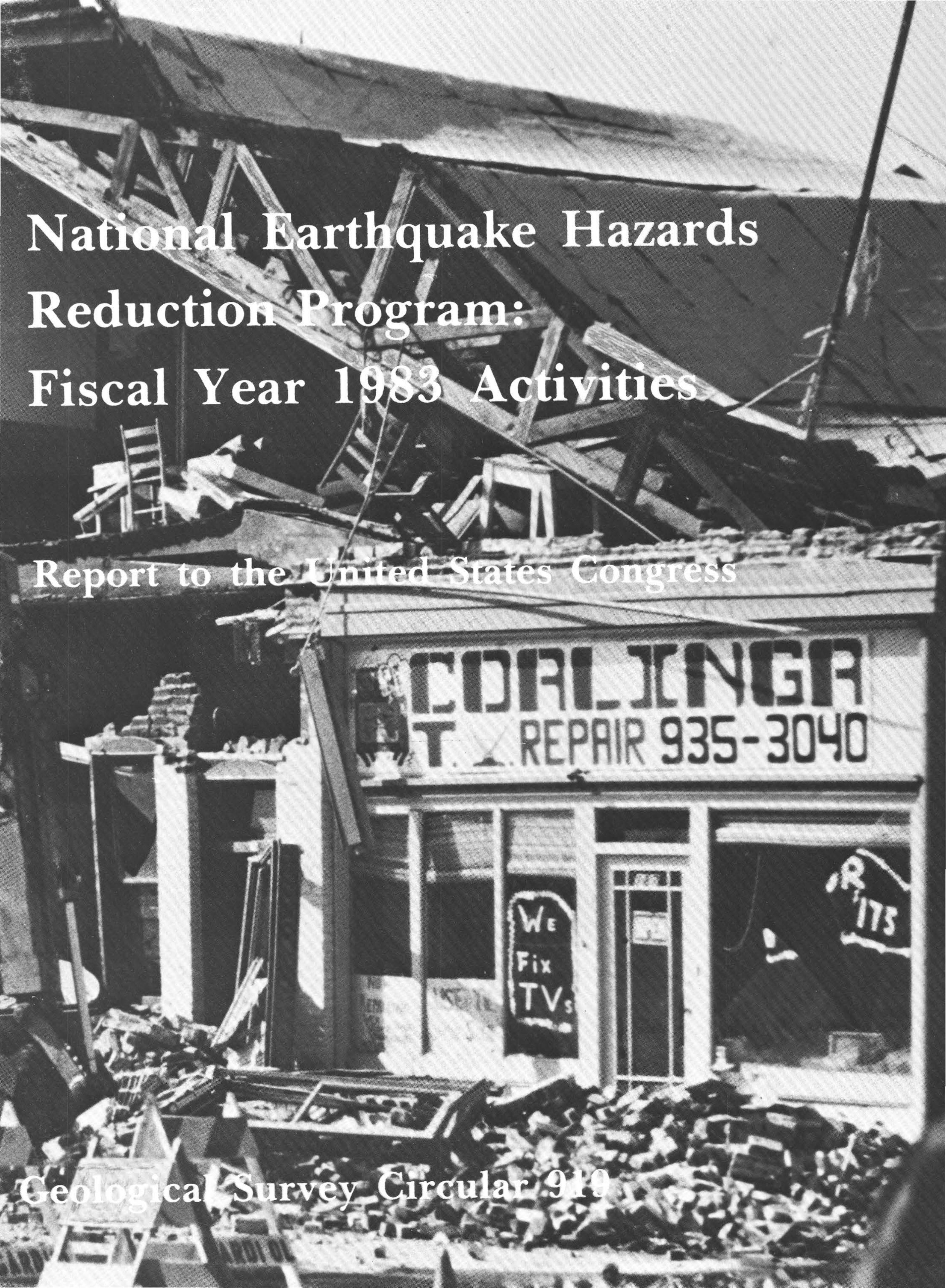
National Earthquake Hazards Reduction Program: Fiscal Year 1983 Activities

Report to the United States Congress



Geological Survey Circular 919

Downtown Coalinga, California, May 1983. A moderate magnitude (M_S) 6.5 earthquake jolted this small oil and farming town at 4:42 p.m., May 2. Most of the town's old unreinforced masonry buildings were severely damaged or collapsed. Almost 200 severely damaged homes had to be demolished. Property losses exceeded $31 million and 47 persons were injured. (Photograph, Volker Corell/Skyline Features.)

National Earthquake Hazards Reduction Program: Report to the United States Congress

Fiscal Year 1983 Activities

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U.S. Geological Survey Circular 919

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Damage in downtown Coalinga, California, resulting from the May 2, 1983, earthquake.

PERSPECTIVES

Shortly before 5 p.m. PDT, Monday, May 2, 1983, central California was rocked by a magnitude (M_s) 6.5 earthquake centered about 8 miles northeast of the small oil and farming town of Coalinga. Intense ground shaking lasting approximately 15 to 20 seconds left much of the town's central business district in ruins and many homes severely damaged. Several fires erupted in the wreckage. Property damage exceeded $31 million. Forty-seven persons were injured, primarily by falling debris.

The earthquake focused renewed attention on the Nation's vulnerability to a damaging earthquake and provided another warning that earthquake safety and disaster preparedness are sound investments. Many of Coalinga's unreinforced buildings, constructed early in the century without earthquake-resistive features, did not survive the earthquake. Relatively newer buildings of reinforced brick or block masonry designed to resist strong earthquake forces performed very well with only minor damage. Simple, inexpensive measures could have prevented much of the damage to the many wood-framed homes that slipped from their foundations. The emergency response by local, county, State, and Federal agencies, planned in advance, worked adequately after the Coalinga earthquake. However, the disaster was very localized, allowing a concentration of resources in a small area. A catastrophic earthquake striking one of the Nation's urban areas would overwhelm emergency response at all levels. Dollar losses in that one earthquake alone could total tens of billions of dollars, and fatalities and injuries could be in the tens of thousands.

In 1977, the United States Congress established the National Earthquake Hazards Reduction Program (NEHRP) to provide a comprehensive, integrated national program to reduce losses of life and property resulting from earthquakes. The Congress recognized that losses and disruption to the individual, the community, the State, and the Nation caused by earthquakes could be substantially reduced through the development and implementation of earthquake hazards reduction measures. The Congress directed the Federal Government to provide a central focus for leading, coordinating, and conducting earthquake research, hazard mitigation, and disaster preparedness. The Federal Emergency Management Agency, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards carry out principal Federal responsibilities for the reduction of losses caused by earthquakes.

There have been significant accomplishments in the NEHRP. Recent developments in the earth sciences have lessened the mystery of earthquakes by providing a better understanding of their nature and effects. Prediction of the size, location, and time of a damaging earthquake is a real possibility. Long-term forecasts of the recurrence of large and great earthquakes in seismic gaps already have proved successful. Considerable progress has been made in understanding earthquake ground shaking and in earthquake-resistant building design and construction. Preparedness and mitigation programs are being developed, coordinated, and implemented at all levels—local, State, and Federal. However, no region of the country is adequately prepared today to face a major earthquake.

The reduction of earthquake hazards is an important national goal. Our agencies will continue to work aggressively as partners in that national effort.

Louis O. Giuffrida, *Director*
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INTRODUCTION

The National Earthquake Hazards Reduction Program (NEHRP) was established by the United States Congress in 1977 to reduce the risks of life and property from future earthquakes in the United States. The Earthquake Hazards Reduction Act of 1977 (Public Law 95-124) directed the President "to establish and maintain an effective earthquake hazards reduction program." The Congress recognized that earthquakes pose perhaps the greatest single-event natural hazard faced by the Nation. An earthquake can affect hundreds of thousands of square miles, can cause damage to property measured in the tens of billions of dollars, can cause loss of life and injury to tens of thousands of persons, and can disrupt the social and economic function of the affected area, and potentially, of the entire Nation. The Congress concluded that losses and disruption caused by earthquakes could be substantially reduced through the development and implementation of earthquake hazards reduction measures.

The Earthquake Hazards Reduction Act of 1977 created the NEHRP and directed the Federal Government to lead, coordinate, and conduct earthquake research, hazard mitigation, and disaster preparedness. In 1978, the President established the Federal program and specified the roles for Federal agencies and recommended appropriate roles for State and local units of government, individuals, and private organizations.

Four agencies—the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), the National Science Foundation (NSF), and the National Bureau of Standards (NBS)—have been authorized funds under the Earthquake Hazards Reduction Act. These four agencies are carrying out principal responsibilities in the NEHRP, as follows:

Leadership and
coordination -------FEMA
Research ------------USGS, NSF, NBS
Mitigation:
Building standards ---FEMA, NBS
Insurance and
financial
protections
and incentives ---FEMA
Hazard identification
and reduction ---USGS
Land use guidance --FEMA
Predictions ---------USGS
Multihazard
coordination
and planning ----FEMA
Federal mitigation,
preparedness, and
response ---------FEMA
Assistance to State and
local governments
and the private
sector -----------FEMA, USGS, NBS
Information
dissemination and
public awareness --FEMA, USGS, NSF, NBS

Other Federal agencies participate in the NEHRP. Most are represented on the Interagency Committee on Seismic Safety in Construction (ICSSC), which is developing mitigation measures for implementation in Federal design, construction, leasing and financing, and regulatory activities. Several agencies have responsibilities within their programs for design, construction, operation, maintenance, and regulation of critical facilities, including dams, hydraulic structures, nuclear reactors, liquid natural gas plants, storage facilities for explosive and hazardous materials, hospitals, and lifelines, such as transportation routes and facilities, energy transmission facilities, water supply systems, sewage disposal systems, and communications systems. One agency operates a tsunami warning system and, along with another, contributes basic data on crustal movements that cause earthquakes. Many agencies have cooperative foreign programs; one agency provides aid and assistance to earthquake-stricken countries.

This *Report to the United States Congress* highlights Federal activities during fiscal year 1983 in the NEHRP. The report includes chapters prepared by 14 Federal agencies describing their activities and accomplishments during the fiscal year and a year-end program evaluation prepared by FEMA. The reports of the four principal agencies receiving authorization under the Act are presented first, followed by the reports of agencies contributing to the NEHRP in various program areas. A companion volume to this fiscal-year activities report (*National Earthquake Hazards Reduction Program, Report to the United States Congress, Overview*) provides a review of the earthquake problem in the United States and a description of the NEHRP that was established to reduce and mitigate that National hazard.

Earthquake damage in Coalinga, California.

FEDERAL EMERGENCY MANAGEMENT AGENCY

As the lead agency for the NEHRP, FEMA is responsible for governmentwide and nationwide program planning, direction, and coordination and for stimulation of actions needed to reduce earthquake hazards. Under its own enabling authorities and in support of the NEHRP, FEMA also is responsible for coordinating Federal emergency management activities (preparedness, response, recovery, and mitigation) for all types of disasters—natural and manmade—and for providing technical and financial assistance to the States and local communities in carrying out their preparedness, response, recovery, and mitigation programs. Included in FEMA's mitigation responsibilities are the evaluation and recommendation of mitigation incentives and mechanisms needed to protect the individual, community, State, region, and Nation against the risk of financial loss and economic disruption associated with a catastrophic earthquake. When a major disaster or emergency is declared by the President, FEMA administers Federal assistance to the State(s), affected local governments, and individual victims and coordinates the disaster relief efforts of other Federal agencies and volunteer organizations.

MANAGEMENT AND COORDINATION

During fiscal year 1983, FEMA continued to strengthen the coordination and management mechanisms within the NEHRP and to ensure that it meets the goals set forth in the Earthquake Hazards Reduction Act of 1977, as amended. Specifically, FEMA has

- Established the Policy Review Board, composed of top policy-level officials of the four principal agencies, to provide guidance on overall program policy issues and to oversee the NEHRP planning, budgeting, and evaluation processes;

- Submitted the Five-Year Plan (prepared in fiscal year 1982) and the Ad Hoc Panel's review comments and recommendations to the Office of Management and Budget (OMB) for consideration, with an endorsement of the Panel's recommendations;

- Restructured and revitalized the ICSSC, establishing its responsibilities under the Interagency Coordination Committee (ICC), with a permanent chairman, a steering committee, a charter, and statements of work for each of the 4 new subcommittees (replacing the 10 previous subcommittees);

- Initiated discussions toward establishing an NEHRP "secretariat" within FEMA to assist in FEMA's review, evaluation, coordination, and reporting functions; and

- Sought State interest for establishing an association of State officials involved in earthquake hazards reduction to provide a forum for the States to exchange information on techniques and programs and to stimulate earthquake hazard reduction programs at the State and local levels and initiated a grant for a national conference on this matter to be held in Seattle in fiscal year 1984.

FEDERAL EMERGENCY MANAGEMENT EFFORTS

One of the primary responsibilities of the Federal Government is to ensure that its own resources are prepared to meet, withstand, and respond to a catastrophic earthquake disaster situation. This responsibility includes its own vulnerability assessment to protect national security capabilities and to ensure economic stability and the continuation of communications and lifelines; its own preparedness and response programs; and its own mitigation programs, including programs to develop techniques, to provide incentives, and to protect the well-being and economic security of the Nation.

Impact Assessment

In late 1980, FEMA was requested by the National Security Council (NSC) to measure the effects of a major earthquake in California on the economy of the State, the region, and the Nation. Although this project is being conducted as part of a joint Department of Defense (DOD)–FEMA program to protect national security capabilities and to assess the economic impacts of catastrophic California earthquakes, the techniques developed and information obtained are transferable to the NEHRP for preparedness planning and mitigation programs.

Utilizing a draft report prepared for the NSC summarizing the relative importance to the U.S. economy of industries and other resources at risk in 21 California counties, a modeling effort was initiated by FEMA to estimate the local, regional, or national economic impacts of a major earthquake event in the area. Considerable progress has been made in designing, developing, identifying, and employing new and existing analytical capabilities that permit detailed simulations to be made of the damages and related losses and the economic and industrial impacts of major earthquakes in the high- and moderate-risk areas of California, on a county-by-county basis. This new methodology concentrates on a significant number of economic sectors and specific types of activities determined to be critical to the economic well-being of the State, the region, and the Nation. The results of this analysis can suggest appropriate protective and response measures needed to reduce the impacts, including the formulation of standby arrangements for the diversion of essential goods and services from other risk areas such as other western regions, the Central United States, and east coast areas.

Contracts have been let to provide data from which FEMA is developing the model and to conduct computerized damage and casualty analyses for several catastrophic California earthquakes. The hypothetical earthquakes to be simulated will be located both in northern and southern California. Contracts also have been let to complete the development of and to conduct detailed computerized analyses of economic and industrial impacts for the hypothetical California earthquakes. These computerized techniques could be applied to evaluate damages and economic effects of a real major earthquake should one occur. The results of this simulation effort will be used to prepare reports delineating the effects of major California earthquakes on the economies of the State, the region, and the Nation.

Federal Response Planning

During fiscal year 1983, FEMA continued to coordinate the development of a national comprehensive plan which involved the entire Federal establishment in planning for immediate response to a catastrophic earthquake in any area of the country. The Subcommittee on Federal Earthquake Response Planning, formed under the NEHRP ICC, serves as the coordinating body of the planning effort and meets during the year as necessary to resolve issues and provide guidance to the Federal agencies required to participate in the development of the Federal Plan.

As a result of the efforts of the subcommittee, a draft *Planning Guide* was developed which established a framework for the plan development. The *Guide* describes the concept of operations, planning assumptions and policies, and roles and responsibilities assigned to Federal agencies participating in the planning development. Extracts from the *Guide* were published as a notice in the *Federal Register* of March 4, 1983, to initiate preparation of the National Federal Plan for Response to a Catastrophic Earthquake. Comments received after publication of the notice were considered and incorporated in the final version of the *Planning Guide*, which was published in May 1983.

The *Planning Guide* will serve as an interim operating plan for response by Federal agencies to a catastrophic earthquake prior to the completion of the Plan. Proposed assignments and responsibilities (as of the end of fiscal year 1983) for completion of the Emergency Support Functional Annexes, which comprise the Plan, are indicated on the matrix. Planning groups for each of these emergency support functions were formed and will be responsible for drafting annexes describing Federal support to the State and local

Proposed assignments by department and agency and primary and support roles (at end of fiscal year 1983).

ESF	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FEDERAL AGENCIES															
* USDA	S	S	S	P		S	S		S		S	S	P	S	S
DOC		S			S	S					S				
* DOD	S	S	S	S		S	S	S	P	S	S	S	S	S	S
DOEd			S			S						S			S
* DOE		S	S			S					S	S			
* HHS	S		S		S	S	S	P		S	S	S		P	S
* DOI	S	S	S	S		S	S		S		S	S			S
DOJ					S	S				S					
* DOL			S			S	S				S				
* DOT	P	S	S	S		S			S		S	S		S	
* ARC					P	S		S					S	S	P
* COE			P			S					S	S			
EPA			S			S					S	S		S	
FCC		S				S									
* FEMA	S	S	S	S	S	P	S	S	S	P	P	P	S	S	S
* GSA	S	S	S	S	S	S	P	S		S		S	S	S	S
ICC	S					S									S
NASA		S				S						S			
* NCS		P				S					S				
NRC						S					S	S			
USPS	S				S	S	S								S
* VA						S	S	S		S	S	S	S	S	S

P—Primary agency responsible for performing the function and/or responsible for the necessary planning to assure that the function will be accomplished.

S—Agency responsible for supporting the primary agency in planning for and participating in the accomplishment of the function.

Emergency Support Functions

1. Emergency Transportation (Surface, Water, Air)
2. Communications
3. Emergency Debris Clearance/Temporary Restoration of Essential Public Facilities and Services
4. Wildland Fire Suppression
5. Welfare Inquiries
6. Coordination of Federal Response
7. Logistical Support
8. Emergency Medical Care
9. Search and Rescue
10. Mortuary Services and Identification of the Dead
11. Technical Assistance
12. Damage Reconnaissance and Assessment
13. Emergency Distribution of Food
14. Public Health
15. Mass Care

*Subcommittee on Federal Earthquake Response Planning governments affected by a catastrophic earthquake.

Based on the number of Federal agencies involved and the complexity of the overall plan objectives, contractor support was initiated to ensure effective plan development, to assist in conduct of a headquarters exercise to test the feasibility of the National Federal Plan, and to help initiate development of a full-scale exercise to test national and Federal regional interfaces in response to a catastrophic earthquake in California.

To continue the coordinated national-regional planning efforts, a second planning forum to discuss issues, problems, and next steps was held in May 1983 between FEMA headquarters and Region VII, VIII, IX, and X Offices. The forum was useful in establishing that the regions will be involved with the same number of agencies as the national Federal planning effort. In addition, the regions have a direct relationship to State and local planning and subsequent exercising that should be supported by the Federal Government. To continue the necessary national-regional interface at the Federal level, additional forums are planned for headquarters and regional office staff members on an annual basis.

Mitigation

Interagency Committee on Seismic Safety in Construction

During fiscal year 1983, the ICSSC provided technical advice and participation in various committees of the non-Federal Building Seismic Safety Council (BSSC), began planning on postearthquake response and mitigation measures that could be used by Federal officials in Federal recovery efforts, reviewed the draft seismic standard for Federal buildings (issued in 1981) for possible update, and published several reports.

Financial Protection Mechanisms and Mitigation Incentives

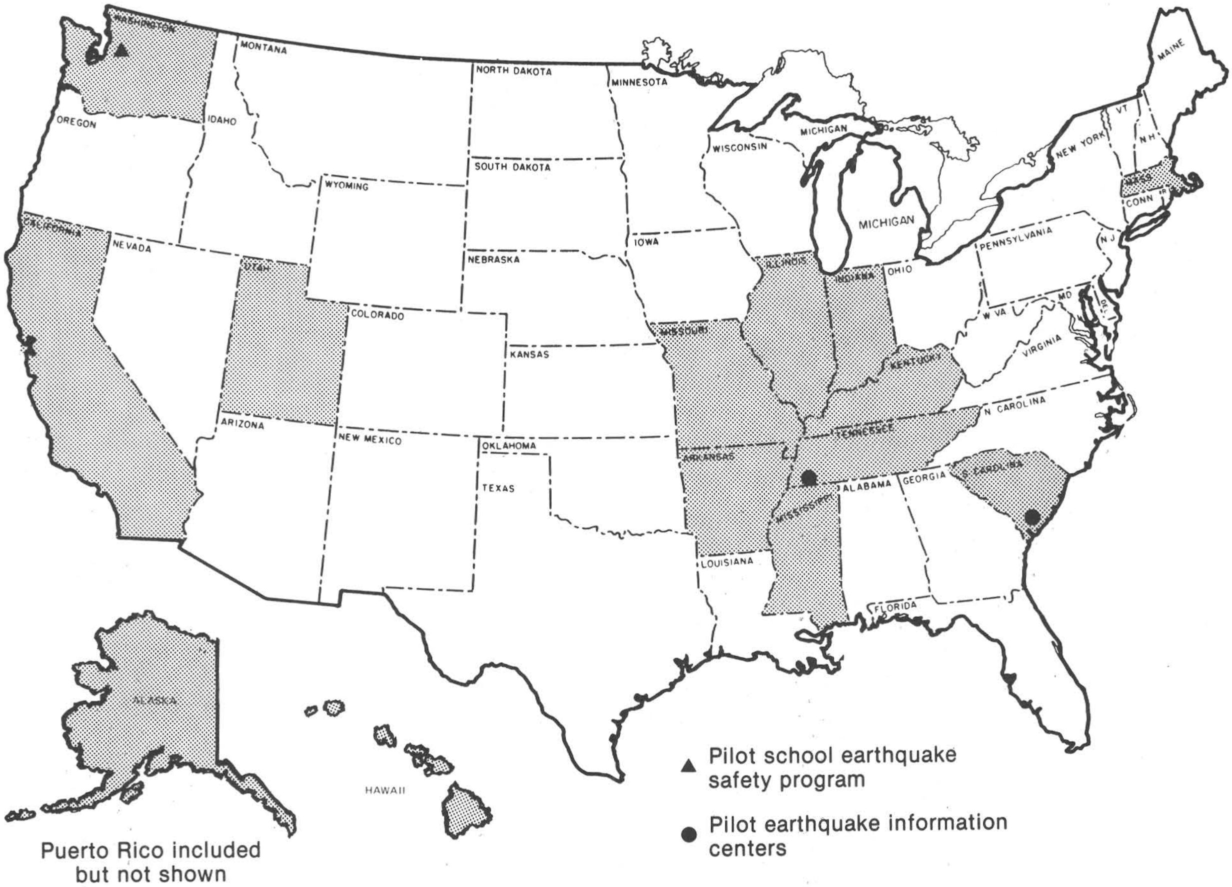
The purchase of earthquake insurance is a recommended means by which property owners in areas of seismic risk can obtain financial protection as warranted by the risk of loss. However, based on the findings of a study completed in fiscal year 1982 and presented in the fiscal year 1982 *Report to the Congress*, FEMA does not feel that Federal involvement is required or that mandatory purchase requirements are necessary at this time.

Public Awareness and Education

During fiscal year 1983, FEMA has provided funding to the U.S. Geological Survey (USGS) in support of a series of workshops for public officials at all levels, scientists and academicians from various disciplines, and representatives of various parts of the private sector to learn more about seismic hazard, to discuss technical issues, to consider present and future actions to reduce earthquake hazards, and to make recommendations regarding program needs and direction. The workshops for which FEMA provided support were held in Charleston, South Carolina, Boston, Massachusetts, and Little Rock, Arkansas, with each focusing on the seismic risks in the area and plans to lessen them. This informative and productive ongoing series has provided a significant contribution to the NEHRP information dissemination and outreach to State and local governments and to the private sector.

ASSISTANCE TO STATE AND LOCAL GOVERNMENTS

In addition to coordinating Federal preparedness and mitigation activities, FEMA provides technical and financial assistance to States and local communities in all segments of emergency management (hazard awareness, assessment, preparedness, mitigation, response, and recovery) for all types of disasters (natural and manmade). To ensure effective emergency management programs at all levels, FEMA continually draws on research being developed or sponsored by other Federal agencies in fundamental studies of physical phenomena, hazards delineation, mitigation measures such as construction techniques, and societal response and socioeconomic impacts associated with hazards preparedness, response, and mitigation. With the exception of Federal lands and properties, emergency management is a



States (shaded) to which the Federal Emergency Management Agency provided technical and financial assistance during fiscal year 1983 in support of State and local earthquake hazards reduction efforts.

State and local government responsibility, with the Federal Government providing supplementary assistance in support of State and local efforts and capabilities in major disaster or emergency situations beyond State and local resources. Federal assistance in hazards awareness, preparedness, and mitigation, however, is provided to assist States and local communities in high- to moderate-risk areas reduce future losses and casualties. These programs are ongoing and cover a variety of hazards, including earthquakes. Increasingly, such programs are developing an integrated, multihazard approach, which is more comprehensive and cost-effective. The following assistance, covering the full range of emergency management activities, was provided in support of State and local programs during fiscal year 1983.

Disaster Assistance—Coalinga, California

Based upon a request received from the Governor of California for assistance to Coalinga and FEMA's evaluation of the situation, it was recommended that Federal assistance be provided; and, on May 5, 1983, 3 days after the event, the President declared a major disaster under the authorities of the Disaster Relief Act. A disaster field office was opened in Coalinga to provide individual and public assistance, to coordinate Federal response and assistance efforts, and to serve as a Federal information center. Mobile homes were brought in to provide temporary housing to supplement the temporary accommodations made available by the community. Following the immediate response period, the city began its recovery process, which is now well underway. However, although reconstruction is occurring, aftershocks continue to indicate the need for earthquake-resistant construction and other mitigation measures during recovery. FEMA continues to assist the community during this recovery and mitigation period and to discuss community reconstruction plans with the City Manager and the City Planner.

Because the earthquake was limited to the immediate area of Coalinga, it, while significant, was not considered to be catastrophic in terms of its Richter magnitude or degree of impact. Under the provisions of the Disaster Relief Act of 1974 (Public Law 93–288), the Governor of an affected State must request Federal assistance through a Presidential disaster declaration. To ensure that Federal resources are available during the immediate response to a catastrophic earthquake, the National Federal Plan presently under development will provide for an expedited declaration process.

Emergency Information and Coordination Center

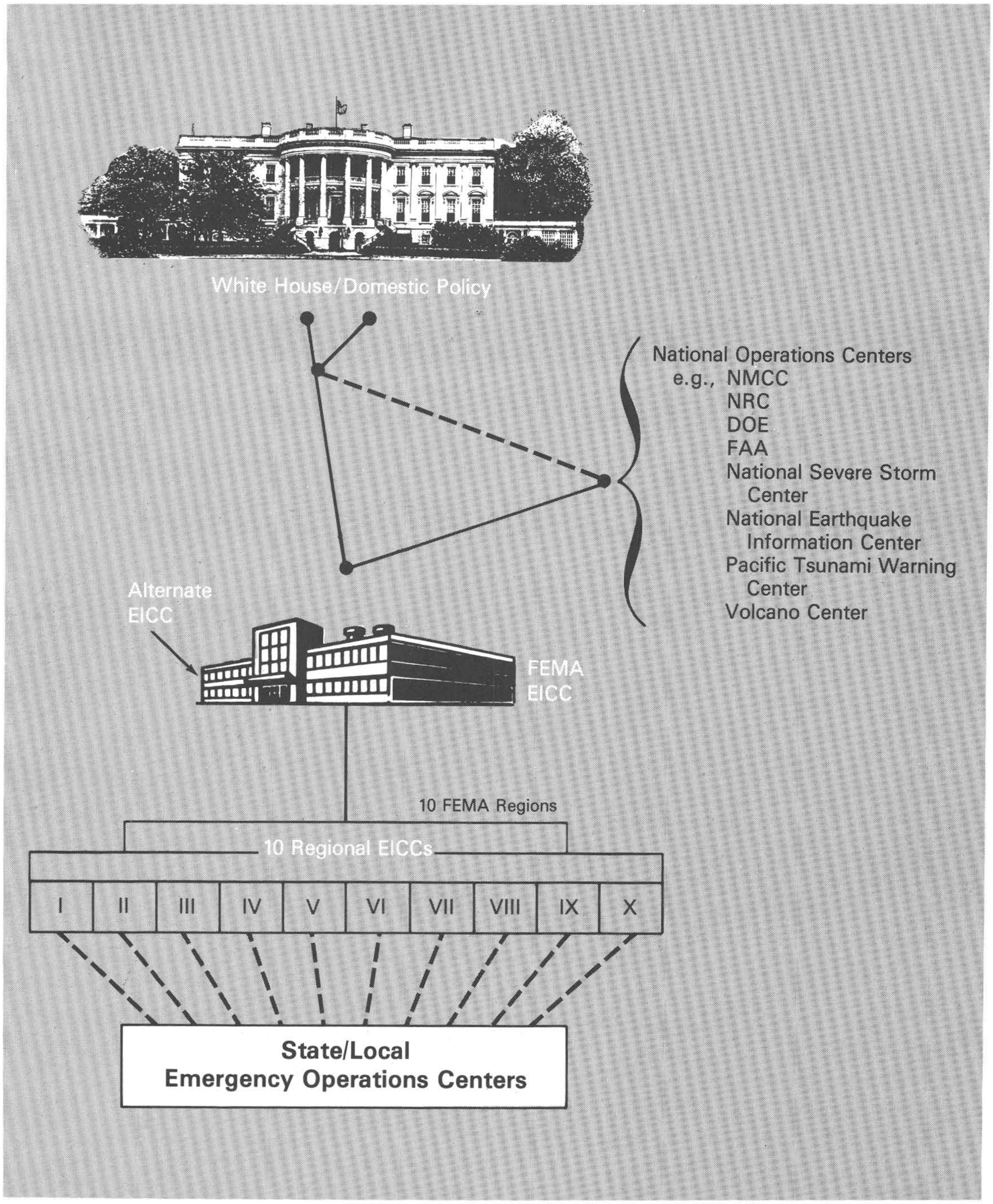
FEMA's Emergency Information and Coordination Center (EICC) provides emergency management authorities throughout the Nation with around-the-clock information, data, and facilities for making accurate and timely decisions, including the communications required for rapid and reliable transmission of those decisions in peace and war. During fiscal year 1983, the EICC supported information and coordination activities for 212 technological hazard emergency or disaster situations and 323 natural hazard emergency or disaster situations (including 87 earthquakes), of which 20 involved Presidential disaster declarations.

Emergency Information and Coordination Center support activities for fiscal year 1983, by event

Event	Number
Technological hazards:	
Radiological events	126
Hazardous materials incidents	72
Fires and (or) explosions	4
Airplane crashes	5
Terrorist incidents	5
Total	212
Natural hazards:	
Earthquakes	87
Volcano activity	8
Tornado warnings and (or) touchdowns	103
Flash flood and (or) mudslide activities	72
Tropical storm and (or) tropical depression activities	28
Hurricanes and typhoons	21
Severe winter storm and (or) blizzard activities	4
Total	323
Requests for Presidential Declarations:	
Gubernatorial requests	55
Major disaster declarations	20
Emergency declarations	0
Total	75

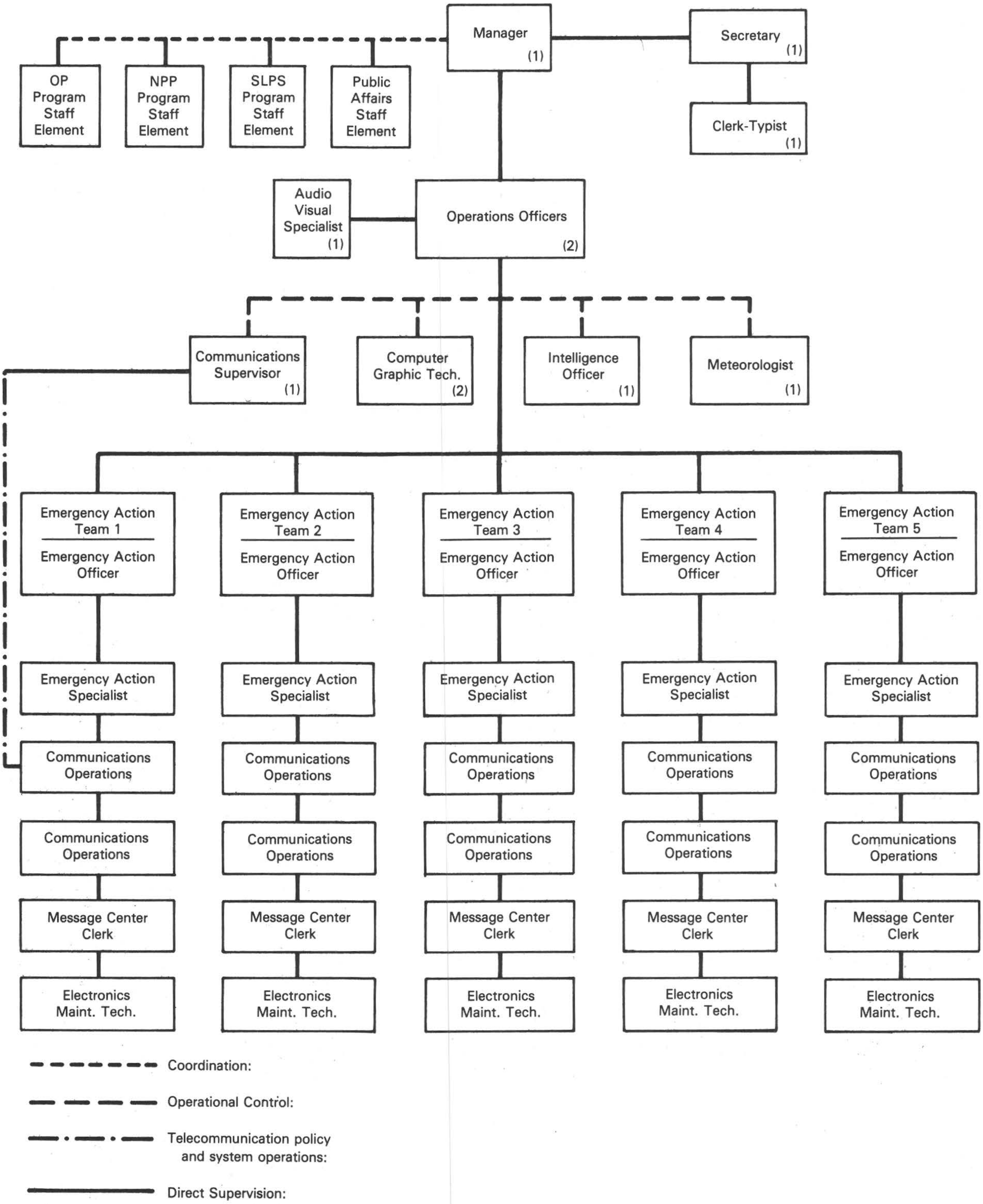
As a natural disaster or emergency situation develops, the EICC receives information from the National Severe Storm Center in Kansas City, the Hurricane Center in Tampa, the National Earthquake Information Service (NEIS) in Golden (Colorado), the Pacific Tsunami Warning Center (PTWC) in Hawaii, or the Cascades Volcano Observatory in Washington State. Information on one or more of such emergencies or disasters is passed on to emergency action teams at the EICC and communicated to and coordinated with the National Operations Centers of the pertinent Federal agencies, the White House, and the pertinent FEMA Regional Offices and State and (or) local Emergency Operations Centers. Each emergency action team includes an emergency action officer (EAO), emergency action specialist, communications operator for coordination and operational control, a message center clerk, and an electronics maintenance technician. Program staff personnel assist the EAO as needed.

For example, on May 2, 1983, at 8:10 p.m. EDT, the NEIS reported over the National Warning System (NAWAS) that an earthquake of magnitude 6.5 occurred in central California (near the town of Coalinga) at 7:43 p.m. EDT. Immediate notification procedures were initiated and all pertinent individuals and (or) agencies had been notified by 9:35 p.m. EDT. The Governor declared Fresno County a disaster area, and, during the following 24 hours, the EICC staff continued to collect data and monitor the situation with FEMA Region IX



The National Emergency Management Network of the Emergency Information and Coordination Center, Federal Emergency Management Agency.

and the California Office of Emergency Services. On May 4, 1983, the Governor's request to the President for a major disaster declaration was transmitted through the EICC, and on May 5, 1983, the President declared a major disaster for the State. EICC staff coordinated with the Federal Coordinating Officer for the disaster in obtaining additional personnel from outside Region IX in support of the Disaster Field Office Operation.



Operational and organizational structure of the Emergency Information and Coordination Center.

Other fiscal year 1983 activities related to EICC operations included a meeting of approximately 100 representatives of Federal agencies and disaster relief organizations in September 1983 to develop a realistic understanding of each agency's capabilities and limitations in emergency communications and coordination facilities to develop an information exchange system that ties all operations centers together and provides support or focus in meeting a national emergency, maximizing the use of available Federal resources in support of unilateral or collective actions.

Hazard Awareness and Education

During the past year, FEMA began discussions with the USGS and the American Red Cross (ARC) concerning the development, review, and field use of informational materials. Educational materials developed around the country in public and private sectors were reviewed. A series of model print materials designed for community use and adaptation were designed. This series includes brochures on home safety checklists, hazard hunts, family earthquake drills, awareness posters, and so forth, which will be pilot-tested in fiscal year 1984. Additionally, two portable exhibits have been developed for community outreach activities of regional, State, and local personnel. Work has begun on a cooperative production of television public service announcements with the ARC. Slides and other visual materials also are being developed for community use. These materials were modifications of existing products developed by individuals and groups in California, and discussions were held with personnel from the Southern California Earthquake Preparedness Project (SCEPP) to draw on their experience in this area.

FEMA also has developed a system that would reduce the confusion and chaos engendered by the electronic media in the event of a catastrophic earthquake. In addition to the Federal response plan for such an earthquake, this prototype system is designed to be applicable to any catastrophic emergency or disaster in any part of the country. Basically, a predeveloped Joint Information Center (JIC) would serve as a central clearinghouse for all disaster information as well as the center for ongoing press briefings by decisionmakers. FEMA is in the process of acquiring state-of-the-art communications and information support hardware for a standby JIC kit for joint use by FEMA Region IX and the California Office of Emergency Services and is planning a series of workshops on the system for information officers throughout the fault areas of the State.

FEMA also will be providing earthquake information along with information on other hazards in support of multihazard education programs, to include a series of Emergency Information Exchanges concerning the application of strategies at the State level; a grant to the Children's Television Workshop, producer of TV's *Sesame Street*; and a series of competitive challenge grants to stimulate local public information demonstration projects.

In addition, FEMA established the framework for a community-oriented earthquake hazards awareness and education program to enhance the knowledge and understanding of various societal groups regarding earthquake phenomena and risks and to encourage adoption of hazard reduction measures by the community and individuals. During fiscal year 1983, program activities in this area focused on transferring information and experience gained from SCEPP and incorporating information and recommendations provided by societal researchers regarding community outreach programs. Specifically, these activities included the following:

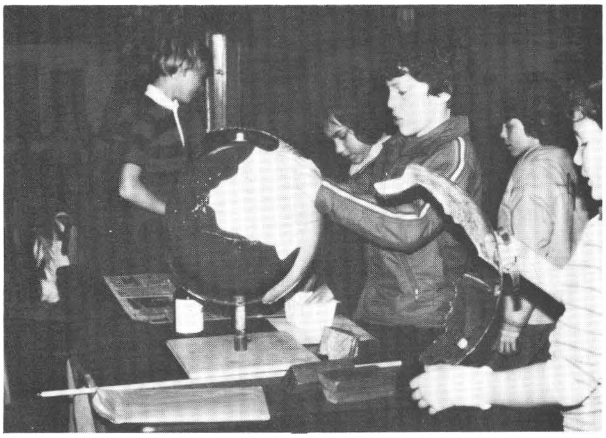
The first in a series of special-topic courses on hazard mitigation was field-tested in the San Francisco Bay area in April 1983. This course, entitled "Earthquake Hazard Mitigation for Utility Lifelines," provides city and county public works directors and engineers with information on how to (1) assess the potential impact of earthquakes on utility systems (gas, water, sewer, electric power), (2) lessen the effects of ground shaking on critical components of these systems, and (3) develop procedures to hasten system recovery following an earthquake.

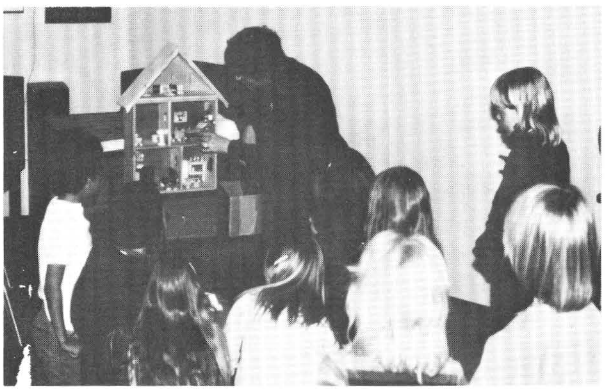
In August 1983, FEMA awarded funds to support two pilot Earthquake Education Centers (EEC's)—one at the Baptist College in Charleston, South Carolina, and the other at the Tennessee Earthquake Information Center in Memphis, Tennessee. These institutions, which have been monitoring seismic networks, are viewed by the scientific community, State and local emergency managers, the media, and the public as authoritative providers of earthquake information (a major selection consideration). These EEC's will provide a wide range of products and services to individuals, families, neighborhoods, schools, and businesses as well as offer opportunities for community members to participate in project development and implementation. These community-oriented EEC's will

- Recruit and train community outreach volunteers,
- Modify existing products and develop new items to address seismic risk in the study area and tailor materials to user styles and levels of knowledge,
- Establish a speakers' bureau,
- Maintain a collection of printed and audiovisual materials for volunteer and teacher use, and
- Develop mechanisms for tracking product dissemination and evaluating the effectiveness of products and services.

In September 1983, FEMA awarded funds to the State Seismologist, University of Washington, to initiate a comprehensive earthquake safety and education program for schools in Seattle, Washington. This project is designed to improve the students' knowledge and understanding of earthquake causes, effects, hazards, and preparedness and mitigation measures and to reduce the vulnerability of the school population to the life-threatening consequences of future earthquakes. The education component of this project will utilize the earthquake curriculum program developed by the Environmental Volunteers in northern California. This program, which includes a comprehensive kit of teaching aids and a training workshop for volunteers and professional teachers, was used this past year by SCEPP as a model program for schools in San Bernardino County. The earthquake safety component will emphasize the need for earthquake drills, will provide preparation and simulation activities, will describe how to assess and mitigate potential life safety hazards (for example, hanging light fixtures, bookshelves, equipment) in school buildings, and will provide guidelines for involving administrators, teachers, parents, and students in developing response and short-term shelter plans. Additional components will address fire safety, first aid, and light search and rescue training as well as provide recommendations for earthquake preparedness and mitigation activities for the home.

In support of its preparedness and mitigation efforts, Alaska has produced brochures on tsunamis, coloring books and posters for use in school programs on earthquake and tsunami hazards specific to the risk area, and





School-based earthquake hazards awareness and education program. *A*, Students are learning about plate tectonics. *B*, Instructors are teaching about home hazards and mitigation measures.

a slide presentation demonstrating correct safety procedures in an earthquake event. Although these materials are directed primarily toward school programs, they are available for community public awareness and education programs as well.

Assistance to State and Local Mitigation Programs

Mitigation is the key to earthquake hazards reduction and, therefore, is the focus of the NEHRP. Lessening the impact of a hazard on property reduces property losses and injury or loss of life resulting from falling debris and structural damage to residential or nonresidential edifices, critical facilities, or lifelines. Unfortunately, however, mitigation at the State and local level is often the phase of disaster assistance most frequently neglected. During fiscal year 1983, FEMA continued to provide financial and technical assistance to the States and local communities in support of their earthquake hazards reduction efforts.

Building Seismic Safety Council

FEMA provides funding to the BSSC, which also receives technical guidance from the NBS. The BSSC has been analyzing and resolving the complex technical, social, economic, and public and private jurisdictional issues of building regulations to facilitate the development and use of consensus seismic codes, standards, and practices. In 1982, under contract to FEMA, the BSSC began a trial design effort to estimate the economic impact that various sectors of the building community would experience in applying refined tentative provisions developed by the Applied Technology Council (NBS SP–510, 1978); to evaluate the applicability (relevance, completeness, practicality, clarity) of the provisions for designers, builders, and regulatory officials; to establish the technical validity of the provisions; to provide information for use in the resolution of future disputes concerning the provisions; and to provide information for use in transferring the provisions to components, building types, and locations not specifically investigated. Phase 1 of the contract, completed in fiscal year 1983, consisted of trial designs of 27 buildings of different design, construction, and occupancy in Los Angeles, Seattle, Phoenix, and Memphis. Phase 2 includes 20 additional buildings in New York, Chicago, St. Louis, Fort Worth, and Charleston. As many as 10 more buildings are expected to be analyzed in a similar manner through voluntary contributions to the effort from the private sector.

Coalinga Recovery

In response to the Coalinga, California, earthquake, representatives of various Federal agencies were convened under the auspices of FEMA to investigate what mitigation actions could be taken in the postdisaster context and as part of the restoration and recovery of the community to reduce Coalinga's vulnerability to future earthquakes. Under the sponsorship of FEMA, a full-time coordinator is working in the community to achieve this goal.

Assistance to State and Local Preparedness Programs

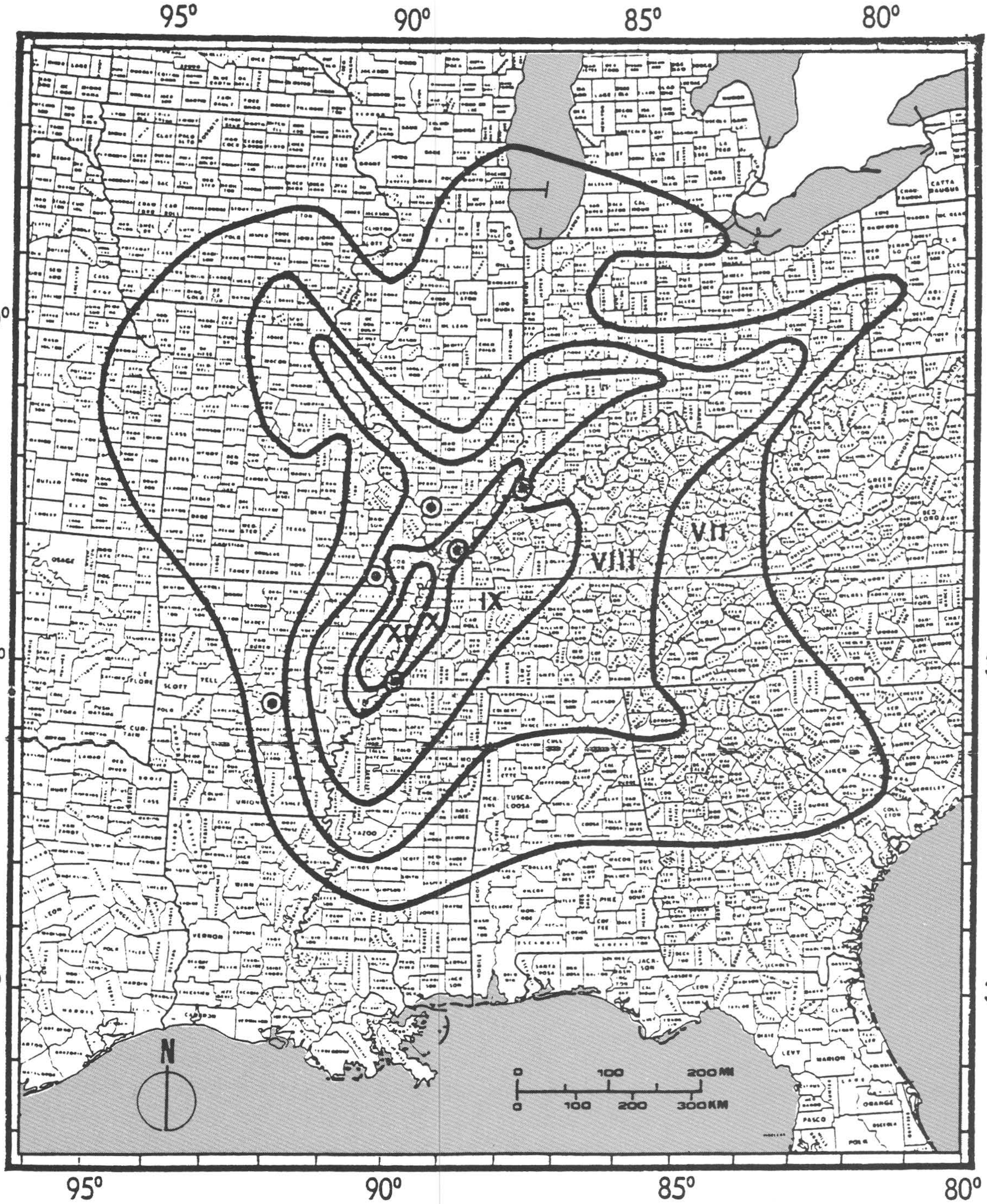
FEMA assistance to State and local earthquake preparedness programs focuses on the preparation of response plans that address the extraordinary problems caused by major earthquakes in high-risk, high-population areas.

Earthquake response planning follows a logical sequence of tasks. From assessments of past and potential seismic activity in the area, vulnerability analyses (loss studies) are made to estimate primary and secondary earthquake effects, the numbers of possible casualties and injured requiring hospitalization, and potential damage to critical and (or) special facilities and lifelines needed for immediate response.

Using data from the analyses, FEMA assists State and local governments in determining the resources required for lifesaving and other emergency operations and in developing response plans. The plans include implementation measures, such as guidelines, procedures, and specific assignments. The final phase of the planning efforts consists of scheduled training exercises.

Central United States

During fiscal year 1983, the USGS completed its report on the estimated effects of a catastrophic earthquake in the New Madrid seismic zone. The report presents estimates of the magnitude, probability of occurrence, and location of an 1811-type earthquake and the levels of damaging ground motion and intensities. A vulnerability analysis of six pilot



Regional intensity map for a potential 1811-type earthquake having an epicenter along the New Madrid fault. Dots indicate the six pilot cities in the vulnerability analysis.

cities (Carbondale, Illinois, Evansville, Indiana, Paducah, Kentucky, Memphis, Tennessee, Little Rock, Arkansas, and Poplar Bluff, Missouri), based on the USGS hazard assessment, was conducted in fiscal year 1983 to provide assessments of potential damage and casualties resulting from such a catastrophic earthquake event. Based on the initial results of this vulnerability analysis, which is under review, and on studies performed in California, a methodology is being developed to conduct a more extensive vulnerability analysis and assessment of the Central States (Kentucky, Tennessee, Missouri, Illinois, Indiana, Mississippi, and Arkansas) with seismic zones of intensity [Modified Mercalli (MM)] IX and above.

