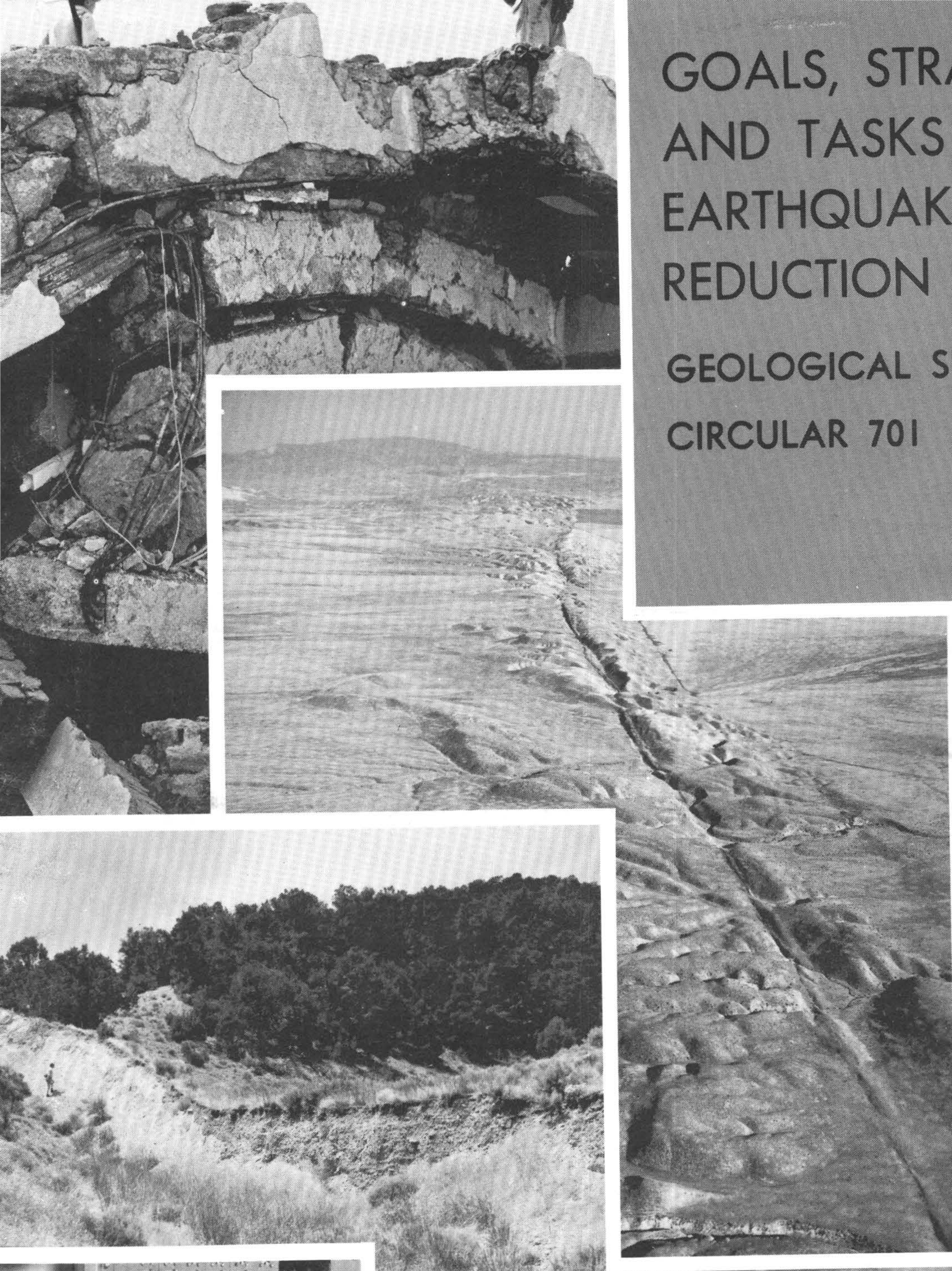
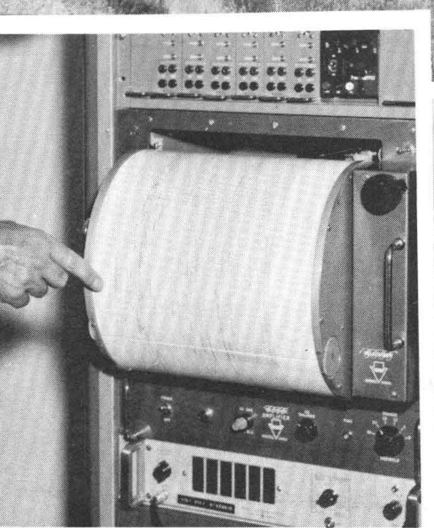
GOALS, STRATEGY, AND TASKS OF THE EARTHQUAKE HAZARD REDUCTION PROGRAM

GEOLOGICAL SURVEY

CIRCULAR 701





GOALS, STRATEGY, AND TASKS OF THE EARTHQUAKE HAZARD REDUCTION PROGRAM

By Robert E. Wallace

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PREFACE

This description of the Earthquake Hazard Reduction Program of the U.S. Geological Survey (USGS) is intended to serve as a guide, a point of departure perhaps, for those involved in directing the program as well as a means of informing other agencies and individuals about its general scope.

The program is designed to provide the background data and understanding needed to reduce earthquake hazards. Goals are set, technical and scientific strategies for reaching those goals are suggested, and a selection of specific tasks to be undertaken within the next several years is tabulated.

In September 1973, the earthquake research programs of the National Oceanic and Atmospheric Administration (NOAA) and the USGS were administratively merged. The combined program under the USGS constitutes the single largest research and data-gathering effort in earthquake hazard reduction in the United States (see organizational charts, p. 26) and includes the major efforts of the Federal Government in earthquake-related studies in seismology, geology, geophysics, as well as important efforts in soils engineering. The new USGS program includes seismic-engineering-data gathering and research conducted for the National Science Foundation, which has the principal Federal responsibility for earthquake-engineering research. In addition, the USGS program interfaces with, serves, or assists efforts in many other Federal, State, and local agencies and provides financial support for substantial research in academic institutions and some State and local agencies.

The program as described is more an ideal to be pursued within the next few years, given adequate funding, rather than simply a statement of what is currently underway. The existing program has evolved over the past decades under the administrative guidance of several agencies, some parts under the U.S. Coast and Geodetic Survey and its successors, the Environmental Science and Services Administration and NOAA, and other parts under the USGS and its subdivisions—the Office of Earthquake Research and Crustal Studies, the Office of Environmental Geology, the Office of Marine Geology, and the National Center for Earthquake Research. Each organizational unit has left its mark on the program.

An opportunity now exists to mold a more effective and better balanced program. But, given the breadth and diversity of program requirements and potentials, ranging from physical science to sociology, from earthquake forecasting to earthquake engineering, and from the most basic research to administrative application, the challenge will be to arrive at something approaching concensus as to proper emphasis. What should be the dollar and man-power expenditure on each of the various components of the program? How can support be developed for work largely neglected to date, or additional support be gained to expand a small ongoing effort to a critical level?

Several dozen scientists and engineers, including members of the Advisory Panel to the National Center for Earthquake Research (now the USGS Earthquake Studies Advisory Panel) have contributed to or reviewed this program statement. In the process of combining the ideas of all these individuals, the author undoubtedly has compromised some strongly held opinions.

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INTRODUCTION

Earthquakes pose a serious and growing threat to the Nation. Of all natural disasters, earthquakes can cause the largest property damage and loss of life. A great earthquake (magnitude larger than 8) in the densely populated areas of the Pacific coast could cause damage in the range of tens of billions of dollars and the loss of thousands of lives. The probability of such an event is high. The best estimate of the long-term average rate of occurrence of great earthquakes along the San Andreas fault is about 1 per 100 years. The last such event was 70 years ago, so that a significant probability exists of another within the next 30 years. Significant additional losses can be expected with a higher degree of certainty from smaller earthquakes.

Potential earthquake disasters are not limited to the Pacific coast. Great earthquakes have also occurred in the Mississippi Valley and along the eastern seaboard. The St. Lawrence Valley, New England, and the Rocky Mountains have also been the sites of significant seismicity.

