STATES, C. M. Wentworth, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2474.

SEISMOGENIC ZONES OF THE UNITED STATES, J. I. Ziony, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2944 or 2214.

I.A.2. Earthquake recurrence and dating of fault movements

CHARACTERISTICS OF ACTIVE FAULTS, GREAT BASIN: R. C. Bucknam, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5089.

TEPHROCHRONOLOGY, CENTRAL UNITED STATES, G. A. Izett, U.S. Geological Survey, Branch of Central Environmental Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-2835.

A NEW METHOD OF ALLUVIAL AGE DATING BASED ON PROGRESSIVE WEATHERING, WITH APPLICATIONS TO THE TIME-HISTORY OF FAULT ACTIVITY IN SOUTHERN CALIFORNIA, Barclay Kamb, California Institute of Technology, Division of Geology and Planetary Science, Pasadena, California 91109, (213) 795-6811, ext. 2109.

CORRELATING AND DATING QUATERNARY SEDIMENTS BY AMINO ACIDS, K. A. Kvenvolden, U.S. Geological Survey, Branch of Pacific-Arctic Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 7150.

PALEOMAGNETIC DATING OF LATE NEOGENE DEPOSITS IN THE ATLANTIC COASTAL PLAIN WITH APPLICATION TO DATING TECTONIC DEFORMATION, SOUTHEASTERN UNITED STATES, J. C. Liddicoat, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964.

CORRELATION AND SEMIQUANTITATIVE AGE-DATING OF SOILS, WESTERN UNITED STATES, D. E. Marchand, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2009.

DETERMINATION OF THE MAGNITUDE AND DATE OF DIP-SLIP FAULTING BY DISCORDANCE IN SETS OF MEAN SEA LEVEL CURVES, W. S. Newman, Queens College of City University of New York, Department of Earth and Environmental Sciences, Flushing, New York 11367.

QUATERNARY DATING TECHNIQUES, K. L. Pierce, U.S. Geological Survey, Branch of Central Environmental Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-2737.

URANIUM TREND DATING OF SOILS, J. N. Rosholt, U.S. Geological Survey, Branch of Isotope Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-4201.

TRENCHING STUDIES OF THE SAN ANDREAS FAULT BORDERING WESTERN ANTELOPE VALLEY, SOUTHERN CALIFORNIA, D. J. Rust, University of California, Department of Geological Sciences, Santa Barbara, California 93106.

TEPHROCHRONOLOGY, WESTERN UNITED STATES, A. M. Sarna-Wojcicki, U.S. Geological Survey, Branch of Western Environmental Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2745.

PALEOSEISMIC INDICATORS IN SEDIMENTS, J. D. Sims, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2252.

QUATERNARY REFERENCE CORE, CLEAR LAKE, CALIFORNIA, J. D. Sims, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2252.

STUDIES OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, F. H. Swan, Woodward-Clyde Consultants, Three Embarcadero Center, Suite 700, San Francisco, California 94111.

TECTONIC ANALYSIS OF ACTIVE FAULTS, R. E. Wallace, U.S. Geological Survey, Office of Earthquake Studies, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2751.

I.B. EARTHQUAKE EFFECTS

I.B.1. Ground Motion

REVISION OF THE MODIFIED MERCALLI INTENSITY SCALE AND SEISMICITY AND RELATED DATA FOR HAZARD

ANALYSIS, S. T. Algermissen, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-4014.

REGIONAL AND NATIONAL SEISMIC HAZARD AND RISK, S. T. Algermissen, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-4014.

A NEW ATTEMPT AT SEISMIC ZONING MAPS FOR SOUTHERN CALIFORNIA, C. R. Allen, California Institute of Technology, Seismological Laboratory, Pasadena, California 91109, (213) 795-6811, ext. 2903.

PHYSICAL CONSTRAINTS ON SOURCE OF GROUND MOTION, D. J. Andrews, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2752.

THREE-DIMENSIONAL MODELING OF NEAR-FIELD GROUND MOTION, Ralph Archuleta, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2161.

INTERACTIVE DATA PROCESSING CENTER FOR GROUND MOTION STUDIES, L. M. Baker, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2881.

STATISTICAL FAULT MODELS FOR GROUND MOTION MODELING, David Boore, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2755.