Other Central U.S. activities included the following:

- Initiation of a formal report series, including an annotated index of all reports published each year;

- Development of a State Earthquake Safety Program to develop a comprehensive seismic safety program covering the goals, objectives, and schedules of all States within the high- to moderate-risk area of the Central United States;

- Development of a Central U.S. Earthquake Consortium of the seven States in the MM IX and above zones to ensure a coordinated and unified program for achieving their mutual goals and objectives regarding earthquake preparedness and mitigation;

- Creation of a Technical Advisory Panel, composed of scientists, emergency managers and planners, behavioral scientists, seismologists, and engineers, to review reports and to provide advice to the States on policies and contract products; and

- Development of a report on the status of Federal, State, and local seismic codes and ordinances in the seven-State area within the Central United States.

Southern California

During fiscal year 1983, SCEPP developed and produced the following:

- Prototype plans for a county, a small- to mid-sized city, a high-rise office work site, and a community-based organization;

- Public information campaign strategies and materials;

- Los Angeles prediction response plan;

- Preparedness guidelines for small businesses;

- Preparedness information for persons with disabilities;

- A model recovery plan; and

- Research information on legal liabilities, disaster assistance capabilities, and insurance availability.

Based on several research projects on the seismic resistance of masonry structures, the city of Los Angeles adopted an ordinance requiring the strengthening of old, hazardous buildings wherever economically feasible or the demolition of such structures. Building owners were given 10 years in which to comply with the new ordinance. In other mitigation efforts in southern California, a pilot data base and study design were tested in San Bernardino County, an area having diverse conditions and land uses and a potentially high risk. The final results and lessons learned through this test will be used to develop a complete regional system.

Additional funding was provided by FEMA to extend for 1 year the SCEPP efforts for continued preparedness projects; to transfer expertise, products, and planning processes to other cities, States, and regions with high to moderate seismic risk; to conduct conferences and workshops with the five-county planning area of southern California; to train local community planners in incorporating the prototype plans for jurisdictional high-risk areas; to initiate an active earthquake education and information outreach program, transferring materials and functions to a regional entity in southern

California for long-term information dissemination effort; to develop a large-city prototype preparedness plan and data base for emergency planning and recovery; and to develop a regional data base for earthquake planning, warning system (based on predictions), and communications system in conjunction with the USGS.

San Francisco Bay Area

In fiscal year 1983, FEMA initiated a cooperative agreement with the California Seismic Safety Commission (CSSC) to develop an adequate preparedness and mitigation program in the nine-county San Francisco Bay area. The project, expected to be completed in about 5 years, involves three State agencies—the CSSC, the Office of Emergency Services, and the California Division of Mines and Geology (CDMG). The project will utilize products developed by and experience gained through SCEPP.

San Diego

During fiscal year 1983, FEMA also initiated a grant to the CDMG to evaluate the risk and probable level of damage associated with seismic activity on the Rose Canyon fault system in San Diego. The study will provide information regarding (1) the probable risk and magnitude of maximum earthquake, (2) a definition of the area likely to be impacted, (3) the expected rate of return of a damaging earthquake, and (4) an estimate of damage to structures, facilities, and the economy of the San Diego metropolitan area. The information obtained will provide the basis for computerization of mapping, trenching, and geophysical data relating to movement and activity along the Rose Canyon fault zone to ensure maintenance and update for future earthquake planning.

Hawaii

The State of Hawaii has completed its Earthquake Response Planning Guide and distributed it to Federal, State, local, and private agencies concerned with earthquake planning and preparedness. Distribution of the plan will be followed by the development of county response plans focusing on local preparedness, response, mitigation, and recovery activities and on exercises to test and refine the State response plan. An education and information program also will be developed to familiarize residents with the particular hazards that exist, the response plans, mitigation measures, and so forth.

Puget Sound

A Five-Year Plan was developed and further research of and coordination with other earthquake project areas was conducted to identify needs and to assess priorities as the preparedness program in this area is strengthened.

Alaska

Because tsunamis are a major part of the earthquake threat along Alaskan coastal areas, earthquake hazards preparedness and mitigation programs include both hazards. Tsunami safety zones have been delineated for 15 communities and will be indicated on maps showing earthquake hazards. Emergency instructions and information on tsunami warning signals will appear on the maps as well.

Charleston, South Carolina

A vulnerability analysis for Charleston (including Berkeley and Dorchester Counties) was initiated in fiscal year 1983 by the State of South Carolina in conjunction with a recently launched State seismic program and with support from FEMA. This study will provide information for use in the development of Federal, State, and local plans for hazard awareness, preparedness, and mitigation programs within the area.

Boston, Massachusetts

During fiscal year 1983, eastern Massachusetts isoseismal mapping and the attendant summary report were completed. In fiscal year 1984, a comprehensive Earthquake Vulnerability/Loss Study will be initiated for eastern Massachusetts. A New England Seismic Safety Council will be established in fiscal year

1984 as a regional body to promote seismic hazard awareness, research, improved structured design practices and disaster preparedness programs.

Multihazard Emergency Management

In discussing FEMA's initiatives in multihazard emergency management, it is appropriate first to discuss FEMA's basic operational approach within the agency. FEMA has reviewed its experience with the full range of programs which it manages and for which it has a coordinating role among other Federal agencies with preparedness, mitigation, and response responsibilities. Based on this review, FEMA has embarked upon an improved method for implementing its programs—the Integrated Emergency Management Systems (IEMS). The IEMS concept applies to all levels of government, all hazards, and all phases of emergency management. By identifying opportunities to develop programs that support and complement each other, Federal, State, and local governments can more effectively and efficiently utilize available funds and resources.

IEMS stresses an integrated approach to management of all types of emergencies, including natural disasters (tornadoes, hurricanes, floods, earthquakes, volcanic eruptions, and so forth) technological disasters (explosions, release of hazardous materials, accidents involving radiological materials, possible nuclear powerplant accidents, and so forth), resource shortages, and attack (war, terrorism). Within these disaster situations, IEMS stresses emergency management elements common to all emergencies, while recognizing the elements which are unique to specific types of emergencies. Those disasters such as catastrophic earthquake events or war, which would affect the Nation as a whole, are accorded special attention and greater Federal involvement and assistance to State and local governments.

General principles applying to the development of IEMS include providing maximum flexibility to State and local governments in achieving commonly accepted Federal, State, and local goals, as well as integrating emergency management planning into mainstream State and local government planning and decisionmaking processes.

As stated in Title III of the Earthquake Hazards Reduction Act of 1977, as amended, ". . . natural and man-made hazards may not be independent of one another in any given disaster. Furthermore, planning for and responding to different hazards have certain common elements." To make maximum use of these commonalities, as requested under the Act and set forth in FEMA's internal management policies, several pilot multihazard projects have been initiated. These projects and their progress to date are as follows:

Workshop on Multihazard Mitigation Strategies

In July, FEMA sponsored a workshop held by the National Academy of Sciences (NAS), National Research Council, and the Advisory Board for the Built Environment. The workshop brought together 29 professionals in the field of natural hazards, including several leading experts and practitioners in the earthquake field, to develop multihazard mitigation strategies. The focus of the workshop was on the identification of commonalities among natural hazards mitigation strategies (including those for earthquakes) as a basis for development of integrated management planning guidelines. The findings and recommendations of this workshop will aid FEMA in integrating earthquake hazards mitigation planning into the range of other emergency planning activities sponsored by FEMA.

Consideration of State Implementation Mechanisms

A contract was let by FEMA to a private consultant to develop guidelines for natural hazards mitigation to be used by the States in evaluating how mitigation is being carried out within their State governmental framework and to determine what organizational, legislative, or other obstacles might exist (and how these obstacles can best be removed) to achieve streamlined and effective mitigation of hazards within the State. Again, the results of this effort will help States to improve their capabilities for mitigating earthquake hazards as well as other hazards by identifying what can be done to improve the effectiveness of State organizational and legislative processes.

Puerto Rico Earthquake and Hurricane Project

A combined earthquake and hurricane project was initiated in fiscal year 1983 by Puerto Rico. At present, data on population at risk and lifelines are being collected and technical and planning committees are being established. Once the problem has been delineated and organizational tasks completed, preparedness planning to save lives and to provide immediate emergency response can be undertaken, followed by other emergency management elements. Reports will be provided on the individual hazards and emergency management elements.

Alaska

As discussed previously, preparedness and mitigation plans in Alaska are multihazard in nature, including the tsunami hazard and earthquakes.

Utah

In 1976, the USGS completed a hazard vulnerability study of the earthquake potential in Utah. The results of that study indicated a potential for a severe earthquake in the State, especially along the Wasatch Front. About 85 to 90 percent of the State population is within the potential risk area. In response to the potential hazard delineation, the Utah Seismic Safety Council conducted further studies and recommended actions to be taken by the State.

One issue of concern was the potential for seismically induced dam failures. The 1976 USGS report projected that the potential risk to human life from the floods resulting from dam failure could far exceed the potential loss of life caused by the seismic event itself. In fact, the potential loss of life related to dam failure is estimated to be an order of magnitude greater than those directly associated with an earthquake, or 23,000 versus 2,300, respectively.

Therefore, in mid-1982, the State of Utah approached FEMA for support of a seismic assessment of the major dams in Utah. During FEMA's assessment of the situation, it became clear that hazards other than seismic activity could be as devastating to the area as a seismic event. For example, canyons that would carry the water flow from a dam failure caused by a seismic event also could carry flash floods (similar to Big Thompson Canyon in Colorado) from thunderstorms or the water flow from a dam failure due to other causes.

In late 1982, the "State of Utah Multihazards Project—Earthquake/Dam Safety/Floods" was initiated to identify all the hazards that might affect the State, to identify the risk to the population, to assess the preparedness planning of the State and local officials to ensure that all hazard impacts were considered, and to prepare mitigation plans. In addition, the preparedness plans were to be examined to ensure that actions taken in regard to one hazard would not increase the risk or impacts of another, including reducing the effectiveness of mitigation measures. Several such problems were revealed in the initial assessment:

> The emergency room of an existing hospital, which was above the elevation of expected flooding, had previously been found wanting when checked for seismic resistance. A planned addition to the hospital was modified to accommodate an emergency room in the seismically safe basement. Thus, it was assumed the public was assured an emergency medical treatment facility. However, while the initial treatment facility would survive floods as bad as any experienced in the area, it would not survive an earthquake, and on the other hand, while the new facility would survive an earthquake, it would not survive a flood. Just east of the City, high in the Wasatch Mountains are several large dams that probably would not survive a catastrophic earthquake. In which case, in about 30 minutes—the time it would take for flood waters to reach the facility—the City would not have an earthquake-resistant emergency facility, thus exemplifying the need for multihazard consideration in emergency planning.

Building on the hazard recognized by the public and officials as a potential "real" threat to the population, dam failure caused by seismic events was made the principal concern, or "lead hazard," for the project and the FEMA's Dam Safety Program provided the initial financial support to the State. By focusing on a lead hazard, the project was able to be initiated quickly and with the requisite support within the State.

The work plan for the preparedness model is now complete, the candidate site-selection criteria for site application of the model is in place, and the final report on the model (including application experience) is expected in early 1984. In fiscal year 1984, the multihazard project concept will be applied in other regions of the country. These efforts will focus on strengthening the model, utilizing an appropriate "lead hazard" for the given area and incorporating particular local needs into the assessment. FEMA will utilize the results of the various efforts to develop generic multihazard preparedness and mitigation guidelines.

U.S. GEOLOGICAL SURVEY

The USGS conducts a national research effort to reduce hazards and risk from future, potentially damaging earthquakes in the United States. The USGS Earthquake Hazards Reduction Program supports fundamental and topical research in earthquake hazards and earthquake prediction to provide earth science data and information essential to mitigate earthquake losses. The program fosters hazard reduction through land use planning, earthquake-resistant design, and emergency preparedness decisions. The program has five elements which focus on major objectives:

- *Regional Monitoring and Earthquake Potential Studies.* Monitor and evaluate the earthquake potential of seismically active areas of the United States.

- *Earthquake Prediction Research.* Conduct research to establish the capability to predict the size, location, and time of damaging earthquakes.

- *Regional Earthquake Hazards Assessments.* Provide evaluations of earthquake hazards and risk in earthquake-prone regions.

- *Data and Information Services.* Provide data and information on earthquake occurrences to the public, scientific community, and other governmental agencies.

- *Engineering Seismology.* Provide strong ground motion data to the engineering community for use in earthquake-resistant design and construction and conduct research to understand the physics of ground motion.

The USGS participates in foreign earthquake investigations and a number of international cooperative projects in observational seismology, studies of strong ground motion, and earthquake prediction to accelerate and enhance earthquake research in the United States. The USGS also conducts an active outreach program to transfer earthquake hazards information to the public and user communities. The USGS Earthquake Hazards Reduction Program is augmented and strengthened through support of complimentary scientific investigations in universities, State agencies, and private companies.

REGIONAL MONITORING AND EARTHQUAKE POTENTIAL STUDIES

The USGS makes seismological and geologic analyses of seismic activity, active geologic faults, and earthquake potential of seismic regions in the United States. These studies are designed to

- Delinate seismically active areas and the extent of seismic zones with regional seismograph networks,

- Determine the geometry and structure of seismic zones through geologic mapping and geophysical analyses, and, ultimately,

- Estimate fault slip rates, maximum earthquakes, and recurrence intervals for active faults and seismogenic zones.

Scientific data collected from regional monitoring and earthquake potential studies form the foundation for work in earthquake prediction and regional earthquake hazards assessments.

Substantial progress has been made in the past several years in estimating the long-term earthquake potential of various seismic zones in the United States. These estimates are based on detailed analyses of current tectonics of seismically active regions as interpreted from geological and geophysical observations. These studies have provided quantitative estimates of slip rates along active faults, earthquake recurrence intervals, and earthquake potential. They have also defined tectonic structures—heretofore unspecified—that give rise to the seismic activity.

Regional Seismographic Networks

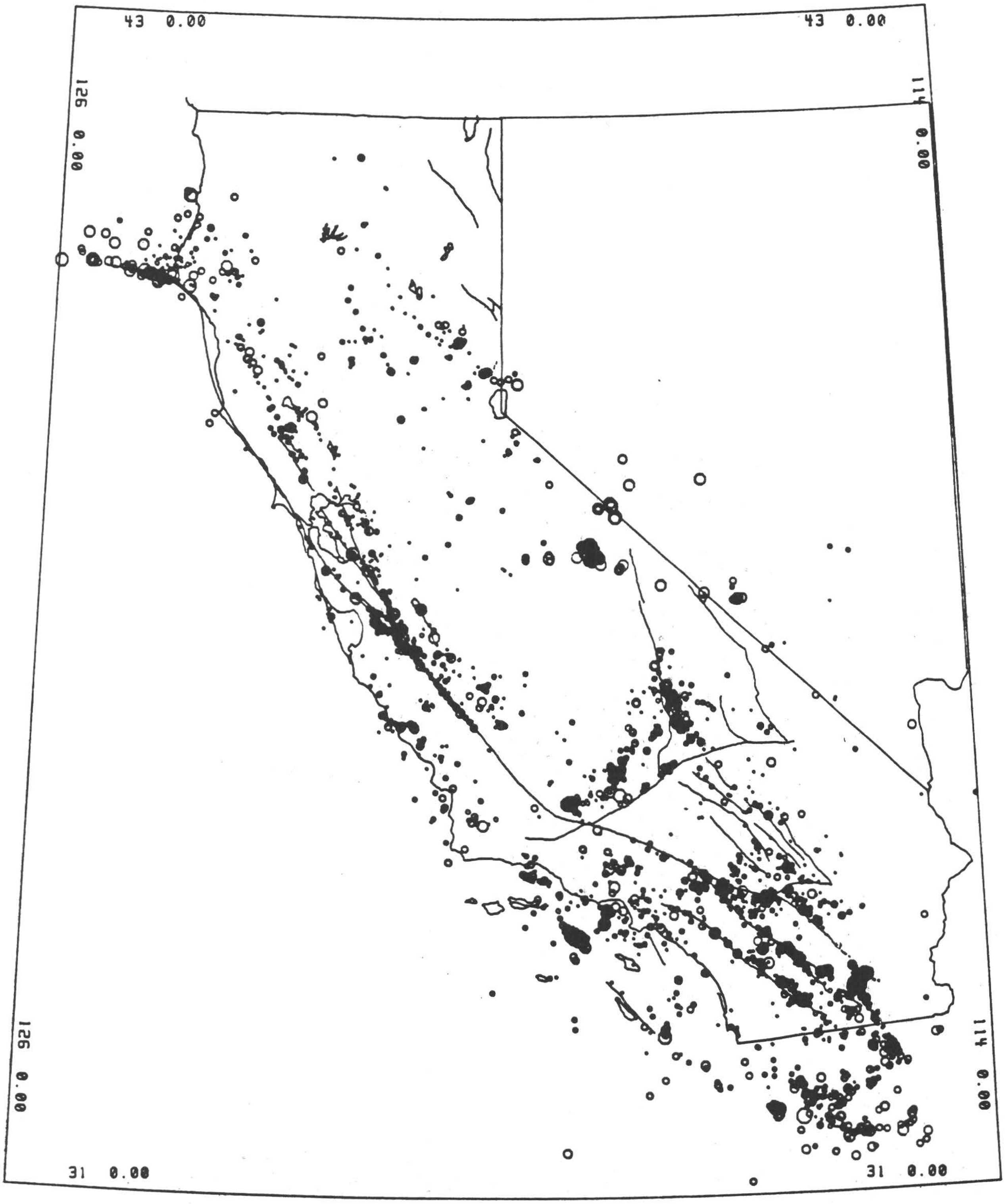
The USGS supports operation of seismographic networks in a number of the seismically active areas of the Nation. These regional networks provide important baseline data for earthquake prediction and hazards assessments through prompt location of earthquake events and high-resolution determination of their parameters (magnitude, depth, and so forth). The data contribute directly to the understanding of earthquakes and tectonic processes causing earthquakes.

In fiscal year 1983, the USGS made significant advancements in the development of online, real-time automatic seismic data processing systems that permit the rapid determination and location of earthquakes recorded in regional seismographic networks. Network data are telemetered to a central collection point where a microprocessor system, constantly monitoring the network in real-time, automatically identifies and picks primary-wave arrivals as they occur. Computer determination of the earthquake hypocenters automatically follows, usually within a few minutes, thus providing early and accurate information on the location and progress of an earthquake sequence while it is occurring. These systems allow for the direct observation of crustal changes that precede, accompany, and follow earthquakes—data critical to earthquake prediction.

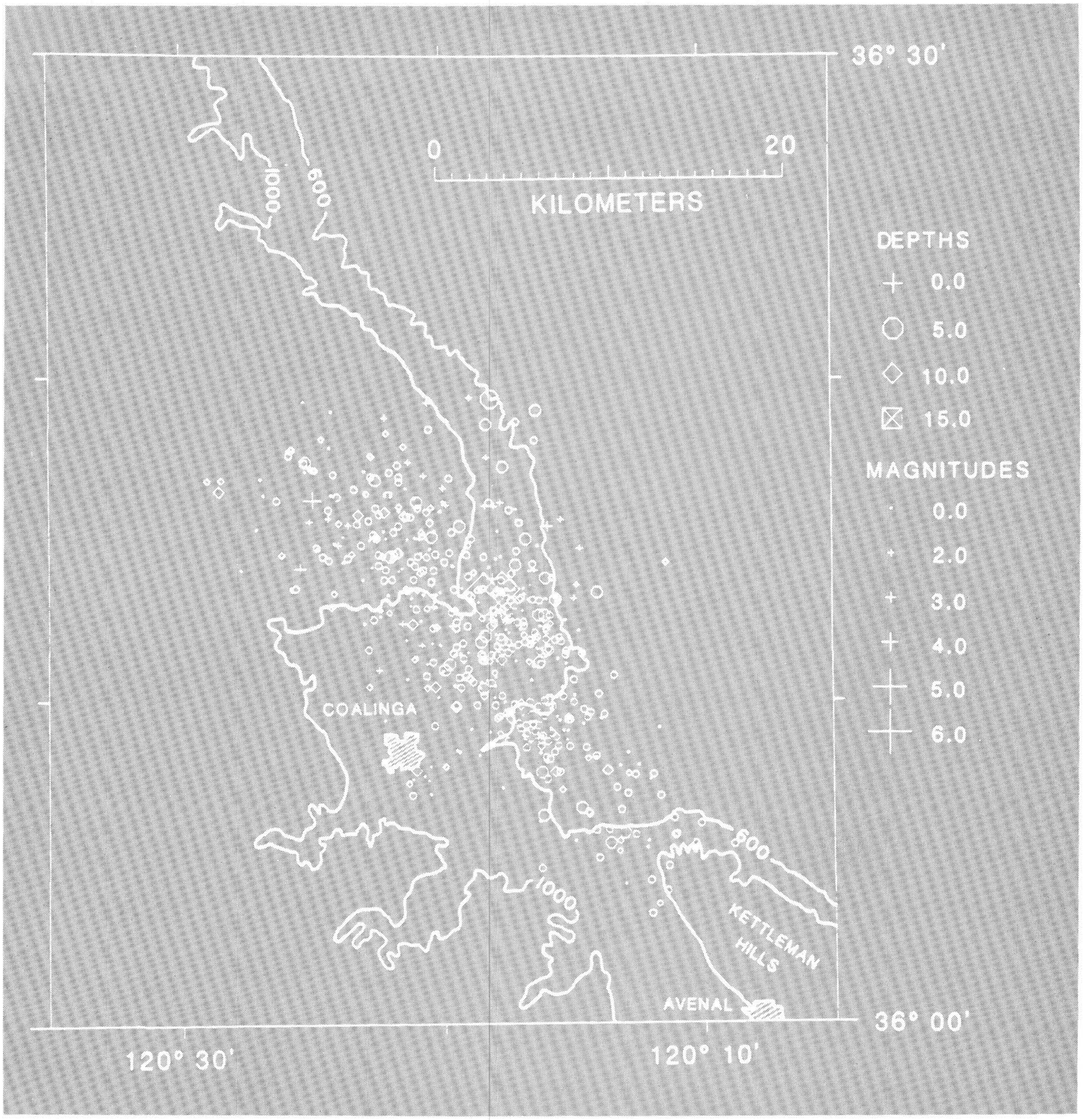
1983 Coalinga, California, Earthquake

The USGS conducted an intensive investigation of the May 2, 1983, Coalinga, California, earthquake. The magnitude (M_S) 6.5 shock, which occurred about 19 miles northeast of the San Andreas fault in the eastern Diablo Range of central California, was located on the eastern edge of the USGS's northern and central California telemetered microseismic network. The USGS responded quickly to the developing Coalinga aftershock sequence, installing 18 portable digital recording systems, 8 analog strong-motion instruments, 12 portable high-gain recording systems, and 4 additional seismic telemetry stations around the

Regional seismographic networks in the United States operated or supported by the U.S. Geological Survey.



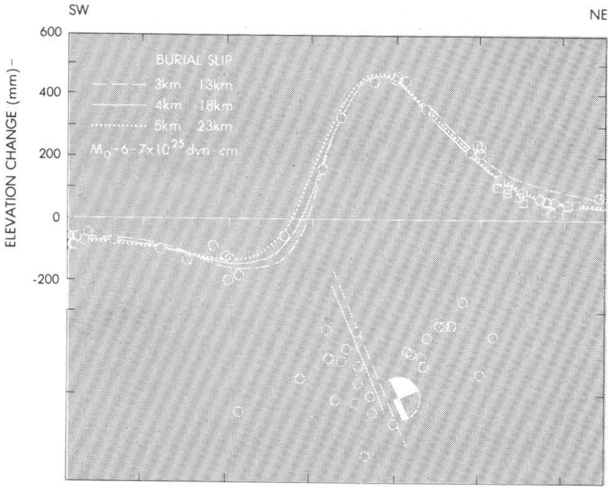
Epicenters of California earthquakes in 1981 having magnitudes greater than 1.5 detected by regional seismographic networks in the Western United States. The northern and south-central segments of the San Andreas fault, which last ruptured in great earthquakes in 1906 and 1857, respectively, are seismically quiet. The occurrence of numerous small events along other faults suggests that strain is apparently released in a nearly continuous manner along those breaks.



Epicenters of the May 2, 1983, Coalinga earthquake and selected aftershocks from May 2 to 12.

earthquake zone beginning 25 hours after the mainshock. Field teams were dispatched to determine if tectonic surface faulting had accompanied the main event and to locate secondary ground failures, including landslides and liquefaction, generated by the earthquake.

USGS geophysicists and geologists determined that the 1983 Coalinga earthquake occurred on a buried fault beneath Anticline Ridge northeast of Coalinga. Examination of elevation changes produced by the earthquake revealed that the May 2 shock elevated Anticline Ridge about 16 inches and lowered the area around Coalinga about 8 inches. Modeling of the elevation changes and seismicity suggest that about 5.9 feet of reverse movement occurred on fault that dips steeply northeast beneath Anticline Ridge. The earthquake rupture



Profiles of elevation changes at Anticline Ridge accompanying the 1983 Coalinga, California, earthquake compared with tectonic deformation predicted from modeling. Reverse movement on a buried fault dipping N. 67° E. best fits the observed uplift and subsidence curve. The hypocenter of the mainshock (focal mechanism), together with hypocenters of aftershocks having magnitudes (M_L) greater than or equal to 3 recorded during the first 4 days, are shown. The data are cast into an azimuth N. 37° W., normal to Anticline Ridge.

moved upward along the fault from a depth of 6 to 7 miles but did not reach the surface, apparently stopping at depth of 2 to 3 miles. Because the rupture did not reach the surface, there were none of the usual cracks and fissures that are clear surface expressions of the fault.

Long-Term Probabilities for Large Earthquakes in California

In fiscal year 1983, two independent studies of the long-term probabilities of large earthquakes along the San Andreas fault system of California were completed. (One study was funded in part by the NSF.) Both studies concluded that there is a significantly higher average probability for a large earthquake in southern California than in the rest of the State.

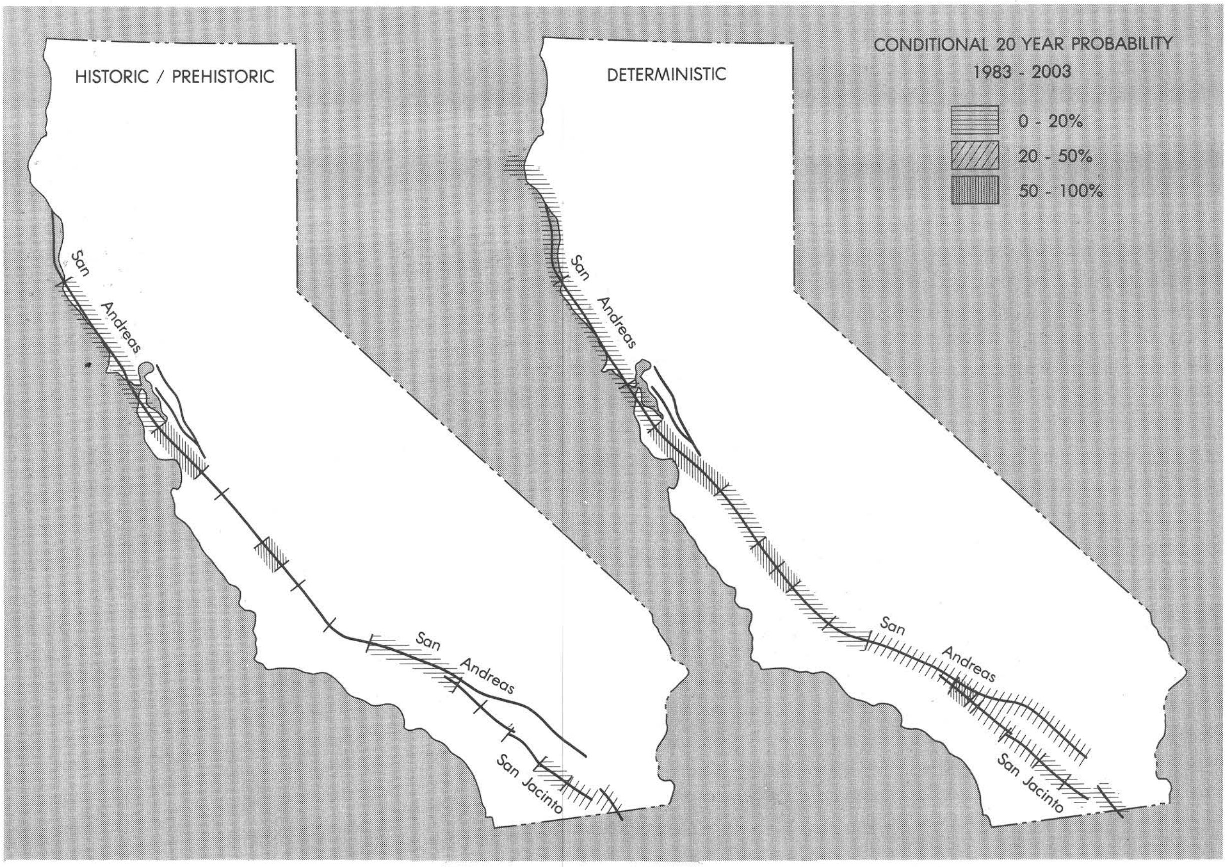
The probabilities were evaluated from geologic evidence of the faults' cycles of earthquake recurrence, taking into account the time elapsed since the last large earthquake on each fault. The highest probabilities were calculated for the recurrence of a magnitude 6 earthquake on the San Andreas fault at Parkfield; magnitude 6½ to 7 events on the northern San Jacinto fault near Riverside and on the San Andreas fault at San Juan Bautista (between San Jose and Monterey); and for a major earthquake on the San Andreas fault north and east of Los Angeles.

Overall, the probabilities for the segments of the San Andreas fault south of the Carrizo segment and for the San Jacinto fault average 2½ times those for the three segments of the San Andreas fault north of the creeping section and for the Hayward fault. This reflects the fact that the last great earthquake in northern California (1906) occurred almost 50 years after the last great event on the south-central San Andreas fault (1857) and that an even longer time has passed since the last great event on the Indio segment of the fault. A growing body of evidence suggests that because of these differences in time to the last great event, all of southern California is farther along in the "seismic cycle" than is northern California. It is believed that the regional stress levels are nearer failure levels, and that moderate to large earthquakes are more likely to occur in the southern part of the State.

A Great Earthquake in the Pacific Northwest?

A growing body of data suggests that a great earthquake ($M \geq 8$) could occur in the Pacific Northwest. In fiscal year 1983, two separate USGS–university seismological teams completed a study of earthquake potential in the Pacific Northwest. They concluded that the Northwestern United States may be a major seismic gap which is locked and presently seismically quiet but which may fail in great earthquakes in the future.

The studies, jointly funded by the USGS and the NSF, explored the systematic differences between subduction zones which are capable of great earthquakes, and the Juan de Fuca subduction zone, which plunges beneath western Washington, Oregon, and northern California. In general, the Juan de Fuca subduction zone is seismically quiet. The 300-mile-long gap in seismicity associated with the Juan de Fuca subduction zone is one of the most remarkable to be found anywhere on the Circum-Pacific seismic belt. The seismologists suspect that the Juan de Fuca plate may be



Cumulative, 20- and 30-year probabilities for earthquakes on selected fault segments of the San Andreas fault system.

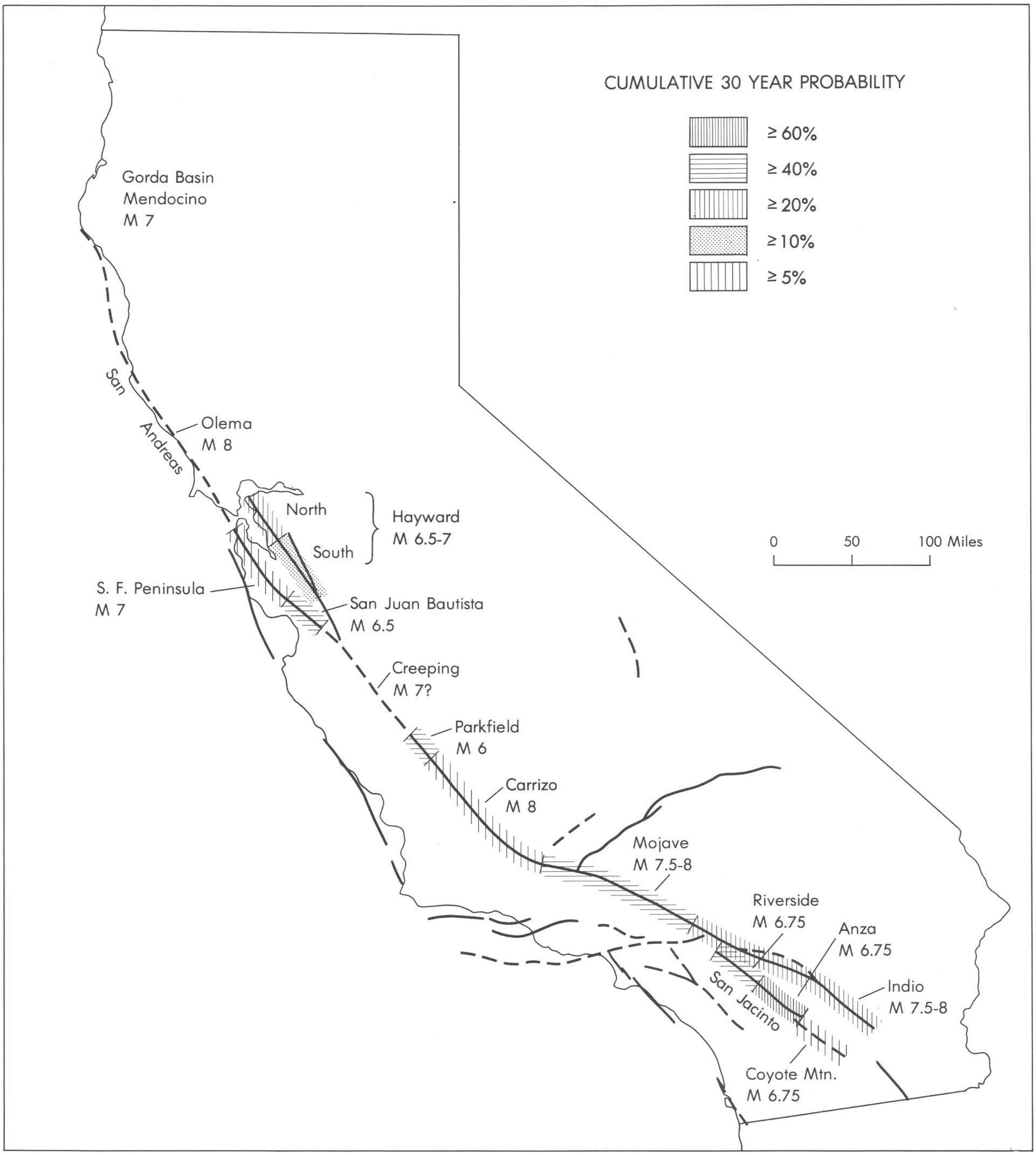
strongly coupled with the North American plate. Although there is a paucity of present-day seismicity (as well as significant historic activity) in the shallow part of the subduction zone near the coast, moderate magnitude, deep-focus earthquakes apparently on the surface of the subducting plate occur beneath Puget Sound.

The seismologists assessment is consistent with that of an earlier, 1980 USGS study which concluded that horizontal strain (as measured by laser geodolites) in the Pacific Northwest are best modeled by coupling between the North American and Juan de Fuca plates, which causes compressive strains perpendicular to the subduction zone.

EARTHQUAKE PREDICTION RESEARCH

The goal of earthquake prediction is to give a warning of large, potentially damaging earthquakes at a time interval long enough to allow appropriate actions by the public and private sectors and with enough precision to avoid sustained disruptive effects that the prediction response may have on society. To accomplish this, the USGS conducts earthquake prediction research through a program that involves Government scientists, interacts with foreign earthquake prediction programs, and provides support for earthquake prediction studies in the academic community and private sector.

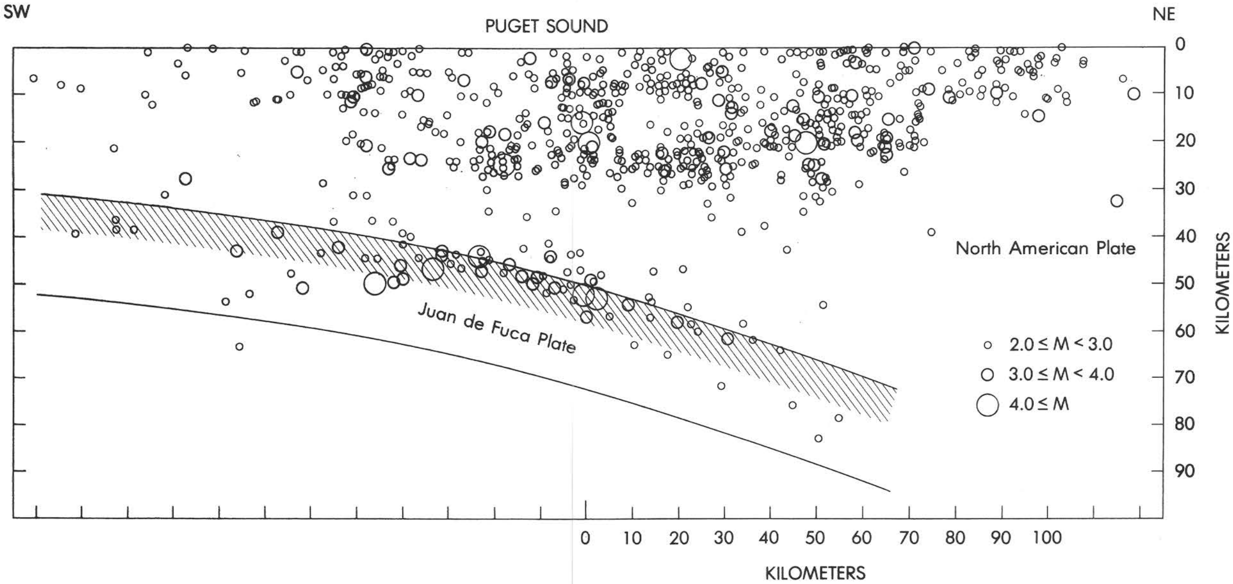
Earthquake prediction research includes field, laboratory, and theoretical investigations of earthquake mechanisms and of the physical characteristics of fault zones. USGS investigations have been focused on central and southern California, Alaska, and several other selected areas in the United States and around the world; the latter because earthquakes in most parts of the United States occur too infrequently to provide field



observations and valid tests of possible earthquake precursors. All possible geophysical precursors of earthquakes must be studied to develop the analytical and instrumental capabilities for prediction.

USGS earthquake prediction research is directed toward

- Collection of baseline geophysical data in areas of seismic risk and development of a fundamental understanding of the physical laws governing the earthquake cycle.
- Development of earthquake prediction methods and techniques to provide a rational basis for estimates of increased earthquake potential and short-term predictions.



Cross section of hypocenters of earthquakes in western Washington, 1970 to 1978, projected onto a plane perpendicular to the coastline. Most small earthquakes have occurred at shallow depths beneath Puget Sound. The deeper, larger magnitude earthquakes appear to outline the surface of the subducting Juan de Fuca plate, which is underthrusting the Pacific Northwest.

- Evaluation in probabilistic terms of the relevance of various geophysical, geochemical, and hydrological data to increased earthquake potential.
- Development of theoretical and laboratory models of the earthquake process to guide observational experiments and to test empirical, predictive techniques.
- Determination of the physical mechanism for reservoir-induced seismicity and development of techniques for predicting and mitigating this potential hazard.

There have been significant advancements in earthquake prediction during the last several years. Long-term forecasts of the recurrence of large and great earthquakes in seismic gaps (segments of plate boundaries that have experienced long periods of seismic quiescence) already have proved successful. Eleven large shocks in the Circum-Pacific region have occurred in major seismic gaps that were identified as sites of high seismic potential. The average interval between major earthquakes on several faults, including the San Andreas, has been identified, permitting estimation of earthquake probabilities. The concept of the seismic cycle has unified geologic and seismologic understanding of earthquake occurrence, allowing for the siting and execution of experimental earthquake prediction experiments by which the time window of prediction may be progressively narrowed.

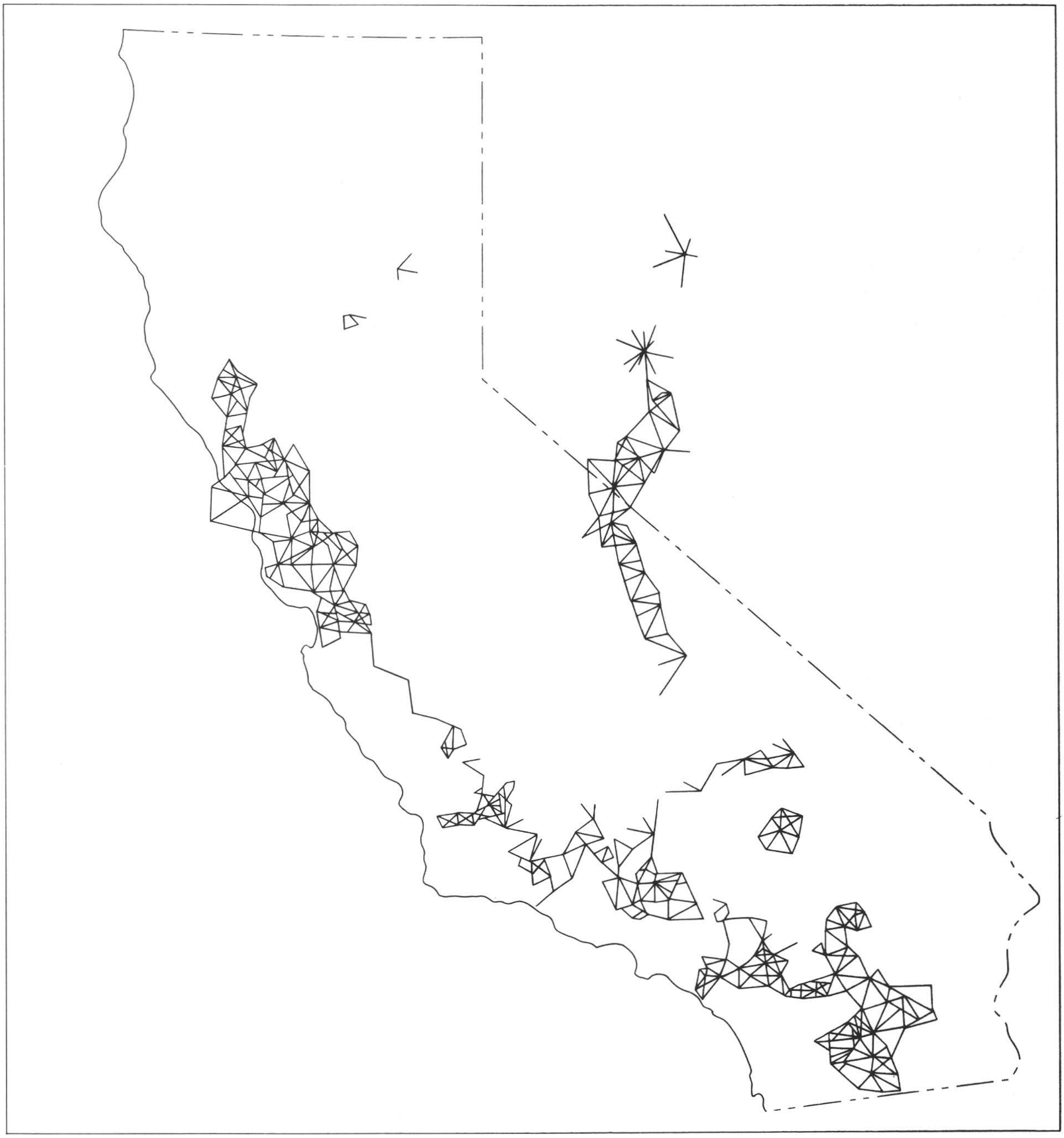
Monitoring for Prediction Research

Earthquakes result from failure processes in extremely complex, heterogeneous, nonlinear, three-dimensional systems which operate on a time scale that is long compared to a human lifetime. The physical processes that culminate in an earthquake are generally hidden from view but are likely to be similar to those processes found in the failure of strained mechanical systems. However, the specific physical laws governing earthquake occurrence are not as well understood as, for example, those governing the weather. Compared to weather forecasting, there are relatively few opportunities to obtain data with which to test and develop theories for earthquake prediction. Development of the capability to model, predict, and perhaps even control these processes depends on their accurate characterization through observation.

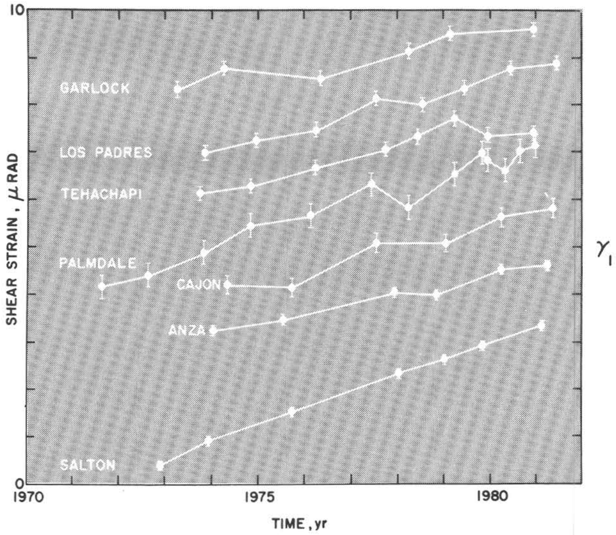
In 1983, the USGS and its contractors continued to develop monitoring techniques and gather basic data on geophysical and geodetic changes associated with strain accumulation and release. Because of the likelihood of a major earthquake in California and of the size of the population at risk, most of these observations were made along the San Andreas fault system of California.

Crustal Strain Monitoring

Earthquakes occur when deformation of the Earth's crust in the vicinity of a fault reaches a critical state and conditions on the fault have evolved to permit rapid release of the accumulated strain by earthquake fault slip. Detection of changes in the state of crustal strain preparatory to earthquake fault slip are of



Geodetic triangulation networks in California and Nevada.



The shear-strain component $\gamma_1 = \epsilon_{11} - \epsilon_{22}$ as a function of time for southern California trilateration networks. The initial level of shear strain for each network is arbitrary.

primary importance for evaluating long- and short-term earthquake potential.

Resurveys of triangulation networks provide a measure of strain deformation. A system of 25 geodetic strain networks in California and Nevada containing several hundred survey lines were remeasured in fiscal year 1983 by the USGS. Strain accumulation along the major fault systems is monitored on an annual basis, with additional remeasurements made when needed. The observed changes are several parts per million per decade. Materials that are being stressed at a constant rate in the laboratory will typically deform at a different rate just before failure. Monitoring activities in fiscal year 1983 were designed to determine the time frame and scale of such anomalous deformation in the Earth preceding earthquakes. Nearly continuous strain observations were made at several sites with a two-color laser device, and short-base crustal deformation and fault offset observations were made at over 200 sites.

Seismic Networks

The capabilities of strain monitoring systems are complimented by seismographic networks, which provide a means for locating active faults and for monitoring the status of strain release processes on those faults. Seismic waves generated by earthquakes can be analyzed to locate the earthquakes and to determine orientations of fault planes, earthquake magnitude, and stress changes caused by the earthquakes. This information, evaluated in the context of the historical seismicity and base-line data in a region, provides a detailed means for recognizing regional and long-term changes in the strain release process occurring on active fault systems. In addition, with rapid processing of seismic data it provides a basis for recognizing immediate premonitory phenomena such as foreshock activity.

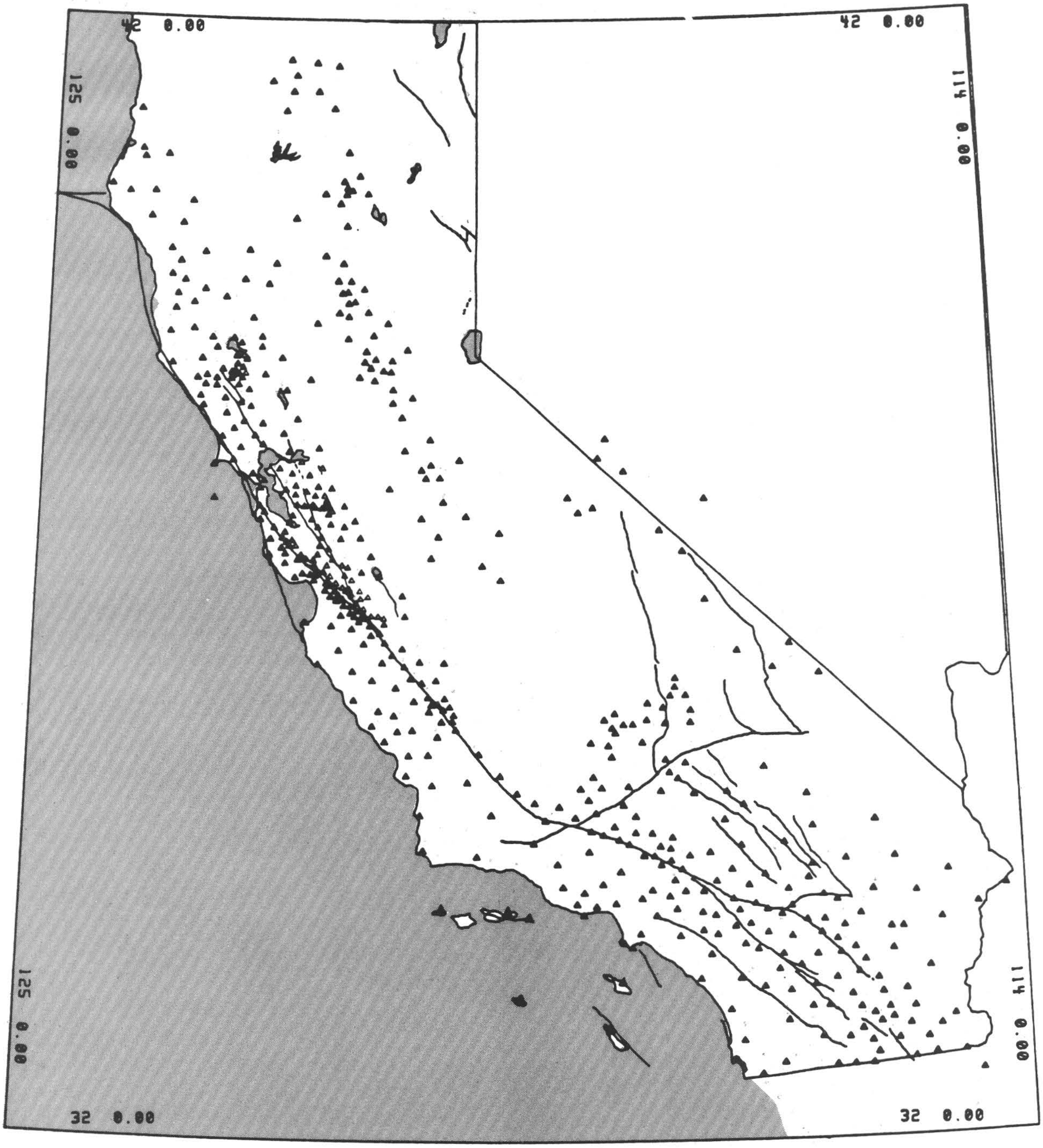
The seismic monitoring effort in California consists of about 500 seismographs. This large, relatively dense array and the data processing system that support it are a major accomplishment of the USGS Earthquake Hazards Reduction Program. Last year, over 8 million seismograms were analyzed, and approximately 18,000 earthquakes were located. Following the initial processing, the data undergo an extensive quality-control procedure, and many events are relocated. The distribution of earthquakes in time and space provides a means of remotely monitoring failure processes at depths to 13 miles and illustrates the complexity of deformation occurring at the boundary between the Pacific and North American plates.