The goals of the national earthquake program are to reduce the hazards to life and property, to mitigate human suffering and economic losses, and to minimize disruptions of business, government, and private activities from future earthquakes. The hazards, however, can never be reduced to zero, and analyses of vulnerability or risk must be prepared to assist the public in developing a rational approach and reasonable attitude toward the risk. A major goal is to achieve an optimum balance between safety and economic cost (fig. 1). As an indication of cost, approximately $100 billion were spent on construction in 1973. If only 1 percent additional cost were imposed in the interest of earthquake safety, more than $1 billion annually would be the price. Thus inappropriate or inadequate mitigation methods could be extremely wasteful, but to sacrifice tens of thousands of lives needlessly would be gross negligence. Only through the development of sound scientific and engineering principles and practices can the system be adjusted for optimum benefit.

STRATEGY OF EARTHQUAKE HAZARD REDUCTION AND MODIFICATION

Earthquake hazards are being reduced by incorporating earthquake resistance in structures, and advancement of proper engineering methods can greatly reduce the hazards still further. The judicious use of land through zoning holds promise of reducing the hazard significantly. Earthquake prediction can open the way for a wide variety of actions to prepare for an impending emergency, and techniques to limit the size of an earthquake could significantly reduce the impact of earthquakes. The capability to determine accurately a low or zero probability of earthquakes in some regions could save billions of dollars in the costs of construction and could provide assurance of the safety of critical structures such as nuclear

Figure 1.—Cutting costs of safety. Advancing earthquake science and engineering can increase safety and reduce the cost of safety measures. More appropriate building codes and better land-use policy can minimize the cost of hazard reduction measures.

reactors. Earthquake insurance can spread the economic losses of a disaster minimizing the impact on the individual, and emergency preparedness can ensure prompt and efficient amelioration of human suffering and economic loss.

The program of earthquake hazard reduction must encourage the development of basic concepts and understanding in the earth sciences and engineering and provide for an efficient flow of the developing concepts into application in hazard reduction processes (fig. 2). This calls for a multitdiscipline, multi-institution undertaking and a continuing appraisal of the interaction of all. In large measure, the

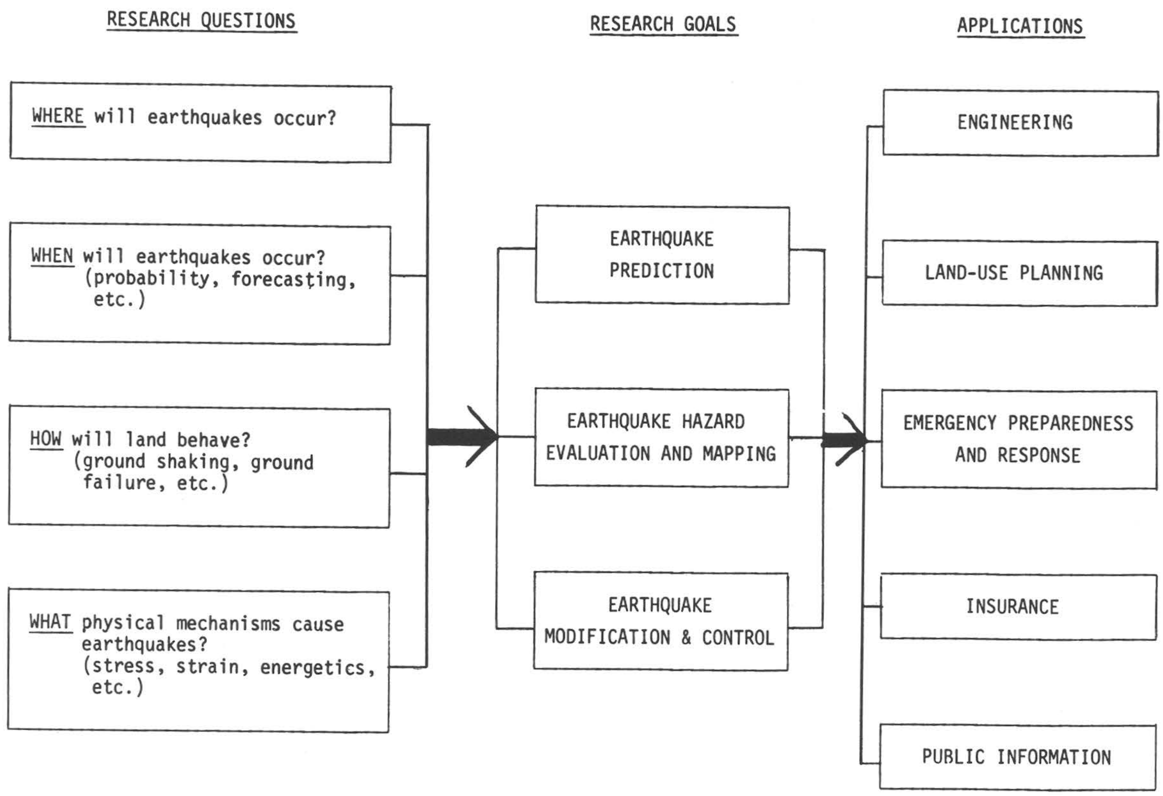


FIGURE 2.—Flow of output from fundamental research in Earth sciences to application in earthquake hazard reduction.

current inadequacy of fundamental understanding of the Earth processes and Earth reactions associated with earthquakes and of the response of engineered systems permits only inadequate response through engineering and public decision-making processes, but measures that are being taken to reduce hazards should be encouraged.

A common fallacy in the establishment of program priorities is to overemphasize the immediate need to apply existing scientific and technological knowledge. Such a priority is axiomatic, but generally the inadequacy of the basic knowledge is the key to its nonuse. The priorities of expediency and immediacy should not be permitted to obscure or obstruct the long-term growth of basic understanding and its orderly application.

The major approaches to hazard reduction are:

Land-use planning.—All the hazards of earthquakes stem from certain behavior of the ground—ground breaking along faults (figs. 3, 4), ground motion (fig. 5), ground failure including landsliding (figs. 4 and 6) and differential settlement, and ground-level changes—or from water bodies disturbed by ground motion (fig. 7). Theoretically, these factors can be expressed in map form, and thus the use of land can be planned to take these factors into account and reduce hazards. For example, critical facilities such as nuclear-power reactors (fig. 8), hospitals or high-occupancy structures such as apartment buildings should not be placed directly astride active faults, and ground subject to the most severe shaking might better be used for recreational areas rather than for high-rise buildings, which result in dense occupancy. Communities can implement long-range plans by governing land use through zoning ordinances and grading codes. Grant agencies can require incorporation of seismic elements in land-use planning.

Engineering design and practice.—Inasmuch as the most immediate hazard of earthquakes

FAULT HAZARD

FIGURE 3.—Fault hazard. The hazard of movement on faults can be reduced by prohibiting structures for human occupancy directly astride known active faults. This photograph, taken after the 1906 San Francisco earthquake, shows offset of a road by more than 20 feet along the San Andreas fault, Tomales Bay, Calif.

results from collapse of manmade structures, building of structures that are resistant to ground shaking and movement accompanying an earthquake will reduce the hazard. Three steps are critical: (1) the appraisal of the possible magnitude of ground motion must be sound; (2) the structural design must be adequate; and (3) the design must be executed properly in practice. The great variety of structures and uses of structures, ranging from high-rise buildings and dams to underground utilities, pose a complex problem. Important structures such as hospitals, fire-fighting facilities, and communication centers must remain operational in the event of a serious earthquake; thus engineering considerations are more complex and demanding for such structures. Communities can employ building codes and standards to ensure public safety through earthquake-resistant structures, and loan agencies can require incorporation of standards that will minimize economic loss. Ordinances governing nonconforming structures, particularly those likely to collapse, can be developed and enforced.