DEVELOPMENT AND ACQUISITION OF INSTRUMENTATION FOR GROUND MOTION STUDIES, R. D. Borcherdt, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2755.

DYNAMIC SOIL BEHAVIOR, A. T. F. Chen, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2605.

SEISMIC ATTENUATION STUDIES OF THE UNITED STATES, A. F. Espinosa, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 345 Middlefield Road, Menlo Park, California 94025, (303) 234-5077.

REGIONAL INVESTIGATIONS OF NEAR-SURFACE SHEAR WAVE VELOCITIES, J. F. Gibbs, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2030.

NUMERICAL METHODS FOR ESTIMATING RESPONSE OF ALLUVIAL BASINS, S. T. Harding, U.S. Geological Survey, Branch of Ground Motion and Faulting, Denver Federal Center, Denver, Colorado 80225, (303) 234-5090.

GROUND RESPONSE IN THE SALT LAKE CITY REGION, W. W. Hays, U.S. Geological Survey, Branch of Ground Motion and Faulting, Denver Federal Center, Denver, Colorado 80225, (303) 234-4029.

GROUND MOTION PREDICTION AT SELECTED STRONG MOTION SITES, W. B. Joyner, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2754.

SEISMIC DATA FOR GROUND RESPONSE MAPPING IN THE SALT LAKE CITY REGION, K. W. King, U.S. Geological Survey, Branch of Ground Motion and Faulting, Denver Federal Center, Denver, Colorado 80225, (303) 234-5087.

MICROZONATION OF THE MEMPHIS, TENNESSEE AREA, W. D. Kovacs, Purdue University, School of Civil Engineering, West Lafayette, Indiana 47907.

CALCULATIONS OF STRONG MOTION AND LOCAL FIELD-FAR FIELD RELATIONSHIPS FOR THE APRIL 29, 1965, PUGET SOUND, WASHINGTON, EARTHQUAKE, C. A. Langston, Pennsylvania State University, Department of Geosciences, University Park, Pennsylvania 16802.

METHODS OF PROBABILISTIC SEISMIC HAZARD ASSESSMENT, R. K. McGuire, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-2874.

EARTHQUAKE INTENSITY AND RECURRENCE, R. D. Nason, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2760.

COMPUTER BASED MAPPING--SAN FRANCISCO BAY AREA, D. A. Olmstead, Association of Bay Area Governments, Hotel Claremont, Berkeley, California 94705.

DATA PROCESSING SUPPORT FOR GROUND MOTION STUDIES, R. B. Park, U.S. Geological Survey, Branch of Ground Motion and Faulting, Denver Federal Center, Denver, Colorado 80225, (303) 234-5070.

PROBABILISTIC SEISMIC HAZARD OF THE OUTER CONTINENTAL SHELF, D. M. Perkins, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-2832.

THE INFLUENCE OF LOCAL SITE GEOLOGY ON STRONG GROUND MOTIONS, H. E. Read, Systems, Science and

Software, P.O. Box 1620, La Jolla, California 92038, (714) 453-0060.

GROUND RESPONSE IN THE LOS ANGELES VICINITY, A. M. Rogers, U.S. Geological Survey, Branch of Ground Motion and Faulting, Denver Federal Center, Denver, Colorado 80225, (303) 234-2869.

GROUND MOTION PREDICTIONS FOR THE LOS ANGELES BASIN FROM A MAJOR SAN ANDREAS EARTHQUAKE, Joel Sweet, Del Mar Technical Associates, P.O. Box 1083, Del Mar, California 92014.

GEOTECHNICAL INVESTIGATIONS FOR GROUND MOTION STUDIES, R. E. Warrick, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2757.

DIFFRACTION OF WAVES BY THREE-DIMENSIONAL SURFACE TOPOGRAPHIES AND SUBSURFACE IRREGULARITIES, H. L. Wong, University of Southern California, University Park, Los Angeles, California 90007.

GROUND MOTION PREDICTION AND EASTERN U.S. EARTHQUAKE MONITORING, F. T. Wu, State University of New York, Department of Geological Sciences, Binghamton, New York 13901.

I.B.2. Ground failure (including liquefaction and landslides)

STUDY OF LIQUEFACTION IN THE NOVEMBER 23, 1977 EARTHQUAKE IN SAN JUAN PROVINCE, ARGENTINA, Ignacio Arango, Woodward-Clyde Consultants, Three Embarcadero Center, Suite 700, San Francisco, California 94111, (415) 956-7070.