Other Monitoring

Various other geochemical and geophysical observations were made at approximately 140 sites. The latter data, which include resistivity, magnetometer, water-well level, radon or helium concentration, and other geochemical observations, measure second-order effects of rock strain and failure. As such, they are usually more difficult to interpret but may exhibit much larger percentage changes than the strain data.

Prototype Earthquake Prediction Network

A prototype operational prediction effort is a necessary evolutionary step toward the goal of an earthquake prediction capability in the Nation. Steps required to upgrade current research facilities in southern California to a



Networks of seismographic stations in California deployed in seismogenic areas and near active faults.

prototype, operational earthquake prediction system were published in fiscal year 1983 in response to a request by the U.S. Congress to develop a detailed program plan for completion of a prototype prediction system by fiscal year 1988. Emphasis in the prototype system would be on integrated monitoring of earthquakes and crustal strain phenomena. Proposed improvements include a network of crustal deformation observatories, with state-of-the-art instrumentation and borehole siting of sensors; a network of digital seismometers; robust telemetry; an imminent alert system utilizing real-time processing; and enhanced data collection, processing, retrieval, and analysis facilities.

Surface tectonic fractures on the San Andreas fault near Parkfield, California, following the Parkfield earthquake of 1966.

Parkfield, California, Earthquake Forecast

A USGS seismologist and a University of California, Berkeley, professor of geophysics (supported by the NSF) have concluded that a moderate-sized earthquake in the magnitude 5½ to 6 range could occur within the next several years along the San Andreas fault in central California near the small town of Parkfield. (Parkfield is located about 25 miles northeast of Paso Robles, about midway between San Francisco and Los Angeles.) They have suggested that the time and size of future Parkfield earthquakes may be anticipated, given the evidence for uniform characteristics of previous Parkfield earthquakes. In a recent analysis of data available for five previous earthquakes which struck the Parkfield area during approximately the last 100 years, the scientists project that the next Parkfield earthquake will likely occur within an 8½ year interval between late 1983 and early 1992. The 20-mile section of the San Andreas fault near Parkfield has generated moderate-sized earthquakes of about magnitude 5¾ at regular intervals. Earthquakes occurred in the same area of the fault in 1881, 1901, 1922, 1934, and 1966. Except for the event in 1934, these earthquakes occurred on a 20- to 22-year cycle. The even spacing of the other events suggest that the probability of an earthquake is greatest in 1987 and 1988. The earlier Parkfield earthquakes were locally damaging in the sparsely populated area east of Paso Robles and were felt north to San Francisco and south to Los Angeles.

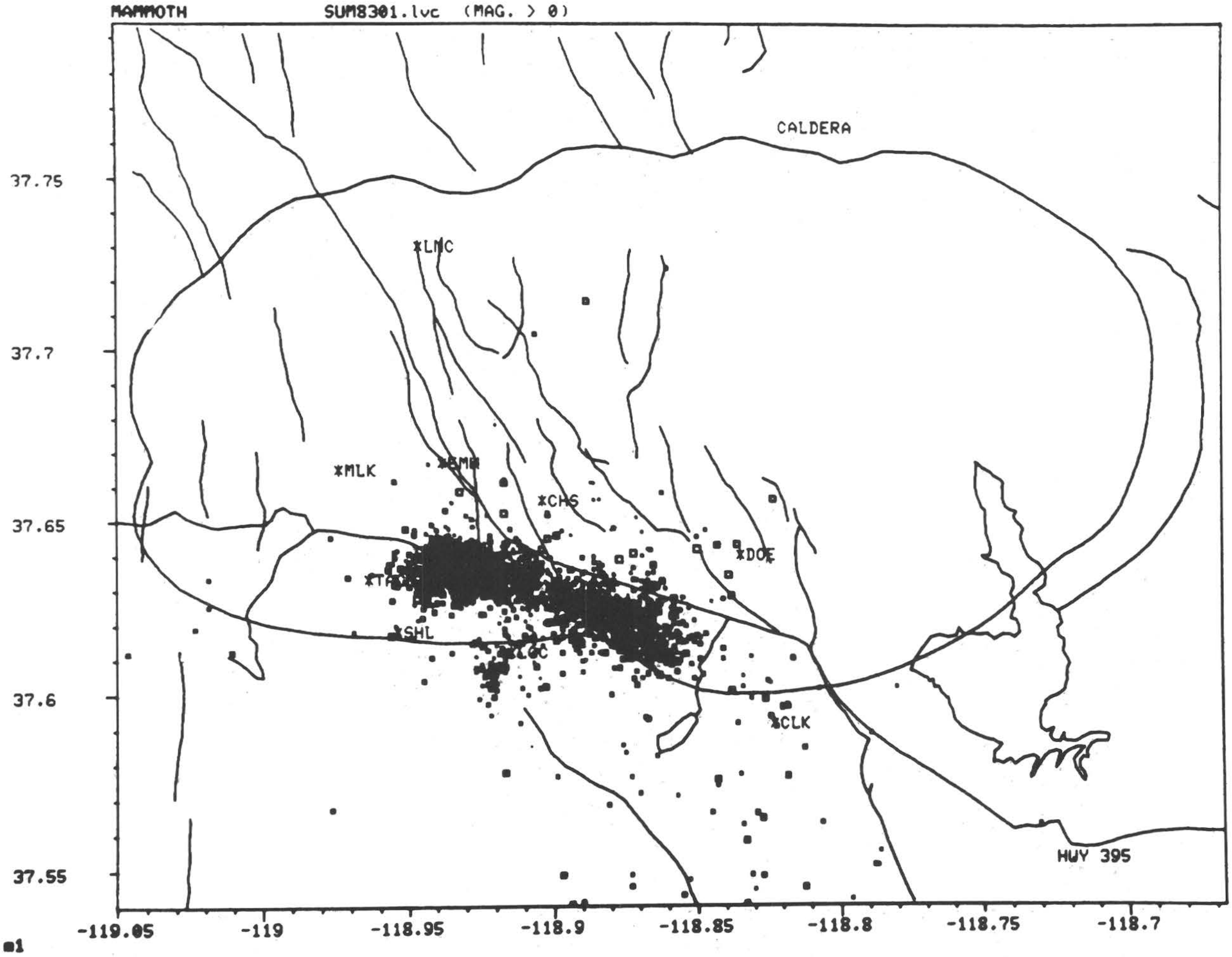
Other researchers at the USGS have developed a computer model simulation of fault behavior to predict the size, location, and time of the next Parkfield earthquake and, most important, the history of ground deformation leading up to the earthquake. The predicted accelerated fault slip and strain preceding the earthquake can be checked against actual surface measurements of fault creep and horizontal distance changes.

The team of scientists believe that the next sizable Parkfield earthquake will likely be preceded by observations of accelerated crustal strain and seismicity. In 1966, small cracks indicative of fault creep were photographed about 11 days before the earthquake, and a water pipe across the fault broke hours before the earthquake. In addition magnitude 5 foreshocks occurred 17 minutes before the 1934 and 1966 earthquakes. These foreshocks were located near the northern end of the section of the San Andreas fault that ruptured during the magnitude 5¾ earthquakes that followed.

The USGS has supplemented its geodetic network in the Parkfield area with a cluster of geophysical instruments to monitor changes in strain, tilt, and fault creep and to record foreshocks that may precede the next Parkfield earthquake.

Long Valley Caldera, California

In early January 1983, a particularly intense swarm of earthquakes occurred slightly more than a mile southeast of Mammoth Lakes, within the Long Valley Caldera. During this time more than 7,000 earthquakes were recorded. The earthquake swarm was yet another in a succession of earthquake sequences that have occurred since 1980 in the Caldera at the eastern foot of the Sierra Nevada. Subsequent examination of seismic and geodetic deformation data collected after the January 1983 swarm revealed that the earthquakes were probably associated with the injection of magma into the ring-dike system along the south moat of the Long Valley Caldera. Deformation between July 1982 and July 1983 of a trilateration network that spans the Caldera



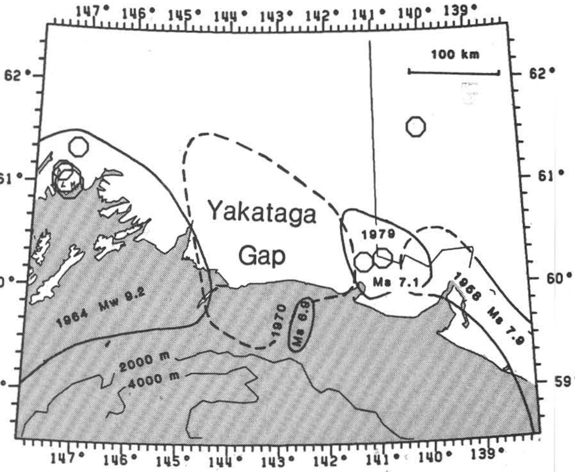
Seismicity in the Long Valley Caldera, California, area from January 7 through January 31, 1983. The outline of Long Valley Caldera and prominent faults are shown by solid lines. Solid dots represent seismic stations used in locating the plotted seismic events.

is consistent with the intrusion of a vertical, rectangular-shaped tongue of magma that extends upward from a depth of 5 miles to within less than 2 miles of the ground surface. Concern that the magma could potentially reach the surface and produce an eruption prompted the USGS in 1982 to issue a formal *notice of potential volcanic hazard* for the Long Valley–Mammoth Lakes area.

Yakataga, Alaska, Seismic Gap

On July 12, 1983, a magnitude (M_s) 6.3 earthquake occurred about 19 miles beneath the Columbia Glacier north of Prince William Sound, approximately 80 miles east of Anchorage, Alaska. The earthquake, which was felt throughout much of southern Alaska, was the largest earthquake in the Prince William Sound region since the great 1964 Alaska earthquake (moment magnitude 9.2). The Columbia Bay shock was one of a number of moderate-sized earthquakes that have occurred in recent months around the Yakataga seismic gap in southeastern Alaska. During the first 9 months of 1983, more shocks of magnitude (m_b) 5.0 or larger have occurred within about 100 miles of the gap than in any one-year interval since 1970 to 1971.

The Yakataga area is believed to be a major seismic gap where one or more major earthquakes having magnitudes near 8 could occur anytime, probably within the next two to four decades. Concern about the implications of the recent Columbia Bay earthquakes in regard to the imminence of a major



Epicenters of seven moderate-sized earthquakes in 1983 in relation to the Yakataga seismic gap (dashed line) and rupture zones of principal earthquakes since 1900 (solid lines). Smaller octagons indicate earthquakes of magnitude (m_b) 5.0; large, magnitude (m_b) 6.0.

earthquake in the Yakataga seismic gap prompted a careful review of the seismicity and crustal strain in the Yakataga area. Seismologists and geophysicists from the USGS determined that no obvious changes in microseismicity or in rates of crustal deformation correlate with the recent flurry of moderate-sized earthquakes near the Yakataga gap, which, therefore, might reflect sudden loading of the megathrust. They concluded that, while there is a continuing potential for a major earthquake in the gap, there is no compelling evidence that the earthquake is substantially more likely to occur in the next several months than in the next decade or two.

Coalinga, California, Earthquake Aftershocks Filled a Seismic Gap

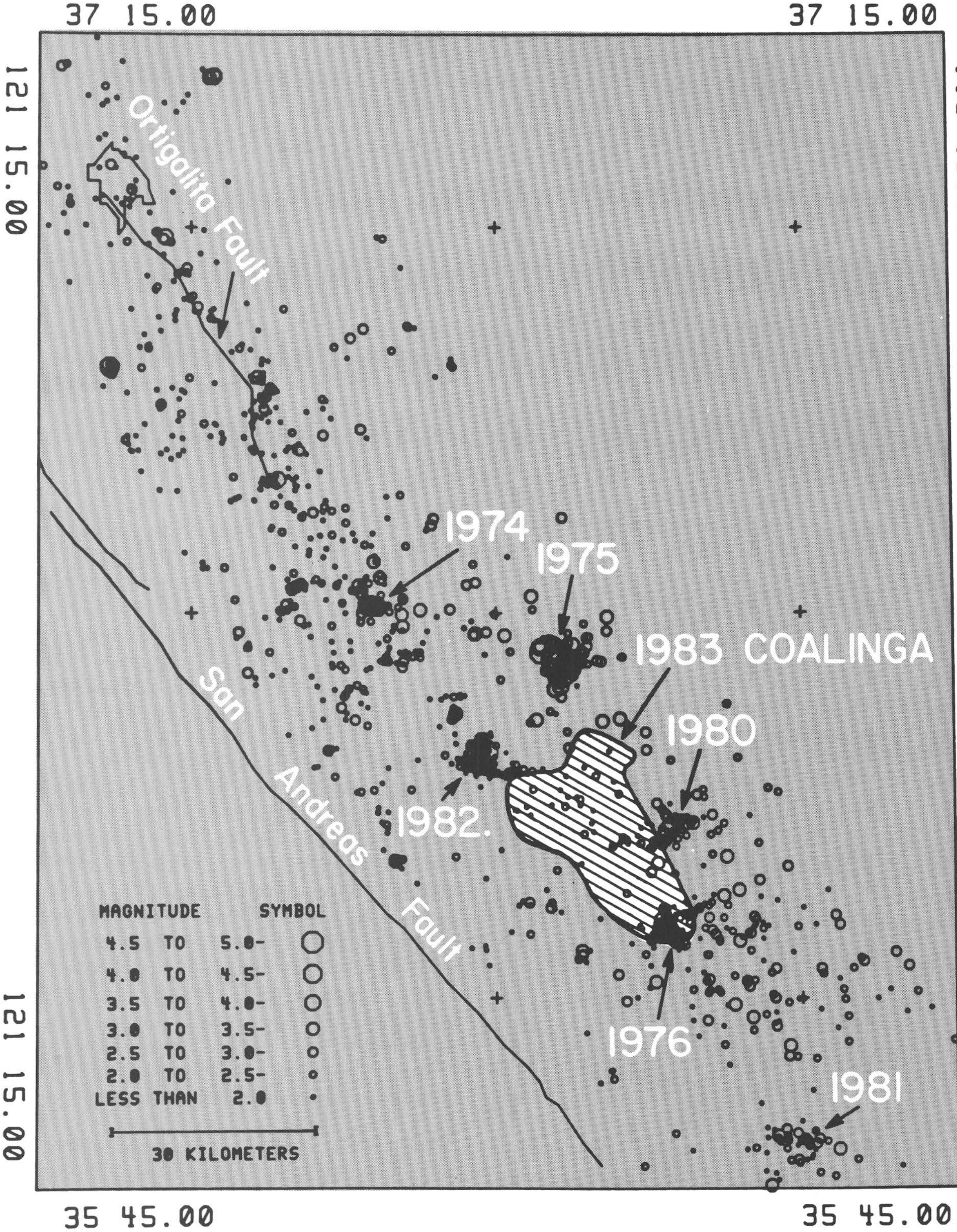
A USGS seismologist discovered that the 1983 Coalinga, California, earthquake sequence filled in a large gap of relative quiescence on the seismicity map of central coastal California for the past decade by comparing the relationship of the Coalinga aftershock zone to seismicity in the east-central Coast Ranges from January 1972 through April 1983. The data show that the 1983 Coalinga aftershock region virtually filled in a gap of relative quiescence between earthquake clusters that had occurred in 1976, 1980, and 1982 along the east flank of the Coast Ranges. The large size of the 1983 Coalinga aftershock region relative to the earlier clusters corresponds to the size of the Coalinga earthquake (magnitude 6.5) relative to the largest shocks in the other clusters (magnitude 5 to 5.5).

Other prominent gaps of seismicity exist in the southeastern one-half of the region. They include the region between the clusters of 1974, 1975, 1982, and 1983 (Coalinga) and the entire region between the band of earthquakes along the San Andreas fault and the clusters of 1976, 1981, 1982, and 1983. These gaps may represent sites of moderate to large future earthquakes.

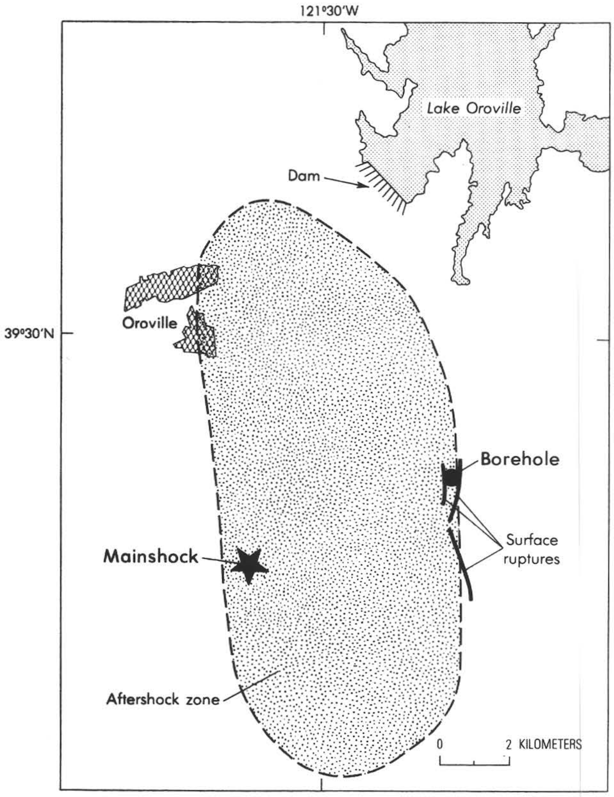
Reservoir-Induced Seismicity

On August 1, 1975, a magnitude 5.7 earthquake occurred near the city of Oroville in northeastern California. The main shock did not cause major damage to Oroville and surrounding communities, but it attracted great public interest because it was only 6 miles southwest of Oroville Dam. This earth-fill dam, the largest in North America, is approximately 780 feet high and has a capacity of 1.5 billion cubic feet. The earthquake was accompanied by a rupture south of the reservoir of the Cleveland Hills fault, which had had no previous historic movement. The aftershock distribution suggested that the fault plane extends beneath the dam and the reservoir.

After the earthquake, there was speculation whether the earthquake had been caused by the reservoir. To help understand why the earthquake occurred, the USGS drilled an approximately 2,000-foot-deep borehole directly through the Cleveland Hills fault to make in situ measurements of stress and the physical properties of the fault zone. The borehole intersected the fault zone at a depth of about 1,100 feet. Ten hydraulic fracturing stress measurements were made in the well, five above and five below the fault zone. Fracture orientation and seismic velocity measurements were made throughout the well. Two unusual features of the observed stress field were noted. First, the magnitude of least horizontal stress exceeded the lithostat (the weight of the overlying rock), despite this being a normal faulting environment. The direction of least



Map of seismicity in the central California Coast Ranges east of the San Andreas fault from January 1972 through April 1983 showing dates of occurrence of prominent aftershock clusters. San Andreas fault earthquakes are not shown.



Epicenter and aftershock zone of the 1975 Oroville, California, earthquake. The U.S. Geological Survey drilled a 2,000-foot-deep borehole between surface ruptures of the Cleveland Hills fault to measure stress in the fault zone.

horizontal compression, however, was approximately east-west, as expected for a north-striking normal fault. The second unusual feature of the stress field was a stress anomaly observed adjacent to the fault zone—the maximum and minimum horizontal stresses increased immediately above the fault and decreased just below the fault. This anomaly has been modeled and is believed to reflect the fact that the slip in the 1975 earthquake was greater at depth than near the surface.

REGIONAL EARTHQUAKE HAZARDS ASSESSMENTS

The USGS evaluates the earthquake hazards of areas in the United States that are at risk from earthquakes. The program strategy consists of conducting investigations using geologic, seismological, geophysical, and geodetic techniques to identify and map those geologic features near or within a given region that are most likely to be sources of damaging earthquakes.

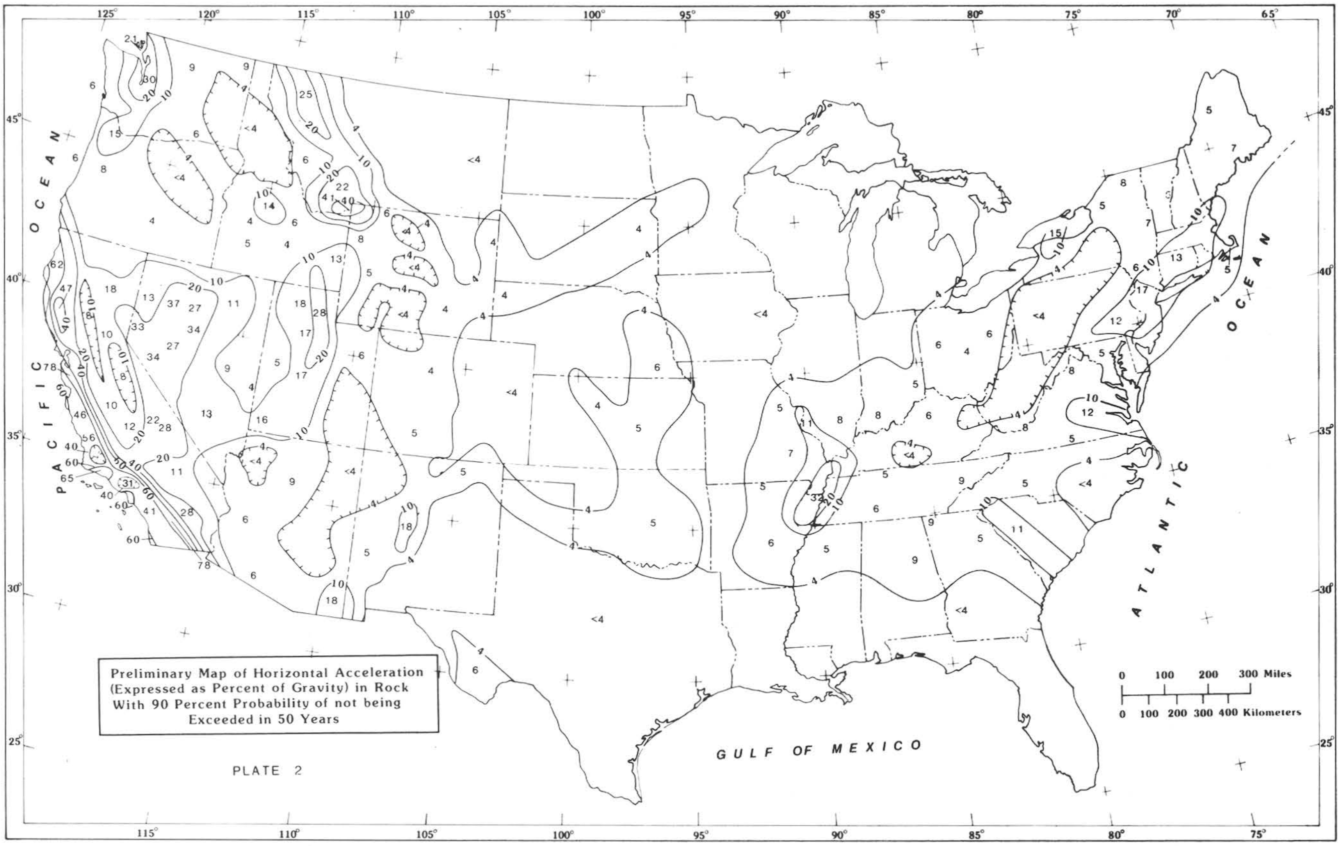
Ground-Shaking Hazard Maps of the United States

A new series of maps depicting earthquake ground-shaking hazards in the conterminous United States and Alaska was completed and published by the USGS in fiscal year 1983. The maps show maximum bedrock horizontal accelerations and velocities expected from earthquakes during exposure times of 10, 50, and 250 years at the 90-percent probability level of nonexceedance. New geological information defining seismogenic zones makes these maps the most detailed evaluation ever of the ground-shaking hazard in the United States. Extensive data recently acquired on Holocene and Pleistocene faulting in the Western United States and new interpretations of geologic structures controlling the seismicity pattern in the Central and Eastern United States are incorporated in these maps. The maps show that the levels of potential bedrock ground motion in the coastal areas of southern California, Puget Sound (Pacific Northwest), and Alaska are higher than previously thought. The major differences result from the greater detail of the seismic source zones used in the new maps. In large areas of the United States, however, particularly in the East, it has not been possible to demonstrate clear relations between specific structures and earthquake occurrence. The potential amplifying effects of soils were not incorporated in the maps but must be considered on a site-by-site basis.

Probabilistic estimates of ground motion for short exposure times (10–50 years) provide a reasonable basis for the earthquake-resistant design of ordinary structures. (An ordinary structure is one having a useful life of 50 to 100 years and a design governed by building codes.) For longer exposure times (greater than 50 years), variability in a few physical parameters, such as seismic wave attenuation and fault rupture, dominates calculations of ground motion and forces the values of peak ground motion to be large.

New Madrid, Missouri, Earthquakes Associated with Reactivated Faults in Ancient Rift

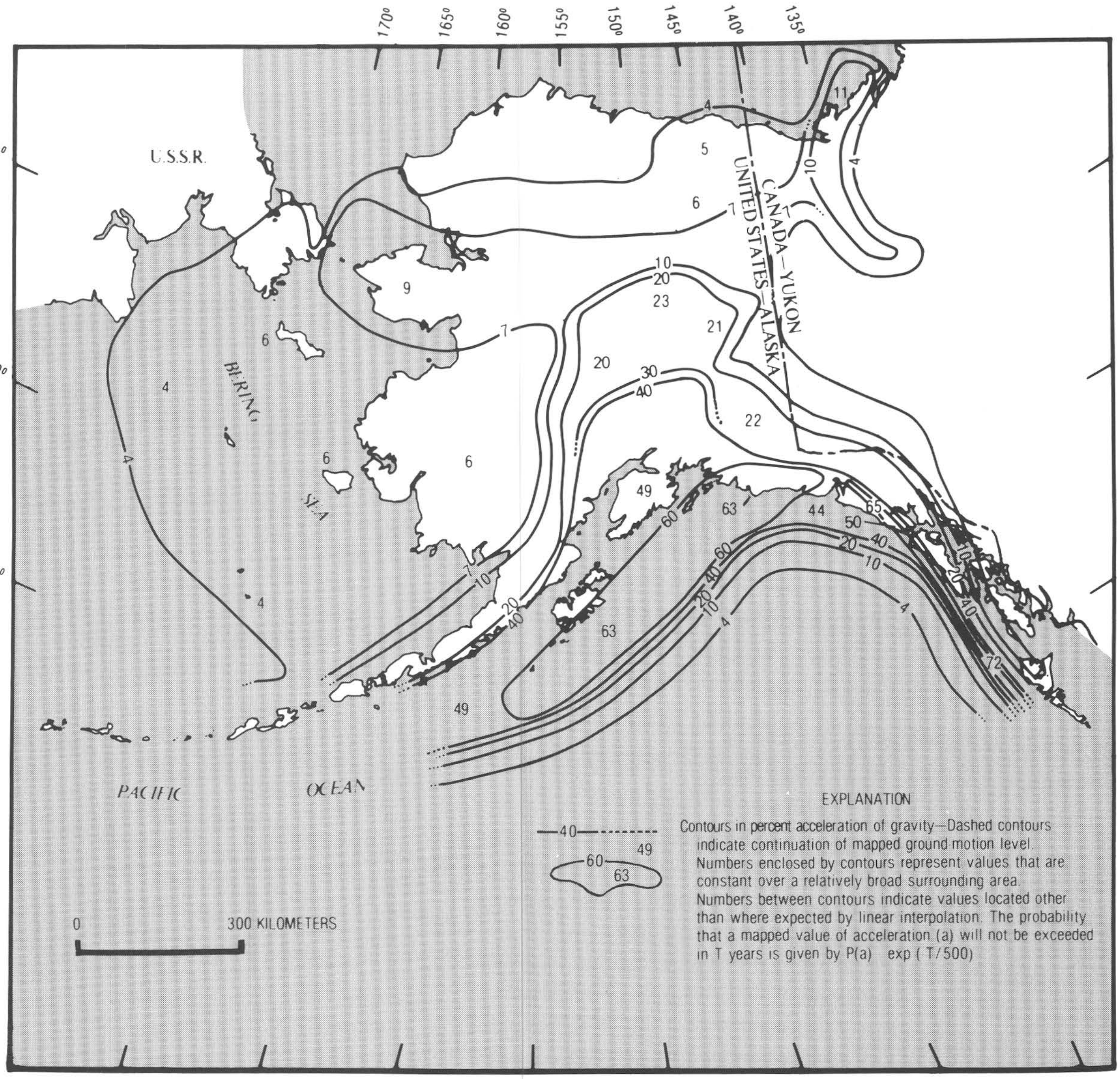
Three great earthquakes, plus 203 damaging aftershocks, occurred near New Madrid,



Estimated horizontal earthquake ground motion (acceleration) on bedrock in the conterminous United States. There is a 90-percent probability that estimated values will not be exceeded in 50 years.

Missouri, in the 3-month interval from December 16, 1811, to March 15, 1812. The New Madrid earthquake sequence produced damaging ground shaking at far greater distances than any other historical earthquake in the conterminous United States. In the 1970's increased public, Federal, and State awareness of the potential earthquake hazard in the New Madrid area and conterminous regions prompted a variety of geologic, geophysical, and geochemical studies at a level of effort greater than any ever before attempted in the Central United States. The multiyear investigation, involving a variety of Federal, State, and university scientific groups, has been funded in large part by the USGS and the Nuclear Regulatory Commission (NRC). In fiscal year 1983 a state-of-the-art assessment of present knowledge about the seismicity and geology of the New Madrid region was published as USGS Professional Paper 1236, *Investigations of the New Madrid, Missouri, Earthquake Region.*

Investigations have revealed that modern seismicity in the New Madrid region is associated with reactivated geologic features of ancient origin. The main seismic zone, which extends over 60 miles in a northeasterly direction from near Marked Tree, Arkansas, to Caruthersville, Missouri, is associated with a zone of arched and faulted Paleozoic rocks and minor faulting of overlying Upper Cretaceous and Tertiary rocks. Vertical offset of the Paleozoic rocks is about 0.6 mile. These zones of faulting and seismicity lie along the axis of a northeast-striking basement rift of late Precambrian or early Paleozoic age. In the southern part of the diffuse zone of seismicity that extends northward from the Ridgely, Tennessee, area to the vicinity of New Madrid, a northeast-striking, high-angle, reverse fault shows about 260 feet of post-middle Eocene vertical movement. An inferred igneous intrusive body lies northwest of the fault. The intrusive activity apparently preceded the faulting but probably was also Cenozoic in age. In the

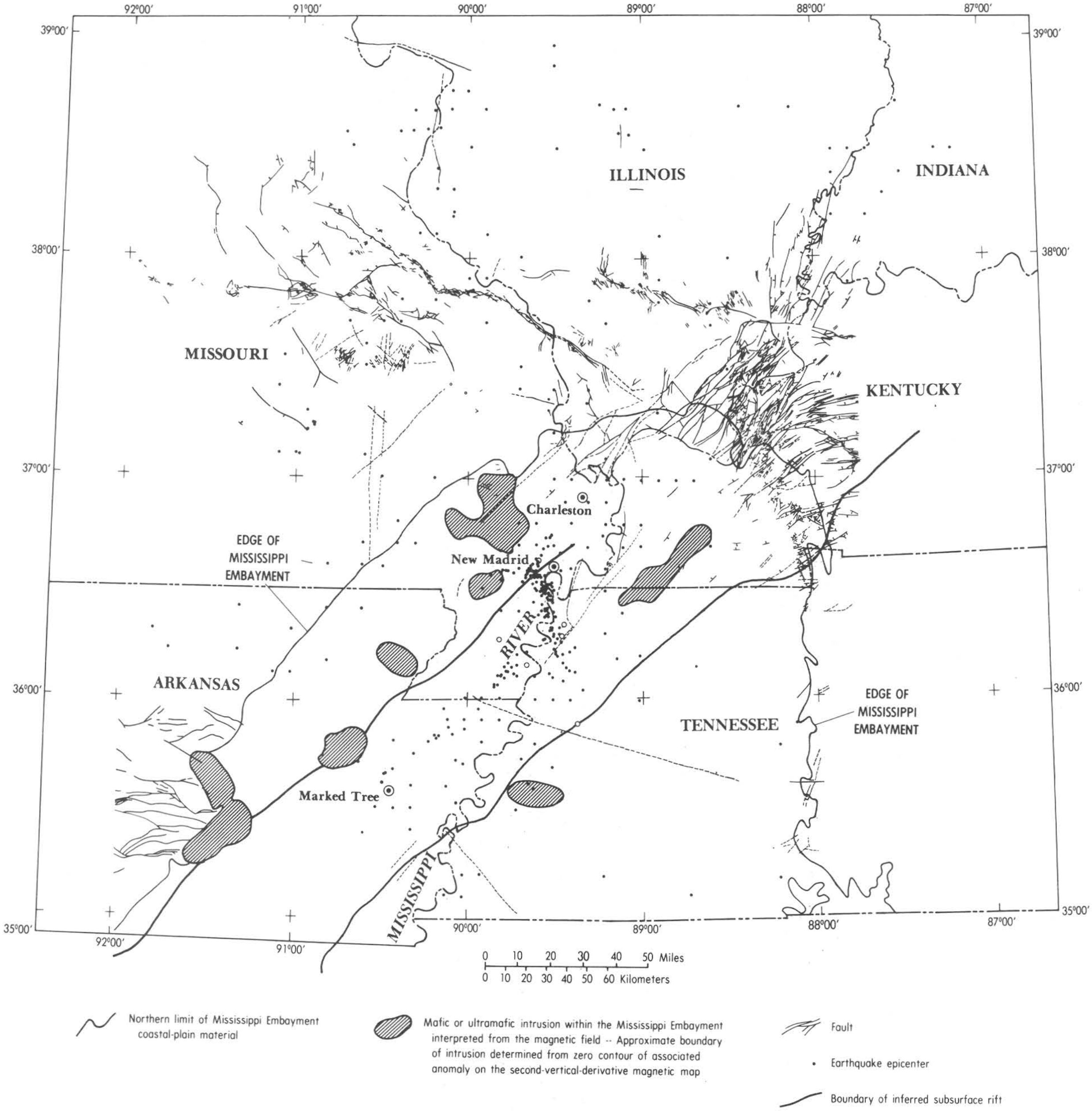


Estimated horizontal earthquake ground motion (acceleration) on bedrock in Alaska. There is a 90-percent probability that estimated values will not be exceeded in 50 years (or 1 chance in 500 that estimated values will be exceeded in 1 year).

vicinity of New Madrid, the upper Paleozoic section is intensely disrupted, possibly by late Paleozoic igneous activity. A northeast-striking seismic zone west of New Madrid appears to be associated with a fault showing mostly pre-Paleocene vertical movement.

Investigations of Charleston, South Carolina, Earthquake of 1886 Continue

Since 1973, the USGS, with support from the NRC, has conducted multidisciplinary investigations of the tectonic and seismic history of the Charleston, South Carolina, earthquake zone and surrounding areas. The goal of these investigations has been to discover the cause of the large intraplate Charleston earthquake of 1886, which dominates the record of seismicity in the Southeastern United States. An understanding of historic and modern seismicity at Charleston and of the tectonic setting of that seismicity would improve the capability to evaluate the potential for additional large earthquakes in the Charleston area and



Generalized fault map of the New Madrid, Missouri, region showing plutons, approximate rift boundaries, and epicenters of earthquakes detected from July 1974 to June 1977.

surrounding regions. It would also help to determine whether the Charleston area differs tectonically in any significant fashion from other parts of the Southeastern United States.

In fiscal year 1983, *Studies Related to the Charleston, South Carolina, Earthquake of 1886—Tectonics and Seismicity* was published as USGS Professional Paper 1313. Although no geologic structure can be unequivocally identified as the source of that earthquake, newly completed seismicity studies discussed in the report provide additional insight into the source area of the earthquake, its relationship to other seismically active areas nearby, and differences between the patterns of activity in the Charleston area and seismicity in the Piedmont province of South Carolina. Most post-1886 seismicity in the Southeastern United States has been concentrated in the Charleston area. Microseismic activity in the Middleton

Damage in Charleston, South Carolina, resulting from the August 31, 1886, earthquake.

Place–Summerville area near Charleston may be occurring on the fault zone that produced the August 31, 1886, earthquake. Several tectonic models have been proposed to explain the seismicity. The microseismicity appears to define a three-segmented seismic zone that strikes northwest and dips southwest. A composite earthquake focal mechanism for several of the events in the Middleton Place–Summerville area suggests reverse dip-slip movement in response to northeast-trending compressive stress. However, relationships between the strike of surface ruptures and (or) focal mechanism nodal planes and the trend of the innermost isoseismal contour for selected earthquakes seem to favor, although not conclusively, a northeast-trending causal fault for the 1886 shock. The strong vertical motions reported in the 1886 meizoseismal area may also indicate dip-slip fault movement. Several investigators have suggested that the 1886 earthquake could have occurred on a reactivated ancient reverse fault.

DATA AND INFORMATION SERVICES

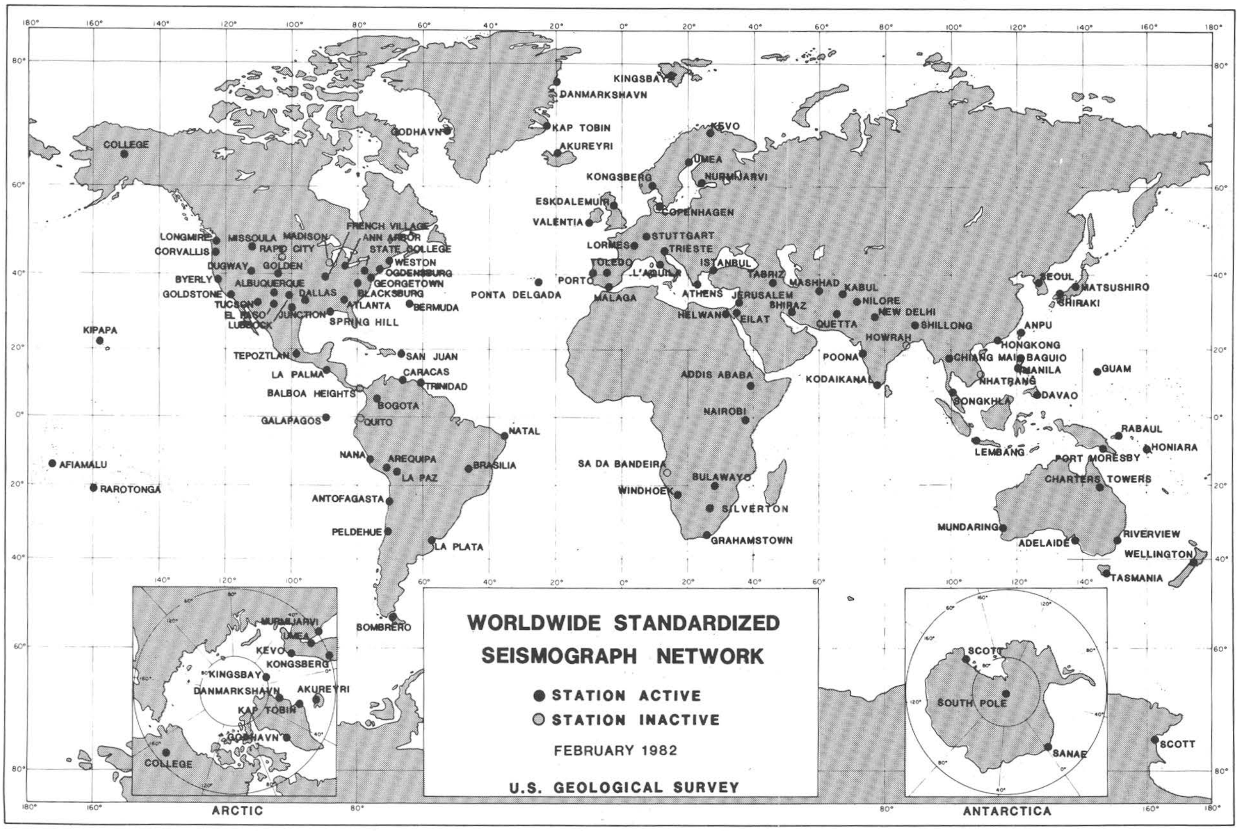
Accelerated progress in the understanding of earthquakes and global tectonics during the past two decades is due in large part to the deployment of global seismograph networks that have generated a seismic data base unprecedented in quality and scope. The USGS supports the operation of two of these networks: the World-Wide Standardized Seismographic Network (WWSSN) and the Global Digital Seismograph Network (GDSN).

World-Wide Standardized Seismographic Network

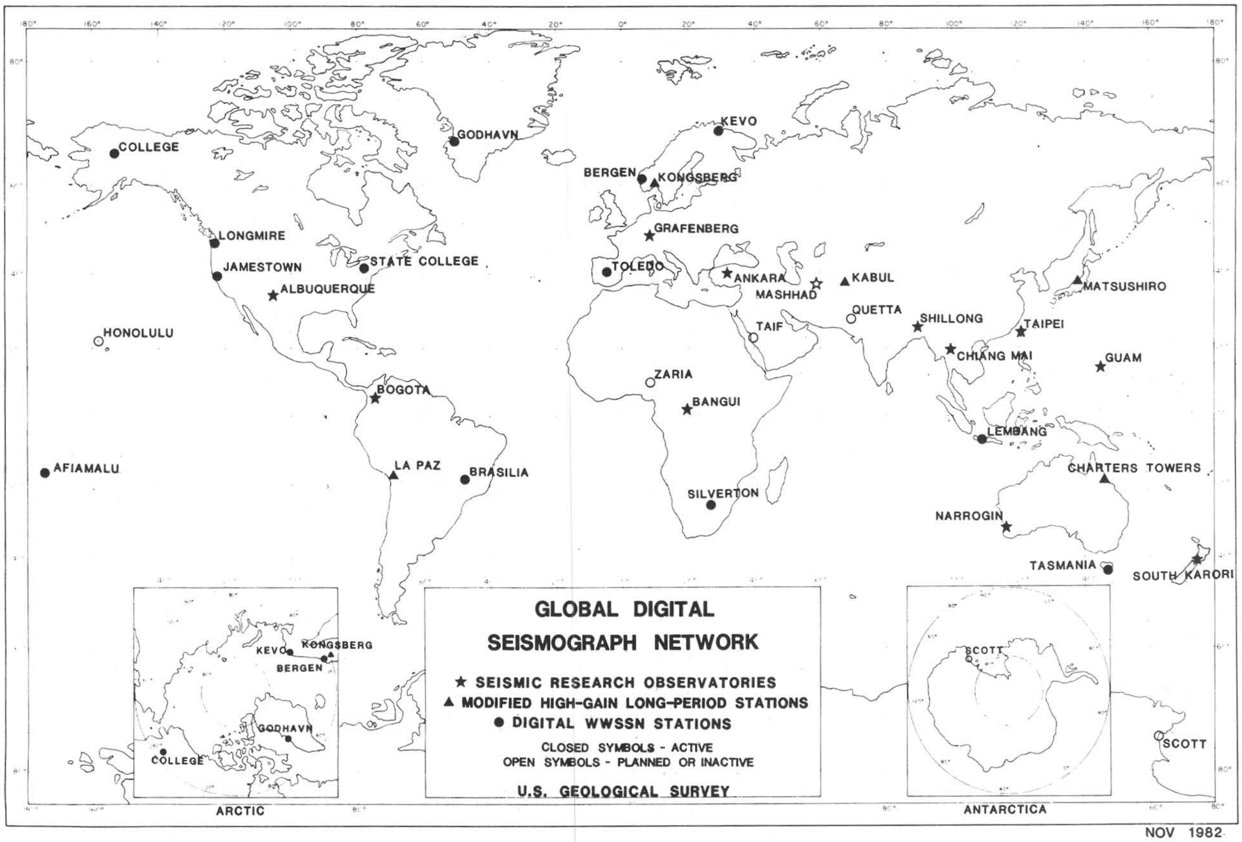
The WWSSN was established in the early 1960's as a part of Project Vela Uniform, a program of fundamental and applied research in seismology managed by the Defense Advanced Research Projects Agency (DARPA). Key elements of the WWSSN are standardized three-component, long- and short-period, uniformly calibrated seismographs, and the means for distributing seismograms to the earthquake research community. The WWSSN today comprises 110 stations operating in 54 countries; its role is to produce the data needed for fundamental research in seismology. The responsibility for managing the WWSSN was transferred to the U.S. Coast and Geodetic Survey (USCGS) in 1963. In 1973 the WWSSN and other elements of the USCGS earthquake program were transferred to the USGS; since 1978, the network has been funded entirely by the USGS under its Earthquake Hazards Reduction Program. Since the inception of the WWSSN, more than 5 million original seismograms have been microfilmed, and 60 million high-quality film copies have been supplied to research workers. Despite the superiority of the more recently available digital seismic data for many purposes, the analog seismograms from the WWSSN remain the foundation for much fundamental seismological research, not only in the United States but also around the world.

Global Digital Seismograph Network

In fiscal year 1980 the USGS assumed responsibility for the GDSN, established by DARPA. The GDSN, which provides extremely high quality digital seismic data for



World-Wide Standardized Seismographic Network.



Global Digital Seismograph Network.

seismological research, is a unique international information resource. Digital recording provides much greater resolution and recording range than analog recording, and the data are available in a format suitable for computer processing and analysis. Data from this network and analog data from the WWSSN are provided to Government, university, and private seismological research activities, are used in studies of plate tectonics, Earth structure, and earthquake source mechanisms, and are the key elements in observational research and in the verification of theoretical hypotheses in all areas of seismology.

National Earthquake Information Service

The NEIS rapidly locates and evaluates the large earthquakes that occur throughout the world, provides data support for the Tsunami Warning System of the National Oceanic and Atmospheric Administration (NOAA), and acquires fundamental data critical to seismic risk appraisal. Products of the NEIS include weekly, monthly, quarterly, and annual reports on earthquake activity, maps of earthquake distribution, and information services to the public. A 24-hour alert service is provided, and appropriate authorities are notified following every potentially damaging earthquake within the United States. This alert allows for the early inspection of dams and other critical facilities for possible earthquake damage. The NEIS also carries out research on the internal structure of the Earth and its effect on earthquake location and severity, seismicity patterns related to the occurrence of large earthquakes, and on the specification of earthquake sources.

ENGINEERING SEISMOLOGY

Records of strong ground shaking near earthquake epicenters are used by engineers and architects in the process of designing buildings and are extremely important in the siting, design, and construction of critical

A seismologist working at the National Earthquake Information Service in Golden, Colorado, monitors a bank of 21 helicorders that record earthquakes detected by distant seismographs deployed around the United States. The seismic data are transmitted by both ordinary telephone lines and satellites.

facilities. Theoretical and interpretive studies that explain the characteristics of strong ground motion and cast observational data in forms more useful to the engineer have been part of the USGS Earthquake Hazards Reduction Program for several years. In fiscal year 1983, responsibility for the National Strong Motion Network, a network of instruments designed specifically to record strong earthquake ground shaking, was transferred to the USGS from the NSF. The transferred observational responsibilities have been combined with analytical efforts to form the engineering seismology element.

The objectives of the engineering seismology element include the following:

- Operating the National Earthquake Strong Motion Network and an associated data center. This network currently consists of 500 strong motion accelerographs designed to record very strong ground motion near the source of damaging earthquakes. These instruments are located in seismically active regions of the United States.

- Archiving strong-motion records and disseminating them to engineers, designers, private institutions, and government agencies concerned with the siting, design, and construction of critical facilities and the establishment of seismic design provisions of building codes.

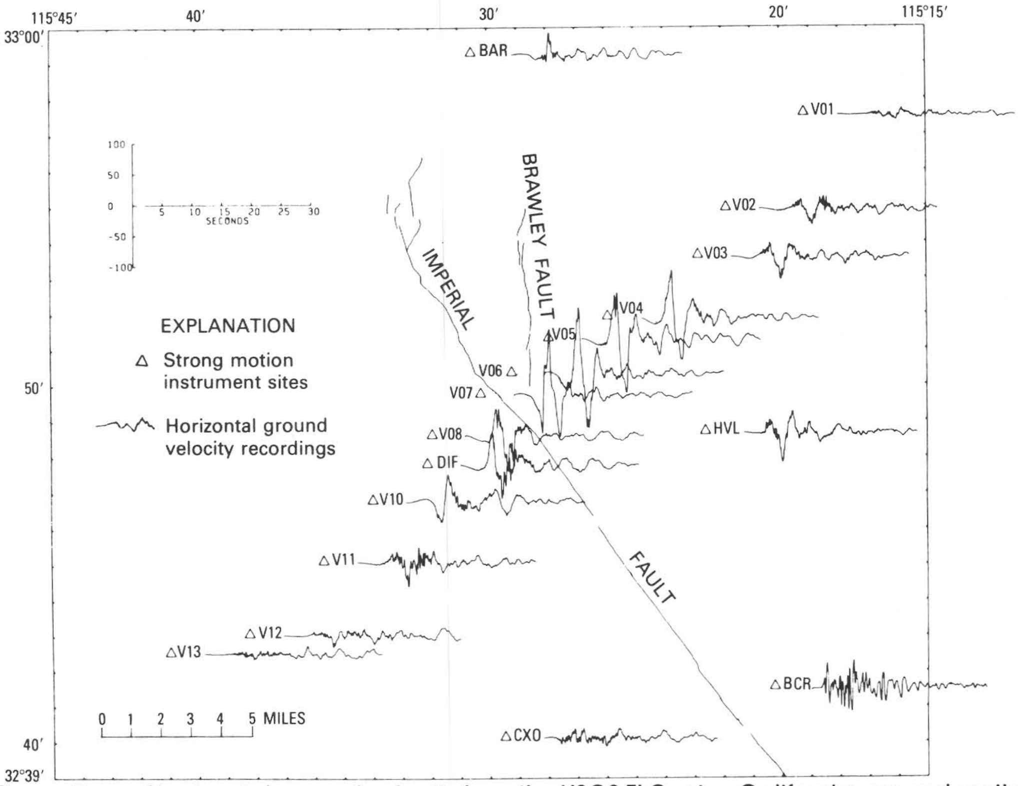
- Devising techniques and procedures for presenting the strong-motion data in a format more useful than its raw recorded form.