Prediction and control.—An analogy between weather prediction and earthquake prediction is instructive. The value of weather prediction or forecasting and hurricane and tornado warning has been clearly demonstrated over the years, despite the yet-imperfect understanding of atmospheric phenomena. Similarly, earthquake prediction, including the elements of what, where, when, and estimates of the reliability of the prediction or forecasts, can have great economic and social benefit. Numerous lines of research give promise that forecasting (fig. 9) of at least some specific earthquakes—their expected time, magnitude, and place—should become feasible within the next several years. As earthquake prediction and forecasting improves, the public use of techniques to reduce the hazard will be more immediate and appropriate. Building codes and land-use controls will be put into practice more readily if long-term forecasts are a reality, and insurance can be more appropriately tailored in cost and coverage to the real needs. Emergency preparedness can be more effectively and economically administered. The concept of earthquake control (fig. 10) implies the eventual possibility of

LAND-USE PLANNING

FIGURE 4.—Land-use planning. Houses should not have been built astride the 1906 break of the San Andreas fault or on potential landslide developing in crushed rock along the fault zone. Photograph along San Andreas fault, Daly City, Calif. Heavy line is position of 1906 fault break; dotted line is approximate boundary of fault zone.

relieving tectonic stresses on faults and thereby reducing the catastrophic effect of earthquakes. The size of earthquakes theoretically could be reduced, or the potential for an earthquake might be eliminated or postponed. In the immediate future, it is necessary to know more precisely how to avoid inadvertent triggering of earthquakes—which, unfortunately, has happened—in the development of waste-disposal wells, reservoirs, and other activities of man. Techniques to be developed under this program conceivably could be applied to triggering slip

LAND-USE PLANNING

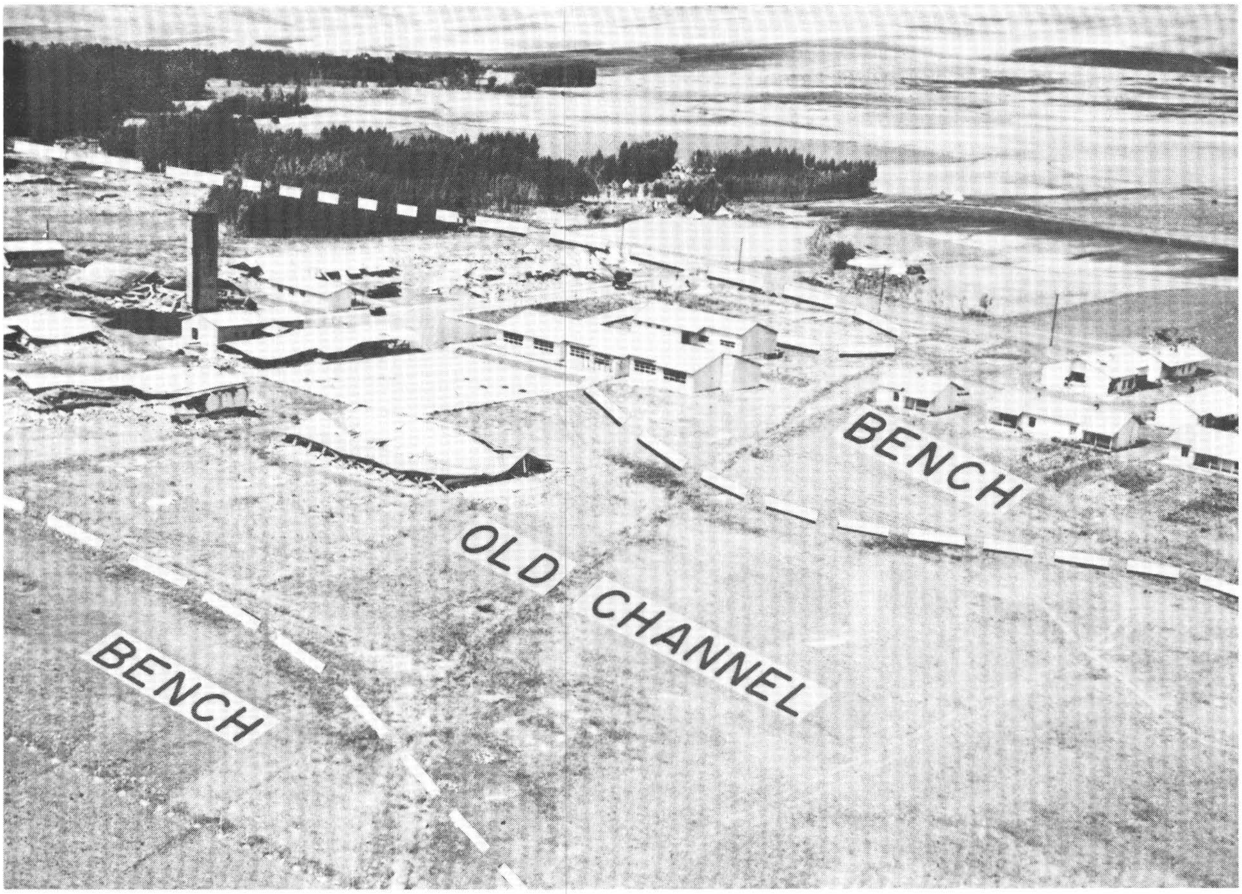


FIGURE 5.—Land-use planning. Damage on different types of ground may be very different. At Varto, Turkey, 12 of 14 buildings on "old channel" material collapsed. On "bench" material no buildings collapsed.

on potentially active faults and thus reducing the possibility of a damaging earthquake.

Insurance.—Insurance cannot directly reduce the total hazard of earthquakes, but it can spread the risk and the economic impact of a disaster. Furthermore, it has, or can have, the effect of encouraging adoption of hazard-reduction measures. The insurance capacity of all private companies combined cannot cover a potential loss of between $10 and $40 billion, the amount of loss that can be expected from one major earthquake occurring in a major urban area. As a result, even though earthquake insurance is available, it is not aggressively sold, and the number of policies in effect covers only a small fraction of potential damage. The National Flood Insurance Act includes many procedures that might be modified and applied to earthquake insurance. Hazard-mitigation methods must be coupled to any insurance program; otherwise, insurance can tend to encourage unsafe practices. In order to make earthquake insurance more feasible, the Earth sciences must develop a far more quantitative and precise prediction of the characteristics and distribution of earthquake effects, including maps and analyses of these factors.

Emergency preparedness and response.—Many preventive and protective measures can be taken before an emergency to reduce the hazards of an earthquake, and plans can be prepared for prompt, efficient handling of casualties and problems after an earthquake. Communications systems, such as between hospitals and police units, can be developed, serums and medicines can be stockpiled, and alternate

LANDSLIDE HAZARD

FIGURE 6.—Landslide hazard. Landslides triggered by earthquake shaking constitute one of the most severe hazards of earthquakes. Techniques of identifying unstable ground coupled with land-use zoning can reduce the hazard. Photograph shows landslide area at Turnagain Heights, Anchorage, Alaska, after the earthquake of 1964 (U.S. Army photo).

transportation routes can be planned. Exercises and tests designed around earthquake scenarios are becoming standard practice to develop a continuously updated plan of administrative action by an ever-changing group of public officials.

Risk, vulnerability, and public information.— The public needs a far better evaluation of the