DEVELOPMENT OF TECHNIQUES FOR EVALUATING SEISMIC HAZARDS ASSOCIATED WITH EXISTING CREEPING LANDSLIDES AND OLD DAMS, R. E. Goodman, University of California, Department of Civil Engineering, Berkeley, California 94720, (415) 642-5525.

EARTHQUAKE-INDUCED LANDSLIDES, E. L. Harp, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2529.

GROUND FAILURES CAUSED BY HISTORIC EARTHQUAKES, D. K. Keefer, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2557.

GROUND FAILURE RELATED TO THE NEW MADRID EARTHQUAKES, S. F. Obermeier, U.S. Geological Survey, Branch of Engineering Geology, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-6469.

EVALUATION OF THE CONE PENETROMETER FOR LIQUEFACTION HAZARD ASSESSMENT, G. R. Martin, Fugro, Inc., 3777 Long Beach Blvd., Long Beach, California 90807, (213) 595-6611.

EARTHQUAKE INDUCED LIQUEFACTION AND SUBSIDENCE OF GRANULAR MEDIA, S. Nemat-Nasser, Northwestern University, Department of Civil Engineering, Evanston, Illinois 60201.

INFLUENCE OF GROUND MOTION ON GROUND FAILURE, R. C. Wilson, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2967.

EXPERIMENTAL MAPPING OF LIQUEFACTION POTENTIAL, L. T. Youd, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2529.

PRELIMINARY ASSESSMENT OF LIQUEFACTION POTENTIAL IN AND NEAR SAN JUAN, PUERTO RICO, L. T. Youd, U.S. Geological Survey, Branch of Engineering Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2529.

I.B.3 Surface faulting and other earthquake-related hazards

STATISTICAL ANALYSIS AND GEOMETRY OF SURFACE FAULTING, M. G. Bonilla, U.S. Geological Survey, Branch of Ground Motion and Faulting, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2245.

EARTHQUAKE-RELATED HAZARDS IN AND NEAR HILO, HAWAII, Jane Buchanan-Banks, U.S. Geological Survey, Branch of Engineering Geology, Hawaiian Volcano Observatory, Hawaii National Park, Hawaii, Hawaii 06718, (808) 967-7328.

EARTHQUAKE HAZARDS, UPPER COOK INLET - SUSITNA LOWLAND REGION, ALASKA, Oscar Ferrians, U.S. Geological Survey, Branch of Alaskan Geology, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2247.

I.B.4. Post-earthquake studies

MOTAGUA FAULT, GUATEMALA, AFTERSLIP STUDY, R. C. Bucknam, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5089.

SEISMOLOGICAL FIELD INVESTIGATIONS, C. J. Langer, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5091.

POST-EARTHQUAKE FIELD INVESTIGATIONS, R. A. Page, U.S. Geological Survey, Office of Earthquake Studies, 345 Middlefield Road, Menlo Park, California 94025, (415) 323-8111, ext. 2461.

I.C. EARTHQUAKE LOSSES

AN ALTERNATING MARKOVIAN PROCESS FOR EARTHQUAKE OCCURRENCES, H. C. Shah, Stanford University, Department of Civil Engineering, Stanford, California 94305, (415) 497-4128.

A STOCHASTIC AND BAYESIAN MODEL FOR HAZARD MAPPING AND FOR ESTIMATING EARTHQUAKE LOSSES, H. C. Shah, Stanford University, Department of Civil Engineering, Stanford, California 94305, (415) 497-4128.

DEVELOPMENT OF DATA BASES, PARAMETERS, AND METHODS FOR CONVERTING GROUND MOTION TO EXPECTED DOLLAR LOSS FOR HIGH-RISE BUILDINGS, R. E. Scholl, URS/John A. Blume and Associates, 130 Jessie Street, San Francisco, California 94105, (415) 397-2525.

DEVELOPMENT OF AN EXPOSURE MODEL FOR THE UNITED STATES BUILDING WEALTH AND ANNUAL ECONOMIC LOSS CONSEQUENCES OF THE VARIOUS SEISMIC RISK MAPS, J. H. Wiggins, J. H. Wiggins Company, 1650 South Pacific Coast Highway, Redondo Beach, California 90277, (213) 378-0257.

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