- Conducting research to define analytical and empirical procedures used to estimate the level and character of strong ground motion for application to engineering design, taking into account the frequency content, peak, and RMS ground acceleration and velocity, the duration of ground shaking, the effects of local soil conditions, and the geometrical relationship of the recording site to the earthquake source (which, if not considered, can yield misleading interpretations).

Imperial Valley, California, Earthquake of 1979

On October 15, 1979, one of the largest California earthquakes in the past decade occurred on the Imperial fault near the border between the United States and Mexico. The magnitude (M_L) 6.5 earthquake generated the most valuable set of strong-motion accelerograph data yet recorded from a damaging earthquake. These data include the first set of ground-motion records ever obtained close to faults that ruptured during a moderately strong earthquake, as well as the first set of records from an extensive array in a severely damaged building and on a highway overpass bridge less than 1 mile from the fault rupture.

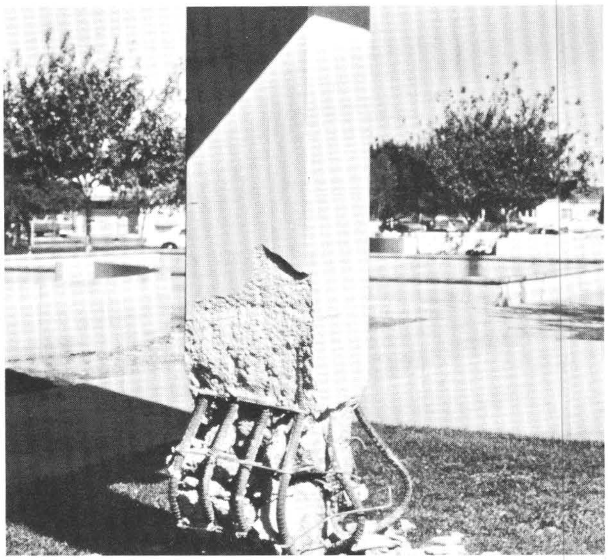
Studies of the information were documented in USGS Professional Paper 1254, *The Imperial Valley, California, Earthquake of October 15, 1979*, which was published in fiscal year 1983. Of particular importance to engineering seismology are the data obtained from the El Centro ground-motion array, a 13-accelerograph, 28-mile-long linear array oriented perpendicular to and crossing the



Recordings of horizontal ground velocity from the USGS El Centro, California, ground-motion array and four other strong-motion sites in the Imperial Valley during the Imperial Valley earthquake of October 15, 1979.

Imperial fault near El Centro; and from the El Centro differential array, a 6-accelerograph, 1,000-foot-long linear array designed to record changes in wave forms over short distances. Strong-motion data from the 28-mile-long array provide information on the nature of shaking close to and at increasing distances from the fault rupture, whereas those from the differential array are particularly applicable to the study of earthquake-induced stresses in such extended structures as bridges, dams, pipelines, and large mat foundations for nuclear power stations. These data also include the largest vertical ground accelerations yet recorded anywhere in the world, 1.66 *g* (gravational acceleration).

From the point of view of a structural engineer, the strong-motion data recorded in the severely damaged six-story Imperial County Services Building in El Centro are the most significant obtained from this earthquake. Data from the building's 13-channel accelerograph system, designed specifically for acquiring information that could lead to improvements in engineering design practice, provide a complete description of building response before, during, and after the occurrence of structural damage. These data are valuable because the time and



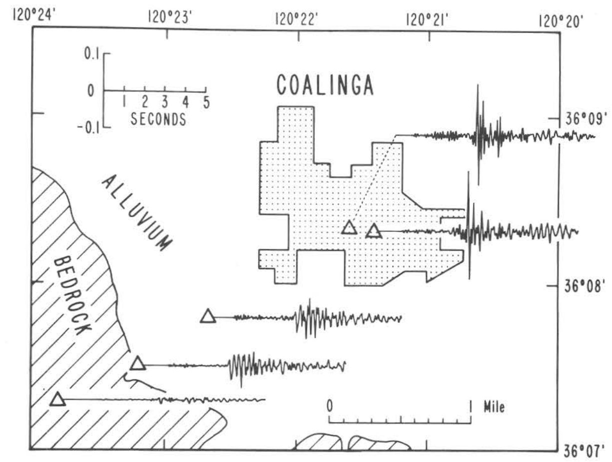
One of the partially collapsed reinforced-concrete columns of the six-story Imperial County Services Building, El Centro, California, damaged during the Imperial Valley earthquake of 1979.

mechanism of structural failure can be inferred directly from the records. In conjunction with the records from a nearby free-field station, these data also provide important information on soil-structure interaction at the building site.

Coalinga, California, Earthquake

Although no records were obtained close to the causative fault in the Coalinga, California, earthquake in the area of heavy damage, strong motion instrumentation operated by the USGS provided records of the ground shaking generated by the main May 2, 1983, shock and several of its aftershocks. This information augments the current data base and can be used to study the amplitude and frequency content of ground shaking in damaging earthquakes.

Aftershock recordings obtained in Coalinga, which is located in an alluvium-filled valley, and at nearby sites located on bedrock suggest that certain frequencies of shaking were considerably larger in Coalinga than at bedrock sites less than 2.5 miles away. This increased shaking due to the alluvium beneath Coalinga suggests that soil amplification may



East-west component of ground velocity from a magnitude 4.3 aftershock of the Coalinga, California, earthquake as recorded on a newly developed computerized General Earthquake Observation System. Several thousand similar on-scale recordings of ground velocity and acceleration provide an extensive data base for inferring the nature of seismogenic failure on the Earth's crust and the characteristics of damaging levels of strong ground motion.

have contributed to the damage experienced in the mainshock.

FOREIGN INVESTIGATIONS

The USGS participates in foreign earthquake investigations and in a number of international cooperative projects in observational seismology, studies of strong ground motion, and earthquake prediction to accelerate and enhance earthquake research in the United States.

Yemen Earthquake, December 13, 1982

On December 13, 1982, just after midday (12:12 p.m. local time), a magnitude (M_s) 6.0 earthquake struck the central highlands of North Yemen, about 45 miles south of the capital, Sana'a. Although ground shaking was not especially severe (maximum intensity was probably only MM VII–VIII), the earthquake caused widespread collapse of unreinforced stone, masonry, and adobe structures. At least 1,700 persons were killed (the total number of deaths has been estimated at close to 3,000), and more than 1,500 were injured. Government reports estimated that about 400,000 (nearly one-half the population of the striken area) were left homeless. More than 300 villages were affected, 20 to 25 of them totally destroyed.

Several days after the earthquake, the USGS was invited by the Saudi Arabian Deputy Ministry of Mineral Resources to join a multinational investigation of the moderate, but destructive earthquake. Two USGS scientists arrived in Yemen on December 28 and remained there through January 10, 1983. They documented surface geologic effects of the earthquake and deployed a network of 10 smoked-paper portable seismographs and one three-component digital instrument to monitor aftershock activity. No tectonic surface faulting was located, but four zones of linear northwest-trending extension cracks were discovered in the epicentral region. Thousands of aftershocks, including many felt earthquakes and a damaging magnitude 5.3 event on December 30, were recorded. The data collected by USGS scientists and other team members suggest that the earthquake sequence was caused primarily by dilatant cracking. Preliminary analysis of the

Yemeni villagers recover possessions from the rubble of a building leveled by the December 13, 1982, earthquake as rescue workers clear a street in the distance. The earthquake occurred in a densely populated region between Sana'a and Dhamar. (Photograph, *undro news.*)

Much of the unreinforced stone masonry in Risabah, Yemen, collapsed during the December 13, 1982, earthquake. The city was approximately 6 miles from the epicenter of the magnitude 6.0 shock.

seismic data indicates that the distribution of aftershocks roughly corresponds to the zones of surface ground cracks; the aftershocks were from 0.6 to 4.7 miles deep. The scientists infer that extension in the epicentral source region reflects local uplift at the surface over an area up to 9 miles long and 6 miles wide, most probably related to the upward movement of magma at depth. The December 13 earthquake occurred in an area of geologically recent volcanic activity; at least one reported historic eruption occurred about 9 miles southeast of the earthquake epicenter.

People's Republic of China

The USGS conducts 14 projects under an Earthquake Studies Protocol signed by the United States and the People's Republic of China (PRC). In May 1983, at the invitation of the Director of the PRC State Seismological Bureau (SSB), a delegation of senior USGS administrative scientists, led by the Director of the USGS, visited China to review the U.S.-PRC Earthquake Studies Program. The review coincided with the Third Annual U.S.-PRC Science and Technology Commission meetings in Beijing.

The primary purpose of the visit was to give USGS scientists an opportunity to meet with personnel of the SSB. The American scientists wished to determine the current structure and content of China's earthquake research program, to examine the equipment and field installations that are used in the SSB's experimental earthquake prediction program, and to learn of the methods that the Chinese use to prepare and evaluate earthquake

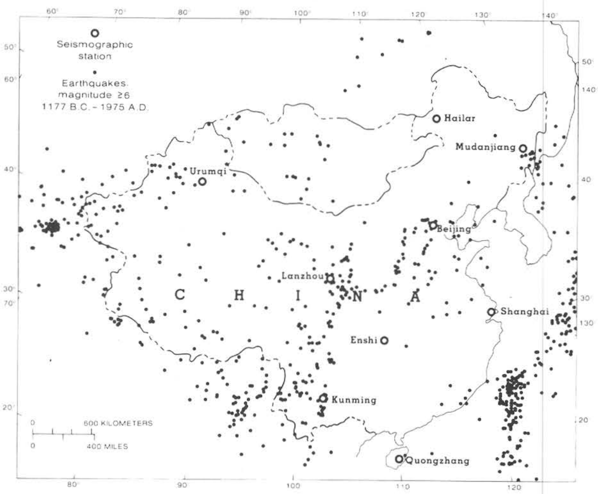
U.S. Geological Survey Director Dallas Peck and State Seismological Bureau Director An Qiyuan (center) discuss the United States-People's Republic of China Earthquake Studies Protocol during the Third Annual U.S.-PRC Science and Technology Commission meetings held in Beijing, China, in May 1983.

predictions. The visit also enabled the USGS group to evaluate the current status and future potential of the U.S.–PRC Earthquake Studies Program.

During the May visit, USGS Director Dallas Peck and Gao Wenxue, Vice Director of the SSB, signed a formal agreement establishing a cooperative project to design, construct, and operate a China National Digital Seismic Network. The network will provide high-quality digital seismic data that will afford an opportunity to analyze the characteristics of large damaging earthquakes in one of the most seismically active regions of the world.

The USGS group met with agency directors and representatives from the SSB Institute of Geophysics, the SSB Institute of Geology, the Center for Earthquake Analysis and Prediction, and the Yunnan Province Seismological Bureau. From the discussions, it was clear that the SSB enjoys broad support from the Government and the public in its continuing efforts to predict the size, location, and time of damaging earthquakes. Numerous earthquake research facilities have been built recently in China, and many more are planned.

CHINA DIGITAL SEISMOGRAPH NETWORK



A National Digital Seismograph Network is being designed by the U.S. Geological Survey for the People's Republic of China. The network will consist of advanced recording seismic stations deployed in nine cities across China. Each station will contain an event-detection and recording system. Seismic data collected by the stations will be shipped to a central processing facility in Beijing, where the data will be integrated and analyzed. A prototype station is now under construction.

Several members of the USGS team traveled to southern China to examine the SSB's primary earthquake prediction experiment site in western Yunnan Province, where USGS and SSB scientists are working cooperatively to predict earthquakes. Yunnan Province is a region of high seismicity where a major damaging earthquake is believed imminent. At the SSB earthquake prediction research site, SSB scientists are carrying out a well-planned set of experiments, many of which are located in strategically distributed tunnels. The USGS has provided much of the equipment in the tunnels (and retains title to it), and is training and assisting Chinese personnel in data measurement and analysis. The SSB tunnel experiments permit the simultaneous measurement of different geophysical properties at a common site. Independent measurements of possible earthquake precursors can be made and compared in a multivariate manner. The USGS team concluded that the Chinese have one of the world's most advanced and complete earthquake prediction experiments.

IMPLEMENTATION OF RESEARCH

Since fiscal year 1978, the USGS Earthquake Hazards Reduction Program has sponsored an active program of outreach. The objectives of the program are to

- Establish "good neighbor" partnerships with Federal, State, local, and private elements in the United States.
- Identify local expertise in every part of the Nation, stimulate interested persons to accelerate their learning about earthquake hazards, and foster the implementation of a seismic safety policy.
- Disseminate research results and information produced by the USGS to the various users, including Federal agencies, State and local governments, engineers and scientists engaged in research and consulting, professional organizations, model code groups, and others.

The USGS has convened a dozen regional workshops since fiscal year 1978 to foster implementation of measures to reduce earthquake hazards in earthquake-prone areas of the United States. Scientists and Federal, State, and local officials have come together in a series of meetings where earthquake hazards information and its applicability have been explained. These meetings have proved to be important catalysts in the successful mitigation of earthquake hazards. The workshops have brought together producers and users of information at all levels of government, academia, and the private sector, and have provided forums where scientists and planners have been able to interact, debate issues, and create plans for achieving specific goals. Five of the workshops were held in fiscal year 1983:

Organization of a Workshop on Geologic Hazards in the U.S. Virgin Islands

Representatives of the USGS, FEMA, and the National Park Service met April 4 to 8, 1983, in St. Thomas, Virgin Islands, with officials of the U.S. Virgin Islands to organize a workshop on geologic hazards in the Virgin Islands. The 25 participants identified a wide range of specific information needs on geologic hazards, particularly earthquake hazards. Preliminary plans were made to hold a workshop in 1984 that will address all aspects (scientific, engineering, societal, and preparedness) of the many geologic hazards problems in the Virgin Islands and will focus on specific subjects or needs identified by the workshop attendees. Participants from other nations in the Caribbean—especially those having relevant experience to share or those having mutual interests and problems—will be invited to attend the workshop.

The planning meeting discussed the likely impacts of the recurrence of the magnitude 7¾ to 8 Virgin Islands earthquake of November 18, 1867. This earthquake today would cause considerable physical damage and extensive societal disruption from ground shaking, tsunamis, ground failures, and regional tectonic deformation. The response and recovery period would be complicated by the high probability that the Virgin Islands might be totally isolated for as much as several days.

"The 1886 Charleston Earthquake and Its Implications for Today," May 23 to 26, 1983

In May 1983, a conference on the Charleston, South Carolina, earthquake of 1886 gave 150 scientists and individuals of diverse background from government, academia, and the private sector an opportunity to discuss the implications of that earthquake in terms of research, earthquake preparedness, and earthquake-resistant design in the Southeastern United States. The meeting was cosponsored by the USGS, NSF, NRC, FEMA, and the NBS, and by South Carolina State and local agencies. The conference reviewed hypotheses about the tectonic origin of the 1886 earthquake and suggested experiments that might be undertaken to resolve the continuing scientific debate.

Conference participants recommended a number of measures to assure that earthquake research and earthquake hazard mitigation will continue in the Eastern United States. The conferees strongly encouraged the South Carolina Geological Survey and the recently formed South Carolina Seismic Safety Consortium to continue their efforts to heighten public and governmental awareness and to improve preparedness for possible future large earthquakes in the Southeast. The NRC received technical guidance in establishing research priorities to evaluate the earthquake risk to nuclear facilities in the Eastern United States. The USGS was urged to continue its integrated multidisciplinary research program on the origins of Eastern U.S. seismicity, emphasizing the refinement and resolution of seismotectonic models of the 1886 Charleston, South Carolina, earthquake. The NSF was encouraged to continue funding research in the Southeast that will increase fundamental earthquake knowledge.

"Continuing Actions to Reduce Losses from Earthquakes in the Northeastern United States," June 13 to 15, 1983

A 3-day workshop was convened in June 1983 at the Massachusetts Institute of Technology

(MIT) in Cambridge to identify continuing actions to reduce losses from future earthquakes in the Northeastern United States, and to foster cooperation for a strong national network of concerned federal, regional, State, and local governments and individuals in the private sector. The workshop, which was cosponsored by the USGS and FEMA, was attended by 75 individuals representing all levels of Federal, State, and local government; private industry; and the academic community. Participants learned about the nature of the earthquake threat in the Northeast and the current capabilities to respond to such an earthquake. Formation of a Northeast Regional Seismic Safety Commission was proposed in the workshop.

"Site-Specific Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design," July 26 to 28, 1983

Forty-two scientists and engineers representing academia, industry, and State and Federal Government met in Santa Fe, New Mexico, to discuss a problem that has provoked controversy in the scientific and engineering community since the 1920's—the effects of soil and rock on ground motion and the implications for the design and construction of earthquake-resistant structures. The workshop was sponsored by the USGS and the NRC. In a state-of-the-art review, a majority of the participants indicated that, although existing geologic, geotechnical, and ground-motion data bases are adequate for modeling site response and incorporating its effects in earthquake-resistant design in the Western United States, they are insufficient for similar modeling in the Eastern United States. The conferees noted that the existing earthquake ground-motion data base is incomplete for high strain levels; all earthquake ground-motion data were recorded at low strain levels relative to those achieved in the laboratory.

Participants proposed multiple experiments to examine ground motion at both low and high strain levels, to reduce uncertainty in earthquake-design parameters that incorporate site response, and to improve site-dependent response spectra. The participants recommended that the USGS immediately implement measures to create a comprehensive national strong ground motion data base. They also recommended that two- and three-dimensional strong-motion instrument arrays be deployed to capture strong ground motion at locations where the potential exists for a large earthquake. The conferees noted that, although these arrays now exist in Japan and in Yugoslavia (the network in Yugoslavia was erected with funding from the NSF), no similar array exists in the United States.

"Continuing Actions to Reduce Losses from Earthquakes in Arkansas and Nearby States," September 20 to 22, 1983

The status of earthquake preparedness in Arkansas and in adjoining Mississippi Valley areas was reviewed in a workshop convened at North Little Rock in late September 1983. The workshop was jointly sponsored by the USGS, FEMA, and the Arkansas Office of Emergency Services. The 75 workshop participants assessed the implications of the recurrence of damaging earthquakes in the New Madrid seismic zone. Losses from another great earthquake like those that shook New Madrid, Missouri, in 1811 and 1812 would probably exceed the losses from any prior natural national disaster, and the participants concluded that no State in the Mississippi Valley is adequately prepared to cope with such a catastrophic earthquake. They urged that multidisciplinary earthquake-hazard reduction efforts by the USGS, FEMA, the State of Arkansas, and others be continued.

The conferees noted that, in the next 5 to 10 years, progress toward adequate earthquake preparedness must be accelerated. Such efforts will require a partnership of government, business, and academia employing experts in earth science engineering, architecture, city planning, social science, and emergency management. In this partnership, the USGS would be requested to

- Foster closer working relationships between Federal and State governmental agencies.

- Conduct geologic and seismological research in the Mississippi River area to define the seismic cycle of faults in the New Madrid seismic zone and to characterize

Arkansas Earthquake Workshop, September 22, 1983. Reo Hosman (left), Southwestern Bell Telephone, and Roy Popkin (center), American Red Cross, listen as Maurice Robinson of the Arkansas Electric Cooperative Corporation describes how an earthquake in or near Arkansas might affect regional electric production and distribution. Robinson concluded that another major earthquake like those that occurred in 1811 and 1812 near New Madrid, Missouri, could severely disrupt utilities in Arkansas and neighboring States and that restoring service could take as long as 2 years. (Photograph, *Arkansas Democrat.*)

known seismic source zones in terms of their potential for generating a damaging earthquake.

- Monitor regional seismic activity by using seismic arrays like those operated by St. Louis University and others.

- Deploy strong-motion accelerographs to record, whenever possible, strong ground motions for use in designing earthquake-resistant structures.

- Complete geologic and seismic studies in six cities in the Mississippi Valley area as part of a program initiated in 1981 by FEMA–Region VII.

- Convene workshops to accelerate the transfer and utilization of earthquake hazards research and the development of loss-reduction measures.

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NATIONAL SCIENCE FOUNDATION

The NSF's activities related to earthquake hazard mitigation include research in the earth sciences; engineering, architecture, and planning for earthquakes; and the social sciences. These activities are supported through the Earth Sciences Division and the Civil and Environmental Engineering Division.

THE IMPLICATIONS OF PLATE TECTONICS

The concept of plate tectonics states that a small number of rigid plates form the Earth's outer surface and that the movement of these plates relative to one another is responsible for earthquakes and mountain building. The deposition of ores, burial of plant and animal life to form fossil fuels, volcanic eruptions, and many other phenomena are the consequences of plate tectonic processes. There is still much that scientists do not know about this revolutionary concept, including the answer to the underlying question of what causes the plates to move.

The main goal of this research is a better understanding of plate motions and interactions. When researchers know much more about how and why plates move, they will have the basis of a much better understanding of many processes in the Earth, including the causes of earthquakes.

Substantial advances have been made in this area in recent years. A number of these advances were detailed in the 1982 Report to the Congress. In what follows, further progress made in 1983 in several selected projects is briefly highlighted.

Recent Studies of Continental Lithosphere Tectonics and Related Seismic Activity

During the past year, the Consortium for Continental Reflection Profiling (COCORP) has carried out a deep seismic reflection profiling program consisting of field studies, data analysis, and interpretation, which has led to a number of insights on the structure and tectonics of the lithosphere and on the relation of these topics to seismic activity.

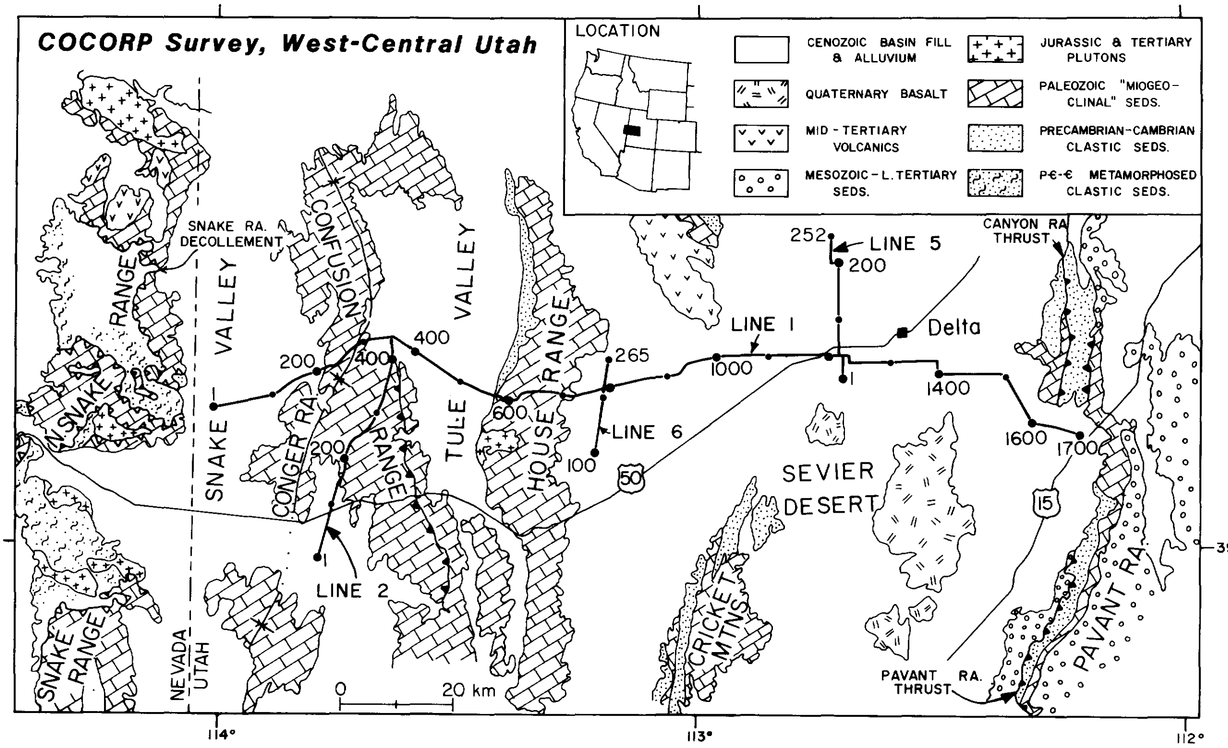
COCORP is currently completing the final segments of a traverse that spans the entire Basin and Range province and adjoining parts of the Sierra Nevada and Wasatch Plateau. Interpretation of the data for the segments surveyed in the early phases has already produced surprising results. In western Utah, outcropping Cenozoic normal faults can be traced to shallow detachments that extend to depths of at least 10 miles over distances of more than 60 miles. Portions of these detachments also may have been Mesozoic thrusts.

Many, perhaps all, Basin and Range earthquakes may be associated with such faults, but at least near the borders of the province it appears that some earthquakes are too deep to be associated with these shallow features. Thus, the nature of some earthquakes of the region may now be better understood, while others remain enigmatic.

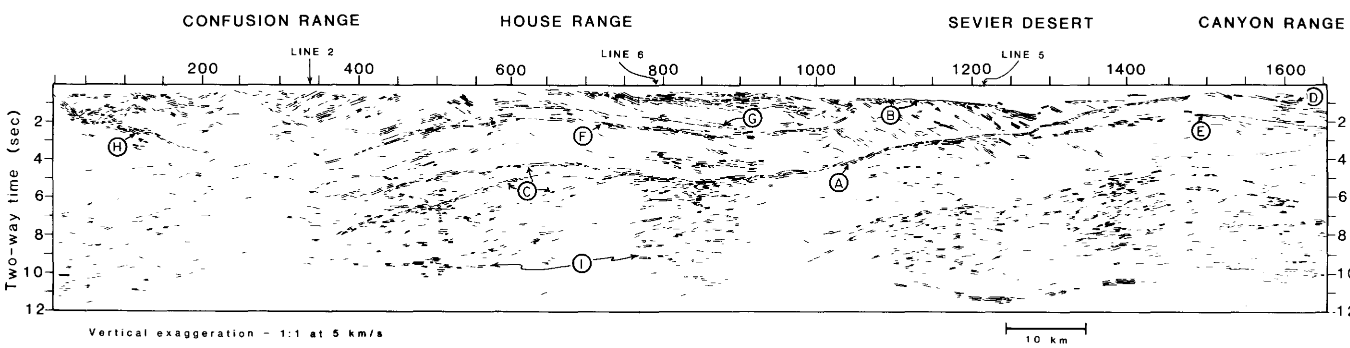
In the Sierras, east-dipping Mesozoic thrust faults, some of which show evidence of reactivation in the opposite sense in the Quaternary and hence have the potential for modern earthquakes, were traced at moderate angles of dip to lower crustal depths. This observation may be of considerable importance in understanding modern tectonics of the area. One such fault bears the veins of the Mother Lode gold deposit and may have served as a conduit for mineral-bearing solutions. An interesting feature of some relevance to earthquake studies is the consistency of reflections from the vicinity of the Mohorovicic discontinuity, which seems to be fairly uniform in depth over the whole Basin and Range province.

In the Death Valley region, a strong reflector at a depth of about 9 to 13 miles resembles a reflector in the Rio Grande Rift that was found by using earthquake data and was identified as a mid-crustal active magma body. The Death Valley reflector is not yet as well corroborated as the New Mexico reflector, however.

In the Mojave region, several west-dipping faults with earthquake potential were mapped during COCORP surveys. One reflector at a depth of 9 miles appears to be continuous beneath the Garlock fault, suggesting that the dip of the fault changes greatly with depth, or that the brittle-ductile transition is shallow, or that the lower crust is in some other way decoupled from the upper crust.



Consortium for Continental Reflection Profiling survey, west-central Utah.



Line drawing abstracted from all of Consortium for Continental Reflection Profiling line 1: A, Sevier Desert detachment; B, Pliocene basalt; C, possible splaying of Sevier Desert detachment at depth; D, Pavant Range thrust (?); E, another possible Mesozoic thrust fault; F and G, Mesozoic thrust faults, perhaps correlative with the Pavant and Canyon range thrusts (F appears to have been reactivated by Cenozoic extension); H, Snake Range decollement; I, reflections from the Mohorovičić discontinuity.

Extensive reprocessing of the COCORP data from the vicinity of Coalinga, California, the site of a recent destructive earthquake, revealed information on the sedimentary rocks of the Great Valley and the shallow underlying basement but not on the deep basement. Faults found in the shallow basement and deeper sediments had locations, attitudes, and offsets such that modern movement along one or more of them could account for the Coalinga mainshock and many of the aftershocks.

THE EARTHQUAKE PROCESS

Present understanding of the details of the earthquake process comes mainly from seismic signals measured at large distances from the source. Consequently, the models used by seismologists today are generally not able to describe the variety of observed near-source features completely.

However, the prediction of earthquakes and destructive ground motion hinges on a thorough understanding of the mechanical processes leading to and causing an earthquake. Both preearthquake phenomena and the ground motion caused by the earthquake are tightly linked with the faulting process itself. Detailed measurements of geophysical fields associated with near-source preearthquake deformation must be made in the neighborhood of the seismic fault.

What physical parameters are the most critical and what details of rock properties cause an earthquake are not yet known. The failure criteria of crustal rocks and the role of preearthquake deformation must be understood in order to calculate the reinitiation of motion on the fault and to determine the total seismic energy that is released. In addition, the material properties and the nature of the geology affect the amount of energy released and the characteristics of the generated motion.

Much remains to be investigated, but a number of achievements have been made in recent years. Some of those made during 1983 are briefly outlined below.

Application of Digital Data to Earthquake Source Studies

Quantification of earthquakes is one of the principal tasks of seismology. The distribution of seismicity, the size of the events, the orientation of the forces acting at the focus, and the temporal history of the rupture process are not only of great scientific interest but also have profound practical implications for estimating of seismic risk and developing appropriate building codes.

The parameters routinely used to describe a seismic event are its epicentral coordinates, focal depth, origin time, and magnitude. For events of special interest, the polarities of the signs of the first arrivals are studied to obtain nodal plane solutions, which, in turn, indicate orientation of the compression and tension axes, under the assumption that an earthquake is a plane shear failure. During the past decade, significant developments have taken place in both theory and data quality that have shown that many earthquakes are not pure plane shear failures.

In elastodynamic terms, an earthquake is caused by the sudden release of stress in the Earth. The difference in stress, before and after the earthquake is termed the stress drop, and the volume integral of the stress drop, which has the dimensions of (force times distance), is termed the moment or moment tensor.

The body forces, equivalent to the stress drop, are said to constitute the source mechanism of the earthquake. The balanced double-couple system of forces, equivalent to plane shear failure, has been almost universally adopted in studies of the source mechanism of earthquakes. However, if an earthquake should have, for example, a partly isotropic moment tensor (implosive component), then studies of its source mechanism based on the a priori assumption of a system of double couples must fail to reveal the isotropic part. It is clear that a procedure in which the elements of the moment tensor can be determined directly from the seismic data is preferable to one that imposes a priori restrictions.

It is also important that each of the elements of the moment tensor be independently determined as a function of time. Such a general approach can be helpful in establishing the sequence of events at the source and provide data for testing the applicability of various dynamical source models.

Such a procedure is being applied at Harvard University. In fact, the systematic study of earthquake parameters using digital data from the GDSN and the International Deployment of Accelerometers Network is now in its third year. Centroid-moment tensor (CMT) solutions were evaluated for 308 events that occurred during 1982, and so far results have been obtained for about 150 earthquakes of 1983. Each month the results are sent to the NEIS, which incorporates them in the monthly listings of the preliminary determinations of epicenters. Collected data also are published in international journals.

The results are beginning to have an impact on regional studies of seismicity as well as on the general perception of earthquake processes. Display of several hundred solutions suggests that for shallow sources the deviation from a double-couple mechanism is a function of seismic moment. The double-couple model is a good approximation for very large events (M_0 greater than 10^{27} dyne-centimeter), but for many intermediate-sized earthquakes the plane shear failure model is inappropriate; Mammoth Lakes, California, earthquakes are a good example. The question of whether these intermediate-sized earthquakes can be explained by complex faulting on different planes or by a different mechanism, such as magma injection, could be answered if the response of digital stations were better in the range of frequencies from 0.2 to 1 Hertz. Development and deployment of high-quality, digital, broadband seismographs is one of the important needs in the area of basic studies of earthquake processes.

An example of use of the CMT method in regional studies is the investigation of the mode of deformation in the Tonga subduction zone. Because of the high level of deep seismicity, this region can be studied using data from a relatively short period of time. Harvard seismologists combined information contained in ISC Bulletins on the overall distribution of seismicity with the geometry of failure indicated by the CMT results. The results indicate that the concept of a subduction zone as a smoothly bending, coherent slab needs modification. Their detailed analysis of seismicity shows a complex, cross-cutting pattern of interacting shear bands and leads them to view the seismic zone as that part of the convective flow which, through a particular combination of temperature, composition, and strain rate, accomplishes its deformation through episodes of shear instability.

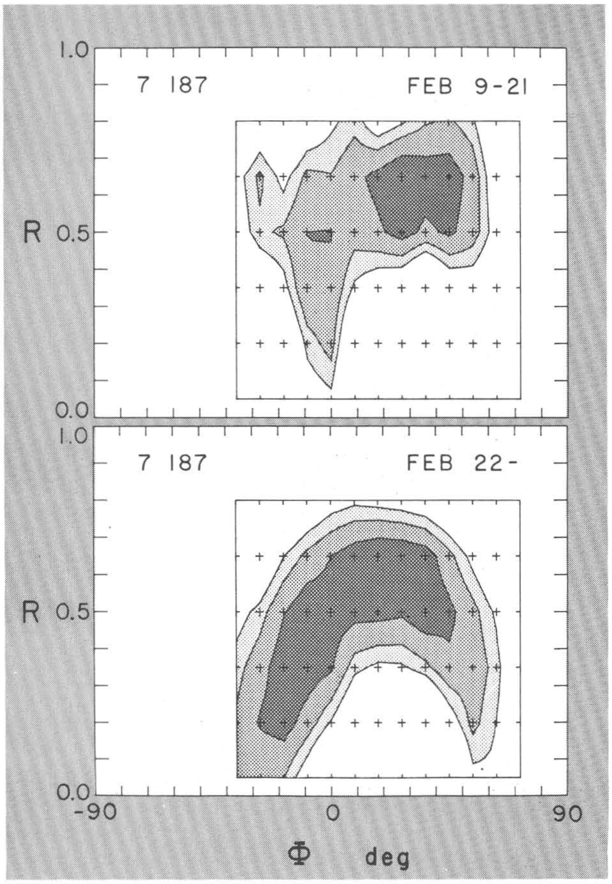
At present, the taped data arrive at Harvard 2 to 2.5 months after an event. The technology exists for transmission of the data in real time. The CMT method enables very rapid estimation of the size and mechanism of an event. The ability to provide such values within 1 to 2 hours after an earthquake would be valuable to society as well as to science. In addition to prediction of the tsunami effect, for earthquakes that occur in populated but remote areas, estimates of the potential damage could help in planning the rescue effort. From the scientific point of view, studies of aftershock series and postseismic deformation could be much better designed if the size and mechanism of the main event were known.

Stress in the Crust and Earthquake Focal Mechanisms

The state of stress within the Earth's crust controls what types of earthquake may occur. For any single state of stress, there is a family of possible earthquake focal mechanisms. Conversely, any single focal mechanism (slip in a particular direction on a fault of known orientation) is consistent with a range of possible stress states. These ambiguities have made it difficult for scientists monitoring the seismicity in an earthquake-prone area to determine whether a change in the typical focal mechanisms of the small earthquakes in that area represents a change in the overall state of stress or merely a shift of the slip or strain to a different subset of faults within the same area.

Recently, scientists at Brown University developed a technique for rigorously testing hypotheses concerning changes in the state of stress. From a family of earthquakes of differing focal mechanisms, limits are placed on the possible orientation of the three principal stress axes. Unlike traditional approaches, the new technique also provides an estimate of the relative magnitude of the stresses through a parameter called R, which is the ratio of the difference between the intermediate and minimum principal stresses to the difference between the maximum and minimum principal stresses. If the limits on the possible stress orientations and magnitudes for two different subsets of earthquakes do not overlap, then there must be a change in the state of stress.

This technique was applied to the aftershock sequence of the February 9, 1971, earthquake in San Fernando, California. On the basis of a shift in the type of faulting in the aftershocks, it had been suggested that a shift in the orientation of the principal stresses occurred on February 22, 1971. The simplest explanation of the observed change in focal mechanism is that slip just shifted to a different set of subsurface faults in the aftershock zone.

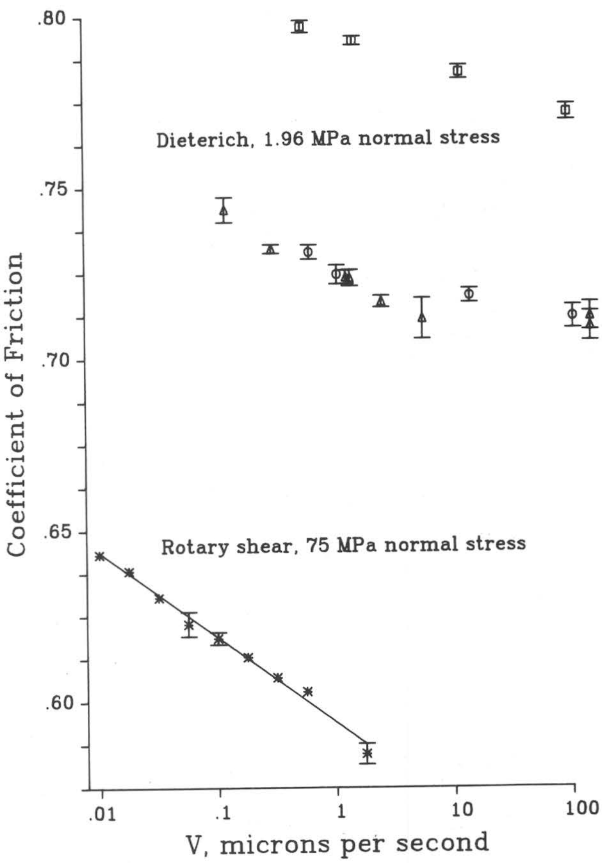


Results of testing for a change in stresses during the San Fernando earthquake aftershock sequence. Top, contours of confidence levels using 55 aftershocks through February 21, the date of the proposed change. Bottom, contours of confidence levels using 20 aftershocks occurring after this time. In both cases, the maximum stress axis is nearly horizontal, dipping 7 degrees, and nearly north-south, striking 187 degrees east of north. R describes the relative size of the principal stresses and ϕ, the orientation of the minimum stress axis. Shaded regions from darkest to lightest represent models within the 50-percent, 95-percent, and 99-percent confidence limits. Because the 50-percent confidence regions for the two sets of aftershocks overlap, there is no requirement for a change in regional stress.

Rock Friction Constitutive Experiments As Related to Theory of Earthquake Instability

Earthquakes result from a mechanical interaction between the material within fault zones and the surrounding rocks. The surrounding rocks gradually become distorted prior to an earthquake and rebound elastically during an earthquake; this behavior is relatively well understood. The mechanical behavior of the rocks in the fault zones is less well understood; this behavior is being studied in order to understand the entire earthquake process better and to discover phenomena that will allow successful earthquake predictions.

In order to understand the mechanical behavior of fault-zone rocks, scientists at Brown University are conducting laboratory experiments on the frictional behavior of sliding rock surfaces. These experiments are being conducted in a rotary shear apparatus



Coefficient of friction as a function of sliding velocity. The data points at the top are for three experiments reported by James H. Dieterich, U.S. Geological Survey; the important consideration is the slope defined by the data and not the offset between the data sets. The stars represent the Brown University data obtained at elevated normal stress, and the line is a least-squares fit to the data.

specifically designed for this and similar research. Two advantages of this apparatus are its abilities to investigate sliding under high pressures and to investigate large displacements, a combination not found in other machines used for this kind of research. This capability permits a better approximation of conditions that actually exist in the Earth.

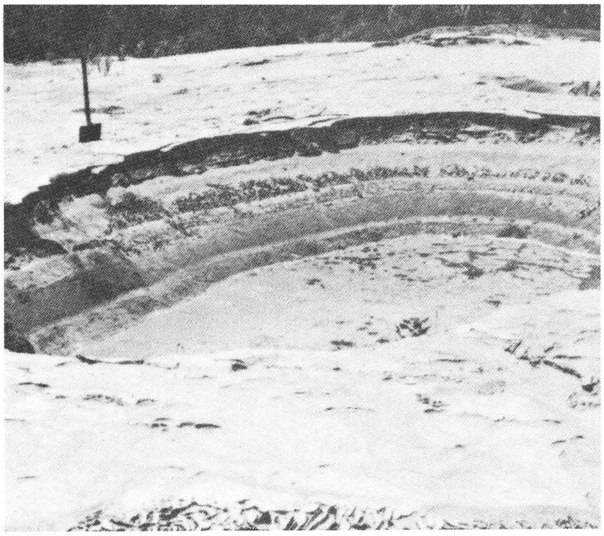
One of the most important considerations determining whether a fault will slide with stable motion or with episodic earthquakes is whether the frictional resistance to sliding increases or decreases as the velocity of sliding increases. Theoretical analyses by others have shown that an earthquake will occur only if the frictional resistance *decreases* with an increase in sliding velocity. Previous experimental work by others on the velocity dependence of frictional resistance has shown conflicting results. An extensive series of experiments by scientists at the USGS and at Cornell University has shown that frictional resistance does decrease with increasing velocity. Using these results, they have developed a constitutive description of rock friction. However, these experiments were at very low pressures compared to the pressures experienced by natural faults. Experimental studies by another group at the USGS have shown an increase in resistance with increasing velocity in experiments conducted over a range of pressures, including ones appropriate to faults in the Earth. The recent work at Brown has produced a significant result bearing on this controversy. At an intermediate pressure it is found that the frictional resistance decreases with an increase in velocity. Furthermore, the quantitative dependence on velocity is almost the same as was found by the USGS workers at a much lower pressure even though their coefficients of friction are higher because of the lower pressure (normal stress). The implications of this are far reaching. Perhaps most important, the Brown results strongly suggest that the type of constitutive description of the frictional process that has resulted from the earlier USGS experiments is indeed applicable at higher pressures, and that the description probably applies to natural faults.

To apply laboratory-scale experimental results to large-scale faults in the Earth, it is necessary to have a theoretical understanding of the processes involved and to have theoretical models of those processes that allow changes to be made in the scale-dependent parameters. Theoretical analyses of earthquake instability are being conducted at Harvard University, and, in a collaborative effort, the results are being compared with the laboratory experiments at Brown. This comparison allows a check on the theory so that it can be validated and, if necessary, modified. Without this, there cannot be sufficient confidence in the theory for it to be used in understanding and predicting earthquakes. The Harvard group has investigated both a simpler, linear (small amplitude) and a more complex, nonlinear (large amplitude) instability theory. Several recent results from the experiments at Brown show that it is necessary to use the more complex, nonlinear theory. First, experiments show asymmetrical behavior on increasing and decreasing the velocity of sliding: velocity increases from steady-state sliding cause an instability in the sliding (a "miniearthquake"), whereas velocity decreases from steady state sliding do not cause instability. This asymmetrical behavior is predicted by the nonlinear theory but not by the simpler, linear theory. Second, it is found that large changes in velocity after steady sliding will cause instability, but small ones will not. Again, nonlinear theory is necessary to explain this observation. Third, there is a wide range of conditions in which periodic quasi-stable oscillations in sliding velocity occur at the rock surface even though the remote driving velocity is steady. This oscillatory behavior is predicted for the linear theory only at a single set of conditions, whereas the nonlinear theory predicts it should be widespread. Hence, the laboratory observations clearly demonstrate that the more complex, nonlinear theory is needed in order to understand many of the important features of the mechanical behavior of the earthquake process.

SITING AND GEOTECHNICAL EARTHQUAKE ENGINEERING RESEARCH

The importance of understanding the dynamic earthquake response of surface and subsurface ground conditions, illustrated by the destructive Turnagain Heights landslide of the

Typical liquefaction ground damage experienced in May 1983 earthquake near Tokoi, Japan.



great Alaska earthquake of 1964 and the near-catastrophic collapse of lower San Fernando Dam during the San Fernando earthquake of 1971, was seen once again in the May 1983 earthquake centered at sea about 62 miles off the shore of Japan near Akita in the northern island of Honshu. The earthquake disturbances at the ocean floor produced tsunami waves that caused heavy damage to shoreline structures and resulted in a loss of 100 lives along the coastal area. In addition, earthquake ground motion caused extensive liquefaction of inland ground areas beyond the area hit by the tsunami, resulting in the destruction of several noncoastal structures.

Siting and geotechnical earthquake engineering research programs sponsored by the NSF encompass measurement and analysis of strong ground motions, studies of soil-structure interactions and investigations of the stability of ground structures such as dams and abutments, and studies of potential ground damage to lifeline structures such as utility lines and communications systems. Information obtained from these individual but interdependent segments of research provides a better understanding of the dynamic effects of earthquake ground motion on structures and facilitates the development of engineering approaches to reduce potential damage to property and risks to human lives.

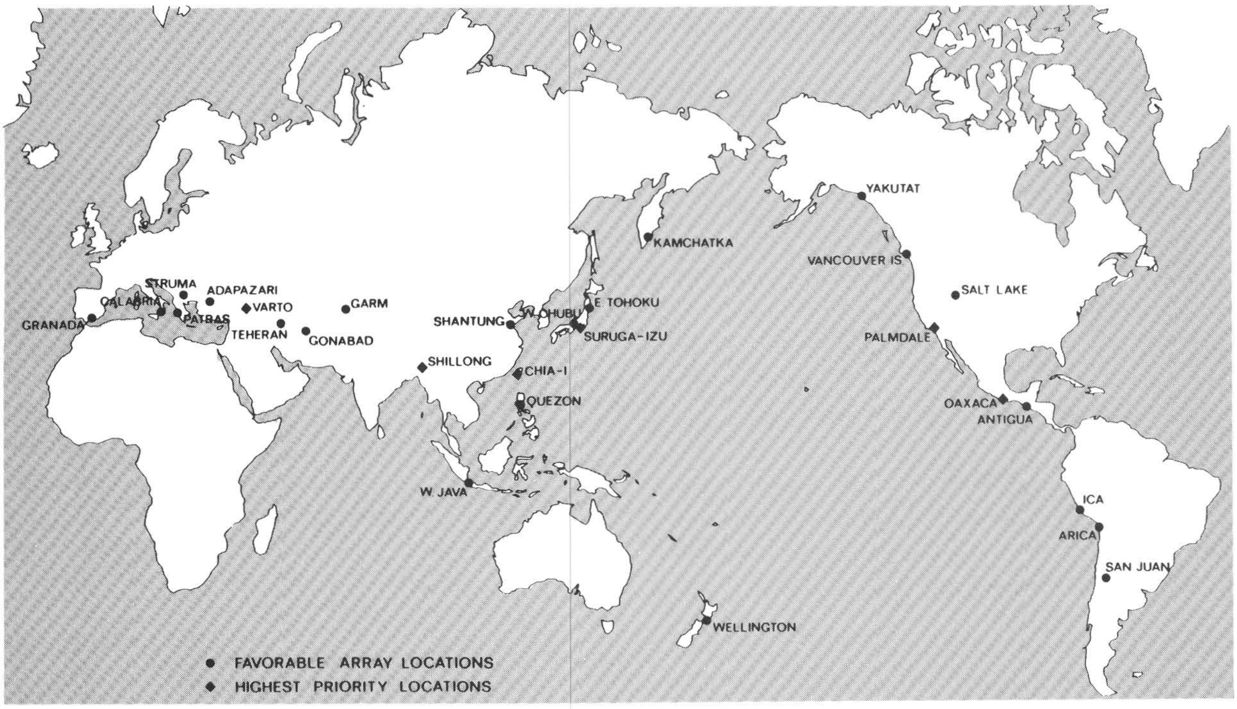
Earthquake Ground Motion

Measurement and analysis of destructive ground motions in order to obtain quantitative values essential to the study of structural response and geotechnical earthquake engineering for hazard mitigation are continuing; 5,500 strong-motion instruments are now installed and operational in seismically active and earthquake-prone areas in the United States and around the world. Ground motion data, collected from more than 55 destructive earthquakes, have helped to narrow the uncertainty limits in estimating ground motion probabilities in a given area and in assessing the probable site-specific effects of earthquakes in the area.

On the recommendation of a strong-motion instrument array workshop, sponsored by the NSF and held in cooperation with the United Nations in 1978, the NSF initiated research programs for the installation of instrument arrays at designated high-priority sites around the world. To date, cooperative research projects have been initiated with India, Mexico, Taiwan, the PRC, and the Soviet Union for the installation of strong-motion arrays, and these arrays are providing a wealth of data.

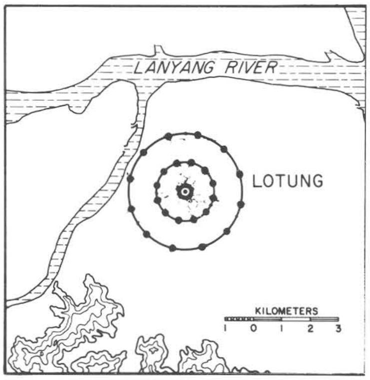
Lack of strong-motion data needed to identify wave types until now has limited the reliability that could be placed on wave form data used for earthquake-resistant design of structures. The design practice, therefore, was to assume wave motion that is constant across the whole foundation of the structure. However, the innovative instrument array code, SMART-1, deployed in Taiwan, has produced a high rate of data acquisition, recording strong-motion data from nearly 20 earthquakes to date. The analysis of the data has helped to identify wave types associated with strong ground motions. Correlations obtained from actual wave forms across the Taiwan array show significant deviations and make untenable the assumption that wave motion is constant across the whole foundation of a structure. On the basis of these data, new theoretical approaches are being formulated to allow application of strong-motion data to earthquake-resistant design of large bridges, dams, and other structures.