INDIRECT HAZARD

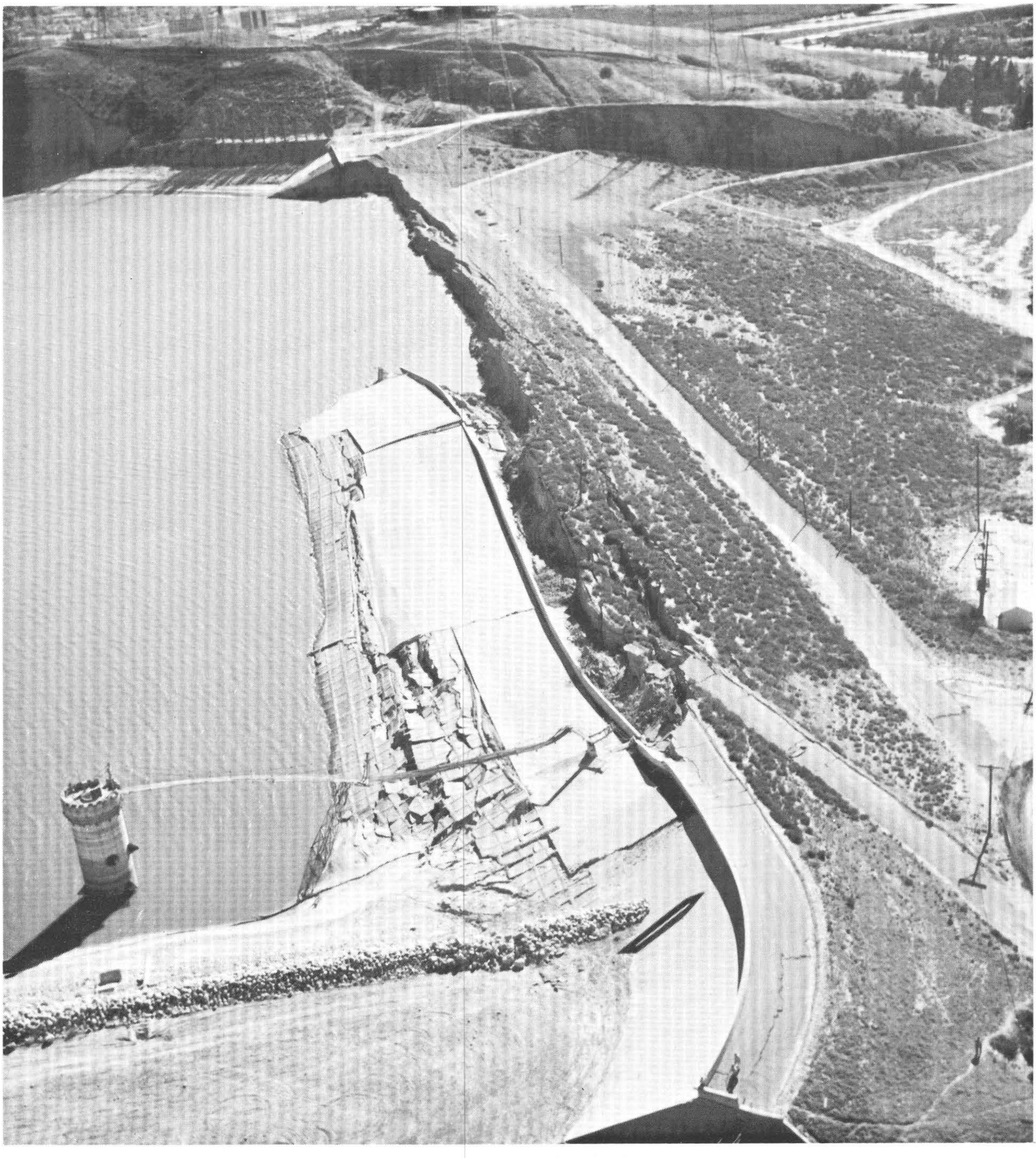


FIGURE 7.—Indirect hazard. Van Norman Dam almost collapsed in the San Fernando earthquake of 1971. If it had, tens of thousands would have drowned.

risk to which they are exposed from earthquakes. In the absence of a credible realistic evaluation, the response of individuals ranges from panic to complacency. With this confusion, communities and public bodies cannot respond entirely rationally, and the adoption of even simple hazard reduction practices is very difficult. If reliable assurance could be given of

NUCLEAR POWER DEVELOPMENT DELAYED BY EARTHQUAKE HAZARD

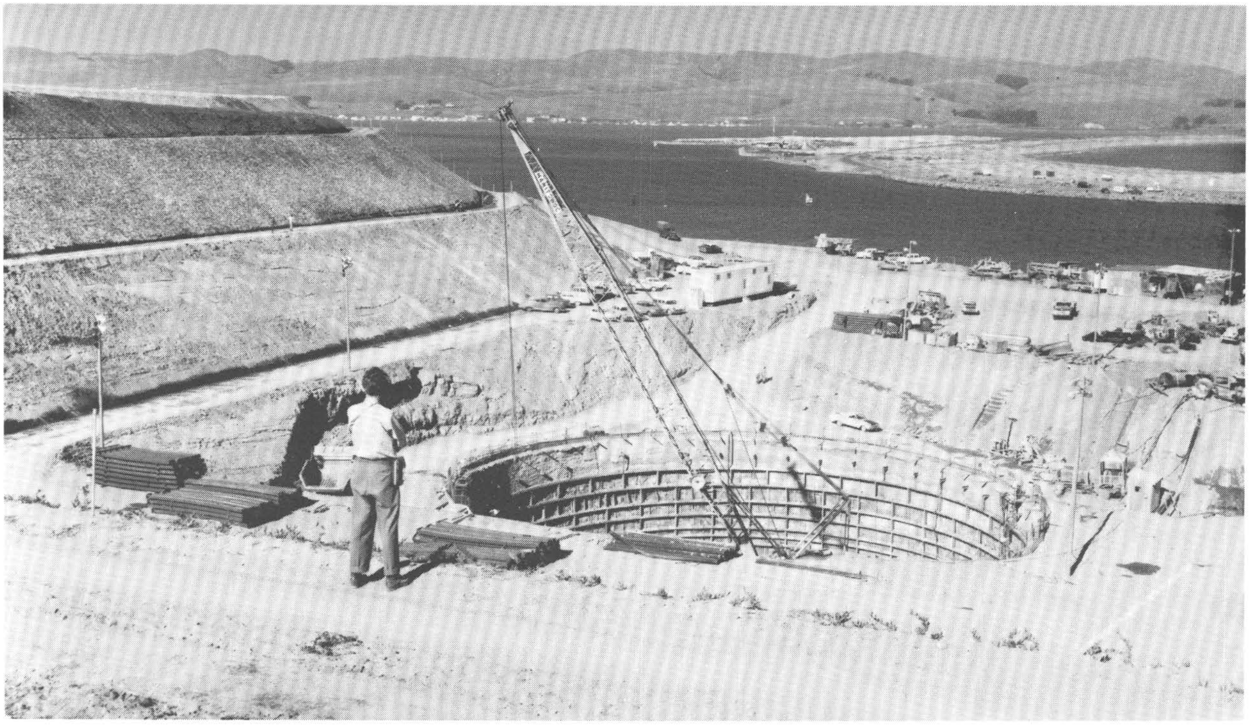


FIGURE 8.—Nuclear power development delayed by an earthquake hazard. Because of the fault hazard, this site for a nuclear reactor at Bodega Bay, Calif., was abandoned after expenditure of millions of dollars and years of time in site preparation. If data on the fault had been available, the waste of time and money could have been avoided.

low- or no-earthquake hazard in some regions, billions of dollars in construction costs might be saved. Dissemination of existing information to the general public is of high priority, and additional appraisals of risk and vulnerability are prerequisites to improved public response.

EARTHQUAKE HAZARD REDUCTION PROGRAM

The Earthquake Hazard Reduction Program of the U.S. Geological Survey is designed to carry the major Federal responsibility for earthquake-related research in the Earth sciences, both basic and applied, that is required for earthquake hazard reduction. The program will emphasize the development of basic understanding of fundamental seismological, geophysical, geological, tectonic, and soil mechanics principles without which the cumulative state of the sciences cannot adequately serve practical needs. A balance of effort, however, will be sought between fundamental and applied studies to ensure an efficient transfer between the two. A program of seismic engineering financed by the National Science Foundation is conducted by the USGS. In addition, the program is intended to be responsive to the needs and programs of numerous other Federal agencies concerned with the hazards of earthquakes. Among these agencies are the Federal Disaster Assistance Administration, Atomic Energy Commission, Advanced Research Projects Agency, Department of Housing and Urban Development (HUD), National Bureau of Standards, Veterans Administraton, Department of Health, Education and Welfare, Department of Transportation, Bureau of Reclamation, and the U.S. Army Corps of Engineers. The program of the USGS will be implemented by utilizing not only the internal research capa-