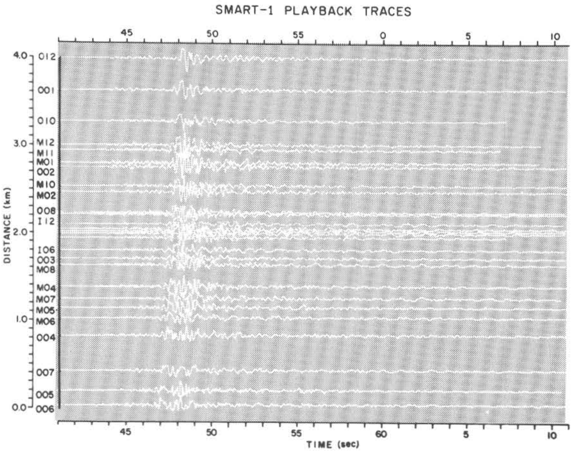
A network of 12 digital strong-motion accelerographs, installed through a project conducted by researchers from the Institute of



Favorable worldwide locations for strong-motion arrays recommended by the 1978 National Science Foundation United Nations Strong Motion Workshop.

SMART-1





Layout (and recorded data) of the innovative SMART-1 array conceived and executed by Drs. Bruce A. Bolt and Joseph Penzien of the University of California, Berkeley, in conjunction with the National Taiwan University.

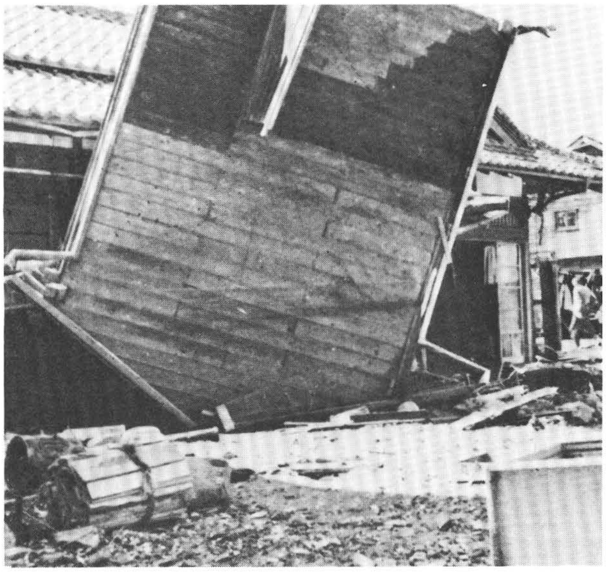
Geophysics Planetary Physics, University of California, San Diego, in cooperation with the Engineering Institute of the National University of Mexico, is operating in the Mexicali Valley area of the Mexican state of Baja California Norte. This network has recorded data from two major earthquakes and several smaller aftershocks. The data obtained have enabled a comparative evaluation of digital and analog instrumentation. Recorded data to date indicate that the first-generation digital recording devices have great advantages over analog recording methods because of their greater dynamic range, increased flexibility for recovering the initial motions, and rapid playback. This comparative study of instrument performance is new and will have a significant impact on the development and use of new generations of digital strong-motion instrumentation for field studies.

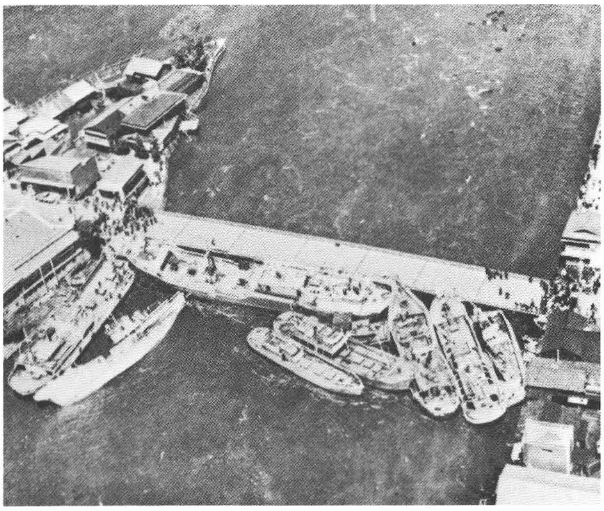
During the past year, significant advances were made in the parametric analysis of near-field ground motions, increasing understanding of the influence of large geological discontinuities such as faults and slips on earthquake strong-motion characteristics. Researchers at the University of California, San Diego, developed models to represent near-field ground motions for oblique and dip-slip faults. The results showed that the slip directions and the angle between the rupture front are important factors in determining the amplitude of peak ground motions. A correlation of the field instrumentation data with analysis results indicate that the observed high-frequency motions are much smaller than motions calculated using fault models. In a related study, researchers at MIT used strong-motion data obtained from the San Fernando earthquake and simulated time histories of tilt, strain, and rotation generated near earthquake faults. The results of this numerical simulation study also showed that the computed values of disturbances were far below the amplitudes of ground motions measured during earthquakes. These findings have helped to establish the discrepancies between observed and calculated values of ground motions. The major damage during earthquakes appears to be caused by translation motions, which are highly dependent on site-specific soil conditions.

Applied Research Associates, Inc., completed work on an initial research project to design large-scale earthquake ground motion simulations by using high explosives. Analyses were performed to define the ground motion spectrum as a function of explosive array height and homogeneous site material properties. The results of this study improve the ability to predict ground-motion environment simulated by detonation of high-explosive arrays. This study is a first step toward developing an effective on-site simulation system for earthquake ground motion. Strong-motion networks are rapidly expanding around the globe and are now able to provide adequate field data on earthquake strong motions. Emphasis now must be placed on maintaining these instruments operationally and improving analytical techniques. Information relating to geotechnical data should be combined with corresponding strong-motion data in a data bank accessible within this country and abroad for use in site-specific analyses.

Field measurements of strong motion, thus far, have been close to the ground surface. Accurate analysis of soil-structure interactions requires quantitative data on the variations of ground motion with depth in various geological structures. Currently, prototype, down-the-hole measurement of strong motion is being performed on an experimental basis. Reliable techniques to record strong motions at some depth from the ground surface must be developed. Such a development will offer the potential of breaking new ground in ground motion analysis for earthquake engineering.

Although a reliable and reproducible experimental method of simulating strong motions under field conditions is not yet available, experimental techniques using high-explosive arrays have the potential for simulating dynamic ground responses. Ongoing studies on high-explosive techniques must be expanded to include appropriate selection and multiple detonation of chemical and gaseous explosive arrays to simulate ground motions and produce the frequency range of interest to earthquake engineering. The successful development of field experimental technique earthquake ground motions on site will have far-reaching impacts for large-scale experimentation in earthquake engineering.





Examples of 1960 tsunami damage in Japan as result of an earthquake in Chile, hundreds of miles away.

Tsunami Engineering Research

Earthquakes on the ocean floors generate tsunamis, waves that generally radiate outward from the source and across the ocean at speeds of hundreds of miles per hour and heights of up to several tens of feet as they reach a shoreline. Many thousands of miles of coastal area in the United States, Canada, Mexico, Central and South America, Japan, the Philippines, and the Pacific islands are exposed to the tsunami hazard. The tsunami hazard and techniques to mitigate it are of concern to scientists, engineers, planners, architects, regulatory groups, city and State officials, and the general public. NSF-sponsored research efforts represent a major portion of the tsunami engineering research performed in the United States.

Dr. W. G. Van Dorn of the University of California, San Diego, advanced new findings on tsunami characteristics based on tide gauge records. This research shows that the time decay of a tsunami is uniformly exponential and that the relative tsunami energy is roughly proportional to the seismic energy. On the basis of analysis of the 1960 tsunami data (caused by an earthquake in Chile), a general regression line by which to calculate relative tsunami energy as a function of seismic energies has been developed.

The process of tsunami propagation close to the shoreline is a nonlinear phenomenon that includes wave breaking, wave run-up and run-down, and overland flow. Dr. J. Hammock of the University of Florida determined specific nonlinear interactions in tsunamis by using complex numerical modeling techniques. The results of this research will enable engineers to calculate long, nonlinear tsunamis. In related work, Dr. Frederic Raichlen of the California Institute of Technology (Caltech) made significant advances in his research in predicting transient response of harbors to nonlinear tsunamis impinging on the shore. This numerical model handles a variable-depth harbor with vertical boundaries. The model permits estimates of the effect of run-up and run-down at a harbor and dissipation of tsunami energy in the shoreline by "roughness elements" (structures, trees, and other ground-related elements).

A joint U.S.-Japan tsunami workshop was organized and held in Tsukuba, Japan, in May 1983—one week before the May 26 tsunami in Japan. This timely workshop facilitated an exchange between U.S. and Japanese scientists and engineers regarding scientific and research progress being made in the field of tsunamis. The Japanese, who are in the forefront of tsunami engineering research, are directing their efforts toward solving site-specific problems because of the frequent tsunami occurrences and the consequent loss of life and resources near coastal areas of Japan. The workshop provided information useful in establishing U.S. research priorities and in identifying possible cooperative research projects with Japan.

Available warning systems are inadequate for warning of an impending tsunami, especially during the first hour of tsunami generation. Development of an effective tsunami prediction and warning system, essential to preparedness planning and mitigation of tsunami hazards, will rely on technological improvements in existing warning systems and in wave gauge data systems. Research on numerical modeling techniques is continuing; however, engineering analysis based on site-specific seismic data is needed for prediction of a tsunami at a given coastal location. Studies also are needed to verify these models and to effect technology transfer for use as a preparedness and mitigation tool. Evaluations of the construction and cost-effectiveness of tsunami protective structures such as dikes, seawalls, river gates, and breakwaters are needed as well.

Soil Dynamics and Ground Structure Interaction Seismic Response of Foundations and Earth Structures

The extent of damage to a structure during an earthquake generally depends on the dynamic response behavior of soil and injury inflicted by other sources. Engineering research investigations during the past year have increased the scientific understanding of soil-structure interactions and have produced engineering parameters for use in earthquake-resistant design of foundations and earth structures. Such foundation and earth-structure design evaluations are complex, especially if the base of a large structure is buried well below the ground surface or if it is desirable to provide a pile foundation for a partially buried structure.

In theoretical evaluations, it frequently has been assumed that the soil beneath and adjacent to a structure behaves in a linearly elastic manner under earthquake excitation, that is, in a way that leads to completely recoverable deformations that are directly proportional to the excitation forces. In recent years, however, researchers have been attempting to depart from this assumption of linearly elastic soil behavior to better predict seismically induced forces and deformations. Although this newer approach is becoming increasingly feasible with the development of more powerful digital computers, numerous theoretical and numerical issues have emerged solely as a consequence of allowing for nonlinear soil behavior.

Researchers at Carnegie-Mellon University found it practical to separate the soil into two regions, linear and nonlinear. Most importantly, they found it feasible to use prescribed excitation input to the boundary of the nonlinear region and were able to demonstrate the approach through the solution of a classical analytical problem. The results are of great importance to researchers who wish to analyze specific nonlinear soil-structure interaction problems.

Advances also were made in modeling soil-structure interactions and in examining the behavior of pile groups subjected to dynamic loading. The behavior of a pile group is generally more frequency-dependent than is the behavior of a single pile. Researchers at the University of Houston found a simple but practical method by which to analyze dynamic pile group effects. The results for several cases demonstrate the process by which dynamic conditions in a pile group affect the dynamic response of a pile-supported structure and provide specific engineering parameters by which to improve seismic design of pile foundations.

Retaining walls are among the most common civil engineering structures. Large movements and actual failures of retaining walls are common in almost every major earthquake; thus, efforts to develop systematic and rational seismic design methods and criteria for retaining walls are of great importance. Researchers at MIT were successful in formulating a reliable prediction rule for retaining structures. The results have helped to improve the confidence level in the design. However, experimental validation and field verification of the prediction method are needed.

One of the major conceptual and computational difficulties in performing dynamic analyses of soil-structure interaction is the three-dimensional modeling of structures with embedded foundations. Researchers at the University of California, Berkeley, developed a hybrid method by considering the total soil-structure system as a near field, consisting of the structure and surrounding soil, and a far field, representing its interface with a semi-infinite halfspace. This modeling approach was successful and resulted in a simple, powerful, and economical method of analyzing the dynamic response of soil-structure interaction.

Research emphasis was placed on developing appropriate experimental verification procedures for soil-structure models and arriving at quantitative parameters for the design. One such accomplishment is the verification tests for embankments and slopes developed by Dames and Moore, Inc., in cooperation with Caltech. A nonlinear predictive model was simulated successfully in a centrifuge. This verification method provided quantified parametric relationships for determining engineering characteristics of soils under dynamic loading conditions. In a related research effort, MIT used the centrifuge technique to verify dynamic-scaling laws. This research extends the range of applicability of experimental verification tests that can be carried out in the laboratory.

With the success of the verification test research, a workshop was organized by MIT in conjunction with the University of California, Davis, in May 1983 to bring together geotechnical earthquake engineering researchers and users to assess the potential for a general-purpose ground-motion simulator and to develop a design specification for such a simulator for the large geotechnical centrifuge at the National Aeronautics and Space Administration (NASA) Ames facility, which is expected to be operational in fiscal year 1984. The workshop participants concluded that a centrifuge system could advance the state of the art of large-scale experimental verification tests for geotechnical earthquake engineering and recommended that an earthquake simulator be designed and developed for the large centrifuge.

In a related research effort, researchers at the University of Washington successfully used an 8- × 6- × 4-foot shaking table with innovative instrumentation systems to simulate dynamic Earth pressures exerted by sands against retaining walls. The results of the model tests were used to estimate the forces on prototype structures subjected to earthquake loading. The method of approach and the instrumentation techniques developed in this study are new and could have a far-reaching potential for evolving appropriate engineering parameters for use in practical seismic design of retaining walls.

The development of computation procedures on nonlinear effects of soil-structure interaction is continuing. Application of the nonlinear methods must be advanced to answer site-specific geotechnical issues. A verified and acceptable procedure for analyzing dynamic ground interactions on special structures such as offshore platforms, coastal facilities, tall towers, and foundations with special soil characteristics is not currently available and must be developed.

Field data and input on quantitative parameters of soil and ground characteristics are not currently sufficient for developing reliable, effective seismic-resistant designs for structures. The state-of-the-art techniques available to measure field parameters of soil characteristics are ineffective and must be improved. Research should emphasize the development of new and improved methods of measuring in situ soil characteristics without disturbing the soil strata and keeping as close to original in situ conditions as possible.

Research to develop experimental methods to verify predictive relationships for soil-structure response continues. The research efforts are aimed at site-specific and quantitative parameters that account for geological factors such as faults, slips, and folds and that can improve the state-of-the-art design procedures.

The ever-increasing use of subsurface facilities and emerging concepts in underground space utilization warrant increased research efforts to study the problems of earthquake interference in underground tunnels, mines, and other subsurface structures. Research must be initiated to provide criteria for aseismic design of underground structures and to understand the seismic impact on ground-water hydrology of subsurface structures and mined openings. The results of these research efforts will have a wide-ranging impact on basic and engineering research on earthquake engineering issues associated with underground storage, subsurface lifelines and transportation, ground subsidence under critical facilities, toxic waste disposal, and nuclear waste disposal.

Soil Liquefaction

Dynamic response of loose or medium-dense saturated sands is generally accompanied by an increase in pore water pressure and resulting movement of water from voids. This pore pressure development in soils as a result of ground vibration turns a sand into "quick" or liquefied conditions. Liquefaction causes large and sudden ground settling, resulting in tilting or collapse of ground structures. If liquefaction occurs in or under a sloping soil mass, the entire mass flows laterally to the unsupported side causing a "flow slide." Liquefaction of sand lenses within clay deposits played a major role in the large coastline slide experienced in the Turnagain Heights area of Anchorage during the 1964 Alaska earthquake.

A major thrust was made in the earthquake engineering research program to obtain fundamental information on liquefaction phenomena. Laboratory studies have identified several soil characteristics that contribute to liquefaction. These results, correlated with case-history data obtained in the field, have increased the basic understanding of the physical processes leading to liquefaction.

Only limited field data are currently available on liquefaction. Researchers at the University of California, Davis, and the Institute of Engineering Mechanics, Academia Sinica in Harbin, China, cooperated on a project to obtain measurements of liquefaction sites in the Tangshan and Tianjin areas of China, where severe liquefaction occurred during the 1976 Tangshan earthquake. The information obtained from these field measurements, correlated with comparative laboratory tests, indicates the importance of measuring in situ soil fabric parameters such as grain size, intergranular filling, and the composition of soil constitute matrix to estimate liquefaction potential. The results of this study have increased the geotechnical data base available to study liquefaction behavior of soils and have provided new information needed to assess the adequacy of current methodologies used in predicting liquefaction.

The reliability of predicting liquefaction of in situ sand deposits was further advanced through an integrated study by researchers at Purdue University in cooperation with Japanese researchers at the University of Tokyo. Field measurements of liquefied sand strata in California and in Japan were made at several locations showing peak accelerations from past earthquakes. These data were compared with corresponding experimental measurements in simulated soil samples. This integrated analysis indicated that cyclic shear strain is a fundamental parameter for liquefaction and

controls the increase in pore pressure induced by dynamic excitation. It also led to the development of a practical methodology for in situ assessment of the liquefaction potential of sand deposits.

Researchers at the Georgia Institute of Technology developed a set of criteria, on the basis of the minimum volume of deformable sand required to produce liquefaction, by which to estimate the damage potential of liquefaction. This study could lead to the development of a simple but practical model by which to estimate the risk of liquefaction in sand deposits and a decision analysis framework based on an understanding of liquefaction phenomena.

Reliable field measurements of dynamic soil property parameters and pore pressure effects are fundamental to understanding liquefaction phenomena. Laboratory measurements generally are made in simulated samples that do not adequately represent in situ conditions. The results of experiments made in the laboratory, therefore, have a degree of uncertainty in evaluating liquefaction under field conditions. Reliable field measurement techniques for examining liquefaction parameters in situ without disturbing original conditions are necessary and must be developed.

Laboratory methods to measure pore pressure buildup in granular materials require sophisticated instrumentation systems. Advanced instrumentation systems must be added to existing triaxial test devices to facilitate tests under controlled strain conditions and to measure soil-fabric interactions and pore pressure buildup. The laboratory data from such experiments must be correlated with appropriate analytical investigations and field measurements to understand the liquefaction process.

A concerted effort must be made to assimilate data from all global case studies where liquefaction did not occur during earthquakes and all field and laboratory data on liquefaction. Generation of such a data base will help to establish a coordinated approach on liquefaction research by the technical community and all Federal agencies involved in liquefaction research, including DOD and the NRC.

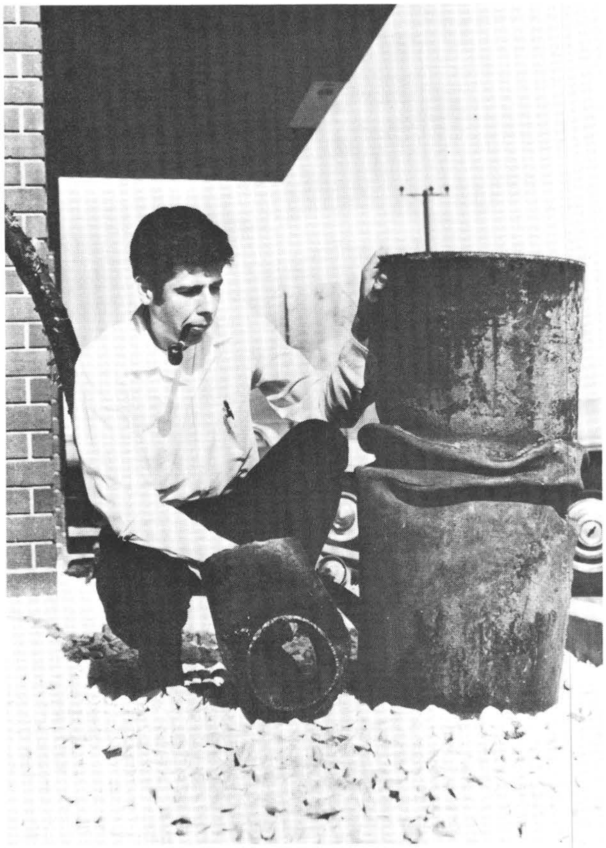
Nondestructive characterization of soil at Tangshan earthquake site using electrical probe for the evaluation of soil liquefaction.

The effect of incomplete saturation of soils on liquefaction is not fully understood. Experimental and analytical studies are necessary to verify this effect on liquefaction phenomena. New investigations must be made to quantify the effect of cementing materials such as clay, silt, and weakly cemented sands and their modification of soil fabric characteristics. An understanding of soil fabric and its influence on liquefaction behavior has the potential to provide methods and means of site modification to minimize liquefaction.

Lifeline Earthquake Engineering

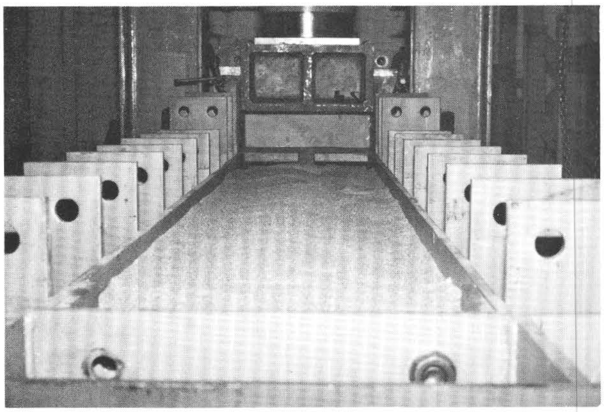
Lifeline earthquake engineering is an emerging and important field of investigation pertaining to the study and development of economically feasible engineering safeguards for critical and essential services such as energy supply, transportation, water, power supplies, and communications systems during earthquakes. Lifeline systems such as natural gas and oil pipelines, water sewage lines, and subsurface tunnels generally are severely damaged during strong earthquakes, presenting public health and safety hazards and causing severe disruption within the area and beyond. For example, in the 1906 San Francisco earthquake, extensive fire damage and epidemics resulted from disruption of the water supply and the loss of potable water, respectively. Water, sewer, and natural gas transmission systems were seriously damaged in the major earthquakes in Alaska (1964), San Fernando Valley (1971), and Coalinga, California (1983). NSF-supported research on lifeline earthquake engineering, initiated in 1975, now comprises a major share of all lifeline engineering research investigations in the United States.

Geotechnical and structural performance characteristics of lifelines must be evaluated in terms of earthquake response. The research work completed by Cornell University has focused on detailed, case-history evaluations of buried pipeline response to lateral spreading and reverse faulting during the 1971 San

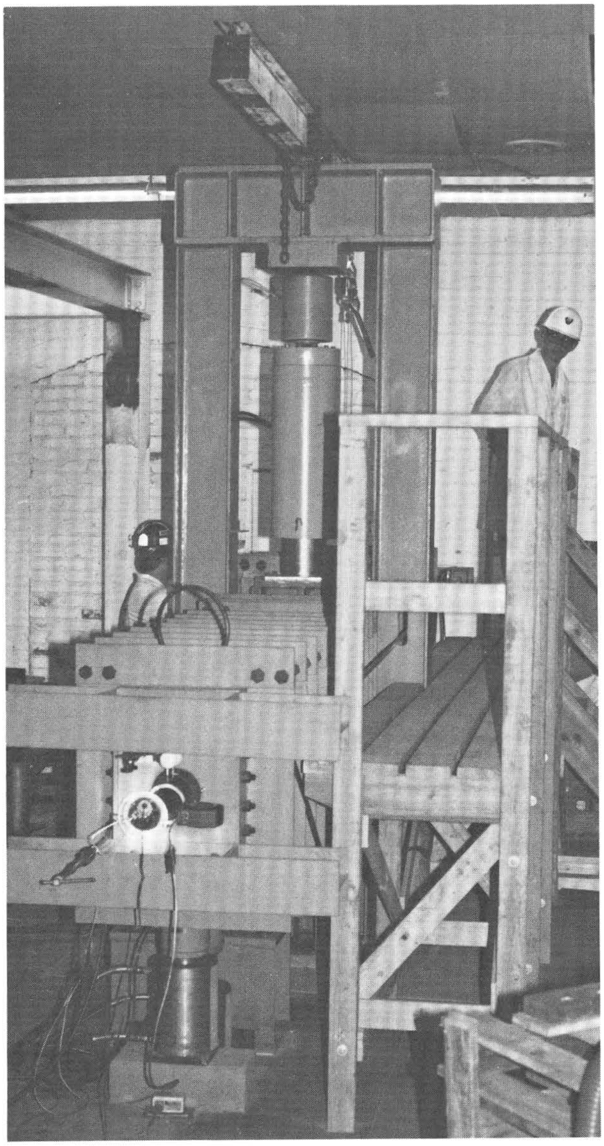


Pipeline, 16 inches in diameter, damaged during 1971 San Fernando earthquake.

Fernando earthquake. The Cornell work has shown that compressive ground movements represent one of the most significant hazards to continuous steel pipelines and that oxacetylene welds constructed before 1930 are particularly vulnerable. Recommendations and simple-to-use engineering formulas have been developed to minimize the risk of compressive damage at fault crossings.



This case-history research on pipeline response to lateral spreading, the first of its type, was a multidisciplinary investigation that drew from data supplied by the USGS, the Los Angeles Division of Water and Power, the Southern California Gas Company, the Metropolitan Water District of Southern California, the Mobil and Getty oil companies, and a variety of geotechnical consultants. Principal benefits of the research include an improved means of identifying landforms susceptible to liquefaction-induced landslides



Layout of test frame for buried pipeline failure tests using system developed by National Science Foundation cooperative research project with the Defense Nuclear Agency.

and a better understanding of the geological constraints on lateral spreading.

Merritt Cases, Incorporated, in Redlands, California, designed and developed a single shear-test device for conducting tests on pipelines under simulated fault displacements. This new device provides a means of verifying the failure characteristics of conduits and pipelines to measure shearing, tension, and frictional factors and to assess lifeline response to earthquakes.

Research completed at the University of Colorado, Boulder, provided dynamic response characteristics of pipelines to moving loads. The numerical analysis research shows that the maximum pipe wall displacements occur in a soft soil at long wavelengths. This study provided guidelines for designing appropriate installation procedures to minimize earthquake damage to lifelines.

The importance of research in lifeline earthquake engineering has been well recognized in recent years. Providing answers on several technical issues in the field of lifeline earthquake engineering is important to several critical and high-technology industries; utility companies; and local, State, and Federal units and agencies, including DOD. The research community and groups using research results must reach a concensus on critical problems that merit priority consideration for research in lifeline earthquake engineering.

Experimentation methods to test lifeline failure characteristics are being developed and will continue to be studied in order to provide effective verification of analysis techniques to improve lifeline performance during earthquakes. Because of the importance of oil and gas storage and coastal facilities to Japan, the main focus of Japanese earthquake engineering research programs in recent years has been on lifeline earthquake engineering investigations of these facilities. U.S. lifeline earthquake engineering investigations of the impact of earthquakes on oil and gas supply lines and shoreline facilities in the United States also are needed and must be initiated.

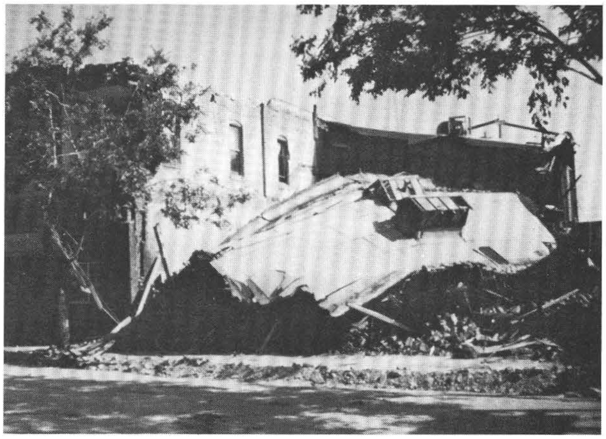
STRUCTURAL ENGINEERING ANALYSIS AND EXPERIMENTATION

The earthquake that occurred on May 2, 1983, near Coalinga, California, caused more than $33 million in property damage, primarily to older, unreinforced masonry buildings in the downtown section of the city. The unreinforced masonry buildings, which compose the bulk of those that failed, were constructed long before seismic-resistant construction regulations were adopted and consequently were not inherently seismically resistant. In many other cities in areas of high seismic risk throughout the country, most of the buildings are also older and not seismic resistant. Although the downtown section of Coalinga recently had been renovated in appearance, the buildings had not been strengthened to resist seismic forces. Although strengthening methods are available, the short-term costs generally outweigh the potential long-term benefits in decisions regarding seismic strengthening. More efficient retrofitting methods are needed to encourage building owners to commit funds to upgrade their buildings and reduce the risk of damage and death in earthquake-prone areas. Several newer masonry buildings in Coalinga designed to withstand seismic activity suffered no damage or only slight, repairable damage. Although these buildings are only one- and two-story structures, the benefits of seismic-resistant design and construction were plain.

Many residential structures were shaken off their foundations or tilted because they lacked attachments to the foundation or stiffened side walls to resist the lateral forces brought on by the earthquake. Home builders and contractors of small and light construction have not had the benefit of information on seismic-resistant design and construction because research in this area is still in the beginning stages.

A prefabricated, one-story, steel building shed its light exterior skin cover because neither the connections of the panels nor the panels themselves had been designed to be seismically resistant. More information is needed on the low-rise buildings to supply decision makers with the necessary data to design these buildings for seismic regions and to develop seismic regulations to include these structures.

The brick or stucco veneer on several masonry and(or) adobe buildings broke away because the veneer was not attached to the walls and lacked sufficient stiffness to resist the lateral motions produced by the earthquake. Other nonstructural features (for example, ceiling



Destruction of unreinforced masonry buildings, showing wall failure and collapse of top stories, during the Coalinga earthquake of May 1983.

lights, interior partitions, and furniture) also suffered damage. Additional data on these nonstructural features are needed in order to develop structural mitigation techniques to reduce damages and the threat to human life.

Some newly constructed buildings designed in accordance with the latest research information and seismic design guidelines and regulations survived the earthquake forces with little or no damage. Had instruments been attached to some of these buildings, studies could have been made of the dynamic response of these buildings. Such studies of a natural event provide insight into the desirable aspects of design and construction practices that small-scale experiments cannot provide. By attaching instruments to various types of building in regions of high seismicity, experimental data of immense benefit to the research and construction communities could be obtained. Such information would be comparable to that obtained on an earthquake simulator and would serve the same purpose.

Structural Analysis

An earthquake such as the Coalinga event illustrates the many facets of the structural engineering portion of the earthquake research program at the NSF. The broad objective of the structural dynamic analysis and experimental program is to develop research information that will be useful to design engineers, architects, planners, building officials, and code-writing bodies at the local, State, and Federal levels as well as in the private sector.

The structural analysis research projects develop innovative concepts applicable to the three-dimensional structural framework for buildings and express these concepts in the form of computer programs for design office use. Other computer programs are developed to predict the dynamic behavior of materials, components, subassemblies, and planar systems when subjected to the equivalent forces and motions of an actual earthquake. Developing mathematical analyses of the nonlinear behavior of the structural system and of its constituent materials is of utmost importance to designers.

This type of analytical treatment is absolutely necessary to evaluate and predict the dynamic behavior of a building during an actual earthquake. The building distortion that results from an earthquake is an indication that the material has been stressed far beyond its linear range. Computer programs not only must be economical within themselves but must result in an economical building as well. Developing innovative analytical computer programs for conventional and unique building configurations is a major goal of the dynamic analytical portion of the earthquake program.

Structural Experimentation

The dynamic structural experimental program is essential for several important reasons. Foremost among them is the validation of theoretical concepts developed by analysis to predict the behavior of the structural systems in the building. Mathematical analyses are based on assumed conditions of behavior of the material as well as the structural system as a whole. To apply a mathematical computer program to an actual design of a building, the engineer must have confidence in the program; this confidence can be assured by experimentation. Other important reasons are to validate field practices of construction details and to determine the effect of nonstructural components.

In a reverse situation, that is, one in which experimental data on the behavior of a building are acquired by a controlled experiment on a full-scale building, or data are obtained from an instrumented building which survived an earthquake, the dynamic performance of the structure may be determined by mathematical methods referred to as the process of system identification. This technique is employed to great advantage to develop computer programs that may be applied to determine the seismic vulnerability of existing buildings as well as in the design process for new buildings.

Existing Buildings

The most important application of the performance type of dynamic computer program is for the determination of the seismic resistance of existing buildings constructed before seismic regulations were adopted. When an existing building is determined to be less than adequate to resist seismic forces, the owner has two options: to demolish the building and construct a new one or to strengthen the building and to upgrade its serviceability to higher standards or as close to them as local codes will permit.

The need for factual data and design information on the repair and strengthening of existing buildings, especially unreinforced masonry structures, is paramount in the experimental program to mitigate earthquake hazards. Economical and effective methods for strengthening existing buildings of reinforced concrete and steel are also needed by engineers in order to upgrade these structures to a safe limit. The same strengthening techniques may be applied to the repair of buildings that suffer minor damage during an earthquake and that can be salvaged at a minimum cost.

Nonstructural Components

Failed nonstructural components in a building have in many instances been too costly to repair or replace and thus have mandated demolition of the entire building even though the principal structural framework was only slightly damaged, if damaged at all. In addition, the greatest loss of life in a building results from the dismemberment of the nonstructural components. Research projects have been studying many varied methods to overcome or reduce the damage resulting from the dislocation of nonstructural components.

Building Configuration

Another aspect of designing safe buildings for seismic regions is the configuration of the building in terms of floor plans and the symmetry or nonsymmetry of the evaluation of the structure. Research is underway, by analysis and experiment, to determine the dynamic behavior of unconventional buildings. In order to obtain the greatest benefit from the analytical research, concepts and field practices must be verified by experiment.

Experimental Facilities

Current experimental facilities for the various models, components, subassemblies, and three-dimensional structures are inadequate to conduct all the required experiments. Therefore, a major research initiative is underway to determine the informational needs of the practicing engineers and the experimental facilities that will be required to perform the experiments to develop the design data.

Base Isolation and Energy Absorption

The concept of isolating a building from earthquake motions by installing elastomeric pads for the foundation supports is receiving increased attention by researchers. The pads absorb the motions from the ground, thus reducing the motion affecting the building and consequently reducing the forces acting on the structure. Basic research has been done; however, much more fundamental research is needed on the mechanical properties of the elastomers and the modified structural analysis for the building. Other types of energy absorbers that will reduce the forces acting on a building, such as pulsers, pneumatic devices, and mechanical devices, are being studied as well.

Highlights

Computer Analysis Program

Computer analysis programs have been developed for the linear dynamic response of buildings considered as three-dimensional structures, loaded by three directions of forces representing the earthquake input. Several studies extended computer analysis programs to include the nonlinear behavior of the structural system as well as the nonlinear behavior of the material. Many of these computer programs were developed at the University of California, Berkeley, and other universities. Improvements are constantly being made to make the programs more realistic and more economical to process. Some programs are being adjusted for the new trend toward microcomputers in the office.

An immensely important computer program recently developed by Agbabian Associates of El Segundo, California, is concerned with the dynamic behavior of long bridges with many supports and with end embankments. This program will enable designers to evaluate the seismic performance of long, multispan bridges with simply supported spans or continuous girders or box girders over several spans.

Another important aspect in computer analysis development has been the process of reducing, revising, and rewriting portions of a computer program derived from research in order to make it useful, economical, and easily understood by the practicing engineer. A program for the three-dimensional analysis of buildings has been developed by Computech, Inc., of Berkeley, California. Named "Combat," the program enables engineers to analyze a building framework for the internal forces acting on each component by which the member is proportioned for steel or reinforced concrete, or other material.

Design of Reinforced Concrete Structures

The design of reinforced concrete structures is a complicated process because of the interrelationship of the reinforcing steel embedded in the concrete and the lack of complete understanding of the dynamic behavior of the concrete when resisting internal forces. Recent research into shear transfer and bond characteristics of reinforced concrete slabs, plates, and beam-to-column connections by investigators at the University of California, Berkeley; Cornell University; the University of Illinois; and the University of Texas, Austin, has experimentally determined the predicted resistance of reinforced concrete. The investigators have submitted their findings in the form of recommendations for design to be considered for adoption by the technical committees and code committee of the American Concrete Institute. With the adoption of these design recommendations as a code provision, this research can be applied to the design of reinforced-concrete buildings for seismic zones.

Masonry Buildings—Unreinforced

The most vulnerable type of structure in an earthquake region is the unreinforced masonry building that was constructed without benefit of information on seismic-resistant design and before code requirements were adopted. Several projects by the University of California, San Diego, and a joint venture group of ABK (composed of three small engineering firms in the Los Angeles area: Agbabian Associates, S. B. Barnes and Associates, and John Kariotis Associates) contributed to the design information used by the city of Los Angeles as the basis for adoption of the first ordinance in the region requiring the strengthening of old, hazardous buildings wherever economically feasible or the demolition of such structures. Owners of buildings are allowed 10 years in which to meet the requirements of the new ordinance.

Reports and Workshops

Earthquake engineering efforts have resulted in several reports and workshops during fiscal year 1983:

- *Earthquake Engineering Research—1982: Overview and Recommendations* was produced by the Committee on Earthquake Engineering Research of the NRC-NAS. The report is a review of the accomplishments achieved during the past 14 years and includes many recommendations for future research and experimental facilities needed to develop earthquake mitigation measures.

- The University of Michigan published a four-volume series of the *Proceedings of the U.S./Japan Cooperative Earthquake Engineering Research Program on the Repair and Retrofit of Structures.* The series contains research papers concerned with analysis, risk, economics, repair methods to be applied to damaged buildings, retrofit methods to strengthen existing buildings, procedures to estimate damages caused by earthquakes, and similar topics.

- A workshop to discuss analysis and design of reinforced concrete structures was conducted by Dr. Robert D. Hanson of the University of Michigan in conjunction with the PRC. The report, *Proceedings of the U.S./PRC Workshop on Seismic Analysis and Design of Reinforced Concrete Structures,* was published and widely distributed. The volume includes papers from both countries on the subjects of design of connections for precast concrete panels, seismic behavior of precast walls, damage evaluation and assessment, repair and strengthening of structures, and code requirements.

- A workshop was conducted in New Zealand by the Applied Technology Council of Palo Alto, California, in conjunction with the government agencies and university researchers of New Zealand to discuss seismic design of highway bridges. The workshop brought together national bridge experts from both countries to exchange information and discuss current seismic design practices, field construction methods, analysis techniques, and future research needs. The meeting was very beneficial to both countries and paved the way for cooperative efforts in the field of bridge engineering. The report of the meeting, entitled *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges,* was widely distributed to bridge engineers in the United States and New Zealand.

- On the basis on research of architectural configurations for seismic-resistant design, Mr. Christopher Arnold of Systems Development, Inc., of California published a text for use by engineers and architects, faculty of architectural and engineering schools, and building officials. Guidelines are provided to assist architects in designing safe and economical buildings in seismic zones. The relationship of building configuration in plan and elevation to the seismic resistance of the resulting structural system was investigated. The research synthesized and collated a great many academic research projects on the dynamic response of buildings and components.

- Dr. James Kelly of the University of California, Berkeley, has been investigating the possible use of elastomeric (rubber) pads to be placed under a building or bridge to isolate the structure from the full effect of earthquake motions. Experimental research by Dr. Kelly has indicated that the base isolators can be used safely to isolate a structure and thereby reduce the effect of earthquake motions and minimize the potential damage to the structure and its contents. As a result of the basic studies and structural engineering considerations, the four-story Law and Justice Building for the county of San Bernardino, California, will be constructed on elastomeric pads. Approximately 100 pads, 3 feet in diameter and 16 inches high containing layers of steel plates and natural rubber, will be installed as the foundation for the building. This building is the first in the United States to use the base isolators to "float" the building.

SOCIOECONOMIC STUDIES

Despite its relatively modest size, the Coalinga earthquake caused significant damage and social and economic disruption to the community. The tasks faced by Coalinga and the assisting outside organizations—damage assessments, search and rescue, recovery and rehabilitation, and postdisaster mitigation planning—are problems that will be experienced on a greater scale following a major earthquake in a large urban area in the United States. As many California officials have observed, the Coalinga disaster offers a number of lessons for emergency managers and decision makers, including the needs for (1) giving more careful attention to where buildings are located, (2) developing meaningful preparedness plans, (3) devising means for organizational coordination during disasters, (4) improving emergency communications, (5) enhancing public awareness of the earthquake risk, and (6) increasing the use of knowledge derived from science and engineering in efforts to mitigate the impacts of future earthquakes.

In the aftermath of the Coalinga, California, earthquake, a woman sits alone amid the wreckage of what once was her home—an experience particularly devastating and frightening for senior citizens, who are on fixed, and generally low, incomes. (Photograph, Rick Browne/Picture Group.)

The social science and policy research on hazards supported by the NSF through its Division of Civil and Environmental Engineering focuses on the issues demonstrated by the Coalinga disaster. This research, which pays particular attention to the responses of individuals, groups, organizations, and communities that are threatened or affected by earthquakes, addresses such questions as: What are the social and economic consequences of earthquakes? How do people adjust to such threatening situations? How can private citizens, decision makers, and organizations respond more effectively to earthquake hazards? Research on such topics should lead to reducing the vulnerability of threatened populations as more is learned about how best to implement land use plans and building codes, as more effective emergency preparedness measures are devised, as the public at risk is better informed about earthquakes, and as timely relief and rehabilitation services are provided. In fiscal year 1983, NSF supported research on the role of socioeconomic and legal factors as incentives and disincentives to eliminate hazardous conditions, earthquake preparedness planning at the State and local levels, disaster recovery, and the nature of selected existing hazard information dissemination programs.

Postearthquake Research

As noted, the Coalinga earthquake disaster has provided the opportunity to learn important lessons for dealing with future earthquakes. Soon after the earthquake, researchers supported by the NSF went into the field to study on the key problems that followed in the wake of the disaster. Results from these research efforts should benefit decision makers, practitioners, and the public in coping with seismic hazards.

Everett Rogers of Stanford University and his associates launched a field study of the media response to the Coalinga earthquake shortly after learning of the event. Their research findings should be particularly instructive because only a handful of studies of this kind previously have been carried out. The study focused on the operations of the news media at the disaster site, including how reporters actually gathered their information, and on the coverage given the event by newspapers and the electronic media in the region.

The Coalinga earthquake became a major media event. For example, the day after the disaster more than 200 media personnel reportedly converged on the site. The study by Rogers and his associates will provide important information on preparations that public officials should make for dealing with the media following an earthquake, including the kinds of questions they should be prepared to handle, the logistical support media personnel will require, and a general indication of the kinds of opportunities and constraints that on-the-scene media personnel present.

In another study, Joanne Nigg and Alvin Mushkatel of Arizona State University (ASU) investigated the emergency response following the Coalinga earthquake. City, county, State, and Federal organizations involved in the emergency activities were studied along with private groups such as the utility companies, the ARC, Salvation Army, and various church groups. This initial study was followed by a major survey of community residents, both victims and nonvictims. The focus of the second study was on the residents' level of preparedness for earthquakes, their immediate reactions to the event, and their interaction with agencies charged with providing relief and recovery services. The research by the ASU team will be useful to emergency service organizations as well as to agencies delivering assistance aimed at long-term recovery.

A study conducted by Steven French of California Polytechnic State University considered the redevelopment phase of the Coalinga disaster. The study focused on the impact that the earthquake had on subsequent land use decisions. Rebuilding activities were monitored through local building and planning agencies and other relevant organizations. The study was designed in part to be beneficial to decision makers who are presented with the increased opportunity for using land use planning as a mitigation tool that is often provided when the public's attention is focused on a recent disaster.

Other studies on the socioeconomic aspects of the Coalinga earthquake are planned. Some of these projects, such as ones on family and community recovery, have been funded already by the NSF. The entire set of studies will provide one of the most comprehensive perspectives on the socioeconomic aspects of any earthquake to strike a community in the United States. As is true of the research discussed throughout this section, results from these studies will be made available through appropriate dissemination channels.

Research in Multiple Regions

As the NSF's program of research on earthquakes has evolved, significant attention has been given to research sites in California. Given the nature of the risk in that State and the fact that much of the research conducted there has implications for other parts of the country, California will continue to receive attention from the program. However, because either a moderate or major earthquake threat exists in most States, increased consideration is now being given to other regions of the country as well.

For example, the NSF increasingly has turned its attention to socioeconomic issues in the New Madrid area, in part to complement research, preparedness, and mitigation programs undertaken by the USGS and FEMA. With NSF support, Thomas Drabek and his colleagues at the University of Denver recently completed a study that compared earthquake hazard mitigation efforts in Missouri, which is part of the New Madrid region, with those in the State of Washington. This study offers useful insights regarding the nontechnical difficulties that can emerge in fledgling mitigation programs.

Alvin Mushkatel and Joanne Nigg of ASU have undertaken a major earthquake study in several central States, including Tennessee, Arkansas, Missouri, and Illinois. The study is determining the major incentives and disincentives for developing and implementing earthquake hazard mitigation policy in the area, the public's receptivity to seismic safety initiatives and planning programs, and the status of disaster preparedness and planning efforts. FEMA is cooperating with the research team sponsored by NSF and is providing additional funding so that special attention can be given to evaluating selected hazard information dissemination initiatives in the region.

Earth scientists such as those at the USGS are giving more attention to analyzing seismic risk in the Eastern United States, including South Carolina, and FEMA is working with groups in South Carolina to develop public education and other related programs. The NSF is also aware of the need for research and related activity in that region. With NSF support, Blaine Roberts of the University of South Carolina recently completed a study which simulated the regional effects of earthquakes. Because of its seismic history, the Charleston, South Carolina, area was chosen as the model site for the simulation. One of the contributions of this study is the identification of new measures that can be used to estimate economic losses from earthquakes.

In addition, research was completed recently by Richard Olson and his colleagues at the University of Redlands on the evolution of earthquake mitigation policy in Utah. Like the previously mentioned studies, this research broadens our perspective on the socioeconomic aspects of earthquake hazard mitigation and preparedness outside California.

Learning from Other Countries

Many earthquakes and other disasters occur with significant frequency overseas. In spite of obvious cultural differences between societies, these events offer U.S. social researchers the opportunity to learn a great deal about the social response to hazards and disasters, which can prove useful to decision makers and emergency managers in this country. This is reflected in NSF-sponsored research underway in fiscal year 1983 on the social aspects of hazards and disasters overseas.

Frederick Bates of the University of Georgia completed a major study on the long-term effects of the 1976 Guatemala earthquake. This is the most comprehensive investigation completed to date on the social and economic consequences of such an event. The implications of this work for the American emergency management community are numerous. For example, insights are provided on ways to improve the management and delivery of both short- and long-term aid to disaster-stricken communities.

Rocco Caporale and his associates at St. John's University are conducting related research in Italy on the impacts of the 1980 Italian earthquake. This work complements not only the research by Bates but also work that is being conducted on disaster recovery in the United States by such investigators as Claire Rubin at George Washington University and Robert Bolin at New Mexico State University. When completed, Caporale's work, along with the projects conducted at U.S. sites, will significantly expand the knowledge base on disaster recovery from which officials responsible for disaster recovery can draw.

Of all the seismically active countries in the world, Japan leads in developing and implementing mitigation and preparedness programs. Thus, it is generally agreed that much can be learned from Japan on these matters. With this in mind, Henry Lambright of Syracuse University recently completed a study on earthquake mitigation and preparedness in Japan. Lambright has been able to compare efforts on the Japanese scene with those in the United States and to identify preparedness approaches developed by the Japanese that, with suitable modifications, could be adopted in the United States.

Utilization Research

There is significant variation in the degree to which existing scientific and engineering knowledge is used to mitigate and prepare for earthquakes. However, the reasons for this are not yet clearly understood. Particular attention needs to be given to identifying the key factors that encourage the use of existent knowledge in the hazards field by decision makers, practitioners, and the public.

In fiscal year 1983, a new project was begun by Jack Kartez at Washington State University under NSF sponsorship to examine the extent to which communities adopt emergency response strategies that have been recommended by social science research. One of the goals of the project is to enhance research utilization by revealing the most effective methods for linking investigators with potential users of information.

Also in fiscal year 1983, important case studies on the utilization process were completed by Gwen Moore and Robert Yin of the Cosmos Corporation. The case studies analyzed how and why innovations in earthquake research from both engineering and the social sciences were used for practical and policy purposes and the policy implications of these experiences. By the end of 1983, two case studies of the projected set of nine were completed. One case study analyzed the utilization process in connection with research on unreinforced masonry buildings; the other traced the utilization process in connection with research on the legal liability of local government for its earthquake hazard reduction actions. Moore and Yin are providing a series of reports that is intended to lay the groundwork for improved use of research in the hazards field.

DISSEMINATION OF RESEARCH RESULTS

In fiscal year 1983, as in previous years, the NSF continued to take steps to disseminate research results to users, often in conjunction with other agencies. The dissemination activity has been aimed at a number of relevant audiences, including architects, engineers, building officials, government officials, and researchers. Numerous channels of communication have been used to inform users of research results. Some examples are highlighted below.

Centers and Clearinghouses

The Natural Hazards Information Center at the University of Colorado continued to receive major support from the NSF as well as additional funding from the USGS, FEMA, NOAA, and the U.S. Army Corps of Engineers. The Center reached several thousand hazards and disaster specialists in government, business, and the research community through its bimonthly publication, the *Natural Hazards Observer,* which summarizes recent research results and discusses hazards research applications and programs. Research results also were disseminated by researchers to emergency managers and decision makers at the Center's annual hazards workshop.

NSF continued to support the National Information Service for Earthquake Engineering (NISEE). With components located at the

University of California, Berkeley, and the California Institute of Technology, NISEE disseminates earthquake engineering and related information through library services, computer software, and publications. NISEE distributes more than 35 computer programs developed from analytical procedures and verified when possible by experimental methods. This activity has been instrumental in providing practitioners with the tools to design safer and more economical buildings of all types.

A great deal of research information also is disseminated through clearinghouse projects such as the Architecture and Engineering Performance Information Center at the University of Maryland and the Earthquake Loss Estimation project at Harvard University. These special topics centers archive and distribute material upon request.

Seminars

With NSF support, a professional organization, the Earthquake Engineering Research Institute (EERI) held three regional seminars on earthquake engineering. Researchers discussed their seismic research activities at the seminars and thus were able to bring important results and concepts to the users more rapidly than is normally the case.

As a result of the highly successful seminars, EERI is publishing expanded versions of the seminar presentations in a monograph series that can be used as classroom texts and for reference material for practitioners. Eight volumes have been published, and it is anticipated that several additions will be made during the next few years.

Conferences and Reports

In fiscal year 1983, the NSF joined several other agencies and organizations in supporting a major international conference in Los Angeles on earthquake mitigation and preparedness in cities. Researchers and officials from around the world attended the conference and exchanged information and practical experiences. The conference was organized by the city of Los Angeles.

A major international conference held every 4 years on a worldwide basis, the World Conference on Earthquake Engineering, is being planned for San Francisco in July 1984. The conference is being sponsored by the EERI, the U.S. member of the International Association of Earthquake Engineering, with some financial support from NSF. This forum provides an excellent opportunity for researchers throughout the world to present their results and discuss them with other international experts. This activity benefits all nations in that it accelerates the pace by which research results are disseminated to the entire community of earthquake researchers, research users, and decision makers.

A recent report by the Applied Technology Council, entitled "Guidelines for the Seismic Design of Highway Bridges," funded by the Department of Transportation (DOT), was based on research information and data resulting from projects funded by NSF; of the participants in the development and preparation of the DOT report were NSF grantees.

Special reports are prepared frequently by the Committee on Natural Disasters of the NRC, which on occasion works with the EERI postearthquake inspection teams to investigate the impacts of earthquakes. Several earthquakes were investigated during the past year. Also, reports were published on the recent Italian and Algerian earthquakes and distributed to the design community. These reports feature lessons learned from the analysis of buildings that failed as well as those that successfully withstood seismic motions and forces.

NATIONAL BUREAU OF STANDARDS

NBS responsibilities address two problem areas: safe, economical new construction and assessment and mitigation of hazardous existing facilities.

It is important that new construction not add to the earthquake problem. Safe and economical new construction may be achieved by improved, nationally applicable seismic standards for new buildings. Structural, geotechnical, mechanical, architectural, and economic studies supported by the NSF over the past 7 years have produced substantial advances in abilities to model and predict the earthquake response of various built elements. However, this knowledge must be synthesized to develop design criteria that will provide consistent safety among the various built elements and various materials or technologies for each. Moreover, design criteria must be developed to fit methodologies appropriate to the responsible design profession. Evaluation and measurement methods consistent with practices of design, manufacture, construction, and inspection must be developed to implement the design criteria.

Since existing hazardous buildings are probably the greatest source of danger to the population during a severe earthquake, it is also necessary to develop techniques to identify the most hazardous buildings, to develop nondestructive methods to determine the properties of the buildings and their components in place, and to define the strength and energy-absorbing capacity provided by various techniques of strengthening and repair.

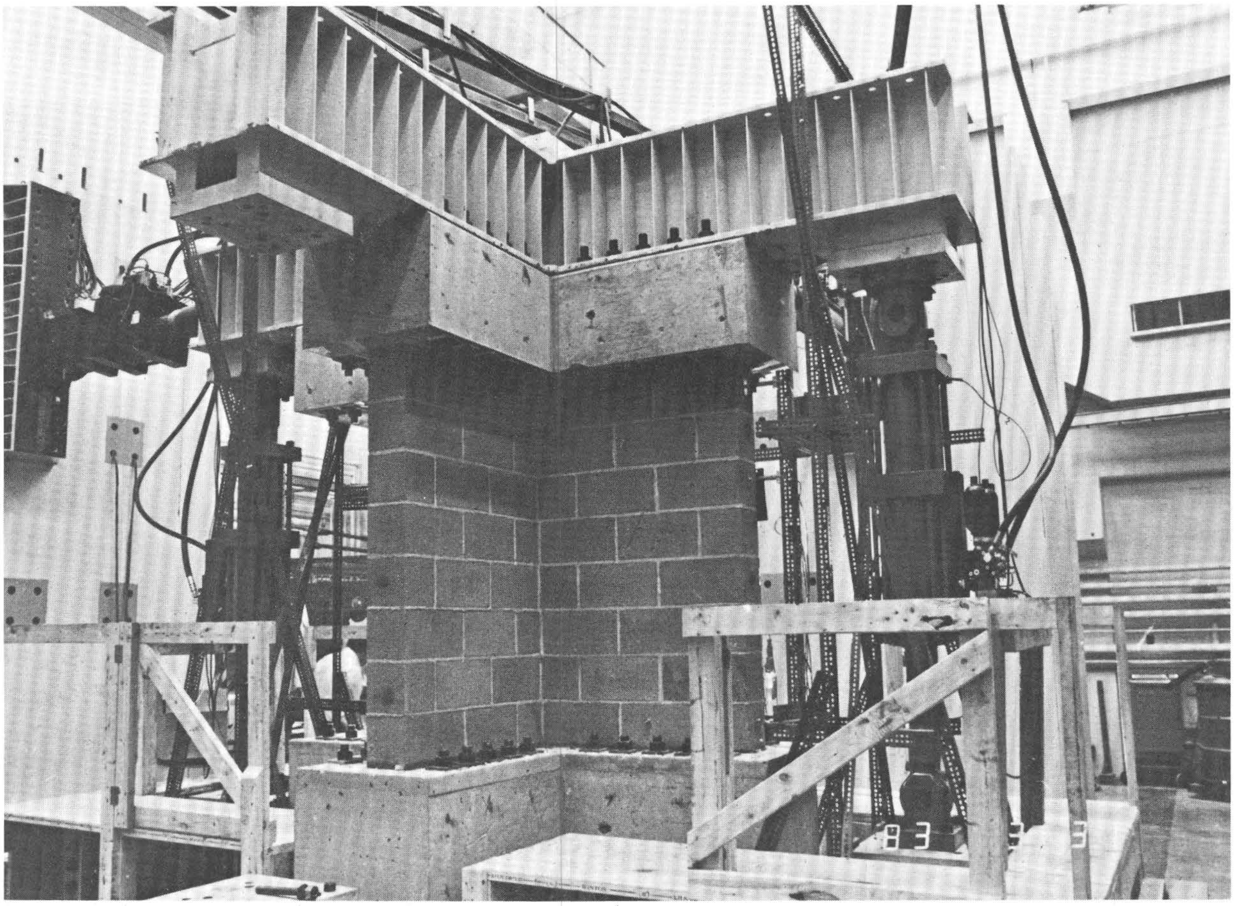
To address these issues, the NBS program was established to improve building design and construction practices by conducting fundamental research necessary to establish consistent standards that include reliable measures of the performance of buildings and their environment during an earthquake and to provide technical support in the development of seismic design in construction standards for consideration and subsequent application in Federal construction and encouragement for the adoption of improved seismic provisions in State and local building codes. Currently, the major thrusts of the NBS earthquake program are (1) improved design criteria and standards, (2) more reliable measures of the effects of natural forces on buildings, (3) safety evaluation of existing buildings, and (4) postdisaster investigations.

The NBS laboratory research program is designed to provide the necessary information on which to base advanced structural design criteria for improving seismic response of new and existing building structures. Specifically, it is aimed at meeting the most urgent research needs in filling the gaps in building codes and standards and in developing new criteria and making recommendations for repair and retrofit of existing structures. The research is conducted in cooperation with other Government agencies, practicing engineers and architects, professional organizations, trade associations, building owners, product manufacturers, standards and regulatory organizations, and university researchers. In planning this work, close liaison is maintained with these individuals and organizations. These interactions assist in identifying and assigning priorities to research problems in earthquake engineering. They also ensure that NBS efforts are coordinated with other work.

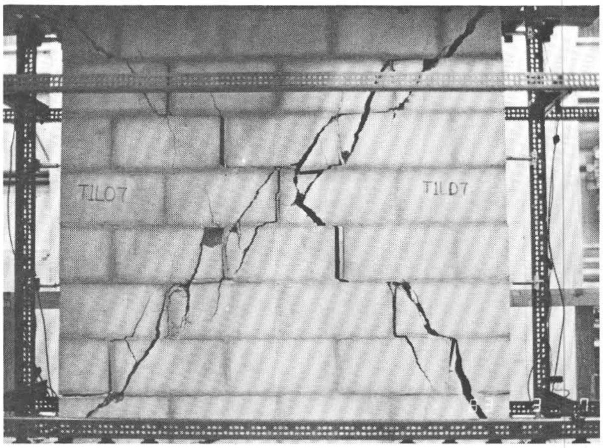
RESEARCH ACTIVITIES

In fiscal year 1983, construction of a computer-controlled, three-dimensional testing facility for earthquake structural research was completed. This unique facility uses seven hydraulic actuators operating under computer control to apply three-dimensional effects of cyclic loads and (or) displacements. Computer-controlled data acquisition and processing completes the testing facility.

The three-dimensional facility is currently being used in studying the basic energy-absorbing mechanisms and strengths of masonry shear walls subjected to simulated seismic loading. This research is being conducted in order to develop rational design techniques for masonry shear walls. The research base will be applicable for use in evaluating existing construction as well as for designing new construction.



This computer-controlled tridirectional test facility uses seven hydraulic actuators to apply three-dimensional effects of loads and (or) displacements to test specimens.



Seismic resistance of masonry shear walls is being examined by means of the tri-directional test facility.

Additional research efforts include improved in situ testing techniques for use in site evaluation and studies on the cyclic strain approach for the evaluation of the potential for soil liquefaction during earthquakes. Two proposed standards based on this research are being considered for adoption by the American Society for Testing and Materials.

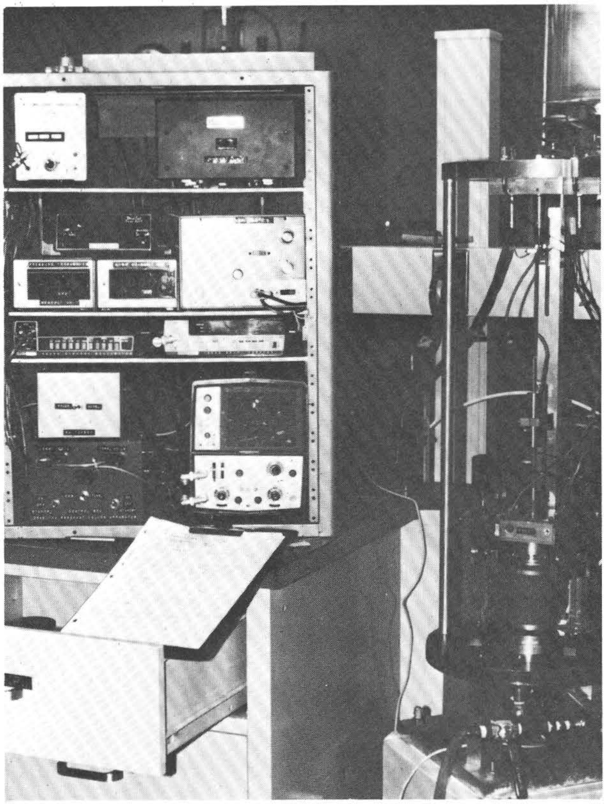
Large-scale testing is an important component of the structural laboratory work. Current work on large bridge columns will extend understanding of the performance of very large structures and will provide data that are not currently available. Both full-scale performance of large deformations and the effect of size on test results will be studied to determine if research on small specimens can be safely extrapolated to the large sizes actually being used in bridges. This work is being supported by the NBS, the Federal

Field studies are being conducted to determine the energy delivered in the widely used standard penetration test.

Highway Administration (FHWA), the NSF, and the California Transportation Department.

IMPROVED SEISMIC PRACTICES

The NBS has worked closely with FEMA in establishing and supporting the Federal ICSSC and in assisting and participating in the non-Federal BSSC. The NBS, along with others, has assisted FEMA in its review and planning of earthquake-related Federal research. These efforts have led to considerable improvement in seismic design provisions for building codes and in standards and practices for both private and Federal construction.



The resonant column device is being used to study the cyclic strain approach to evaluate the potential for soil liquefaction.

The ICSSC, chaired by the NBS, currently is examining a number of problems of importance to the Federal Government, including studies on the use of a uniform seismic design standard (and selection of requirements) by Federal agencies, work on existing buildings, protection of lifelines, and response of the ICSSC to damaging earthquakes. In addition to its role as Chair, the NBS is providing technical support for these activities. The NBS and the ICSSC are cooperating with the BSSC; ICSSC members participate on BSSC technical committees and Board.

At the request of FEMA, the NBS has provided technical studies throughout the BSSC's evaluation program. With financial support from FEMA, the NBS worked with the BSSC Trial Design Overview Committee to prepare a trial design plan for evaluation of seismic provisions being studied by the BSSC and prepared a report on amended seismic provisions to be used as the basis for the trial designs. Additional studies are being conducted as the Trial Design Program continues.

INTERNATIONAL ACTIVITIES

Through its leadership of the Subpanel on Wind and Seismic Effects of the U.S./Japan Program on Natural Resources, NBS, along with the NSF, has encouraged the formulation of a cooperative program on large-scale structural research. With funding from the NSF, research is now underway in Japan and the United States on steel structures. Laboratory work on the seismic resistance of reinforced concrete structures is complete. Other NBS cooperative programs include

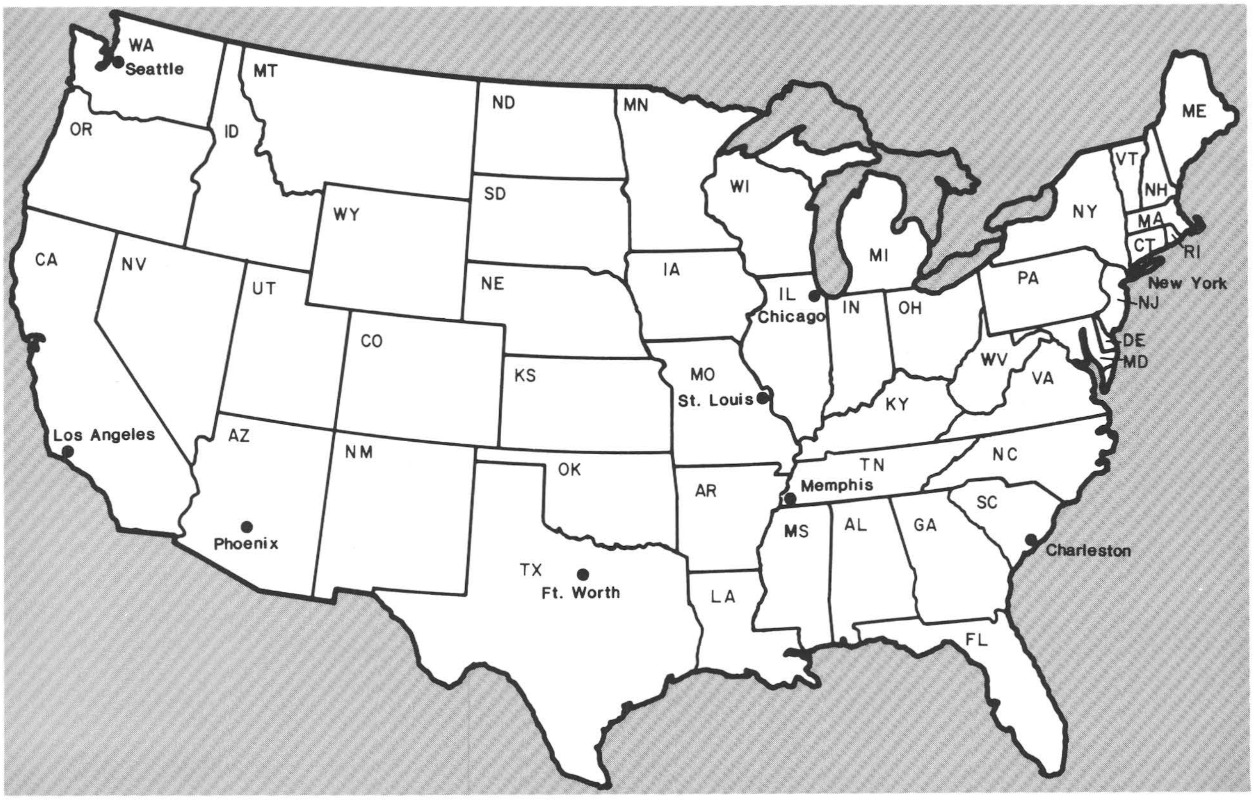
- A cooperative program with the French national laboratory for building research (Centre Scientifique et Technique du Bâtiment), which includes a new project on seismic repair and retrofit of existing buildings, and

- Cooperative programs with Yugoslavia on seismic design criteria, including the criteria being evaluated by the BSSC, masonry shear wall resistance to seismic loading, bridge columns, and potential of soils to liquefy.

NBS represents the United States on the Conseil International du Bâtiment pour la Recherche, Étude et la Documentation (CIB) [International Council on Building Research]. U.S. participation in the CIB has led to the establishment of an international working commission on earthquake hazards reduction, which is chaired by a representative of the NSF. The NBS also participates as a member of a control board to improve seismic design requirements of Algeria, with the USGS providing overall guidance for the control board.

IMPLEMENTATION

The success of Federal programs for reducing earthquake hazards can be measured in terms of the extent to which the results are used by various mission agencies and private sector building owners and users and the extent to which the results are incorporated in new standards and improved design practices. The working relationships that the NBS has established with groups throughout the building community provide an effective means for achieving this implementation. The NBS building research staff members participate actively in standards development in the private sector as well as at Federal, State, and local levels, with 67 staff members participating in 270 distinct standardization activities. These implementation and coordination efforts have resulted in the adoption of research findings in standards and codes. For example, the NBS serves as Secretariat of the American National Standards Institute Committee A58, which is responsible for developing the voluntary consensus standard, entitled *Building Code Requirements for Minimum Design Loads in Buildings and Other Structures*. This national standard for design loads, including earthquakes, was revised in 1982.



Buildings in nine cities are being studied to evaluate the use of new seismic design provisions as compared to those in current use.

Earthquake damage in Coalinga, California.

Agency for International Development, Office of U.S. Foreign Disaster Assistance

The Agency for International Development, Office of U.S. Foreign Disaster Assistance (AID/OFDA), has supported activities in earthquake hazards reduction in the developing world since 1979. The OFDA early warning and disaster preparedness program of seismic monitoring, tsunami modeling and hazards analysis, earthquake risk and hazards mitigation, engineering seismology, and related training has increased more than eightfold in the past 4 years. This expansion reflects the increasing importance AID has placed on early warning, preparedness, and mitigation as means of reducing the disaster death toll resulting from geological hazards.

The goal of the AID earthquake hazards reduction activities is to reduce death and human suffering caused by earthquakes, volcanoes, tsunamis, and landslides. This goal is being accomplished by assisting disaster-prone countries to achieve a high degree of self-sufficiency and technical competence in seismic-related disaster avoidance and mitigation. The following OFDA objectives will be accomplished, in part, by fiscal year 1985:

- Increase lead time for seismic related disaster early warning and contingency planning (that is, earthquake forecasts from probabilistic assessments of seismic potential).

- Integrate early warning systems output with hazard reduction activities, country preparedness, and AID development objectives.

- Upgrade and integrate foreign national and regional geophysical monitoring networks; catalog historical seismic data and prepare regional risk maps.

- Evaluate relative vulnerability of less-developed countries to seismic-related disasters and develop regional mitigation and preparedness strategies.

- Strengthen Third World seismological institutions and orient foreign scientists and civil defense officials in the application of new technologies for earthquake disaster mitigation.

The goal of these activities is to establish a comprehensive U.S. strategy for international earthquake hazards mitigation and disaster preparedness.

In the past 2 years, AID/OFDA has implemented the following major activities related to earthquake hazards mitigation in less developed countries:

- Installation of a radio-telemetered seismic network in the Fiji Islands; study of hazards related to the Suva/Mbennga seismic zone; and evaluation of seismic risk in the Fiji–Vanuatu region of the southwest Pacific Ocean.

- Development of comprehensive simulation models of the Pacific Basin tsunami hazard for both open ocean and near-shore wave propagation following hypothetical earthquake events along the west coast of South America.

- Installation of an advanced seismological and strain meter network for central Peru and an automatic earthquake detection and data processing facility in Lima.

- Investigation of and analysis of earthquake risk and disaster mitigation in the Andean region in cooperation with the U.S. Geological Survey (USGS) and Centro Regional de Sismologia para America del Sur.

- Development of national earthquake hazards reduction programs, including upgrading of seismic networks in Panama, Ecuador, El Salvador, Guatemala, Dominican Republic, and Costa Rica.

- Establishment of an orientation program in engineering seismology and earthquake engineering for Southeast Asian nations in cooperation with the Southeast Asian

Association of Seismology and Earthquake Engineering (SEASEE) and USGS.

- Establishment of a Southeast Asian regional earthquake hazards mitigation program through SEASEE and upgraded selected national seismic monitoring networks.

- Coordination of the first International Workshop for Mitigation of Natural Hazards in Latin America at Lima, Peru, in cooperation with the American Institute of Architects Foundation and Latin American counterpart organizations.

- Provision of emergency funding assistance to USGS in support of continuing operation of the Global Seismic Network.

- Establishment of a portion of the U.S./Japan Cooperative Program in conducting international seminars on seismology and earthquake engineering.

- Development of a prototype near-shore, real-time tsunami warning system for Chile using Geostationary Operational Environmental Satellite (GOES) telemetry in cooperation with NOAA's Pacific Marine Environmental Laboratory.

- Development of an earthquake monitoring and earthquake risk analysis program with the National Autonomous University of Mexico under the U.S./Mexican Agreement for Cooperation on Natural Disasters.

- Establishment of a technical assistance program in cooperation with the European Economic Community to draft uniform building codes for wind and seismic effects in the Leeward Islands of the Caribbean Basin.

- Provision of financial support to the 1983 city of Los Angeles International Earthquake Conference, including funding for the attendance of many foreign participants.

DEPARTMENT OF DEFENSE

DOD has been involved actively in the accomplishment of the stated objectives of the Earthquake Hazards Reduction Act of 1977, as amended. Historically, as local and State seismic safety codes were adopted, DOD applied these codes in the design and construction of DOD facilities. Following the Alaska earthquake of 1964, DOD increased its programs of research and criteria and standards development. The Tri-Service Seismic Design Manual, which was published first in 1966, provides guidance for incorporation of earthquake-resistant design and construction measures. DOD earthquake hazard mitigation activities include research, investigations and studies, education programs for designers and constructors, development of design criteria and standards, and development and increased use of computer-aided methods of aseismic structural design. Coordination activities have been established and maintained with other Federal agencies, national foundations, international programs, and engineering societies.

RESEARCH

DOD agencies have been involved actively in research leading to the development and improvement of methods, criteria, and standards to improve the earthquake resistance of buildings and dams. This work is being accomplished primarily in service laboratories: U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois (Military Construction); U.S. Army Waterways Experiment Station (WES), Vicksburg, Mississippi (Civil Works); and the U.S. Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. The U.S. Air Force research activities have been limited; Army and Navy research results have been applied to the Air Force program as appropriate.

INVESTIGATIONS AND STUDIES

At present, during the design of new building facilities and the upgrading of existing facilities, the seismic hazards are considered and proper earthquake-resistance measures incorporated. However, each service has many existing facility installations on which most of the facilities were designed and built before the earthquake hazard was well defined and understood. Therefore, an important DOD activity has been assessing existing facilities in terms of the seismic hazard and developing a schedule for upgrading those buildings found to be seismically deficient by present standards at the earliest opportunity.

The Navy has established a standardized procedure for making site seismicity studies. The NCEL has developed computer codes for search of historical records, statistical analysis of historical data, and Monte Carlo techniques for evaluation of potential earthquakes originating on known faults. Studies of existing facilities include 7 hospitals, all drydocks, and screening of approximately 6,200 other buildings located in Seismic Zones 3 and 4. Approximately 735 were found to require structural investigation, and a preliminary evaluation showed 460 of those to be less than adequate. Detailed studies have been completed for approximately 100 structures. In addition, detailed studies have been completed for approximately 40 structures in Zones 3 and 4 that were scheduled to be modernized or rehabilitated or were slated for major repairs. Upgrading has been initiated for approximately 50 structures.

Data from 74 detailed studies (not including hospitals) yield an average cost of upgrading of approximately $300,000 per structure. The replacement cost for those structures is approximately $292 million. The NCEL has been developing a methodology for establishing the most cost-effective level of seismic resistance in a structure.

The Army is completing a prototype research project at Fort Ord, California, on development of a hazard indexing and prioritizing system for use in upgrading the seismic resistance of existing buildings. Nineteen buildings were screened for detailed structural analysis and were considered for structural strengthening. Those considered essential to the mission of the base and required to have a postearthquake operations capability would be given first priority. The results obtained using the Navy's preliminary rapid seismic analysis procedure are being compared with results obtained from the General Service Administration's SAFEM software program. The Air Force plans a similar investigation of its bases using the Army's procedure.

New and existing hospitals in areas of high seismicity are considered to be vitally needed after a major earthquake, and mission-essential facilities are being investigated for seismic resistance and designed to ensure their postearthquake operational capability. All seismic strengthening of existing hospitals to date has been accomplished in conjunction with the upgrading of mechanical, electrical and safety systems to meet the accreditation standards of the Joint Commission on the Accreditation of Hospitals. Existing barracks and bachelor officers' quarters are being upgraded for seismic resistance in conjunction with renovation or modernization projects.

DESIGN CRITERIA AND GUIDELINES

Following the damages suffered by facilities in the Alaska earthquake of 1964, the Tri-Services published a technical manual, *Seismic Design for Buildings*, in 1966 under the management of the U.S. Army Corps of Engineers. The Tri-Services Ad Hoc Committee reflected the trend toward increased design requirements and increased estimates of risk and the concern for the adequacy of existing structures. The manual, which was based upon the Uniform Building Code, added recommended details not available in other publications. The second edition, published in 1973, reflected the lessons learned from the 1971 San Fernando earthquake and included the latest changes to the Structural Engineers Association of California's (SEAOC) Recommended Lateral Force Requirements. The design and details of tie-downs, braces, and anchorages for electrical, mechanical, and other utility systems were incorporated. The third edition, published in 1982, included the latest design concepts and the 1980 SEAOC design recommendations. Two additional seismic design guidelines being developed—one for new essential facilities and the other for existing essential facilities—will require analysis of such buildings by the latest dynamic methods to incorporate the most cost-effective earthquake-resistant methods.

SEISMIC INSTRUMENTATION PROGRAM

The Corps of Engineers' Strong-Motion Instrumentation Program provides insight into the safety of existing and new Corps structures and a measure for project performance as well as a data base for earthquake research. When the program was created in 1970, the USGS was contracted to install and maintain Corps strong-motion instrumentation. By fiscal year 1978, however, WES had assumed a significant part of this activity, with primary responsibility for the installation and maintenance of Corps strong-motion instrumentation located east of the Rocky Mountains; the USGS continued to maintain instruments on the west coast. As of 1 May 1982, a total of 104 instrumentation projects were underway in 34 States and one Territory, including 360 accelerographs, 59 seismoscopes, and 27 peak recording accelerographs. Future plans call for an additional 55 accelerographs and 22 peak recording accelerographs.

Significant records of seismic activity were obtained from this instrumentation at Coyote Dam in California and in the New England area during the January 18, 1982, Franklin Falls, New Hampshire, magnitude 4.8 event, from which 13 high-quality records (39 components) were recovered.

Future goals are to revise and update analytical procedures used for assessing the seismic stability of structures and to install devices on Corps structures to minimize on-site inspections after earthquakes. Recently, strong-motion instrumentation systems were installed in two existing Army hospitals, Letterman Army Medical Center, Presido of San Francisco, California, and Silas B. Hays Army Hospital, Fort Ord, California. The Navy has installed seismic strong-motion instrumentation for its dry dock certification program and in a few of the structures at selected locations.

EDUCATION PROGRAM

Because of the urgent need to train field personnel in seismic design, the Corps and the Naval Facilities Engineering Command (NAVFACENGCOM) sponsored two seismic design workshops for their field personnel in

1981. The Army has scheduled seismic design workshops in its 1984 and 1985 training schedule. Several other earthquake analysis courses have been taught by the Corps, such as basic and advanced earthquake analysis courses related to dam design. The Air Force includes seismic design in its course at the Civil Engineering School, Wright-Patterson Air Force Base, Ohio.

COORDINATION ACTIVITIES

DOD has been active in the NEHRP's ICSSC, with representatives from DOD, the Army, the Navy, and the Air Force participating in various subcommittees. Also, DOD components are represented on the BSSC of the National Institute of Building Science, the NSF-NBS Committee on Trial Designs.

Earthquake engineering is one of the topic areas of the biannual conferences jointly conducted by the Corps, Bureau of Reclamation (BuRec), Tennessee Valley Authority (TVA), and the Bonneville Power Administration to exchange information on research and prevent duplication of effort. Other participants have included FEMA, Bureau of Mines, NRC, and Soil Conservation Service (SCS). The most recent in this conference series, the twelfth, was held at the WES in November 1981.

The Ad Hoc Interagency Committee on Dam Safety was established by the Federal Coordinating Council for Science, Engineering, and Technology to prepare Federal guidelines for dam safety. The Department of the Army is represented on the Committee, and the Corps has members on several of the task groups, including those on seismology and on seismic design.

The national strong-motion instrumentation program is maintained by cooperative efforts of the Corps, USGS, Veterans Administration (VA), NSF, and the State of California. Annual meetings are held to exchange information and coordinate instrumentation activities.

In addition, DOD personnel participate in cooperative activities such as providing consultant services on earthquake engineering problems to NRC, BuRec, and SCS; conducting earthquake-related research under sponsorship of NRC; serving as technical reviewers of research proposals submitted to NSF; participating in the EERI, which serves as a clearinghouse for information on research activities for earthquake data; and participating on the technical committees of the American Society of Civil Engineers. Under its research programs, DOD sponsors earthquake-related research at many universities, including the University of California, Berkeley; MIT; Harvard University; and Cambridge University (England).

On an international level, the Corps and NAVFACENGCOM participate along with NBS, USGS, NOAA, NRC, and BuRec on the Joint U.S./Japan Panel on Wind and Seismic Effects, which holds annual meetings to exchange information and data, including methods of analysis and design and data on earthquake ground motions and their effects. Also, the Corps is a member of the interagency Working Group for Coordination for Cooperative Earthquake Research with the PRC.

DEPARTMENT OF ENERGY

It is the policy of the Department of Energy (DOE) to (1) ensure the safety and health of the public, (2) protect government property against accidental loss and damage, and (3) provide safe and healthful workplaces for employees of DOE and DOE contractors. Accordingly, DOE predecessor agencies have been actively involved in earthquake hazard reduction programs. DOE is developing and implementing a program of seismic-resistant design, construction, operation, maintenance, and retirement of a wide spectrum of facilities. DOE earthquake hazard mitigation activities include seismic review of facilities, development of seismic standards and safety guidance, seismic hazard analysis, and dissemination of information to professional organizations, code bodies, and the public. In this regard, DOE has been active recently in supporting the programs of the ICSSC and the National Academy of Sciences.

POLICY

The following DOE headquarters organizational units are responsible for developing and ensuring the implementation of policy relating to earthquake hazard reduction:

- Directorate of Administration (MA),
- Assistant Secretary for Nuclear Energy (NE),
- Assistant Secretary for Defense Programs (DP),
- Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness (EP), and
- Director of Energy Research (ER).

DOE policy is implemented through a system of orders and other directives. Fundamental seismic requirements are listed in several orders. For example, the order entitled "General Design Requirements" states: "The basic building code to be used shall be whichever nationally recognized code is used in the State where the project is located. At a minimum, the 'Uniform Building Code' issued by the International Conference of Building Officials shall be used in the determination of earthquake levels for buildings and other structures except where more stringent requirements are imposed. Use shall be made of site-specific seismic studies and associated seismic hazard models developed for DOE sites." Efforts are underway by DOE to incorporate provisions of the "Draft Seismic Standard for Federal Buildings" into DOE design criteria and to support changes to the building code. The Office of Nuclear Safety, EP, is responsible for appraising the implementation of orders requiring emergency preparedness. These orders include requirements and responsibilities for planning and preparedness for natural phenomena emergencies at DOE sites and for headquarter appraisals of field office implementation. Earthquakes are identified among several other hazards. Specific DOE orders and standards related to earthquake hazards reduction include

- DOE 5480.1A, *Environmental Protection, Safety, and Health Protection Programs for DOE Operations* (EP);
- DOE 6430, *General Design Criteria* (MA);
- DOE 4300.1, *Real Estate Management* (MA);
- DOE 4320.1, *Site Development and Facility Utilization Planning* (MA);
- DOE 5500.2, *Emergency Planning Preparedness and Response for Operations* (EP);
- DOE 5500.3, *Reactor and Nuclear Facility Emergency Planning, Preparedness, and Response Program for DOE Operations* (EP); and
- NE F9-2T, *Nuclear Standard—Seismic Requirements for Design of Nuclear Power Plants and Nuclear Test Facilities* (NE).

SEISMIC SAFETY GUIDE

A *Seismic Safety Guide* has been developed for DOE by the Lawrence Berkeley Laboratory (LBL), a multipurpose DOE facility engaged in large-scale fundamental research and applied science. The guide was based on the experience gained at LBL in a comprehensive review of facilities and operations that resulted in improved seismic safety.

The introduction to the *Guide* describes the rationale and its intended usage as follows:

The Seismic Safety Guide *provides managers of DOE facilities with practical guidelines for administering a comprehensive earthquake safety program. Because of an increasing awareness of seismic risk, such a guide was badly needed. Often the approach to reviewing existing facilities for seismic safety is so overly sophisticated that the actual abatement of obvious deficiencies is delayed, costly, and often legalistic rather than objective. Furthermore, it is widely observed that still today buildings are generally being constructed without benefit of a seismic plan check, a simple process that has proved so effective in actual experience with earthquakes in California.*

Significantly, structural engineers who have observed and studied damaged buildings in the aftermath of earthquakes are generally able to diagnose hazardous deficiencies in existing buildings rather easily and efficiently. It is seldom necessary to carry out elaborate analyses to evaluate the seismic resistance of structures. The process of review does not have to be expensive or complex. Often, the problems found in construction and design are simply the results of failure to implement what has been known and observed about earthquake engineering for many years.

The objective of this Seismic Safety Guide *is to provide practical advice about earthquake safety and engineering to managers of DOE facilities so that they can get the job done without falling into common pitfalls and prolonged diagnosis. This Guide provides the manager with basic guidelines and methodology, but is intended neither as a textbook nor as a substitute for the use of competent consultants.*

The Guide *is comprehensive with respect to earthquakes in that it covers the most important aspects of natural hazards, site planning, evaluation, and rehabilitation of existing buildings, design of new facilities, operational safety, emergency planning, special considerations related to shielding blocks, nonstructural elements, lifelines, fire protection, and emergency facilities. Management of risk and liabilities is also covered.*

The *Seismic Safety Guide* is being distributed through the ICSSC and is available through the National Technical Information Service. It also will be presented at the Eighth World Conference on Earthquake Engineering in San Francisco, California, in July 1984.

SEISMIC REVIEW OF LAWRENCE BERKELEY LABORATORY FACILITIES

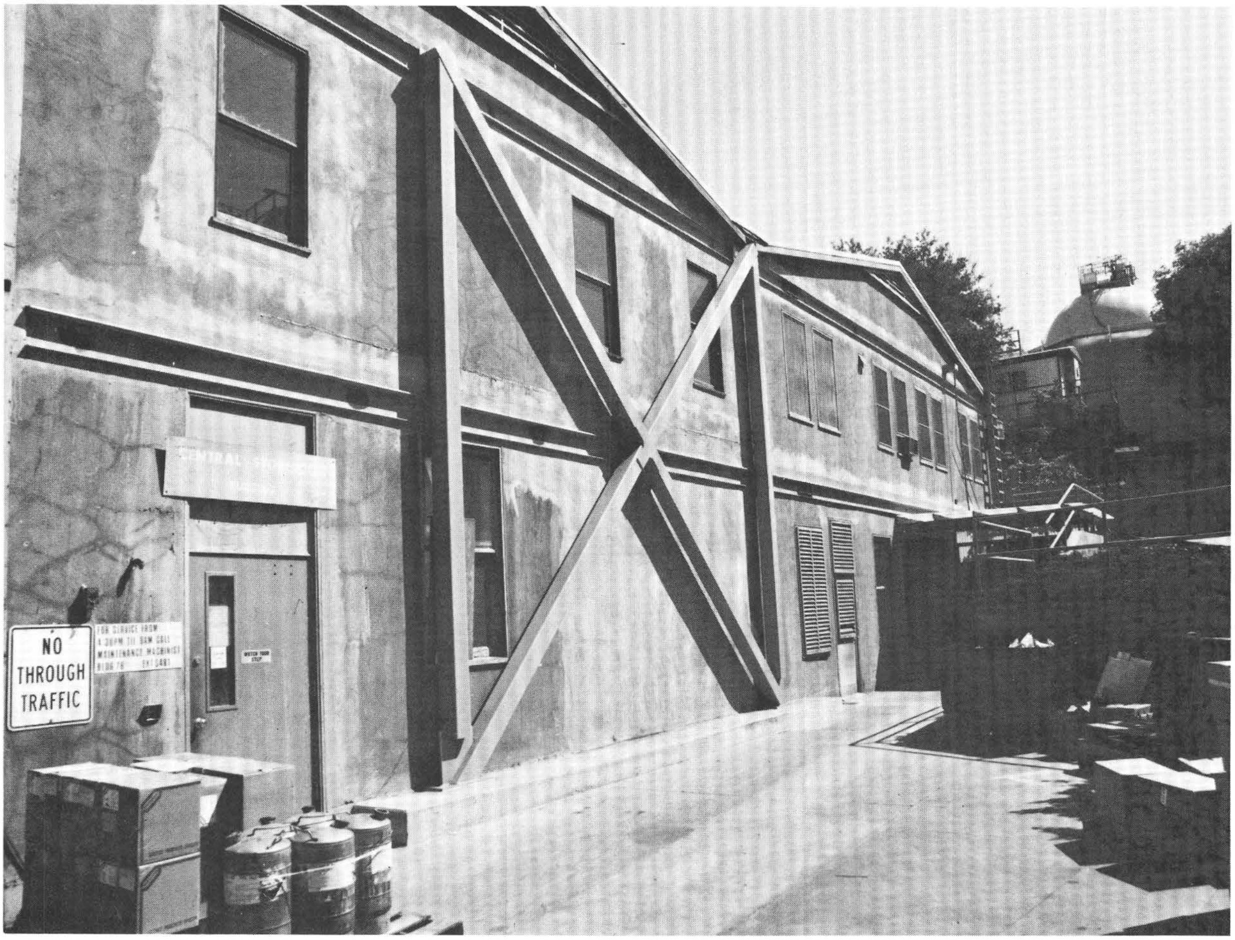
Following the destructive San Fernando earthquake in southern California, LBL, which is located in the San Francisco Bay area and operated by the University of California, began a comprehensive review of its own existing facilities and operations to improve seismic safety. The earthquake safety review revealed that significant structural deficiencies, stemming from many sources, were present in over 50 percent of the buildings reviewed. Several old buildings had no formal lateral-force-resisting system. In other buildings, deficiencies were related to modifications after construction that inadvertently altered the lateral-force-resisting system.

Significantly, most hazardous deficiencies in existing buildings were relatively simple to diagnose. They were quickly found by practical techniques used by structural engineers specializing in earthquake safety. Sophisticated analysis techniques were not required and in fact would have complicated and slowed the entire process of detection and, consequently, correction.

Sixty buildings, as well as critical site utilities and emergency facilities, were inspected.

Changes to Lawrence Berkeley Laboratory Building 50 complex to bring it up to today's earthquake safety standards included removal of the concrete "eyebrows" over the windows and the addition of heavy buttressing at the east end of the wings.


30 MINUTE
PARKING



Earthquake hazard reduction to Lawrence Berkeley Laboratory central storeroom included giant X braces to provide lateral force resistance.

Nonstructural elements and operational conditions also were inspected and analyzed in order to minimize unnecessary hazards. The site proper was studied to identify, delineate, and evaluate natural seismic hazards such as possible fault displacement and earthquake-triggered subsidence and landslides. Special facilities such as shielding blocks, storage for hazardous material, communications centers, medical services, and emergency generators received careful attention. The order of inspection was based on a priority system that considered life safety, emergency recovery capacity, off-site consequences, program continuity, and property value. The order of subsequent projects to abate hazards and improve earthquake safety was based on a separate priority system. This system included consideration of the probability of earthquake occurrence, the structure's probable response, the severity of human exposure and property damage, and the possibility of off-site consequences. The system also evaluated the relative priority of projects to abate other types of risk such as fire, pollution, industrial hazards, and radiation.

Remodeled facade of Lawrence Berkeley Laboratory Building 29 uses wood beams and utility poles to strengthen lateral force resistance.

These priority systems were simplistic and judgmental. Although due process was followed, the level of sophistication and complexity was minimized in favor of decisiveness and practicality. Structural deficiencies and operational hazards that could be corrected easily were promptly abated. When more complex hazards were identified, interim action was undertaken to reduce risks until the process of full abatement could take place. More than 30 buildings at LBL were strengthened; four were evacuated and later demolished. Projects to repair or strengthen structural systems, nonstructural elements, and lifelines were carried out on a priority basis over several years.

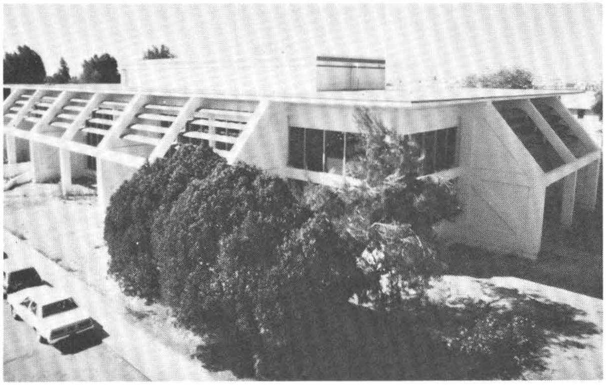
The cost of the earthquake safety survey by LBL's specialized consultants amounted to $50,000, or 0.06 percent of the replacement value of all buildings surveyed, not including contents. Costs for all building corrections totaled about 1.0 percent of replacement value.

SEISMIC REVIEW OF LAWRENCE LIVERMORE NATIONAL LABORATORY

After the San Fernando earthquake of 1971, an extensive program was initiated at the Lawrence Livermore National Laboratory (LLNL) to review structures and seismic hazards ($1.5 million program by the Earth Sciences Division to study earthquakes). Other work followed, and LLNL currently is formalizing a seismic safety committee.

LLNL performed an impact analysis of structures and facilities after the Livermore earthquakes of January 24 and 26, 1980. The results of the study were presented at the DOE Seismic Safety Conference later that year. Several consulting firms also reviewed structural design and response of selected facilities. LLNL is completing a $12 million earthquake hazard reduction program to strengthen structures. An analysis of design and code changes relating

Lawrence Livermore National Laboratory Building 311 as originally constructed under the 1961 Uniform Building Code.



Lawrence Livermore National Laboratory Building 311 structurally upgraded to existing code. The added concrete buttresses are anchored to the ground by means of 3- × 40-foot concrete piers and are attached to the buildings second floor and to the roof.

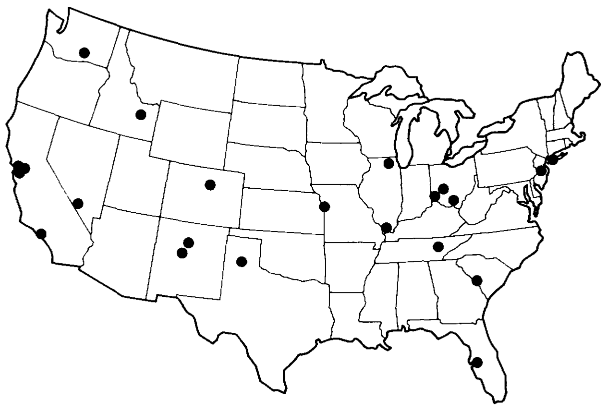
to the effort is to be reported at the Eighth World Conference on Earthquake Engineering.

SEISMIC HAZARD ANALYSIS STUDY

Seismic hazard analyses were completed for major DOE sites throughout the United States in a study by the TERA Corporation under contract to LLNL, managed by D. W. Coates and R. C. Murray, with technical review provided by D. L. Bernreuter. At TERA Corporation, C. P. Mortgat managed the study under the corporate supervision of L. H. Wight. The results of the detailed seismic hazard analysis of major DOE sites are presented in an eight-volume set of reports.

The scope of this study was limited to the gathering, evaluation, and use of information of interest available during the analysis. This information pertains to geology, seismology, earthquake history, and attenuation characteristics. A seismicity model was developed from this information, and the model was exercised with the TERA seismic hazard computer code. The purpose of this methodology and results of this and other natural phenomena studies have been presented by David Coates and Robert Murray and James Hill of DOE (see Bibliography for specific references).

To ensure credible results, sophisticated, well-accepted techniques were employed in the analysis of the seismic hazard. The calculated



Department of Energy sites for seismic hazard analysis.

method used, based on Mortgat's 1977 work, has been applied previously to seismic exposure evaluation of diverse regions. The model developed by TERA was tested extensively and compared with those developed by Cornell, McGuire, and Der Kiureghian.

The historical seismic record for each site was established following a review of the available literature. The resulting seismic record, covering the period 1800 to 1977, was used to identify all possible sources of seismicity that could affect the site. Inadequacies and incompleteness in this record were explicitly considered in the definition of source regions and their activity rates. Subjective geological or geophysical probabilities were introduced in those cases justified by the information. Acceleration and attenuation relations which had been developed by TERA for previous studies proved to be applicable in this analysis.

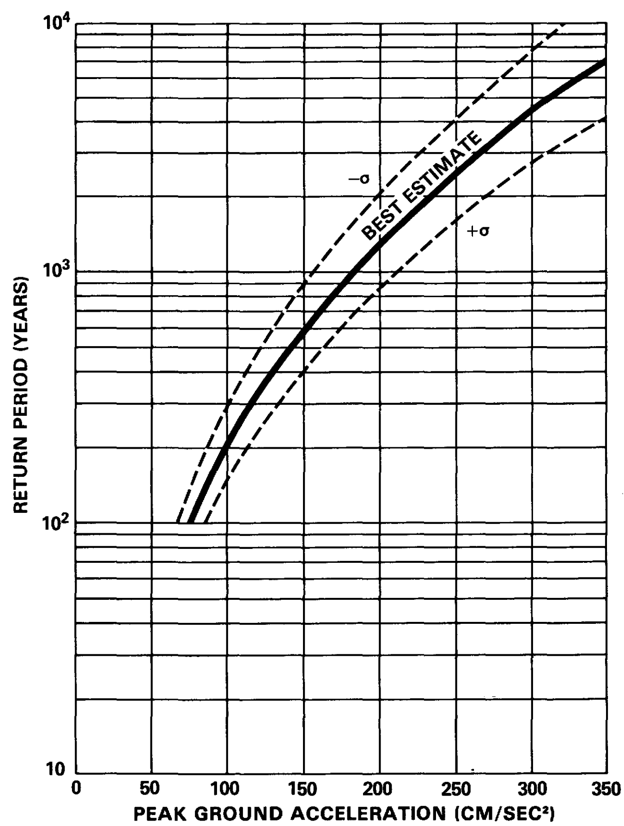
The results of one analysis, which include estimates of the uncertainty, are presented. Best estimate curves indicate that the horizontal peak ground acceleration (PGA) at one site is 7-percent acceleration of gravity (*g*) with a return period of 100 years and 19 percent *g* with a return period of 1,000 years. The curves on either side of best estimates represent lower- and upper-bound confidence limits; they can be considered to be one standard deviation with respect to the best estimates.

These curves provide a basis for selecting seismic design criteria for these sites in terms of free-field PGA. For those structures and equipment that could experience structural amplification, we have chosen the response spectral shapes that we have determined to be most appropriate for the sites.

DISSEMINATION OF INFORMATION

DOE's National Laboratories have presented papers on the results of their earthquake hazards reduction programs at the following world, national, and local conferences:

- Sixth World Conference on Earthquake Engineering;
- Seventh World Conference on Earthquake Engineering;
- Sixth International Conference on Structural Mechanics in Reactor Technology;
- EERI National Meeting;
- ICSSC Agency Seismic Programs Seminar;



Earthquake hazard curves at a Department of Energy site.

- DOE Seismic Safety Conference, 1980; and
- DOE Geophysical Working Group Program Seminars.

The Office of Basic Energy Sciences, ER, chairs the DOE Geophysical Working Group and publishes an annual summary of geoscience and geoscience-related research.

The Office of Operational Safety, EP, maintains a loss control program and issues annual summary reports for all DOE facilities. These reports include property damage caused by earthquakes and other natural phenomena. A topical report recently issued on sprinkler system performance and reliability for 1952 to 1980 describes earthquake bracing requirements.

DOE publications are distributed internally and to the scientific community and also are available through the National Technical Information Service.

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Department of Transportation

In support of the NEHRP during fiscal year 1983, the Office of the Associate Administrator for Research, Development and Technology of the FHWA, undertook a nationwide investigation of the performance and reliability of highway bridge structural details and examined the seismic retrofit problem and approach to strengthening of highway bridges. A methodology was developed to determine if further consideration should be given to seismic retrofit. For bridges that might require further consideration, a detailed retrofit evaluation procedure was developed to determine specific seismic deficiencies of the structure. Finally, retrofit details were developed for practical application to seismically deficient highway bridges.

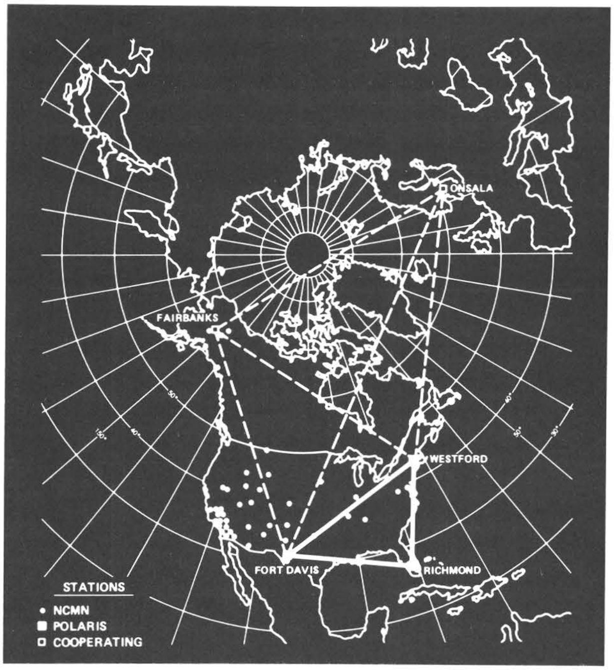
In March 1983, the Office of Emergency Transportation of the Research and Special Programs Administration completed its California Earthquake Residual Transportation Capability Study. This study addressed the capability of the civil transportation facilities in California to survive four postulated earthquake scenarios. The survival of highways, railroads, ports, airports, and pipelines was investigated following hypothetical individual earthquakes of varying intensities along the North San Andreas (Richter magnitude 8.3) and Hayward (magnitude 7.5) faults in northern California and the South San Andreas (magnitude 8.3) and Newport-Inglewood (magnitude 7.5) faults in southern California. Study results will be used by the Office of Emergency Transportation in developing more effective response strategies for earthquake planning in California.