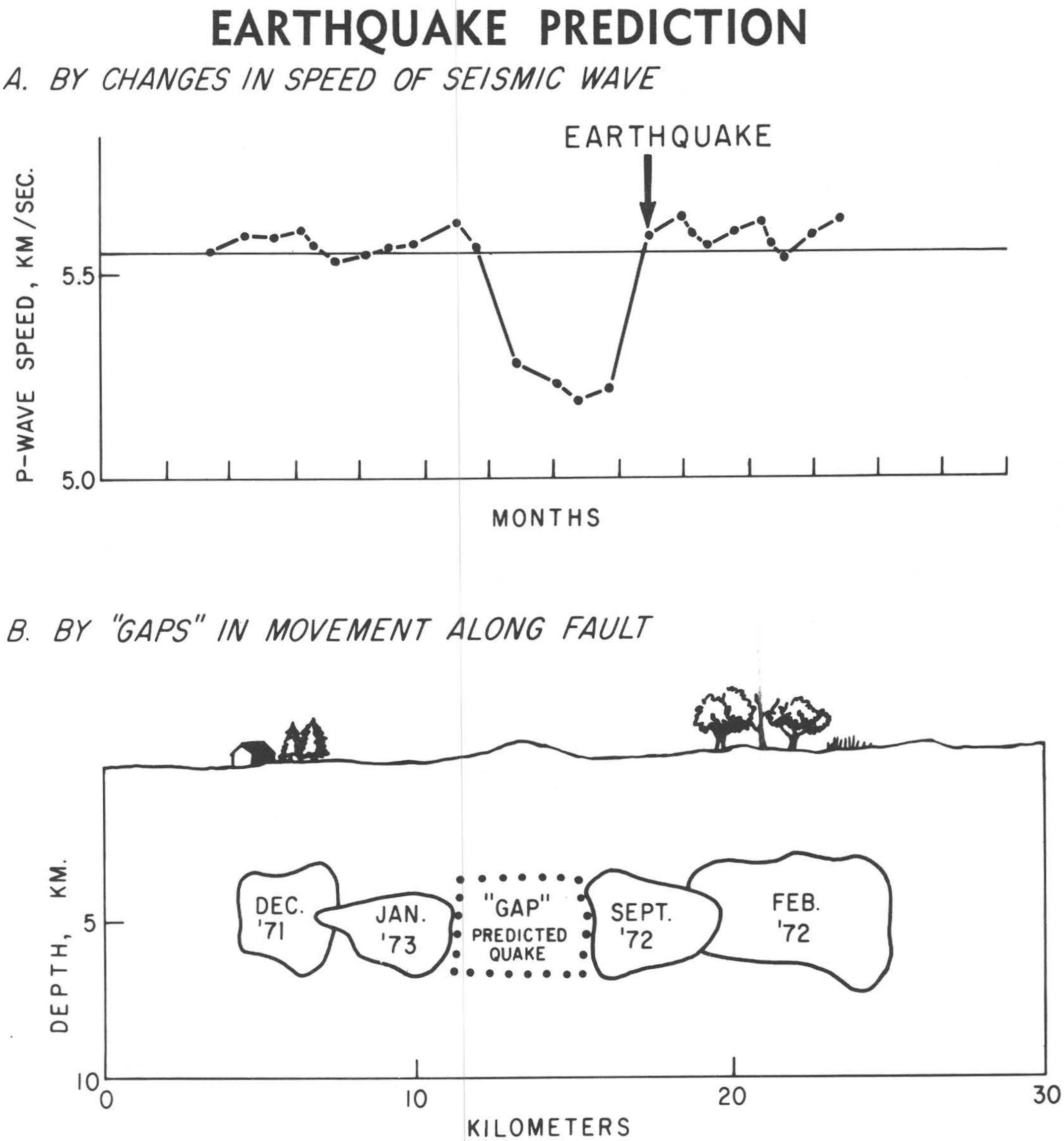


FIGURE 9.—Earthquake prediction. *A*, By changes in speed of seismic wave. Speed of *P*-wave may decrease for months before an earthquake, then rise to normal just before the earthquake. *B*, By "gaps" in movement along fault. Microearthquake mapping identified slip surfaces on the San Andreas fault related to four moderate earthquakes (magnitude 4–5). A "gap" suggests that the next slip and a related earthquake will lie between others.

bilities of the USGS, but also those of the universities, States, and the private sector. A major program of grants and contracts will assist these extramural efforts.

The goals, approach, and specific tasks are described in the following pages for each of the major elements of the USGS program: (1) earthquake hazard mapping and risk evaluation, (2) earthquake prediction, (3) earthquake modification and control, (4) seismic engineering and, in addition, the program of strong-motion instrumentation, which the USGS conducts in cooperation with the National Science Foundation, and (5) earthquake information services. The major program elements are served by supplementary efforts described under (6) postearthquake studies and (7) application and demonstration. The geographic distribution of effort needed within the next few years is also indicated.

EARTHQUAKE CONTROL

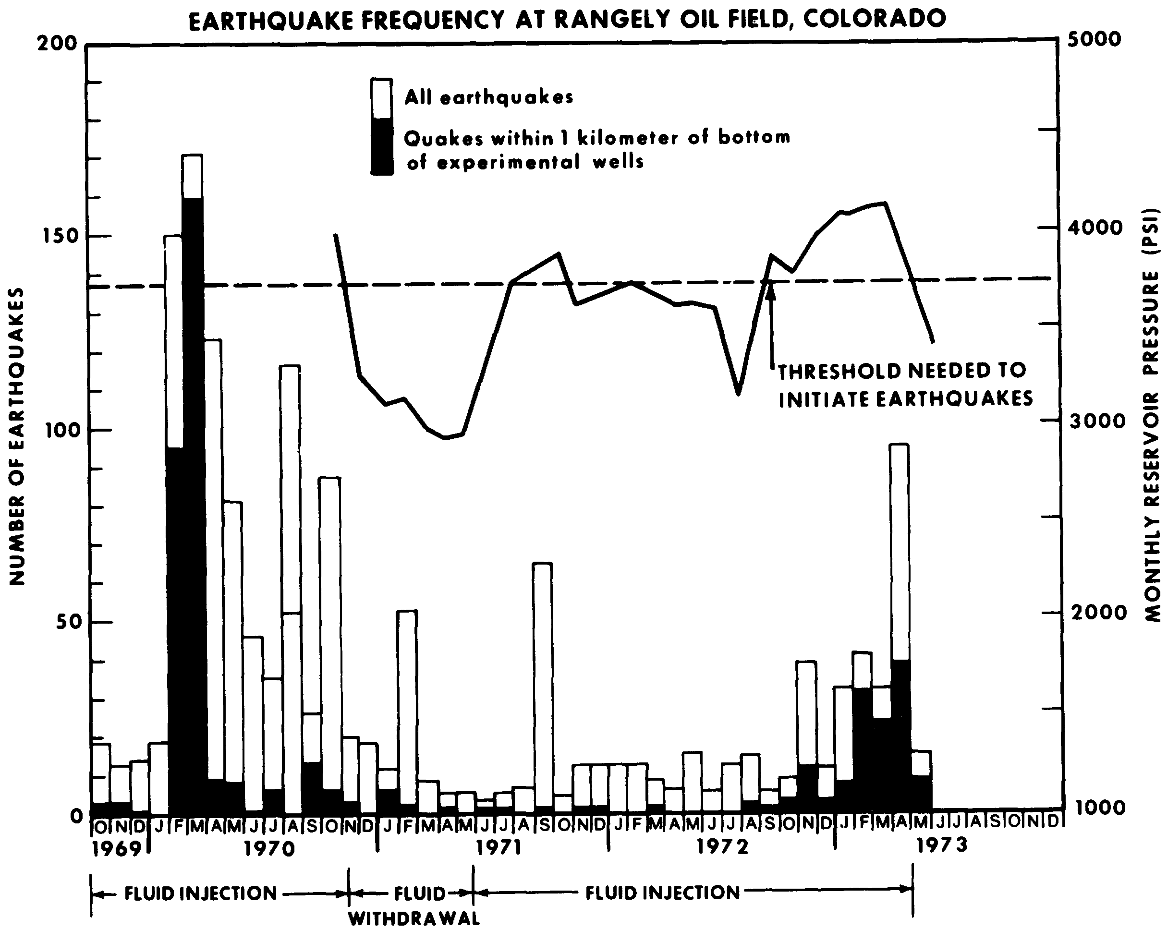


FIGURE 10.—Earthquake control. The level of earthquake activity was controlled at Rangely oilfield, Colorado, as shown in this graph, by controlled pumping so that the reservoir pressure was either above or below a critical threshold level.

EARTHQUAKE HAZARD MAPPING AND RISK EVALUATION

GOALS

- Develop the fundamental understanding of the physical behavior of rocks and soil under seismic conditions as a basis for mapping hazardous areas or defining hazardous situations and risk.
- Identify, characterize, and map earthquake geologic hazards such as ground failure (including landsliding, liquefaction, landspreading, and differential settlement), surface faulting, tectonic elevation changes, and water-related effects including flooding, tsunamis, and seiches.
- Relate geologic and soils information to the problem of strong ground motion as discussed under "Seismic engineering" section.
- Define and evaluate seismic risk as a guide for engineering, social, and economic responses by the general public, industry, and government.