National Aeronautics and Space Administration

NASA's Geodynamics Program contributes to the understanding of the solid Earth through the use of satellite laser ranging (SLR), lunar laser ranging (LLR), and very long baseline interferometry (VLBI) to measure and study the movement and deformation of the major tectonic plates, the regional crustal deformation at plate boundaries, and the Earth's rotational dynamics and to survey and model the Earth's global gravity and magnetic fields. Using SLR, LLR, and VLBI and signals from astronomical radio sources, NASA can determine precisely (within less than an inch) the relative position of points on the Earth's surface separated by several hundred to several thousand miles. The laser and VLBI techniques have been adapted to both fixed observatory-type facilities and mobile (truck-mounted) stations that can be moved to prepared sites.

In laser ranging, the roundtrip time of a pulsed beam of light reflected by a specially equipped satellite (or by retroflectors on the moon) is used to determine the location of the laser station. In VLBI, the time of arrival of radio star signals at two (or more) separate stations is recorded using atomic clocks, and the time difference is used to determine the distance between stations. The same methods are used to determine the instantaneous position of the Earth's polar axis (polar motion) and variations in the Earth's rotational rate. Information on the Earth's gravity field is derived from observations of the perturbations of satellite orbits and from radar altimeter observations of the ocean surface (geoid). The magnetic field information is obtained from direct surveys, that is, by magnetic field satellite.

Under its Geodynamics Program, NASA is measuring regional-scale crustal deformation in the western portion of the continental United States and Alaska. Regional measurements in western South America, the Caribbean Basin, and Europe, made in conjunction with a consortium of European countries, are included in the program to help elucidate crustal processes in highly seismic areas in the United States. Measurements are underway to determine the contemporary rates of motion of the major tectonic plates—particularly the North



Polar (Motion) Analysis by Radio Interferometric Systems network of the National Oceanic and Atmospheric Administration, and the National Crustal Motion Network.

American, Pacific, Eurasian, and Indo-Australian plates—and the internal deformation of the North American plate.

The activities of the Geodynamics Program contribute to the NEHRP by providing scientific understanding of how and why the plates are moving, of the extent of crustal deformation associated with plate interaction, and of the accumulation and release of crustal strain. In addition, NASA-developed technology has been provided to other agencies for operational use. Through interagency agreement, the VLBI technique has been jointly adopted by NOAA and NASA in the establishment of a new polar motion service—the Polar (Motion) Analysis by Radio Interferometric Systems (POLARIS)—and will be used for the new NOAA National Crustal Motion Network (NCMN). Overall, NASA activities are coordinated with NOAA, the USGS, the NSF, and the Defense Mapping Agency through an interagency agreement and a Federal plan for the application of space technologies to crustal dynamics and earthquake research.

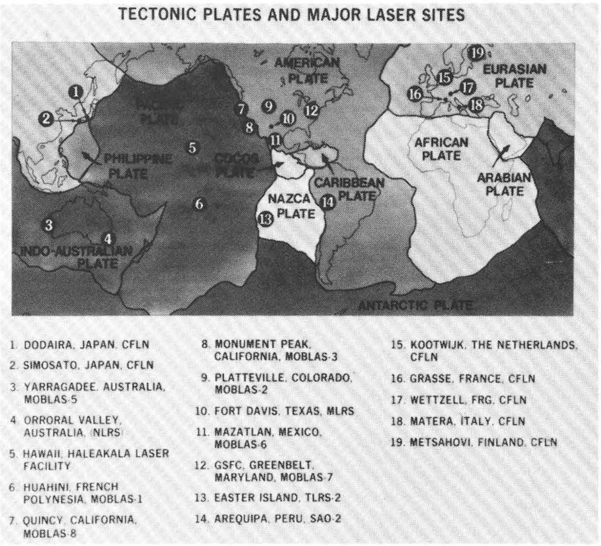
In addition, because of the global nature of geodynamics research, NASA has actively supported the involvement of other countries in its program. At present, 21 countries are participating with NASA in data acquisition and analysis. International agreements have been concluded with The Netherlands, France, Switzerland, England, Italy, Canada, Australia, Japan, and the PRC. In fiscal year 1983, new or additional agreements were concluded with the Federal Republic of Germany, Sweden, Italy, Mexico, Brazil, Chile, and Japan. Agreements are pending, and are expected to be completed by early fiscal year 1984, with Peru, Bolivia, Venezuela, and New Zealand. Additional agreements are expected with Turkey, Greece, and Israel. In fiscal year 1984, NASA plans to negotiate agreements with 17 countries in the Caribbean Basin for studies of regional crustal deformation.

The European WEGENER consortium was formed by European and U.S. investigators to study the tectonics of the Mediterranean. This investigation, which will begin in 1985, will use laser and VLBI facilities in Europe. In addition, the Federal Republic of Germany and The Netherlands are developing mobile laser systems for the Mediterranean research. A reciprocal agreement has been established whereby NASA mobile SLR stations will participate in the Mediterranean research in return for German and Dutch mobile SLR stations participating with NASA stations in the western South American research.

SYSTEM STATUS

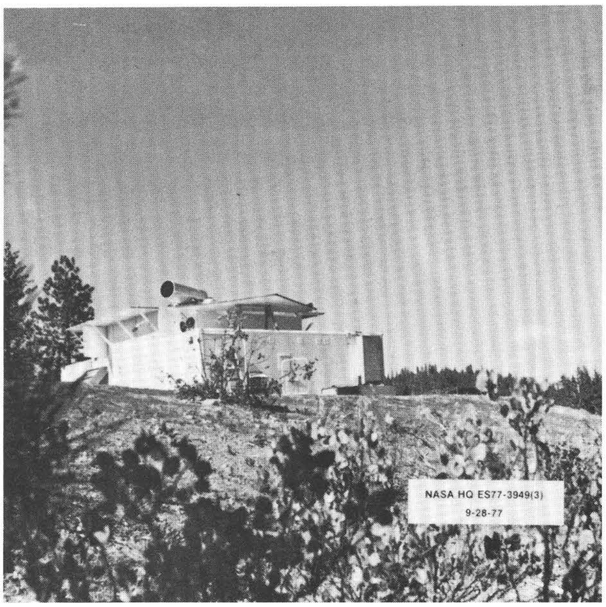
In fiscal year 1983, NASA SLR stations were established in Mazatlan, Mexico, and in the Society Islands in the Pacific. In addition, an SLR station was provided, on indefinite loan, to Italy and was installed at a site near Matera, Italy. Other SLR systems in England, Greece, Austria, and Japan were placed in operation by these countries.

The primary satellite for SLR is the Laser Geodynamics Satellite (LAGEOS). LAGEOS, placed in a stable orbit by NASA in May 1976, is a passive 2-foot sphere with 426 corner cube retroflectors mounted on its external surface. Its expected lifetime is several million years. NASA currently is negotiating an agreement with Italy for a joint project for the development and launch of a second LAGEOS.



Global Satellite Laser Ranging network.

LLR facilities contribute to the study of Earth rotational dynamics, the dynamics of the moon, gravitational constants, and general relativity. Since 1969, LLR at the McDonald Observatory in Texas has shared the use of the 107-inch McDonald telescope. In fiscal year 1983, a dedicated station capable of ranging to LAGEOS and the moon was completed by the University of Texas at Austin, under contract to NASA. This station is expected to be operational in fiscal year 1984. In 1974, NASA provided, on



Typical satellite laser ranging station.

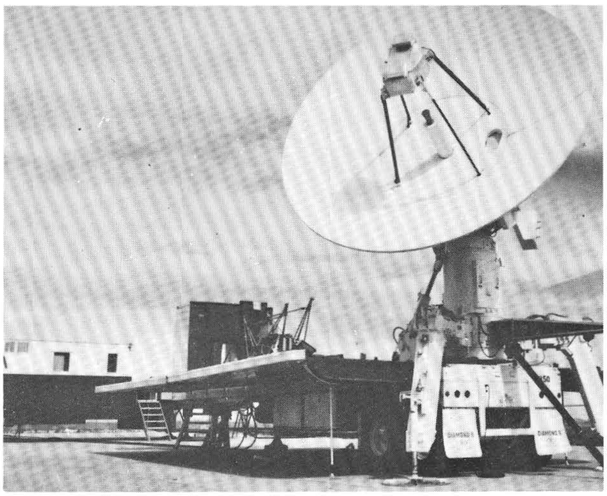
indefinite loan, an LLR station to Australia. This station was successfully installed and operated for several years by the Australians. In 1980, by international agreement, NASA and the Australian National Mapping Division began to upgrade and modify this station for both LLR and SLR. At present, these modifications are underway; they are expected to be completed in early 1984. In 1977, NASA, NBS, and the University of Hawaii installed an innovative LLR system on Maui, Hawaii. Due to technical problems, routine LLR has not been achieved as yet; however, improvements underway are expected to yield LLR by fiscal year 1984.

Fixed VLBI facilities are operational in the United States. Dedicated facilities at Westford, Massachusetts, and Ft. Davis, Texas, form one leg of the POLARIS network. A third POLARIS station at Richmond, Florida, will be operational in fiscal year 1984. Other U.S. facilities include a dedicated station at Mojave, California, placed in operation by NASA in fiscal year 1983; a shared station operated by the Owens Valley Radio Observatory in California; and stations at the Haystack Observatory, Massachusetts; Greenbank, West Virginia (National Radio Astronomy Observatory); and Blossom Point, Maryland (Navy Research Laboratories). VLBI facilities also are operational in the Federal Republic of Germany, Sweden, and Italy. The Radio Research Laboratory in Japan, in cooperation with NASA, is developing a VLBI facility for a joint U.S.-Japan Pacific plate motion investigation, which is to begin in 1984.

In the past decade, SLR precision has improved from meters to centimeters. At the same time, the size of these systems has decreased substantially, which has resulted in a significant increase in system mobility. In fiscal year 1983, a third-generation SLR system—the Transportable Laser Ranging Station (TLRS–2)—was completed by NASA and, by agreement with Chile, deployed to Easter Island for studies of the motion of the Nacza plate.

Similarly, the effectiveness of mobile VLBI stations has been substantially increased. The original station (MV-1) used a 30-foot antenna that required several weeks to move between sites. With a smaller, 13-foot antenna station (MV–2), the time was reduced to a week. In fiscal year 1983, a third-generation system (MV–3) was completed and placed in operation. With this system, data can be acquired at different sites within a few days. Since VBLI measurements of plate motion are required infrequently, MIT, under USGS funding, and NASA have developed special equipment—the Transportable VLBI Data

Transportable Laser Ranging Station at Easter Island.



A third-generation mobile VLBI system.

Satellite Emission Range Inferred Earth Surveying System station.

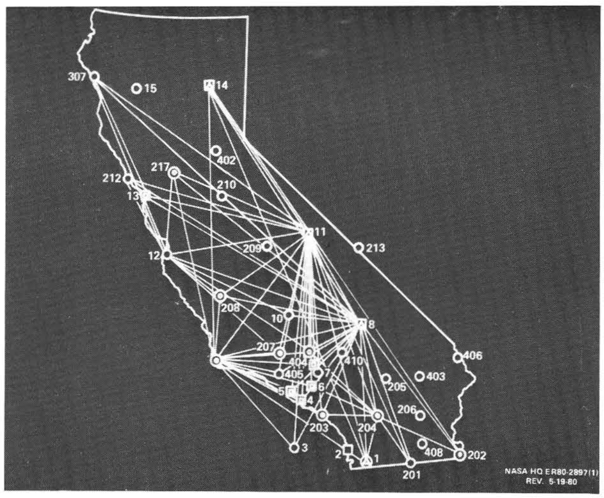
System (TVDS)—that can be adapted to existing radio astronomy antenna systems. The first TVDS (USGS funded) has been in use for several years. In fiscal year 1983, NASA completed TVDS-2 for use in the Pacific and in South America. TVDS-3 is to be completed in 1984, in time for the Pacific plate motion studies with Japan.

NASA, along with other agencies, is developing the use of the DOD GPS satellites for geodetic measurements. The NASA Satellite Emission Range Inferred Earth Surveying (SERIES) System does not require knowledge of the GPS code. In fiscal year 1983, SERIES engineering units, tested over baselines of 13 and 107 miles, demonstrated a precision of 2.4 inches or better in three dimensions. These precisions were limited primarily by the approximately 30-foot inaccuracies in the knowledge of the GPS satellite orbits and by the extent of corrections for atmospheric water vapor. However, recently completed studies by NASA indicate that it should be feasible to use GPS-related systems over baselines of a thousand miles or more and achieve precisions to within an inch or two for observational periods of a few hours. This can be accomplished by using SLR or VLBI-determined locations as fiducial points to reduce the GPS orbital errors and by using water vapor radiometers to reduce the water-vapor-induced error.

MEASUREMENTS AND RESULTS

Since 1972, LLR stations in California, at Quincy and near San Diego, have measured movement along the San Andreas fault system. These data indicate a rate of decrease (shortening) of this approximately 560-mile baseline of 3 ± 1 inches per year. This rate is considerably greater than the 2.2 inches per year predicted by tectonic plate models based on historical geological data. Using VLBI stations in Massachusetts and in Onsala, Sweden, the rate of separation of the North American and Eurasian plates has been determined to be 0.71 ± 0.2 inch per year, which is consistent with the 0.67 inch per year indicated by the Minster–Jordan model. Velocities also have been determined for other plates; however, these data are preliminary and more observations will be required.

Within the United States, the relative motion between VLBI facilities in Massachusetts, California, and Texas has been measured over the past 5 years and is essentially zero (Massachusetts to California: 0.08 ± 0.08 inch per year; California to Texas: 0.3 ± 0.1 inch per year; Texas to Massachusetts: 0.1 ± 0.1 inch per year). Additional measurements are underway at other locations to determine if the North American plate is rigid or if differential motions are compensated.



Location of sites (and baselines) for studies of regional deformation in California.

The highest priority activity within the NASA program is the measurement of crustal deformation in California. On the basis of discussions with other agencies and the advice of the scientific community, a network of sites in California was established in 1980. Initial VLBI measurements for some 16 sites in California were obtained in 1981. In 1982, the number of sites visited was limited by planned upgrade of mobile VLBI systems. In fiscal year 1983, data were obtained at 20 sites. NASA plans to continue these measurements through reimbursable funding provided to NOAA. As provided by a NASA–NOAA agreement, NOAA will continue measurements beyond 1988 as part of the NCMN. The data acquired by NASA and NOAA will be analyzed by NASA investigators and made available to other investigators.

One of the surprising new results relates to studies of polar motion and Earth rotation. Variations in the length of day obtained by SLR and VLBI have been correlated with changes in the total angular momentum of the atmosphere. Similarly, it has been shown by several investigations that a significant portion of the total polar motion (90 percent) is explainable by atmosphere mass movements. These results are surprising because the degree of atmospheric interaction with the solid Earth was not expected to be as great.

FURTHER INVESTIGATIONS

In fiscal year 1984, NASA plans to initiate measurements of crustal motion in Alaska across the Aleutian Trench and to initiate a Pacific plate motion experiment with Japan. The California measurements will be continued and extended to include measurements using TLRS–1 and TLRS–2 of the movement of Baja, Mexico, away from the Mexican mainland. In addition, NASA will participate in an international campaign, Measurement of Earth Rotation and Intercomparison of Techniques, sponsored by the International Astronomical Union. Planning and preparation will be continued for studies in the Caribbean using GPS and for measurements in South America and the Mediterranean. Also, plans are underway for intercomparison tests of several GPS geodetic receiver concepts in fiscal year 1984.

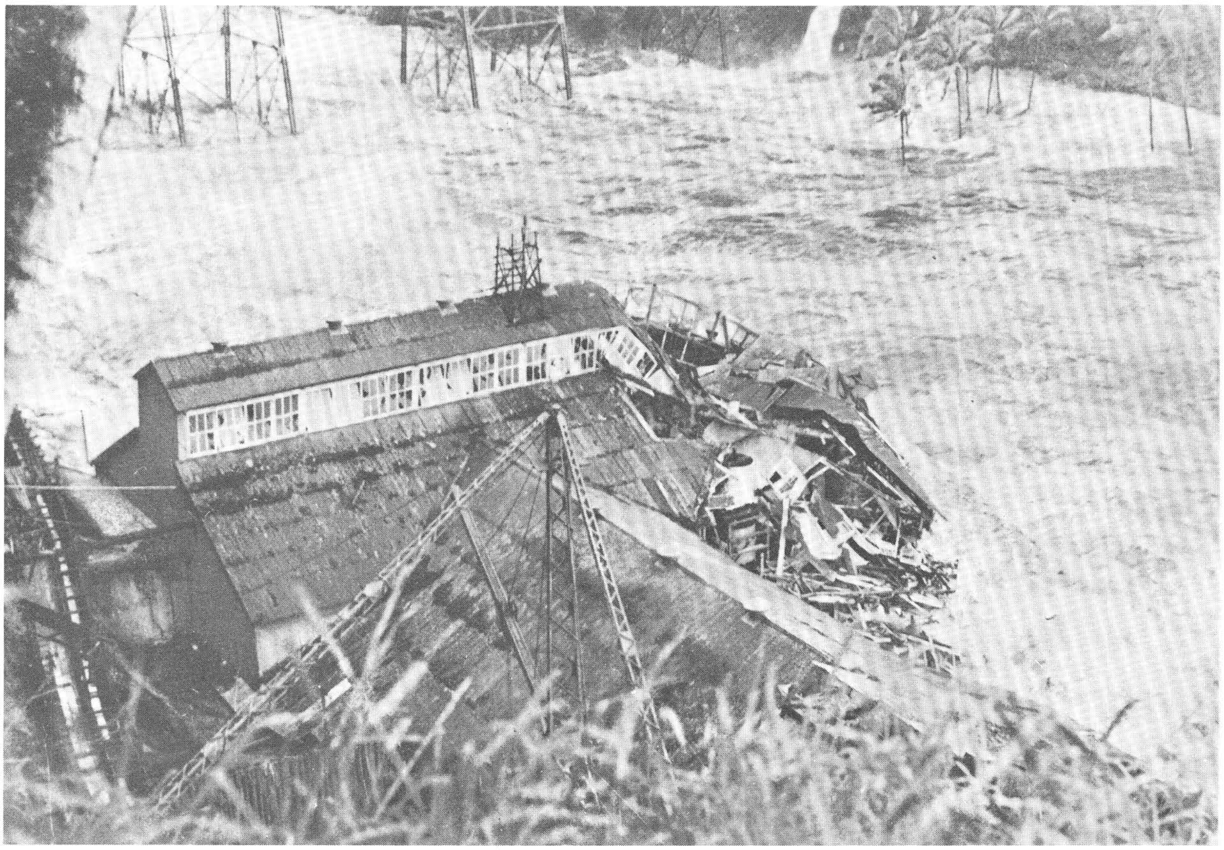
National Oceanic and Atmospheric Administration

TSUNAMI WARNING SYSTEM

Background

Throughout history, tsunamis, or great seismic sea waves, have caused considerable loss of life and property. All regions around and within the so-called Ring of Fire around the Pacific are particularly vulnerable to tsunamis. Although, historically, two of the most destructive tsunamis occurred in the Mediterranean and the Atlantic, most have occurred in the Pacific—the greatest being the tsunami caused by the explosion of the volcanic island of Krakatoa, west of Java, in August of 1883. Waves as high as 130 feet hit nearby islands, wiping out entire villages and killing more than 36,000 people. In 1896, Japan suffered a loss almost as great when an undersea earthquake generated a tsunami that hit the northeast coast of Honshu, killing more than 27,000 people and wiping out 10,000 homes.

Following the Aleutian tsunami of April 1, 1946, which left considerable property damage and 159 dead in Hawaii and destroyed a lighthouse near its source in the Aleutians with a wave surge of over 100 feet, the USCGS [now the National Ocean Survey–National Geodetic Survey (NOS–NGS)], began to develop a means of providing warning to the population of Hawaii of potential tsunamis. The goal was to develop a warning system that would be able to detect and rapidly locate earthquakes in the Pacific region and, if an earthquake occurred in an area where tsunami generation was possible, determine quickly whether a tsunami had been generated. The forecasts developed by the system had to accurately predict arrival times at various places and had to provide adequate warning. Since the system would not operate often enough to justify the maintenance of an extensive communication network, collaboration with the Armed Forces



Destruction in Hawaii caused by April 1946 tsunami.

and the Civil Aeronautics Administration (now the Federal Aviation Administration) was sought, and on August 12, 1948, a tentative communication plan was approved, launching the Seismic Sea Wave Warning System (now the Tsunami Warning System).

Initially the System consisted of the USCGS seismological observatories at College and Sitka, Alaska, Tucson, Arizona, and Honolulu, Hawaii, and the tide stations at Attu, Adak, Dutch Harbor, and Sitka, Alaska, Palmyra Island, Midway Island, Johnston Atoll, and Hilo and Honolulu, Hawaii. Tsunami watch and warning information was supplied to civil authorities of the Hawaiian Islands and to various military headquarters in the Hawaiian Islands for dissemination to military bases throughout the Pacific and to islands in the U.S. Trust Territory of the Pacific. By October 1953, civil defense agencies in California, Oregon, and Washington also were provided with tsunami warning information. Following the great destruction caused by the May 1960 Chilean tsunami, a large number of countries and territories joined the Tsunami Warning System. The Tsunami Warning System became part of the National Weather Service (NWS) of NOAA in 1973.

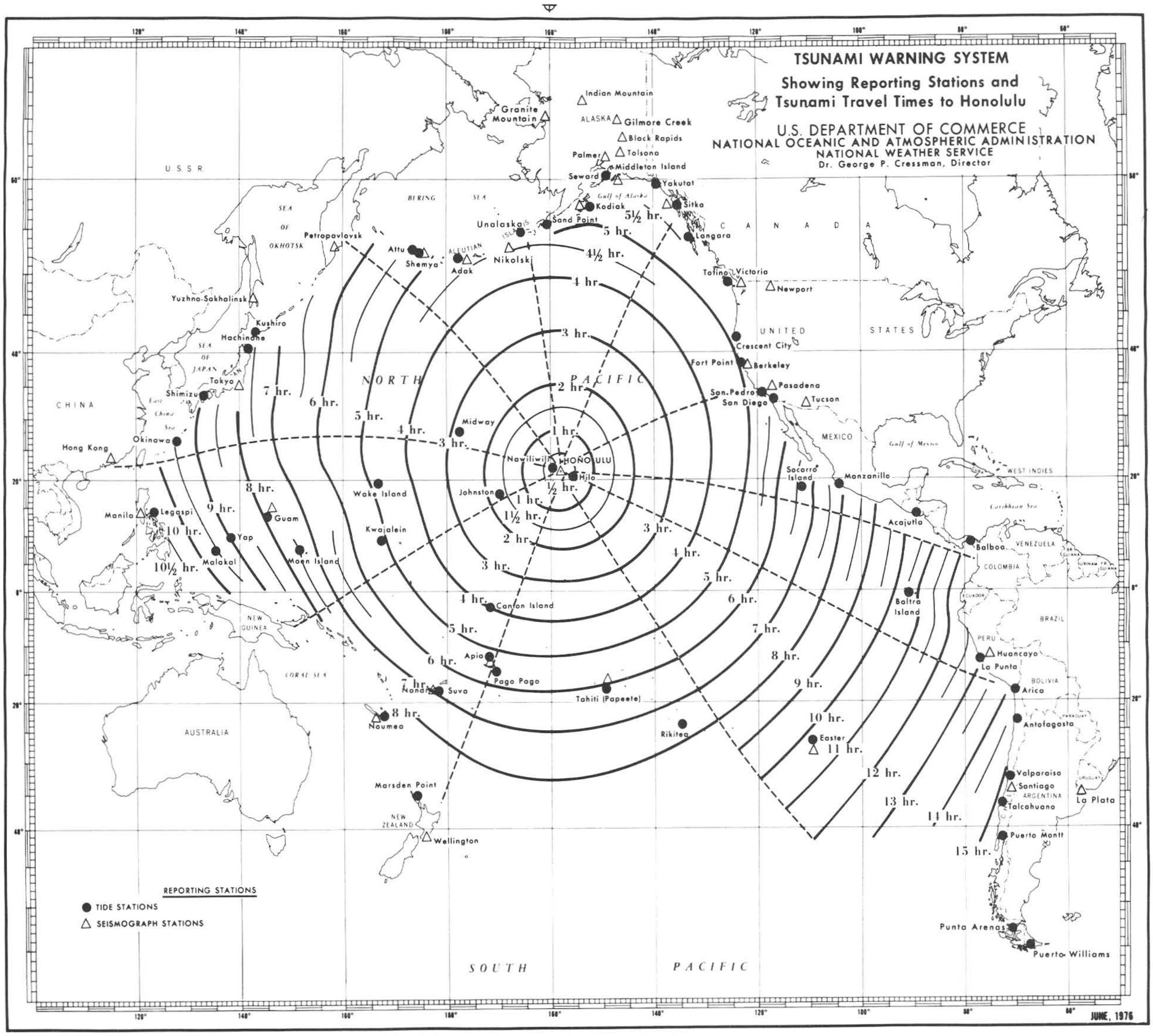
Current System Operation

The warning process begins with detection of an earthquake at the PTWC, located in Ewa Beach, Hawaii, or the Alaska Tsunami Warning Center (ATWC), located in Palmer, Alaska. When sufficient data have been received to locate the earthquake and compute its actual magnitude, a decision is made concerning further action. If the earthquake is located in an area where tsunami generation is possible and the earthquake is strong enough to cause a tsunami, the PTWC requests participating tide stations located near the epicenter to monitor their gages for evidence of a tsunami. For earthquakes of magnitude 7.5 or greater (6.75 or greater in the Aleutian Island region), watch bulletins are issued to the dissemination agencies, alerting them to the possibility that a tsunami has been generated and providing data that can be relayed to the public so that necessary preliminary precautions can be taken. A tsunami watch also may be disseminated by the PTWC upon the issuance of warnings by regional warning centers. (Because the regional warning systems use different criteria for their disseminations, a watch may at times be issued by the PTWC for earthquakes with magnitudes of less than 7.5.)

If evaluation of reports received from tide stations indicates that a tsunami has been generated and that it poses a threat to the population in any part of the Pacific, a warning is transmitted to the dissemination agencies for relay to the public in the affected areas. The dissemination agencies then implement predetermined plans to evacuate people from endangered areas. If the tide station reports indicate that either a negligible tsunami or no tsunami has been generated, PTWC issues a cancellation of its previously disseminated watch.

To lessen the need for human intervention in data collection, NWS, in cooperation with the USGS and NOS, developed tide gages to collect and telemeter data by geostationary satellite and land-line to the PTWC or ATWC, which maintain joint operational control of the system.

The speed at which a tsunami travels outward from the epicenter of an earthquake or large movement of the ocean floor—a speed as great as 600 miles per hour—makes rapid data handling and communication critical. Because of the time currently spent in collecting seismic and tidal data and the speeds of the wave generated by an event, the warning issued by the PTWC cannot protect areas against tsunamis generated in adjacent waters. Therefore, regional warning systems have been established in some areas to provide some measure of protection against local tsunamis in the first hour after generation. The PTWC serves as a regional warning center for Hawaii in addition to serving as an International Tsunami Warning Center for the Pacific Ocean Basin. The ATWC serves as a regional center for Alaska and the U.S. west coast. To function effectively, these regional systems generally have data from a number of seismic and tide stations telemetered to a central headquarters. Nearby earthquakes are located, usually within 15 minutes, and a warning is issued to the population of the area on the basis of the seismological evidence alone.



Stations participating in the Tsunami Warning System and tsunami traveltime to Honolulu, Hawaii.

Fiscal Year 1983 Activities

The major event of fiscal year 1983 was the May 26 tsunami generated by an earthquake, the epicenter of which was about 50 miles off the coast of Akita on the northwest coast of Honshu, Japan. Japan had the least time to react, with only 7 minutes between the shock and the arrival of the first great wave. About 15 minutes after the earthquake, Japan's meteorological agency had issued an alarm to eight coastal prefectures. Unfortunately, in Akita Prefecture the wave struck before many people heard the warning or could escape from the water's edge. In total, the tsunami caused destruction along about 500 miles of the western coast of Honshu and the southwestern tip of Hokkaido and 129 lives were lost.

Clearly, 15 minutes often is still too long for adequate warning and the implementation of preparedness plans, and even the most sophisticated of the regional warning systems often are not fast enough. Therefore, efforts to improve the warning systems are continuing. Research continues in a variety of areas such as wave generation, tide gage technology, and automatic seismic data processing.

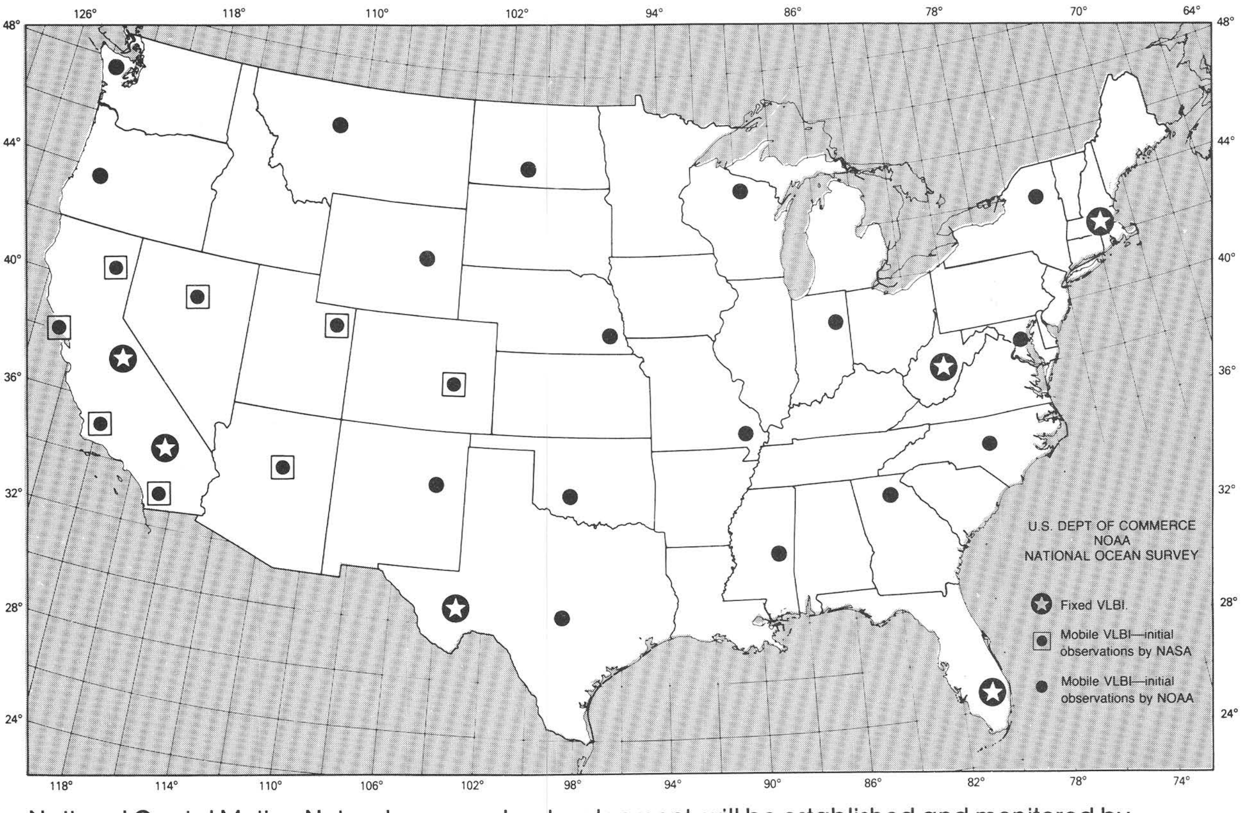
GEODETIC DATA SYSTEMS

National Crustal Motion Network

An agreement signed May 26, 1983, between officials of NASA and NOAA provides for the gradual transfer of mobile VLBI equipment and operations from NASA to NOAA. Under the agreement, NOAA will use the equipment to carry out operational measurements in the United States to meet the needs of the NASA Crustal Dynamics Project (CDP) and to establish and maintain its own NCMN.

The NCMN will rely upon space-measurement systems for geodetic control instead of ground-measurement techniques. Consisting of four fixed VLBI sites across the United States and 40 to 50 additional sites established by mobile VLBI stations, the network will provide NOAA with a basic terrestrial coordinate system throughout the United States referenced to an inertial system through observations of stellar radio sources by fixed VLBI stations. While monitoring crustal deformation across the United States, the network also will establish base stations in the National Geodetic Reference System to which differential positioning with the GPS receivers can be referenced. The NCMN will gain further importance as geodetic observation methods shift increasingly to satellite-based techniques.

The equipment transfer from NASA to NOAA involves a 2-year transition period from January 1983 to January 1985. During this time, NOAA will provide trained operating crews, and NASA will demonstrate the operational status of the systems and transfer owership to NOAA. These systems include three separate mobile VLBI stations as well as a fixed base station. The mobile VLBI systems are MV–1, the original ARIES 30-foot-diameter antenna system; MV–2,



The National Crustal Motion Network, now under development, will be established and monitored by mobile very long baseline interferometry stations.

the second ARIES system, with a 13-foot-diameter antenna; and MV-3, the ORION system, with a 17-foot-diameter antenna. The fixed system, designated the Mojave Base Station, uses a 40-foot-diameter antenna located at the Goldstone Deep Space Network in southern California. All the mobile systems have been built and successfully demonstrated by the California Institute of Technology's Jet Propulsion Laboratory (JPL) in Pasadena, California, under contract to NASA's CDP. The project also is responsible for the refurbishing of the Mojave site, which will serve as a base station to which mobile system observations will be referenced and at which the mobile systems will be maintained between observing sessions. The agreement calls for NGS to acquire Mojave and MV-3 in January 1984 and for transfer of MV-1 and MV-2 during January 1985. Training a NOAA crew for MV-3 has begun at JPL. NOAA's mobile VLBI operation will be managed by the NGS Geodetic Research and Development Laboratory. The NOAA crew for MV-3 and for ground surveying the NCMN sites is being provided by the NGS Operations Branch.

These VLBI measurements provide the greatest available accuracies for measuring base lines of a hundred to more than a thousand miles in length. Typical uncertainties of a few centimeters will permit measurement of the motions of the Earth's crust after obtaining repeated readings at selected sites for several years. Gathering data to monitor and understand these subtle motions related to faulting, earthquakes, plate motion, and other geophysical phenomena was a major impetus leading to the development of mobile VLBI stations.

The initial mobile VLBI instrument, MV-1, was originally developed as a proof-of-concept instrument and consequently is not as highly mobile as subsequent systems. Assembling and disassembling its 30-foot antenna at a new site takes about 14 days, a crew of at least four persons, and the use of a crane and a cherry picker. Since 1973, MV-1 has occupied a dozen sites between La Jolla and San Francisco, California, using radio observatories in Owens Valley and Goldstone, California, as base stations. Because of the time and expense of relocating MV-1, it is expected to serve as a semipermanent base station at Vandenberg Air Force Base throughout the duration of NASA's CDP into 1988.

Much greater mobility was achieved with MV-2, which has a 13-foot antenna system that can be deployed in a few hours after arriving on site. MV-2 has been used by NASA since 1980 to occupy additional sites in California and Arizona. MV-3 is the first mobile system designed specifically for the CDP. Designed and built entirely by JPL under NASA funding, it was intended from the beginning that this system ultimately would be transferred to NOAA for use as an operational system. The MV-3 system was used to gather data in 1982, extending the range of mobile VLBI operations. During June 1983, MV-3 was taken by the NOAA crew 1,200 miles from Pasadena, California, to Platteville, Colorado.

When carrying out mobile VLBI operations, about 24 hours of continuous observations are obtained at each site. Usually 1 or 2 days are required before and after the observing session at a site for setup, checkout, and teardown. Driven by diesel tractors, each mobile VLBI convoy includes an antenna van, an electronics van, and a smaller truck. The convoy, driven by its own crew, can cover 300 to 500 miles per day. Each system is self-contained, requiring no external power. Currently, observation campaigns last about 1 to 2 weeks, with MV-2 and MV-3 each occupying about two sites per week. Observations in support of NOAA requirements for the NCMN will continue throughout the United States for many years.

Geodetic Data Bases

In 1974, NOAA began converting its historical geodetic survey data into machine readable form. All horizontal data have now been converted, and each survey project has been validated. The validation process now continues as the compatibility and connections between horizontal survey projects are being checked regionally. The horizontal data correspond to 250,000 control points and almost 5,000 projects.

Similarly, the vertical survey data for 500,000 points have been converted to machine-readable form. There are 15,000 level lines totaling more than 800,000 miles in length. The leveling data currently are going through the validation process, which will take about 2 more years.

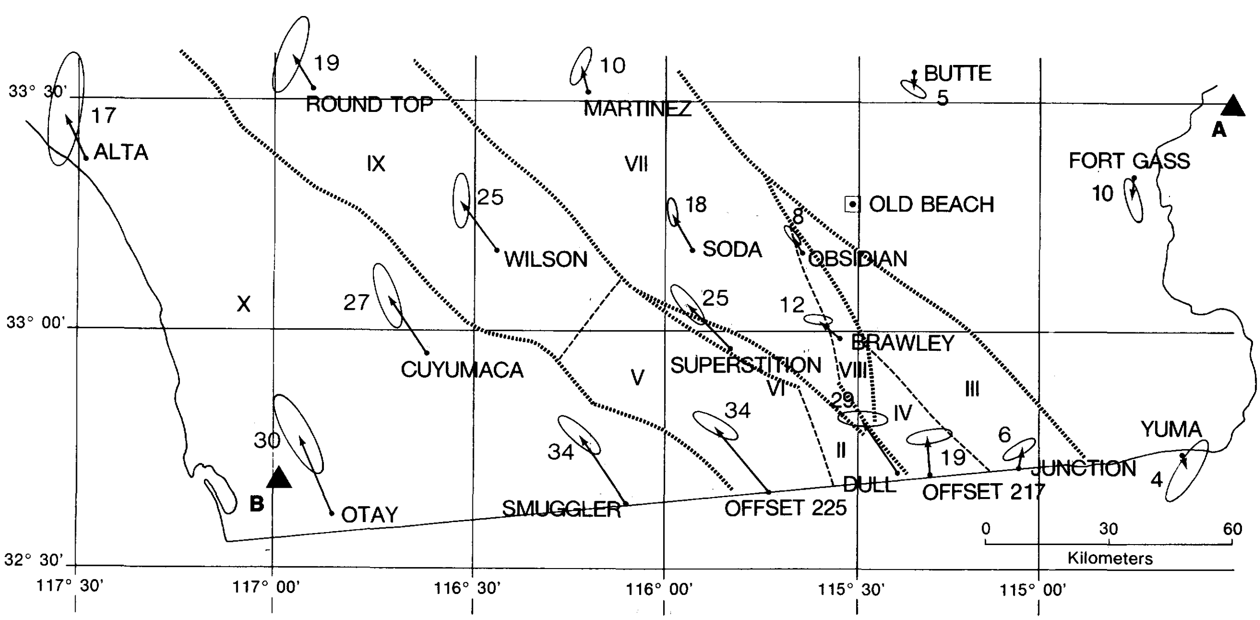
The creation of these two large data bases marks a very important step toward automating studies of crustal strain, coseismic deformation, subsidence, and broad tectonic processes that may relate to earthquakes or volcanism. The data ultimately will be managed so that investigators can connect to the data base remotely, to copy subsets of data for particular studies.

The availability of these data bases to the public will coincide with completion of the two large programs to readjust the National Networks of Geodetic Control. The Horizontal Network adjustment is scheduled for completion in 1985. The Vertical Network adjustment will be completed in 1988.

Regional Deformation of the Earth Models Project

NOS-NGS has undertaken a project to model historical horizontal crustal deformation in seismically active areas of the United States. Model parameters will be estimated from geodetic data observed during the past century. The models will support an international project to improve the position determinations for the monumented stations in the North American Datum, which serve as a reference system for mapping, cadastral, engineering, and scientific activities. The modeling effort also will further understanding of the Earth's crust by relating the historical motion to earthquakes, slip rates across geologic faults, and uniform distortion rates over large geographic areas.

Since 1807, NOS-NGS (then the USCGS), has determined the latitudes and longitudes of over 200,000 monumented stations that span the United States at spacings from about 30 feet to 60 miles. These monuments are "positioned" through a network of geodetic observations that includes angles, taped and electronically measured distances, and astronomically determined azimuths. Currently, geodetic observations for positioning also are obtained by techniques that employ artificial satellites and extragalactic radio sources known as quasars. Today, a 6-mile length can be measured to a precision of a few millimeters, and a transcontinental distance to within an inch or two. Instrument accuracies continue to be improved, and, as they are improved, the reference system must be improved as well.



Secular velocity vectors for selected geodetic stations in the San Diego region of southern California. The numbers designate the magnitudes of the velocity vectors in fractions of an inch per year. The hatched lines denote geologic faults, which help to subdivide the region into districts. The model permits each district to individually translate, rotate, and deform "homogeneously."

Given this need, NOS–NGS and the geodetic agencies of other countries of North America and Denmark initiated a joint recomputation project to determine the positions of all monuments in North America and Greenland. Such a recomputation was last accomplished in the United States in 1927. The present effort will be far more rigorous since advances in computer technology will now enable the use of more sophisticated mathematical techniques and of the more recent scientific theories of the Earth and its environment.

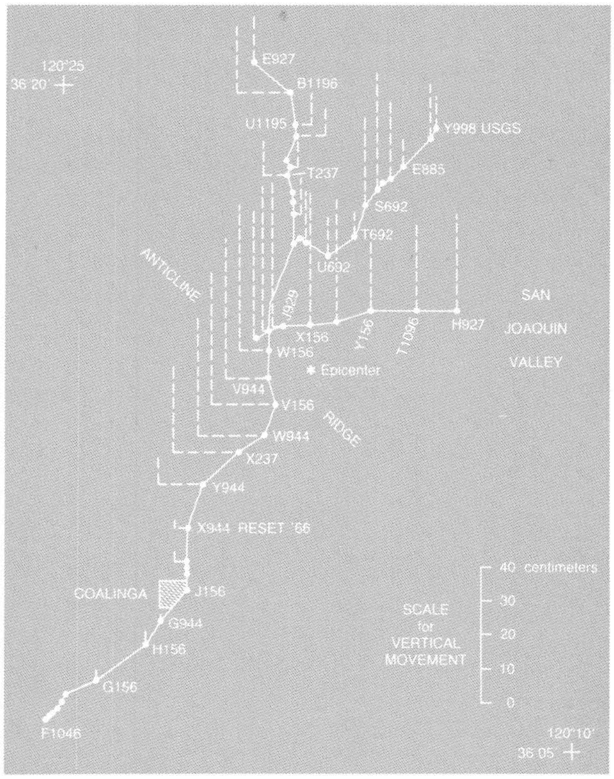
Contributing to the rigor of the new computations, mathematical models will describe the time variability of station coordinates caused by crustal motion. According to plate tectonic theory, the latitudes and longitudes of monumented stations continually change. The rates of these motions have been estimated from geologic and seismic data by using models that assume that the Earth's surface consists of several rigid plates, which rotate at a constant rate about a specific pole. Although these models are acceptable on a global scale for motions averaged over millions of years, significant regional deviations develop when the motions are considered over a time period of decades. The models based upon geodetic data must consider subdivisions of plates that deform with elastic and plastic characteristics. They also must consider both the secular and episodic natures of the motion.

The REDEAM (Regional Deformation of the Earth Models) project will model the horizontal deformation in various regions of the United States. As seismically active areas of the United States containing sufficient geodetic data to support the modeling effort are identified, the areas chosen to be modeled are partitioned into regions, and each region is modeled independently. For example, the State of California has been so identified and partitioned into 16 regions. Other candidates include Alaska, Hawaii, and Nevada.

Analysis of Leveling Data in the Coalinga Earthquake Area

On May 2, 1983, Coalinga, California, was shaken by an earthquake of magnitude 6.5. The earthquake, located west of the San Joaquin Valley beneath the Anticline Ridge, was one of the largest to occur in the area in the past 100 years.

Several epochs of geodetic leveling have been used in Coalinga and vicinity to estimate the changes in elevations caused by the earthquake. In 1960, 1966, 1969, 1972, and 1983 (after the earthquake), a network was leveled in the area where the earthquake struck. Normally, elevation differences obtained from geodetic leveling surveys observed both before and after an earthquake can be used to estimate the vertical crustal motion caused by the earthquake. However, in this instance, subsidence due to withdrawal of water and oil in the area complicates the analysis. Therefore, the 1972 elevations must be corrected for subsidence before computing the elevation changes caused by the earthquake. The final results of the study will vary depending on the method and data used to estimate the man-made subsidence.



Leveling route and computed changes in elevation caused by the 1983 Coalinga, California, earthquake.

The leveling network begins in the mountains (benchmark F 1064) about 6 miles southwest of the city of Coalinga, proceeds in a northeasterly direction passing through Coalinga, crosses the Anticline Ridge, and ends approximately 15 miles north of Coalinga. The preearthquake levelings were run to single-run second-order specifications. The 1983 leveling was performed using first-order, class II double-run specifications.

To estimate the rates of movement in the area, a minimum-constraint least-squares adjustment was performed for each epoch. Benchmark F 1046, a bedrock mark, was assumed to be stable and was chosen as the "datum" (fixed) point for all the adjustments. Prior to the earthquake, this assumption was reasonable. After the earthquake, even the bedrock bench marks may have moved. However, without evidence that F 1046 moved during the earthquake, it was assumed to be stable in order to facilitate the movement computations. The resulting adjusted elevations were used to determine the rates of movement from 1960 to 1966, 1966 to 1969, 1969 to 1972, and 1966 to 1972. The subsidence rates varied considerably from bench mark to bench mark and slowed in the later time intervals.

Stein used elevation changes to estimate fault attitude, geometry, and slip. The earthquake elevation changes were modeled with dislocations embedded in an elastic half-space. He used the 1966 to 1972 rate, deep-well compaction monitors, and fluid pumping records to account for the manmade crustal motion. Because of the regional variation in subsidence rates, as well as the changes in rates, the latest rate, 1969 to 1972, was used in this NGS study.

As expected, the largest changes occurred in the Anticline Ridge area (benchmark V 237 Reset 1956). It appears that in some areas the Coalinga earthquake caused the surface to rise slightly more than 1.5 feet. This study and Stein's do not exactly agree because of the different assumptions discussed earlier. In particular, benchmark H 927 appears to have changed in elevation significantly more in this study than Stein's. However, the final results in the mainshock area are very similar; that is, the changes in elevation on the Anticline Ridge are about 1.4 feet and the major shift occurs between benchmarks Y 944 and X 237.

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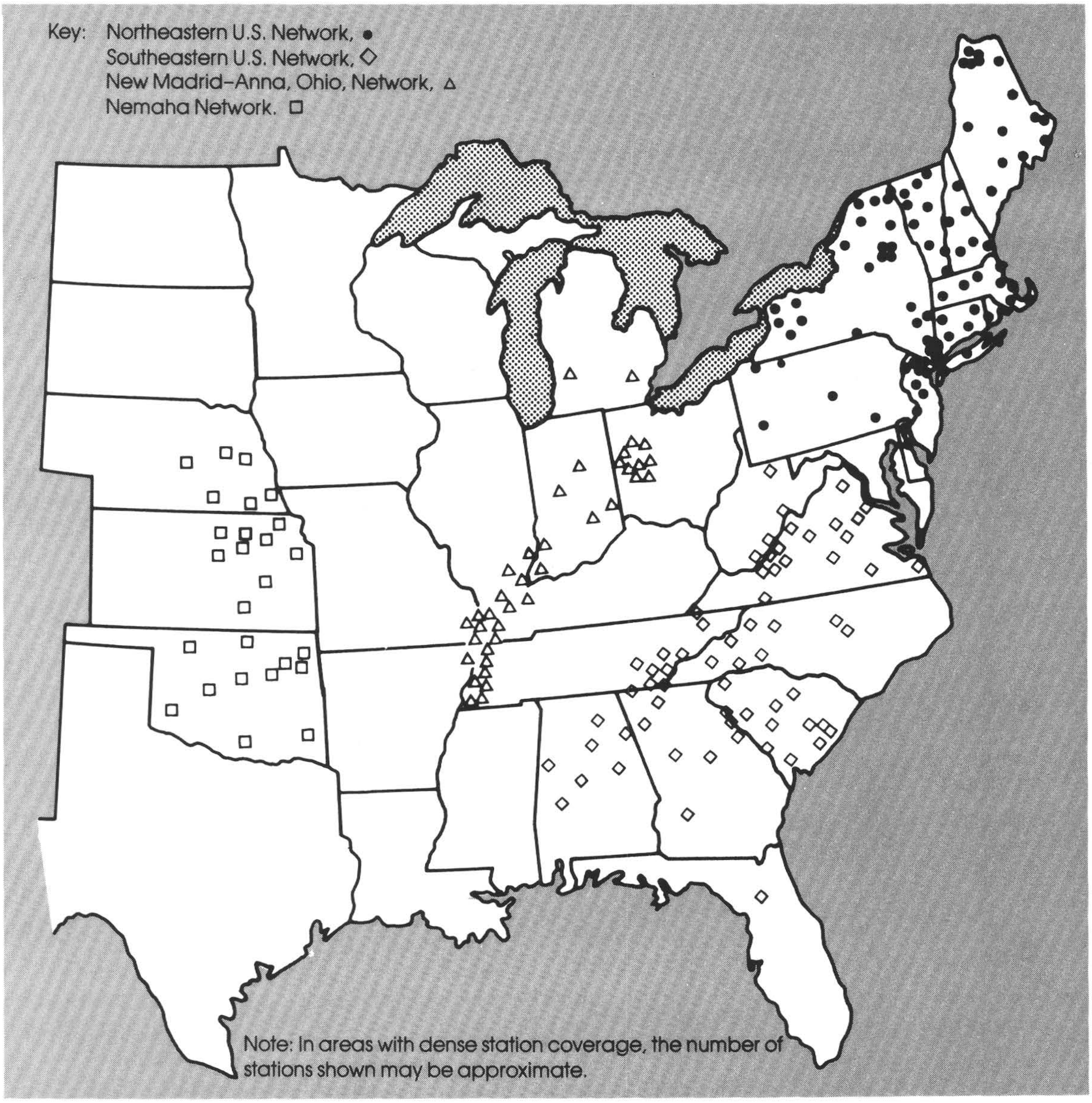
Nuclear Regulatory Commission

In carrying out its responsibilities for ensuring public health and safety in regard to potential hazards associated with nuclear power plants and waste disposal facilities, the NRC has a critical interest in the delineation, assessment, and mitigation of earthquake hazards in the United States as they pertain to nuclear power plant and waste disposal facility siting, design, and construction and in the development and coordination of preparedness plans for these critical facilities and the communities in which they are located. NRC's active programs in these areas contribute to the research, mitigation, and preparedness efforts of the NEHRP.