APPROACH

Two basic steps are involved in achieving the goals. The first is to develop techniques of characterizing, as quantitatively as possible, the physical factors of the Earth that influence the hazardous behavior of the ground. The second is to map or otherwise identify these factors so that the hazards and risk created can be minimized through proper land use, engineering design of structures, or other policy and administrative means. Maps must be developed in formats most useful for the engineer planner, or other users.

For each of the hazard factors indicated, a somewhat different level of knowledge exists. For some factors extensive fundamental research is still required, whereas others are well enough understood for hazard reduction measures to be employed.

Strong motion

At present, the distribution of strong ground shaking on competent (or some other specified) rock during an earthquake can be estimated in terms of probability through an analysis of current seismicity (on the basis of both seismological and geological data) and attenuation of seismic waves. Maps prepared on this basis might be called regional seismic-risk maps. Ideally, maps showing the probability of specified levels of ground acceleration, velocity, and displacement, together with the duration of strong shaking, should be prepared. Maps of these types provide sufficient information for calculating the contribution of surficial geologic materials and soils at each site to ground shaking, provided that certain critical physical parameters of these materials are known.

The estimation of strong ground shaking in terms of probability may also be useful in the evaluation of liquefaction and landslide potential. Relationships between strong ground shaking and liquefaction are fairly well known, so the probability of liquefaction could be mapped if the geological and engineering properties of the surficial materials at the site were known. Quantitative relationships between ground shaking and landsliding are not well known. Consequently, development of estimates of the probability of landsliding will depend on the success of future research.

Although the goals of risk evaluation, hazard mapping, and seismic engineering each demand some unique approaches, the scientific and technical studies for each interrelate and are mutually supportive.

Surface faulting

Active faults can be recognized remarkably well in reconnaissance fashion by their geomorphic expression as observed in aerial photography. Study of high-altitude photographs and side-looking radar images provides reconnaissance evidence of faults. Lower altitude photographs, particularly those taken with low sun angle, then can provide the detailed evidence needed to evaluate the recency of movement. Examination on the ground, including trenching and drilling to expose evidence of offset of Holocene (recent) soil units can indicate the amount, distribution, and recurrence of movement.

Faults that cut the sea floor can be recognized by acoustical profiling techniques. Furthermore, these techniques can show whether or not the faults cut the uppermost or most recent sedimentary deposits, providing evidence of recent activity.

Microearthquake studies based on dense arrays of short-period seismographs permit three-dimensional mapping of seismogenic sections of active faults as well as identification of "locked" sections of major known active faults.

The combination of these techniques provides an effective method of mapping faults and evaluating their potential for surface movements. The main task of this phase of the USGS program is to carry out such mapping and evaluation. Priorities for carrying out the active fault mapping and evaluation will be governed by the projected development of urbanizing areas, by the economic importance of the development and by the relative hazard of different land utilization. For example, the need for nuclear power demands a high priority for early site evaluation of broad regions along the coast of California.

Ground failure

Slopes that have failed by landsliding in the past can be identified by photogeologic means, but their response to seismic shaking in the future cannot be predicted accurately. Better understanding of the mechanics of slope failure is needed so that mapping can express more precisely the expected behavior of a given slope. The approach of the program will be to carry out mapping of unstable slopes in reconnaissance as a first approximation of the extent of the hazard, while at the same time attempting through topical studies to improve the capability to predict behavior under different seismic conditions.

The physical principles of liquefaction and differential settlement are known in a general way, but in most places the lithology and ground-water conditions are not known well enough to interpret the susceptibility to liquefaction and differential settlement. A general evaluation of the problem can be obtained in many areas by reconnaissance mapping of unconsolidated sediments, accompanied by analysis of existing data from water wells and agricultural soil maps. This type of mapping will be done first in selected areas where urban development is imminent.

Tectonic elevation change

Techniques are known for determining the past vertical changes of tectonic blocks, and the assumption can be made that the blocks are likely to continue to move in the same sense in future earthquakes. The techniques include a variety of geomorphic methods such as the analysis of erosion surfaces, areas of deposition in bays or sedimentary basins, or geodetic records.

Few analyses of expected changes in vertical elevation relative to the earthquake hazard have been made, but such analyses should be carried out along coast lines where vertical changes can constitute the most severe hazards.

Water-related effects

The extent of flooding that might result from the collapse of a dam, either natural or manmade, can be estimated and maps prepared. Such map evaluations should be made in areas where flooding constitutes the most severe hazard to man. An engineering study should be included in the evaluation of manmade dams. Damming of rivers by earthquake-induced landslides is a significant hazard to consider in some areas.

Geologic techniques can contribute to the study of past histories of tsunamis and seiches, and these techniques should be applied to evaluate factors of past runup and recurrence of these phenomena.

SPECIFIC TASKS

- Make theoretical and field seismic studies of the influence of local geologic conditions on the amplitude, characteristics, and duration of strong ground shaking.
- Make laboratory and field soil-mechanics studies of the response of surficial geologic materials to large cyclical strains.
- Make studies of the statistical nature of earthquake occurrence, with emphasis on the nature of the distribution and the statistical treatment of aftershock sequences.
- Conduct additional investigations of the historical seismicity of selected areas.
- Investigate the nature of the attenuation of seismic waves in various parts of the country with emphasis on the Eastern United States and Alaska.
- Prepare regional seismic risk maps of the earthquake-prone areas of the country. Initial efforts should be directed toward the preparation of maps of maximum acceleration (with associated probability) for a given return period.
- Conduct research to define mappable parameters that consider the amplitude characteristics of ground motion as a function of frequency.
- Compile and evaluate existing information on faults with known or suspected late Quaternary activity.
- Map in reconnaissance active faults by photogeologic and other remote-sensing techniques in California, Nevada, Utah, Alaska, and other States where these techniques are applicable.
- Develop and improve techniques to date recent geologic (Holocene) features for the purpose of determining long-term strain rates such as the recurrence of faulting and rates of landsliding. The techniques may include studies of pollen, tree rings, soil development, carbon-14 residues, sedimentary structures, and others.
- Map the activity of faults by microearthquake techniques.
- Map active faults under the ocean by subbottom acoustical-profiling techniques.
- Determine activity of faults by strain meters and other geodetic methods.

- Study the soil profiles and recent geologic (Holocene) history of active faults to determine patterns, width, and other characteristics of active zones.
- Map landslides that might be reactivated by earthquakes.
- Develop techniques to determine factors that govern slope stability under seismic loading.
- Analyze slope stability and make slope maps.
- Map those geologic units that will influence the distribution of hazards such as liquefaction.
- Do laboratory and field studies on liquefaction.
- Map areas where the hazard of liquefaction is most severe.
- Analyze geodetic, historic, geomorphic, and stratigraphic records to evaluate the hazards of potential changes in vertical elevation during an earthquake.
- Map areas of potential flooding that results from seismically induced changes or damage to structures.
- Apply geologic techniques to analyses of hazards of tsunamis, seiches, and surge phenomena, particularly recurrence and geographic distribution of past runups.
- Prepare experimental maps similar to the "seismotectonic maps" of the Soviet Union.
- Prepare earthquake geologic-hazard maps suitable for determinations of land-use policy.
- Study the effects of selected earthquakes to learn firsthand how theory and actual ground behavior relate.

EARTHQUAKE PREDICTION RESEARCH AND IMPLEMENTATION

GOALS

- Develop the physical understanding and instrumental means required for forecasting the time, place, and magnitude of earthquakes and to implement and evaluate experimental earthquake prediction systems in highly seismic regions.
- Develop the historical and geological background for estimating earthquake probability and recurrence characteristics.