SEISMIC STUDIES

Because most of the Nation's nuclear power plants are located east of the Rocky Mountains, NRC support of earthquake hazard delineation focuses primarily on the central and eastern



Regional earthquake monitoring networks in the Eastern and Central United States currently supported by the Nuclear Regulatory Commission.

regions of the United States. Seismicity investigations supported by the NRC program contribute to the NEHRP in (1) the definition of seismicity with respect to location, recurrence, spectral characteristics, and other factors, (2) the quantification of seismic hazards and reduction of uncertainty in hazard assessment, and (3) the definition of the relationships of seismicity and crustal structure and tectonics. In contrast to the situation in most of the Western United States, seismicity in the eastern part of the country tends to be more diffuse because the earthquakes are not clearly associated with strike-slip faults and distinctive surface features and because recurrence rates are much lower, increasing the degree of uncertainty in assessing the risk.

NRC supports five regional seismic networks throughout the United States: the Northeastern U.S. Seismographic Network, composed of six local networks with about 130 stations, the Southeastern U.S. Seismographic Network, composed of four local networks with about 65 stations, the New Madrid–Anna, Ohio, Seismographic Network, composed of three local networks with about 65 stations, the Nemaha Ridge Seismographic Network, composed of two local networks with about 25 stations, and the Northern Oregon Seismographic Network, consisting of a single local network with about 10 stations. These networks define patterns of seismicity, delineate seismic source zones, characterize source parameters, and provide basic data for comparison with other geological/geophysical information.

The Northeastern United States has considerable earthquake activity, the most recent event is a magnitude 4.7 earthquake in New Hampshire in January 1982, with magnitude 5.7 and 5.9 earthquakes in neighboring New Brunswick, Canada, during the same period. The region has a complicated tectonic structure and needs more study to resolve questions of earthquake hazards.

The Southeastern U.S. region includes Charleston, South Carolina, which in 1886 was the location of the second largest earthquake in the Eastern United States. Recent data suggest that the source mechanism responsible for that earthquake may not be unique to the Charleston area and have led the USGS to speculate that similar earthquakes could occur in other areas along the eastern seaboard.

The earthquake sequence along the New Madrid structure in 1811–1812 included the most severe shocks generated east of the Rocky Mountains. In addition, because the attenuation of seismic waves is lower in the Eastern United States than in the West, the total area affected by these earthquakes was much larger than that associated with any other earthquake in this country. Given that fact and the population density in that region today, it becomes obvious that a recurrence of such an event would cause numerous deaths and extensive damage. The mechanism of the New Madrid earthquake, which is associated with a buried rift system, is now better understood than the mechanisms of other eastern seismic hazards. A possible connection of this rift with the Anna, Ohio, area has been considered; however, the evidence obtained thus far does not strongly support such a connection.

The Nemaha uplift, which forms a southern extension of the midcontinent geophysical anomaly, is associated with moderate earthquake activity. Except for a few seismically active fault zones associated with the uplift, the relationship between the uplift and the seismicity is unclear. However, seismic activity is present along the entire length of the Nemaha uplift.

The Northern Oregon network, and its extension in eastern Washington supported by the DOE, is located in a region that has generally moderate earthquake activity but in the past has experienced earthquakes as large as magnitude 6.4. The surface geology in this area is dominated by the Columbia River Basalt Group, which obscures deeper structural configurations. A number of hypotheses on the tectonics of the area have been advanced; however, a satisfactory tectonic model has not been developed yet.

These seismic networks form the backbone of the regional investigations conducted by the NRC. Therefore, these networks will continue to be used and, where possible, upgraded. Upgrading will include changing from analog to digital recording and improved or more cost-effective means of data transmission, such as the use of microwave transmission.

A number of significant seismological problems, including hypocentral depth determinations, are not readily solvable with the current narrowband, limited dynamic-range seismographs. Accurate hypocentral depths are required for correlation of seismicity with geologic structures and for earthquake modeling codes that generate synthetic seismograms and calculate spectra and attenuation. Upgrading existing stations to get better depth information is more economical and productive than simply adding more stations.

STRONG-MOTION SEISMOGRAPHS

NRC has initiated a 2-year program to upgrade the seismic networks in the Eastern United States by adding strong-motion seismographs to gain more information on the ground motion produced by larger earthquakes. Instruments already in the field have provided more than 15 strong-motion records from the earthquakes in New Hampshire, New Brunswick, and Arkansas.

NRC also is supporting several programs to analyze and disseminate information obtained from strong-motion accelerograms in the Eastern United States. As part of an NRC-USGS Interagency Agreement, NRC is funding detailed analysis of the New Brunswick and Arkansas data sets along with some field work in New Brunswick in cooperation with Canada. This work will provide more precise data on the crustal structure at the New Brunswick site, which will help to explain the reason for the apparently high accelerations for small earthquakes. In another cooperative program with Canada, NRC is providing support for strong-motion instrumentation in eastern Canada.

GEOLOGICAL/GEOPHYSICAL INVESTIGATIONS

NRC also supports investigations to clarify the relationship between earthquake epicenters, recorded historically and by regional networks, and crustal structure and tectonics. Included in these investigations are both regional studies of geology, tectonics, and crustal stress and topical studies of source parameters, propagation and attentuation characteristics, and site response characteristics. All these factors contribute to an understanding of the seismic hazards that the Nation faces. Although NRC's interest in investigating these hazards focuses on the licensing of nuclear power plants and other nuclear facilities, the investigations also provide information used by others in both the public and private sector in carrying out their various responsibilities.

One of the important benefits of the geological and geophysical investigations is that they can augment the relatively short history of seismic activity on this continent, particularly on the east coast, where recurrence intervals are long. These studies permit delineation of seismic source zones, continuation of crustal structure models, and comparison of focal mechanisms with stress directions measured in situ.

Northeastern Region

Several structures that may be related to seismogenic mechanisms are present in this region. However, the relationship between structure and seismicity and the regional stress distribution are less clear in this area than in some other parts of the Eastern United States.

Some of the coastal parts of Maine, in the vicinity of Passamaquoddy Bay, are subsiding at rates as high as 0.4 inch per year. The subsidence, which is associated with seismic activity, is being investigated in cooperation with the State of Maine. An important aspect of this work is that the subsidence occurs along the Bay of Fundy, which is a Triassic basin—an aspect of importance to other parts of the northeast such as the Ramapo fault area.

A project to measure in situ stress by shallow overcoring in parts of New York and southern New England is contributing to the knowledge of in situ stress directions in that region.

Since the Ramapo fault is a critical structure, it has been targeted for detailed studies in the future. In situ stress measurements by hydrofracturing and multichannel seismic reflection surveys will be conducted to better determine the fault zone configuration. Results from this work will make the relationship between the structure and seismicity clearer. Similar in situ stress measurements will be conducted at the Moodus, Connecticut, seismic zone.

Other critical structures to be investigated for evidence of recent movements may include a Triassic basin, the epicentral areas of earthquakes at Gaza and on Long Island, and the Adirondack uplift. Paleoliquefaction studies, which were successful at New Madrid and Charleston, also may be conducted. Cooperative investigations with the State of Maine into the causes of subsidence along the Maine coast will continue.

Southeastern Region

The Charleston earthquake of 1886 dominates the seismic history of the Southeastern United States, but seismic activity of lower magnitudes has occurred in other parts of the region. The primary issue in the Charleston area is the determination of the causative mechanism of the historic Charleston earthquake. The cause of that earthquake has not been determined with certainty. Numerous hypotheses have been proposed, most of which involve reactivation of older faults. NRC is providing funding support to the USGS, which is conducting most of the investigations in the area.

Two other areas of significant seismic activity in the Southeastern United States are the central Virginia and Giles County seismic zones. Preliminary data from the central Virginia seismic zone show a promising correlation of earthquake hypocentral location and structure defined by seismic reflection profiling. The earthquake hypocenters were found to correlate with an east-southeast-dipping listric fault, which appears to be connected to the decollement of the eastern Appalachians.

The hypocenters in the Giles County seismic zone are below the decollement. Consequently, the observable structure at the decollement surface or in the first mile or two below it are not expected to give information useful in interpreting the seismicity there. Available hypocentral locations have delineated a proposed normal fault as the source zone of the seismicity.

Because, for some time to come, the primary issue in this region will continue to be the determination of the causative mechanism or structure of the 1886 Charleston earthquake, NRC will continue to provide funding for the cooperative effort with USGS in this region. Also, NRC plans to participate in a cooperative effort, funded by the State, the Federal Government, and the oil industry, to investigate the Giles County, Virginia, seismic zone by means of Vibroseis reflection profiling. A deeply buried normal fault, reactivated by modern stresses, has been proposed as the source structure on the basis of the alinement of seismicity. Further Vibroseis profiling is planned for the central Virginia seismic zone because of the promising correlation shown in the preliminary studies. Supportive studies in fiscal year 1984 may include in situ stress measurements and neotectonic studies of young deposits to find evidence of recent movement.

New Madrid-Anna, Ohio, Region

The New Madrid region is the best understood earthquake zone east of the Rocky Mountains. A zone of seismicity follows the trend of a buried rift zone (the Reelfoot rift) that underlies the axis of the south-central Mississippi Valley. The zone of the severe mainshock sequence of 1811–12 is centered at an offset in the rift that is also associated with an uplift. The proposed seismogenic mechanism is a reactivation of the Reelfoot rift into a strike-slip fault zone, which would be consistent with the geologic structure and with fault plane solutions and stress measurements.

Geophysical studies, including seismic reflection profiles, have shown that faults related to the rift extend into the Wabash Valley between Illinois and Indiana. However, a further extension into the Anna, Ohio, seismic area does not seem to be plausible.

Geological and geophysical examination of the proposed northeasterly extension of the Reelfoot rift zone will continue.

Nemaha Uplift

Geologic and geophysical studies along the Nemaha uplift have shown that the uplift may represent a rift zone that is accompanied by clastic-filled basins on the east side, separated from the rift zone by a series of faults. One such fault that is associated with seismicity is the Humboldt fracture zone in eastern Nebraska and Kansas. The Thurman–Redfield and Northern Boundary fault zones in Iowa also are seismically active at present, and they have been intermittently active since Paleozoic time. Although the relationship between the uplift and the seismicity is unclear, seismic activity is present all along the Nemaha uplift, particularly at locations where northwest trending geologic structures or geophysical anomalies cross the Nemaha uplift.

Northern Oregon-Eastern Washington

The largest part of recent geological and geophysical activity in this area has been oriented toward clarifying the structure and seismicity of the Hanford reservation, in view of the proposed locations of a nuclear waste repository and of the Skagit nuclear plant. This work is being done by DOE or by the Washington Public Power Supply System consortium.

TOPICAL PROGRAMS

Source Parameters

The proper characterization of source parameters is important for an understanding of eastern earthquakes. Parameters being studied include source spectra, dynamic and static stress drop, duration, corner frequency, focal mechanism, moment, and magnitude. Variations of the parameters with size and location of earthquakes also are being investigated. The stress drop, focal mechanism, and source spectra provide significant constraints on the source models and the state of stress within active tectonic and geologic features.

The recent (1982) New Brunswick, New Hampshire, and Arkansas earthquakes appear to have a strong high-frequency component in their source spectra. This high-frequency component could have significant impact on the type of plant component which would be susceptible to damage from a small nearby earthquake and could change the importance of documenting the "Tau" effect and its possible frequency dependence.

Propagation and Attentuation Characteristics

Several aspects of the propagation of seismic energy are problematic, including the variation of the attenuation function with distance and the dependence of Q, the attenuation factor, on frequency and direction of motion. Promising work on attenuation has been supported in part by the NRC; however, additional efforts, particularly an investigation of the frequency dependence of Q, are needed. A certain amount of information on the regional variation of Q between 0.5 and 3.5 Hertz has been obtained. Information on the behavior of Q at higher frequencies will be needed in the future.

The NRC plans to continue its studies of propagation and attenuation characteristics on the basis of regional network data. Site response characteristics will be studied in an effort to deal with the problem of ground response in the case of an earthquake greater than the "safe shutdown earthquake." Also, soil settlement and liquefaction may be the subject of future studies, which could include the use of underground nuclear explosions to validate computer codes modeling these phenomena.

Site Response Characteristics

Work currently is underway to evaluate techniques for calculating site response spectra and to develop guidelines in determining response spectra and site response. Site soil response includes the problems of soil settlement and liquefaction, for which there are numerous predictive models but little verification. Soil liquefaction may become a serious issue for nuclear power plants if earthquakes larger than the "safe shutdown earthquake" must be considered. NRC-sponsored research includes work in these areas.

DESIGN APPLICATION

Systematic Evaluation Program

The Systematic Evaluation Program provides ongoing assessment of the adequacy of design (including seismic) and operation of older operating reactors, compares the designs with current safety criteria, and gives a basis for integrated and balanced decisions on backfitting equipment. As a result of this program, the seismic resistance of several reactors was upgraded, including anchoring of safety-related electrical and mechanical equipment and systems.

Probabilistic Risk Assessment

Comprehensive probabilistic risk assessments (PRA's) are being performed for selected nuclear powerplants. Those PRA's reviewed by the NRC that included earthquake-induced sequences have shown these sequences to be important contributors to total plant risk. In some cases these assessments are helping to highlight weak links, the correction of which has significantly reduced risk.

Eastern Seaboard Seismicity

As a result of the USGS clarification in November 1982 relating to the 1886 earthquake in Charleston, South Carolina, the NRC has initiated a series of programs to address eastern seismicity.

NRC has developed a geoscience plan to address eastern seaboard seismicity. The plan is divided into two parts: the seismic hazard characterization of the Eastern United States and a longer term deterministic assessment of the causes of large earthquakes, such as the Charleston earthquake, along the eastern seaboard.

The objective of the first part is the continued development of a probabilistic seismic hazard characterization methodology by the LLNL for the entire region of the United States east of the Rocky Mountains. This methodology is heavily dependent on the use of expert panels. The members of the seismicity panel will give their input regarding seismotectonic zonation, rate of earthquake occurrence, distribution of earthquake magnitudes, and the largest earthquake with its associated uncertainty. The members of the ground-motion panel will identify the most appropriate ground-motion models, including uncertainty. LLNL will integrate the input and produce uniform hazard spectra (response spectra with a certain probability) for different probabilities of exceedance. These will be compared to nuclear powerplant design levels.

In the second part of the plan, specific areas of relatively higher seismicity along the eastern seaboard will be studied deterministically to determine whether tectonic features and processes reponsible for the seismicity can be identified and correlated. This will be accomplished by crustal studies at hypocentral depths to determine whether there is any correlation between crustal structures at hypocentral depths and earthquake hypocenters.

Also, partially in response to an NRC staff recommendation, the nuclear power industry, through the Electric Power Research Institute (EPRI), has initiated an earthquake hazards research program with the objective of reducing the uncertainty in specifying design ground motion for nuclear powerplants. Research will be directed toward specifying both the likelihood of occurrence of earthquakes and the resulting ground motion, given that an earthquake has occurred.

The magnitude 5.8 New Brunswick earthquake of January 1982 was greater than the historical maximum for parts of the New England region. Several nuclear powerplant operators in this region have been asked to evaluate the effect of this earthquake on their design-base earthquakes. NRC also is funding USGS research into the New Brunswick earthquake.

With NRC financial support, the USGS will produce a series of maps estimating earthquake ground motion with probabilities of exceedance of 10^{-4} per year. The series of maps, which will reflect the consequences of assuming a particular seismotectonic model and mode of faulting, will be used to determine what effect different tectonic models have on a probabilistically determined earthquake hazard.

Other Programs

Other NRC programs are concerned with seismic design problems at particular nuclear powerplants. For example, in the Pacific Northwest there is some concern that the Juan de Fuca plate may be actively subducting under the North American plate and that large thrust-type earthquakes may be possible, although none exist in historical records. The USGS has been studying this problem while reviewing the WNP–3 site in Satsop, Washington. The Diablo nuclear powerplant in California is undergoing a reverification of its seismic design adequacy because of the discovery of design errors.

Seismic Design Criteria, Task Action Plan A–40, comprised short-term efforts to reevaluate the seismic design of operating reactors and to review seismic provisions of license applications. As a result, changes are being made to the Standard Review Plan to increase emphasis on seismotectonics and active tectonics instead of tectonic provinces and pre-Quaternary geology.

SOIL CONSERVATION SERVICE

U.S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

The SCS assists land users and owners in the conservation, protection, and enhancement of soil, water, and related resources. SCS has a broad range of programs that use dams as a part of conservation systems. Some of the functions provided by dams are flood protection, sediment control, fish and wildlife habitat, water supply (for livestock, irrigation, municipal uses, and improvement of water quality), and recreation.

SCS is directly involved in the planning, design, and construction of dams. SCS has provided assistance in the construction of about two million water-control practices that involve dams. The vast majority of these are "ponds" that usually require only very small dams. Others may require complex, high dams. More than 37,000 irrigation, 9,000 flood-retarding, and 4,000 multipurpose reservoirs have been constructed as a result of SCS assistance. As a part of the dam inventory made by the U.S. Committee on Large Dams in 1972, SCS reported more than 640 dams that were over 45 feet high. The highest dam designed and constructed to date is 150 feet. Dams as high as 200 feet are included in plans prepared with SCS assistance.

SCS usually describes a dam as a "project dam" or a "nonproject dam." The project dams include those dams installed by SCS cost-sharing programs under the Watershed Protection and Flood Prevention Act or some Resource Conservation and Development authorities. Nonproject dams include primarily those constructed through technical assistance programs under the Soil Conservation Act of 1935. Although project dams are usually larger than nonproject dams, it must be recognized that some nonproject dams may be large and that some project dams may be small. It is the size, importance, and potential for hazard that must be considered and not whether the dam is a project or nonproject dam.

SCS does not own any dams. However, SCS does provide technical and financial assistance to owners and project sponsors. As a nonowner, SCS has only a limited role in operation and maintenance (O&M) activities. If a landowner is provided assistance on a nonproject dam, the SCS role may end when construction is completed. In projects, SCS has O&M agreements with the sponsors that require inspections for the duration of the agreement, usually the economically evaluated project life.

PLAN FOR SAFETY OF DAMS

The SCS Plan for Safety of Dams contains 30 action items that SCS will take within its present authorities. The actions are in response to issues related to dam safety that have surfaced from various sources. These actions are grouped into nine categories:

- Responsibility,
- Inventory,
- Public information,
- Classification,
- Design and construction,
- Geotechnical engineering,
- Operation and maintenance,
- Management, and
- Personnel.

The discussion of the action items indicates the line officer or staff leader who is to take the initial action. Each action will have additional effects throughout SCS in regard to dams.

The action items are generally presented in a conceptual form. Final solutions and details are left to the responsible line officer or implementing division.

Relationships of issues and action items

ACTION ITEMS	Primary Responsibility for Initial Action[1]	GENERAL ISSUES I–1 Importance	I–2 Responsibility	I–3 Classification	I–4 Organization and Staffing	I–5 Inventory	I–6 Operation and Maintenance	I–7 Regulatory Control	SPECIFIC ISSUES II–1 Independent Review	II–2 Risk-Based Analysis	II–3 Personnel	II–4 Inspection	II–5 Quality Control	II–6 Construction Orientation	II–7 Research and Testing	II–8 New Field Data	II–9 Instrumentation	II–10 New Technology	II–11 Sabatoge	II–12 Control of O & M	II–13 Regulatory Authority	II–14 Nontechnical Community	II–15 Emergency Preparedness Plan	II–16 Seismic Forces	II–17 Cost-Saving Incentives	II–18 Geotechnical
RESPONSIBILITY:																										
1–Revise Memo of Understanding	ADM STC		x				x																			
2–Provide States With Assist.	ADM		x			x	x	x				x								x		x	x			
3–Work With Others to Assist. States	ADM STC		x				x	x				x								x						
INVENTORY:																										
4–Inventory Dams	ADM					x						x														
5–Retention of Records	ADM					x						x		x												
INFORMING THE PUBLIC:																										
6–Revise EIS Requirements	ADM	x		x																		x				
7–Public Info Policy	ADM	x		x																		x				
CLASSIFICATION:																										
8–Who Classifies	ADM			x					x																	
9–Documentation	ADM			x																						
10–Guidelines	ENG			x																						
11–Breach Routing	ENG			x																			x			
12–Em. Preparedness Policy	ADM		x	x				x									x					x	x			
DESIGN AND CONSTRUCTION:																										
13–Independent Review	ADM								x																	
14–Coordination	ADM										x			x		x	x									
15–Design Reports	ADM								x					x		x	x									
16–Instrumentation	ADM						x								x		x									
17–Construction Inspection	ADM											x	x	x		x	x									
GEOTECHNICAL ENGINEERING:																										
18–State Leadership	STC				x				x						x			x						x		x
19–Qualified Specialists	ADM														x									x		x
20–NEH Material	ADM																	x						x		x
OPERATION AND MAINTENANCE:																										
21–OSM Plan	ADM		x				x					x								x						
22–Inform Owner	STC	x	x				x													x		x				
23–Safety Inspection	ADM	x	x	x			x	x				x								x						
MANAGEMENT:																										
24–Analyze Capabilities	ADM	x			x						x															
25–Guidelines Workload Anal.	ENG				x						x															
PERSONNEL:																										
26–SCE Responsible	ADM				x						x							x								
27–Professionalism	STC				x						x							x								x
28–Employee Certification	ENG				x						x							x								
29–Guides and Training	ENG				x						x															
30–Changes in Approval	TSC										x															

[1] Key: ADM- Administrator, SCS
STC- State Conservationists
ENG- Director, Engineering Division
TSC- Head, Engineering Staff, TSC

TENNESSEE VALLEY AUTHORITY

The TVA maintains an ongoing program for earthquake hazards evaluation of its power-producing and flood control hydro facilities. In addition, through agency initiative, TVA has taken strong, positive action to define seismicity within its entire region of power distribution. Studies intended to define the relative frequency, characteristics, basic causes, and mechanisms of regional earthquakes are being performed by TVA and through cooperative funding to educational institutions.

INTERAGENCY COOPERATION

TVA readily exchanges seismologic data with the Corps of Engineers, BuRec, USGS, and DOE and is represented at the Interagency Research Coordinating Conference, which reviews research projects in seismicity, earthquake engineering, and soil or rock engineering. TVA also participates on the ICSSC and on the Utility Systems Committee of the Kentucky Task Force on Earthquake Hazards Safety.

In other cooperative activities, TVA has an agreement with DOE to serve as seismological consultant on the Clinch River Breeder Reactor Project (CRBRP), with responsibility to keep DOE abreast of significant seismological issues within the region that may affect the CRBRP. Late in fiscal year 1983, TVA reached an agreement with DOE to assume operation of a seismic recording station at the Oak Ridge National Laboratory. This station, which had been in operation since the late 1960's, was scheduled for closure as a result of funding considerations.

STUDIES RELATING TO MAJOR FACILITIES

Although seismic design activities relating to TVA nuclear plants and hydro projects meet the objectives of the Earthquake Hazards Reduction Act of 1977, they are not being performed as a result of the Act.

Fiscal year 1984 will begin the third year of a 7-year program to evaluate 19 of the TVA hydro projects that were identified for in-depth study to determine compliance with the Federal Guidelines for Dam Safety. Six of the dams are being evaluated for earthquake loading conditions. Liquefaction potential of the foundation and embankment material is one concern, and structural stability is the other. In addition to design studies and possible modifications to the dams, emergency reaction plans also are being developed.

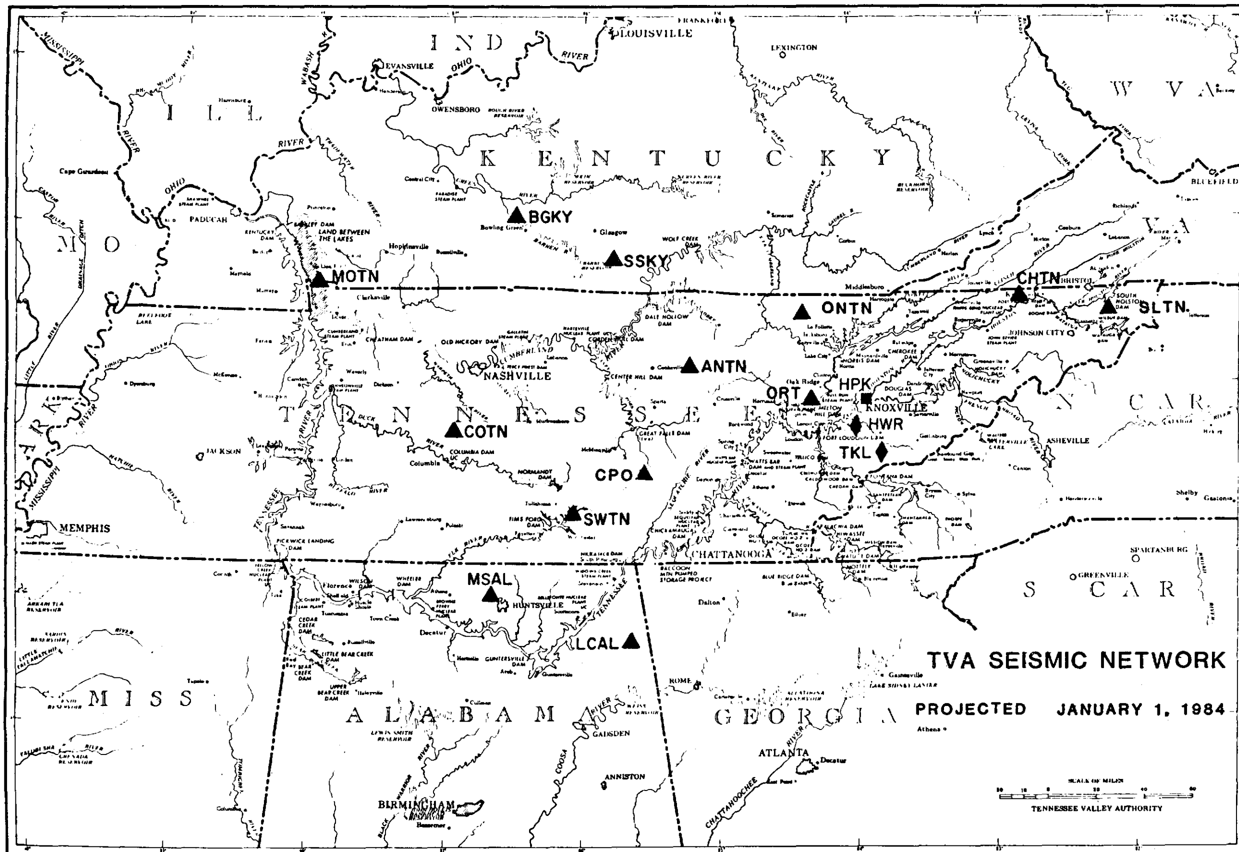
Nuclear plant seismic design is based on criteria developed by TVA and NRC. The NRC also reviews and approves the application of the criteria. Specific TVA activities relating to seismicity are

- Strong-motion instrumentation located at each of the nuclear plants;
- Performance of probable risk analysis studies at the nuclear plants to define the seismic margins;
- Compilation of a catalog listing historical earthquakes in the Tennessee Valley region;
- Initiation of a regional seismic monitoring program;
- Participation in the EPRI study for the Eastern United States to develop a catalog of historical earthquakes, tectonic framework, tectonic provinces, tectonic structure, attenuation models, and analytical techniques for performing seismic hazard studies; and
- Development of emergency earthquake reaction plans for nuclear plants.

Studies evaluating the potential effects of earthquakes on the TVA power transmission system and other facilities also have been started. Particular emphasis is being placed on facilities in the western portion of the TVA region.

SEISMIC MONITORING PROGRAM

The TVA Seismic Monitoring Program is a $2 million internal effort. It was initiated in fiscal year 1982 and will extend through fiscal year 1986, with the goal of defining the relative frequency, characteristics, basic causes, and mechanisms of regional earthquakes.



LEGEND:

▲ANTN – Stations operated by TVA
⧫ TKL – Stations operated jointly by TVA and Memphis State University
■ HPK – Station operated jointly by TVA and Georgia Institute of Technology

Tennessee Valley Authority seismic network.

Seismic studies in the Southeastern States always have been segmented and isolated. In the late 1970's, it became apparent that regional differences in the nature and magnitude of seismic activity and the perception of seismic risk might affect TVA facilities. To realistically evaluate seismic risk within the TVA power region, the Seismic Monitoring Program was initiated. Subsequently, seismometers have been positioned in a broad regional network to include geographic areas of Tennessee and some surrounding States in which instruments had never been placed. Instrumentation also is maintained in the more active zones of the region.

While starting its own program, TVA also is working to increase cooperation among southeastern seismologists through graduate study grants to Virginia Polytechnic Institute and State University, Georgia Institute of Technology, the University of Kentucky, and the Tennessee Earthquake Information Center (a department of Memphis State University). Through this cooperative approach, TVA will integrate its data with the localized activities of institutions and private corporations for expanded regional evaluation. Information from these sources should lead to a better understanding of the causes for earthquakes within the region and may lead to better levels of determining probable locations where earthquakes may occur.

Veterans Administration

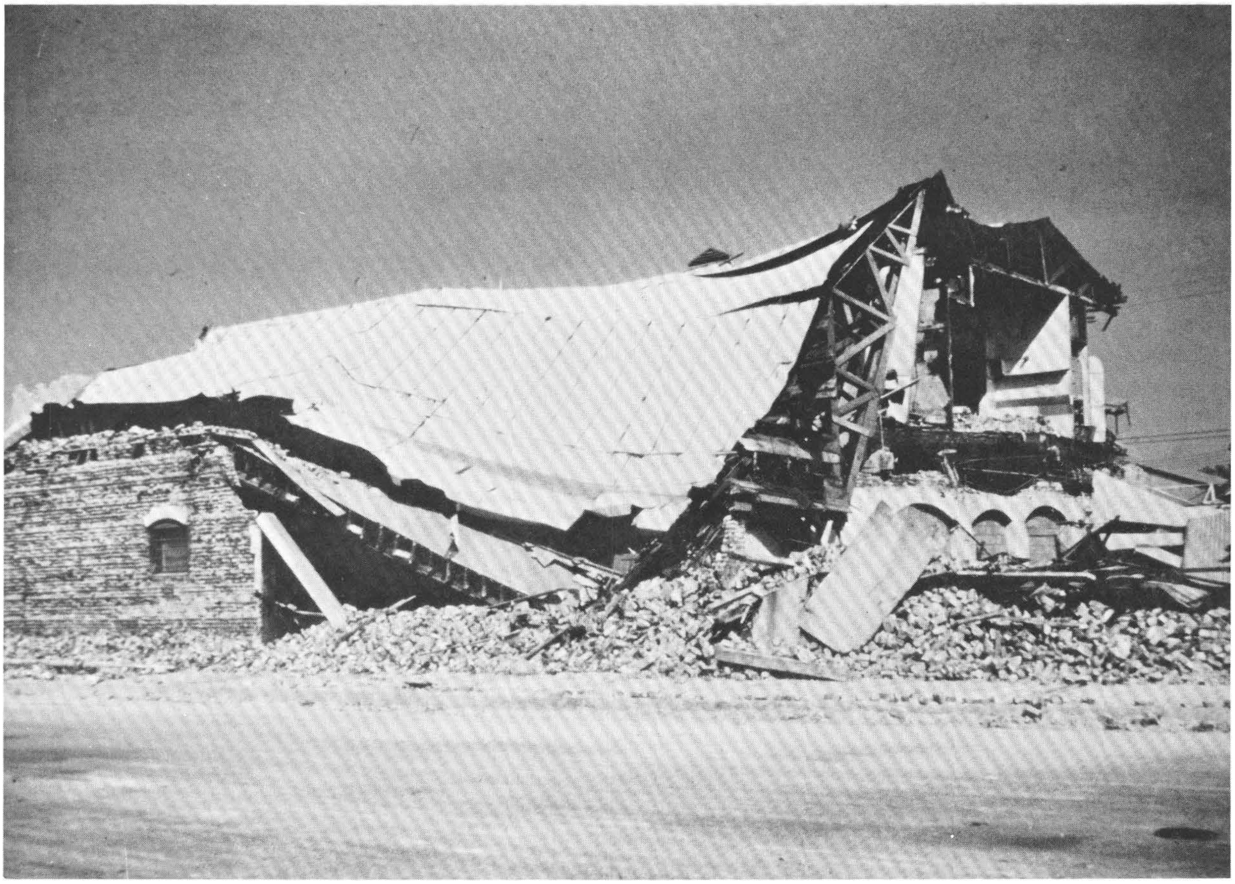
The VA seismic mitigation program, which was initiated following the collapse of the VA hospital at Sylmar during the San Fernando earthquake of 1971, is correcting deficiencies in VA facilities in order to

- Safeguard patients, staff, and visitors at of several hundred medical centers, clinics, nursing homes, regional offices, supply depots, or data processing centers;
- Protect property and other resources;
- Assure continuity of operations or restoration of services; and
- Assist the community and the Nation.

During fiscal year 1983, the VA continued to make significant progress toward meeting these goals and ensuring that critical Federal facilities will be able to withstand a major earthquake. Occupancy at some buildings has been changed to lessen the risk to patients and operating personnel; alterations—in some cases, major alterations—have been made to strengthen deficient structures; and some buildings have been demolished. Included in the VA seismic strengthening program are projects at the VA Medical Center (VAMC), Charleston, South Carolina, and VAMC, Fresno, California, which are nearing completion, and projects in conjunction with renovation projects at West Roxbury, Massachusetts, Memphis, Tennessee, and St. Louis, Missouri.

The VA's ongoing program also has purchased and funded the maintenance of 66 strong-motion instruments at 56 sites throughout the country. The data obtained from these instruments, which are installed by the USGS and NOAA, are analyzed by the USGS and made available to all researchers.

Other earthquake hazard mitigation efforts include programs to (1) anchor mechanical and electrical equipment so it will not be dislodged and disrupted during an earthquake, (2) install an emergency radio network to facilitate direct communication between any VA facility in California and any other VA facility in the United States, (3) provide for emergency utility services (especially water and electrical power), (4) design special earthquake-resistant features for equipment, furniture, and supplies to ensure that VA Medical Centers can function in the postearthquake period, and (5) conduct earthquake drills.



Earthquake damage in Coalinga, California.

Interagency Committee on Seismic Safety in Construction

In 1978, the ICSSC was established as part of the NEHRP to assist Federal departments and agencies involved in construction to develop earthquake hazard reduction measures for incorporation in their ongoing programs.

In meeting its responsibilities, the ICSSC cooperates with State and local governments and private organizations in developing nationally applicable earthquake hazard reduction measures. It is represented on the Board of the BSSC by the VA and has a representative on each technical committee.

Using consensus procedures, the ICSSC recommends earthquake hazard reduction practices suitable for use by Federal agencies. Each Federal agency may adopt these recommendations as required practices through the use of established Federal procedures for implementing regulations.

All Federal departments and independent agencies that are involved in construction are invited to participate in the ICSSC. Each participating department or independent agency is represented by a senior person. Additional Federal agency personnel serve on technical subcommmittees. Persons from the private sector may be invited to participate in ICSSC activities as observers. The ICSSC is chaired by the NBS.

The technical program of the ICSSC is conducted by four subcommittees:

- ***Subcommittee 1: Standards for New and Existing Buildings***
  National Bureau of Standards, Chair

Subcommittee 1 recommends seismic design and construction standards for new and existing Federal buildings, their appurtenances, and nonstructural components, and develops strategies and techniques for the identification and correction of existing seismically hazardous buildings.

- ***Subcommittee 2: Lifelines***
  Federal Highway Administration, Chair

Subcommittee 2 identifies existing guidelines or standards for seismic design, construction, and retrofit of energy, transportation, water, and telecommunication systems; recommends Federal adoption of such standards when found adequate; encourages development of new standards where there are significant omissions; and studies techniques for evaluating the seismic vulnerability of existing lifelines and for improving their resistance to seismic effects and their ease of repair. In addition, the subcommittee considers strategies by which to identify those lifeline facilities important in the emergency, immediate recovery, and long-term economic recovery periods and provides guidance for appropriate levels of seismic protection for each type.

- ***Subcommittee 3: Evaluation of Site Hazards***
  U.S. Geological Survey, Chair

Subcommittee 3 establishes guidelines, procedures, and criteria for site selection and the evaluation of seismic risk and seismically induced geologic hazards to Federally funded, assisted, and regulated construction sites. Hazards that are considered include seismicity, ground shaking, surface faulting and other tectonic deformation, liquefaction, landslides, and tsunamis.

- ***Subcommittee 4: Seismic Practices for Federal Domestic Assistance, Leasing, and Regulatory Programs***
  Department of Housing and Urban Development, Chair

Subcommittee 4 develops strategies for implementation of appropriate standards for earthquake-resistant design and construction of structures and facilities involving Federal domestic assistance (aid, grant, loan, mortgage insurance), leasing, and regulatory programs. The subcommittee deals primarily with policy matters related to application of mandatory standards or guidelines for Federal domestic assistance and leasing and regulatory programs, with consideration of State and local codes. Recommendations are formulated for the implementation of mandatory standards and guidelines and for required regulatory procedures that can be adopted by individual agencies. Specific requirements and exceptions to the mandatory standards and guidelines are indicated for Federal assistance and leasing programs.

During fiscal year 1983, ICSSC activities focused on reorganization, determination of needs for the member agencies, and planning of programs to meet those needs. In addition, the ICSSC, as an entity, has been participating with FEMA and the Subcommittee on Federal Earthquake Response Planning of the Interagency Coordination Committee in order to determine what input the ICSSC can provide and what role it can play in response to an earthquake disaster. This activity does not preclude the particular earthquake response activities of the individual member agencies in terms of the Federal response plan.

Subcommittee activities included the following. On the basis of its review of the comments received on the draft standards, Subcommittee 1 decided that the draft Federal standard should be reviewed and revised. It is anticipated that the revised standards will be reissued in the spring of 1984. Also, the subcommittee is planning a workshop for the spring of 1984 to define a procedure for implementing a uniform Federal standard. Subcommittee 2 has been conducting a survey of member agencies to define the extent of activities in the lifelines area and needs for lifeline work. The subcommittee also has identified the need for an educational workshop on lifelines. It is anticipated that this workshop will be held in the spring of 1984. Subcommittee 3 has issued two technical reports pertaining to site hazards and has a third report near publication. Additionally, the subcommittee is planning a workshop to be held in 1984 to review current USGS seismic risk maps and to discuss their impact on codes and standards. Subcommittee 4 has identified the need to develop "model administrative procedures" for implementation of seismic design standards in the existing Federal rules, regulations, policies, and procedures. Initially, procedures will be developed for leasing and grant programs used for construction or rehabilitation of buildings or other physical facilities. Work will begin on this problem area in fiscal year 1984.

PROGRAM REVIEW AND EVALUATION

As set forth in the requirements of the Act and the Presidential Plan establishing and implementing the NEHRP, a continuing evaluation of the Program is to be made so that the strengths and weaknesses and the successes and failures of the program can be assessed and corrective actions taken as needed. Thus, the Annual Report to the Congress should not only reflect the activities and progress made during the past fiscal year but also provide an evaluation of the NEHRP in attaining its objectives nationwide.

As stated in the Presidential Plan provided to the Congress in June 1978, some actions for earthquake hazards reduction could begin immediately while others would have to await research results or the commitment of financial resources. Highest priorities for immediate action were specified as

- *Establishment of a focus—a lead agency—to provide national leadership and to guide and coordinate Federal activities;*

- *Determination of the interest of States for the development of State and local strategies and capabilities for earthquake hazards reduction;*

- *Completion of Federal, State, and local contingency plans for responding to earthquake disasters in the densely populated areas of highest seismic risk;*

- *Development of seismic-resistant design and construction standards for application in Federal construction and encouragement for the adoption of improved seismic provisions in State and local building codes;*

- *Estimation of the hazard posed to life by possible damage to existing Federal facilities from future earthquakes; and*

- *Maintenance of a comprehensive program of research and development for earthquake prediction and hazard mitigation.*

In 1978, FEMA was established to provide a central focus and coordination center at the Federal level for all emergency management activities (preparedness, response, recovery, and mitigation) for all types of disasters, natural and manmade, and to provide technical and financial assistance to the States and local communities in carrying out their preparedness, response, recovery, and mitigation programs. As such, it was designated as the lead agency for the NEHRP, establishing a focus and providing national leadership as well as guidance and coordination for Federal activities.

The interest of the States in the development of State and local strategies and capabilities for earthquake hazards reduction is evident and growing. The response obtained by FEMA from the States regarding the creation of an association of State officials involved in earthquake hazards reduction indicates an interest in hazards reduction. A national conference is scheduled for fiscal year 1984.

However, while some mitigation measures such as earthquake-resistant construction are available and can be implemented, others must await further research in socioeconomic factors and prediction and exploration of mitigation incentives. Human and economic factors become significant in earthquake hazards reduction because catastrophic events are rare and as yet unpredictable and people have a tendency to either ignore the danger or to postpone allocations of resources for preparedness and mitigation because of the long-term characteristics of the hazard. The fact that many States and local communities in high- to moderate-risk areas are participating in jointly funded Federal-State preparedness and education programs indicates their concern for and commitment to public safety and welfare. It is hoped that as the public becomes more aware of the hazard potential and results of the vulnerability assessments, proper mitigation measures will be adopted and the public will be more willing to utilize hazard reduction measures beyond those required by State and local governments through building and land use ordinances.

Federal response planning has progressed considerably, as indicated in FEMA's fiscal year

1983 activities report. A Planning Guide has been developed and will serve as an interim operating plan for response by Federal agencies to a catastrophic earthquake prior to the development of the Basic Plan and executive summaries of the Emergency Support Functional annexes. This planning activity is being coordinated with the preparedness planning activities of State and local governments, which are in various stages of development depending on completion of vulnerability analyses for high- to moderate-risk areas.

As reported by FEMA and the NBS, seismic resistant design and construction standards have been developed through the ICSSC and and are under review by all Federal agencies. The Federal Government, through the BSSC and mitigation programs in general, is providing leadership and encouragement to non-Federal sectors in adopting seismic-resistant construction standards and is providing additional information as it becomes available through ongoing research efforts. Federal mitigation efforts regarding the upgrading of existing structures are most notable in the VA program described in its fiscal year 1983 activities report.

Following the development of standards for new construction, the ICSSC will begin an assessment of the hazard posed to life by possible damage to existing Federal facilities from future earthquakes. Some agencies with responsibilities for critical facilities have begun an assessment of the facilities for which they have responsibility and have initiated programs to take corrective action regarding these existing hazards. For example, various agencies have begun programs to reduce the seismic impact on hospitals, dams, powerplants, and other critical facilities. These programs and others will continue in future years to provide a gradual strengthening of Federal facilities that must withstand a catastrophic earthquake.

Federal research and development efforts in earthquake prediction and hazards mitigation techniques continue. Although a high priority for immediate action, these activities rely on extensive research that requires continued resource allocations. Developments and ongoing activities in these areas are described by the USGS and the NSF in their fiscal year 1983 activities reports.

In fiscal year 1982, as part of the NEHRP effort to develop a Five-Year Program Plan, as required by the Act, FEMA selected Mr. Karl V. Steinbrugge to chair an independent panel of experts in natural, engineering, and social sciences, voluntary agency representatives, and State and local officials to review the Program Plan and assess the adequacy of the plan and the NEHRP itself in terms of meeting the objectives of the Act. This review and evaluation included the management, programs, progress, direction, and needs of the NEHRP. On the basis of this evaluation, the panel offered recommendations to FEMA regarding the management, direction, and program needs of the NEHRP. FEMA has submitted the report, with a strong endorsement of the findings and recommendations, to OMB for review and submission to the Congress.

The panel's review and evaluation, completed in June 1983, indicated that much has been accomplished since the NEHRP was established by Congress but that much remains to be done to lessen earthquake risk and potential losses in the United States. In its summary report, the panel cited the following accomplishments:

- There is a much clearer understanding about the nature of earthquake fault mechanisms in different parts of the country.

- From historical and geological data much has been learned about earthquake recurrence on faults in the United States. Methods are being developed for making probabilistic assessments of times of increased seismic hazard on a particular fault, a step important to the eventual prediction of earthquakes.

- A new generation of maps of ground shaking has been prepared for the entire United States, providing a much better basis for seismic zoning and building codes and for assessing earthquake hazards.

- The understanding of potentially destructive earthquake motions has been significantly advanced by the measurement of ground motions and structural response obtained during the Imperial County, California, earthquake of 1979 and the Coalinga, California, earthquake of 1983.

- Detailed earthquake loss estimates have been completed for several metropolitan areas, providing a basis for better preparedness planning; additional studies are underway for other communities.

- New and improved seismic standards and building-code provisions have been adopted by Federal, State, and local governments. The American Association of State Highway and Transportation Officials adopted for national application seismic design procedures for highway bridges.

- Improved methods of dynamic analysis are now routinely used to achieve safe yet economical designs of special structures. These structures include dams, power plants, offshore structures, and other facilities.

- Hundreds of professionals, primarily engineers and geoscientists, have been educated and trained with the support of the Act's research program.

- There has been an expanded program of information dissemination to engineers and other practicing professionals, local officials, and the public. Workshops sponsored in different parts of the country have brought together businessmen, local leaders, government officials, and scientists to identify steps that can be taken to reduce the earthquake hazard in their regions. These workshops augmented the traditional ways (publications and meetings) in which research results are transmitted.

- SCEPP, a jointly funded State and Federal effort, has brought together many diverse local groups to identify and implement measures to reduce anticipated losses during future earthquakes and to prepare possible predictions. This project serves as a model for efforts in other areas.

- In many parts of the country, there is a much greater awareness of the hazard posed by earthquakes and a better understanding that it is possible to reduce the hazards. This awareness has assisted, for example, in the enactment by the city of Los Angeles of an ordinance requiring the strengthening or elimination of its old hazardous buildings.

However, while these accomplishments are important, the panel points out that much remains to be done. Further research is required in the fields of seismology, earthquake prediction, earthquake engineering, and societal response to hazards and disasters. Further effort is needed to implement the results of research through codes and standards of practice so losses and suffering caused by earthquakes are reduced. Specifically, the panel recommended the following program changes and improvements:

Management

- Stronger leadership by FEMA;

- Financial support by other principal agencies of the program planning and coordination costs;

- Creation of a strong, independent advisory panel to provide expert advice on a regular basis;

Research

- More extensive postdisaster mitigation studies here and abroad, funded by a small, no-year revolving fund;

- Modernization of existing earthquake engineering research facilities; and

- Comprehensive evaluation by FEMA/Office of Science and Technology Policy of the Nation's future earthquake engineering, experimental, and testing capabilities.

To accomplish the goals and objectives of the Act and the needed program improvements, the panel recommends an increase in the resources dedicated to the NEHRP. All indications are that the time before a catastrophic event of regional or national impact is quickly running out. The principal issue is one of time—the time before a catastrophic event and the time needed to prepare for and mitigate it, including predicting its actual place and time of occurrence if at all possible.

Although the recommended improvements to the NEHRP research program depend upon budget allocations, the managerial recommendations can be adopted directly by FEMA. In fact, several actions to strengthen the management of the NEHRP have been taken during fiscal year 1983, as indicated in FEMA's report on its fiscal year 1983 activities report. FEMA will continue to monitor the program as to its effectiveness in meeting the goals set forth by Congress and will advocate changes as needed.

ACRONYMS

AID	Agency for International Development
ARC	American Red Cross
ASU	Arizona State University
ATWC	Alaska Tsunami Warning Center
BSSC	Building Seismic Safety Council
BuRec	Bureau of Reclamation
CDMG	California Division of Mines and Geology
CDP	Crustal Dynamics Project
CIB	Conseil International du Bâtiment pour la Recherche, Étude et la Documentation
CMT	Centroid-Moment Tensor
COCORP	Consotrium for Continental Reflection Profiling
CRBRP	Clinch River Breeder Reactor Project
CSSC	California Seismic Safety Commission
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EAO	emergency action officer
EDT	eastern daylight time
EEC	Earthquake Education Center
EERI	Earthquake Engineering Research Institute
EICC	Emergency Information Coordination Center
EPRI	Electric Power Research Institute
FEMA	Federal Emergency Management Agency
FWHA	Federal Highway Administration
GDSN	Global Digital Seismography Network
GOES	Geostationary Operational Environmental Satellite
ICC	Interagency Coordination Committee
ICSSC	Interagency Committee on Seismic Safety in Construction
IEMS	Integrated Emergency Management System
JIC	Joint Information Center
JPL	Jet Propulsion Laboratory
LAGEOS	Laser Geodynamics Satellite
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
LLR	lunar laser ranging
MIT	Massachusetts Institute of Technology
MM	Modified Mercalli (Intensity Scale)
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAVFACENGCOM	Naval Facilities Engineering Command
NAWAS	National Warning System

NBS	National Bureau of Standards
NCEL	Naval Civil Engineering Laboratory
NCMN	National Crustal Motion Network
NEHRP	National Earthquake Hazards Reduction Program
NEIS	National Earthquake Information Service
NGS	National Geodetic Survey
NISEE	National Information Service for Earthquake Engineering
NOS	National Ocean Survey
NWS	National Weather Service
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NSC	National Security Council
NSF	National Science Foundation
OFDA	Office of U.S. Foreign Disaster Assistance
O&M	operations and maintenance
OMB	Office of Management and Budget
PGA	peak ground acceleration
POLARIS	Polar (Motion) Analysis by Radio Interferometric Systems
PRA	probabilistic risk assessment
PRC	People's Republic of China
PTWA	Pacific Tsunami Warning Center
REDEAM	Regional Deformation of the Earth Models
SEAOC	Structural Engineers Association of California
SEASEE	Southeast Asian Association of Seismology and Earthquake Engineering
SCEPP	Southern California Preparedness Project
SCS	Soil Conservation Service
SERIES	Satellite Emission Range Inferred Earth Surveying
SLR	Satellite Laser Ranging
SSB	State Seismological Bureau (People's Republic of China)
TLRS	Transportable Laser Ranging Station
TVA	Tennessee Valley Authority
TVDS	Transportable VLBI Data System
USCGS	U.S. Coast and Geodetic Survey
USGS	U.S. Geological Survey
VA	Veterans Administration
VAMC	VA Medical Center
VLBI	very long baseline interferometry
WES	U.S. Army Waterways Experiment Station
WWSSN	World-Wide Standardized Seismographic Network

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