APPROACH

Many observations made in various parts of the world indicate that large earthquakes have been preceded by anomalous ground-surface deformation, an increase in local seismicity, variation in the composition of water from wells or springs, and other physical changes. Systematic seismic studies in search of precursor events, which have been made near Garm in Tadjikistan, USSR, have revealed apparent changes in the velocity of *P*-waves, in the elastic properties of rocks in the source region, and in the orientation of small earthquake fault sources before large earthquakes. Application of modifications of one of the Soviet techniques has been successful in the retrospective prediction of several earthquakes in the United States. To a large extent, these leads, which give great promise for earthquake forecasting, represent an empirical approach. Indeed, given a sufficiently widespread and dense network of sensors to monitor changes that presage earthquakes and given sufficient experience, the empirical approach might be used successfully to forecast some earthquakes. But in the long run, data gathering and interpretation must be designed in the framework of a fundamental understanding of earthquake causes and mechanisms. As the fundamental understanding grows, the ability to forecast accurately will improve. Given valid models, the extremely significant evaluation of areas that will not have damaging earthquakes for specific periods of time should be possible.

Principal requirements for the fundamental studies related to earthquake prediction include:

- Accurate delineation of the physical properties and principal structural elements of the crust and upper mantle in the study area.
- Adequate monitoring of strain accumulation and release, microearthquakes, and other manifestations of earthquake-related changes in the region. (Deep in-situ stress measurements would be of great value but are not yet practicably obtainable.)
- Detailed laboratory data on the behavior of rocks as a function of composition, temperature, confining and pore pressure, shearing stress, and strain rate over the ranges of

these variables found in the crust and upper mantle.

- Rapid, effective methods of analyzing vast quantities of monitored field data and presenting the results for consideration in an actively updated computer-based model of the region.
- Effective methods and adequate staff and computer facilities for maintaining and updating a dynamic computer-based model of the crust and upper-mantle earthquake-generating system, for evaluating the significance of monitored field data in terms of the current state of the model, and for formulating predictions of impending earthquakes.

The concepts of global plate tectonics probably provide the correct outline of the processes that ultimately are responsible for earthquakes, but to be useful for prediction, that outline must be strengthened and fleshed out with many important details on the constitution and behavior of the boundary zones between plates that generate earthquakes. Some of these studies should be made under the earthquake hazard reduction program, but the overall pursuit of plate-tectonic concepts should be as broad as all the Earth sciences combined.

The first major prediction experiment has been organized around an intensive coordinated microearthquake-, strain-monitoring-, tectonic-analysis program in a 50- by 300-kilometer region cut by the San Andreas fault system in central California. The immediate objective of the work is to delineate the major physical and kinematic features of the earthquake-producing crust-and-upper-mantle system and to develop efficient methods for recording and interpreting the most obvious symptoms of changes occurring within it, that is, earthquakes and strain changes. In addition, detailed and specific experiments are planned and are presently underway to test empirical and theoretical models for earthquake precursors.

A worldwide search for premonitory effects will be made through cooperation with scientists of other countries.

SPECIFIC TASKS

Some tasks can be done with instruments and methods that are now ready for application. These include:

- Establish telemetered short-period seismic networks to locate microearthquakes (and thereby map faults within the crust), to provide data on the physical properties and elastic regime of the crust, and to search for premonitory seismic-velocity changes in the crust surrounding the foci of impending earthquakes.
- Install telemetered tiltmeters to monitor strain changes continuously at many locations to document slow deformation of the crust and to detect the onset of rapid changes that may precede earthquakes.
- Employ surveying techniques (especially leveling and trilateration with the laser geodolite) to monitor gross regional deformation across the major fault zones, that is, to detect the relative movement of plates and platelets.
- Install creepmeters and short alinement arrays to monitor displacements within fault zones.
- Do the geologic mapping and supporting studies to identify active faults, locate and date the most recent breaks, and evaluate other evidence of recent deformation.
- Conduct laboratory studies of the physical properties and mechanical behavior of rocks under conditions found in the crust and upper mantle.
- Simulate deformation and faulting in realistic Earth models by computer modeling.
- Employ multiparameter correlation of recorded microearthquakes, strain patterns, strain events, and other features to search for evidence of propagation of strain or slip events through the network.
- Use crustal-refraction seismic systems and portable seismograph networks for special topical studies of the Earth's structure, aftershock sequences, earthquake-source parameters, and similar features.
- Use geothermal logging equipment and interpretive techniques to develop information on temperature as a function of depth (and position relative to the fault) in the crust and upper mantle.
- Analyze the geologic and tectonic characteristics of highly seismic areas in which experimental prediction will be conducted.
- Carry out limited, exploratory deep drilling

and direct examination and instrumentation of fault zones at depth.

- Analyze the geologic record of active faulting and tectonic changes, particularly of the last 50–100,000 years, in highly seismic areas.
- Investigate the validity of earthquake-prediction methods developed in the Soviet Union, Japan, China, and other foreign countries.
- Explore global systems of crustal plates and fractures that control earthquake generation.

Some instruments and methods require further testing or development or are too costly for extensive use at present. Development of these are specific tasks that may be pursued. Examples are:

- In-situ stress measurements by hydraulic fracturing or borehole strain-relaxation measurements.
- Quartz-tube strain meters or other short-base shallow-burial strain meters.
- Multibeam laser-ranging instruments to increase the precision of free-air-path distance measurements (possibly to a few parts in 10^8).
- Long-period, broad-band, large-dynamic-range seismographs to record a broader spectrum of ground motion for improved studies of earthquake sources.
- Water-level recorders and volumetric-strain meters of high stability and sensitivity.
- Stable high-sensitivity recording magnetometers to search for magnetic precursors to seismic events.
- Widespread systematic monitoring of water composition at flowing springs or wells to search for geochemical precursors to earthquakes.
- Extensive drilling and direct examination and instrumentation of fault zones at depth.

EARTHQUAKE MODIFICATION AND CONTROL

GOALS

- Determine the feasibility of limiting the magnitude of earthquakes on active faults.
- Design subsurface waste-disposal operations and reservoir siting so as to prevent inadvertent triggering of earthquakes.

APPROACH

Theory and both laboratory and field experiments have shown that the frictional resistance to shear failure in rock can be changed by altering the fluid pressure along potential or existing failure surfaces. By appropriately modifying fluid pressures along active faults, it is theoretically possible to strengthen and weaken the fault so as to prescribe in advance the maximum rupture length in an earthquake. The rupture length will be determined principally by the distribution of shear stress and the frictional strength (modified by fluid pressure) along the fault surface. For determining the required pattern of fluid-pressure changes, we rely on three-dimensional finite-element models of the fault zone in which the parameters of stress, fluid pressure, and material properties can be assigned arbitrarily. An existing numerical model predicts the distribution of pore pressure required to limit the fault length and determines additional source parameters such as magnitude of the earthquake, slip, and stress drop. Laboratory experiments will be conducted to simulate the numerical model and test the validity of the physical assumptions it contains.

The complexity of natural fault zones will require models with a greater, but yet unknown, degree of sophistication. A field test similar to the laboratory experiment in concept, but on a scale of tens of meters, is therefore planned. A site for the experiment that contains an existing, appropriately stressed fault in a well-exposed outcrop, such as a quarry, will be sought. USGS and university investigators will collaborate in determining the state of stress and frictional properties of the rock. The fault zone will be instrumented for measurement of the static and dynamic strains generated by the earthquake induced. This cooperative project is intended to provide not only a field test of the feasibility of earthquake control but also a unique opportunity for understanding the relationships between the parameters of the earthquake source and testing models of earthquake precursors.

If earthquake control is ever to be possible, the San Andreas fault zone must be amenable to the required alterations in its fluid-pressure regime, and test holes are planned for measurement of fluid transmissibility, in-situ stress, and material properties. In addition, a prototype intensive-monitoring experiment will be started on a limited part of the San Andreas fault. Detailed measurements of strain and seismicity and an analysis of the geologic structure will be made so that a finite-element computer simulation of the fault may be tested against observations.

A search for an active fault in a suitably remote area will be undertaken. If the smaller scale experiments prove successful, the preparations for an active experiment will be considered.

SPECIFIC TASKS

- Develop effective economical techniques of measuring absolute in-situ stress.
- Establish the mechanics of fluid flow through fracture systems in reservoirs.
- Establish criteria for evaluating potential seismic hazards in planning waste-disposal sites and reservoirs.
- Test accuracy of numerical methods for calculating fluid-pressure changes in fractured rocks by comparing with observations in the field.
- Carry out small-scale (meters to tens of meters) field test of fluid injection.
- Develop instrumental monitoring systems of selected areas that may be considered for future active testing.
- Monitor and analyze selected fluid-injection projects that become available.
- Monitor and analyze selected reservoir projects that may be developed.
- Make intermediate- and large-scale laboratory tests of fluid-injection procedures in various rock types and under various conditions.

SEISMIC ENGINEERING

The seismic-engineering program is being conducted by the USGS largely in cooperation with other agencies. The principal financial support is from the National Science Foundation, and the strong-motion instrumentation programs of most other Federal, State, and local agencies are being coordinated through, or assisted by, this program.

GOALS

- Develop a basis for estimating the principal characteristics of strong ground motions to be expected from future earthquakes. Spectral characteristics, attenuation rates, influence of source, travel path, and local site conditions are of special concern.
- Determine the elastic and inelastic response of representative types of structures, and determine the influence of the foundation conditions on this response. Utilize these data to improve procedures for modeling the dynamic characteristics of structures and their response to earthquakes.
- Coordinate the strong-motion instrumentation programs of Federal, State, and local agencies into a national strong-motion instrumentation program.
- Cooperate with other agencies and engineering organizations in the development of seismic-design procedures and earthquake hazard analyses.

APPROACH

The major data-gathering effort of this program is through the deployment of strong-motion instruments. In the past, the greatest number of instruments have been placed in buildings, dams, or other structures, but more effort has been made recently to determine ground motion in free-field situations. Although numerous records have been obtained from the existing strong-motion instruments, the analyses and interpretations of these records indicate that the amount and type of data are inadequate. The Panel on Strong-Motion Seismology (Karl V. Steinbrugge, chairman) of the Committee on Seismology, National Research Council-National Academy of Sciences, recommended in 1973 "an immediate increase in the number of strong-motion instrument stations in the United States by approximately 2,000 with at least 500 of the new stations installed east of the Rocky Mountains." The panel also recommended "that the program be carefully planned so as to optimize its usefulness and effectiveness in all parts of the country" and emphasized an integrated approach ranging from pure research to applications with short-term payoffs.

The seismic-engineering program will draw heavily on data and interpretations developed under the prediction and hazard-evaluation programs. The nature of soil and geologic units and of seismic source and configurations are among the many inputs that must come from these companion programs.

The coordination of the strong-motion instrumentation programs of several agencies had led to what can be considered a national program, but as yet an optimum program has not been achieved. A better distribution of instrumentation both geographically and by type of structure is needed. Cooperative efforts with other agencies and engineering organizations in the development of seismic-design procedures and hazards analyses has been very productive, and these efforts will continue.

The planning of arrays of instruments to determine the nature of the ground motion is based on the seismic history and anticipated nature of the earthquake source for each region of the country. An appropriate balance must be achieved between the desire for a rapid accumulation of data from frequently occurring small events and the necessity to obtain an adequate amount of data for the less frequent major events. A high priority is being placed on arrays to determine the attenuation of motions from all earthquakes of magnitude 7.5 or greater. In conjunction with the ground-motion arrays, additional instrumentation that will be useful in the determination of the source parameters and source mechanism is planned.

Because of the nonlinear nature of the response of soils and structures, data are sorely needed in areas in which damaging levels of motion occur. The influence of the flexibility of the foundation material on the response of structures is important.

Two-thirds of the strong-motion accelerographs in the country have been installed to determine the response of structures (largely buildings and some dams). Most of these instruments have been purchased by other agencies, and many were installed by private building owners to satisfy code requirements. As a result, an optimum distribution of the instrumented structures has not developed even though the maintenance costs for these instruments have, in the past, been absorbed by the Federal program. These maintenance costs are being shifted to the instrument owners, which will permit a redirection of Federal funds into a series of more integrated and effective experiments. Since numerous outside agencies and organizations have a primary interest in the instrumentation of structures, criteria and guidelines on structural instrumentation are being prepared. These will be circulated to various organizations and agencies for their review and information.

In order to interpret the records obtained from the strong-motion instrumentation, the dynamic characteristics of the sites and structures must be known. Some documentation of the physical characteristics of each site and each structure is obtained at the time that the instruments are installed. This documentation must be supplemented by appropriate measurements of the dynamic properties of the sites and structures. Analytical investigations are being conducted in conjunction with the interpretation of the records and as a guide to the development of the instrument arrays.

As the number of strong-motion instruments that record each earthquake has increased, a greater effort has been required to process the data quickly and accurately and disseminate them to the cooperating agencies and organizations. Several data-processing schemes are being investigated. In addition, the instrumentation and the format for recording the data are being continuously reviewed in the light of developments that might lead to improved data-processing procedures. The reports and publications that are used to list and to summarize the strong-motion data are being reviewed in order to evolve a more effective means of dissemination.

SPECIFIC TASKS

- Deploy two-dimensional arrays of strong-motion instruments to determine the spectral characteristics and attenuation of ground motion in regions where damaging earthquakes are most likely to occur.
- Deploy additional strong-motion instruments in dense two- and three-dimensional arrays to investigate the influence of local geology, soil conditions, and topography on the spectral characteristics and amplitude of strong ground motions.
- Compile and evaluate the existing data on the spectral characteristics and attenuation of strong ground motions.
- Conduct analytical investigations of the

spectral characteristics and attenuation of surface motion to be expected from different earthquake sources.

- Compile descriptions from existing information on the site characteristics of all strong-motion instrument sites.
- Investigate the dynamic site characteristics at each site where a significant strong-motion record has been obtained.
- Evaluate the influence of site conditions on the spectral characteristics and amplitude of strong ground motions.
- Develop guidelines for the instrumentation of representative types of structures in order to determine their elastic and inelastic response to earthquakes.
- Develop criteria for an optimum national program of instrumentation of structures.
- In conjunction with the regional arrays in seismically active areas, install instruments in representative types of structures to determine their elastic and inelastic response to earthquake.
- Compile available information on the analytically and experimentally determined dynamic characteristics of instrumented structures.
- Measure the dynamic characteristics of all instrumented structures utilizing ambient vibrations. For selected structures, conduct forced-vibration tests to determine the nonlinearity in their elastic response.
- Compile and evaluate the existing data on the response of structures to strong ground motions, particularly with respect to the nonlinear and inelastic response.
- Develop the capability for processing the strong-motion records, for reproducing original and processed data, and for rapidly disseminating the data to cooperating organizations and agencies.
- Contact all organizations and agencies that deploy strong-motion instruments and compile data on the location and characteristics of such instrumentation. Disseminate this information to any organization contemplating the installation of additional strong-motion instruments.
- Disseminate the information on strong ground motion and structural response to engineering organizations concerned with structural-design codes and manuals.

EARTHQUAKE INFORMATION SERVICES

GOALS

- Provide accurate information on the location, magnitude, and relevance of all earthquakes worldwide of magnitude 6½ or larger and U.S. earthquakes of magnitude 4 or larger within 1–2 hours.
- Locate as many earthquakes worldwide as can be accurately and rapidly determined with data collected cooperatively from stations throughout the world.
- Publish research-quality earthquake hypocenters and magnitudes for the use of the seismological research community.
- Collect, interpret, and publish Modified Mercalli intensity (felt) data on domestic and foreign earthquakes.
- Provide a focus for public and technical inquiry for information on earthquakes, seismicity, and related topics.

APPROACH

A well-defined need exists for the notification of disaster-relief agencies, scientists, and the public when significant earthquakes occur within the United States. This need also exists when disastrous earthquakes occur in heavily populated regions throughout the world. The USGS National Earthquake Information Service (NEIS) is responsible for rapidly locating such earthquakes and issuing notification to the proper authorities, scientists, and the public within 1–2 hours of the occurrence. For 1–2 days after the occurrence of a disastrous earthquake, the alerting service also acts as a clearinghouse for information from and to the stricken area.

At present the principal sources of arrival time and amplitude data are from an eight-station telephone network to the alerting service at NEIS, and from tsunami-warning stations by teletype. Additional data can be obtained by direct teletype inquiry to a few universities in California. It is important that the telephone data network and the rapid university response be expanded to cover the Central and Eastern United States and overseas stations that fill gaps in worldwide coverage.

The USGS Preliminary Determination of Epicenters (PDE) Program collects observations from seismic stations throughout the world and locates about 5,000 hypocenters annually. This is an international service that provides the data base for much of the research in seismology. The publication of the PDE hypocenters is accomplished within a few weeks of the occurrence of the earthquakes. Monthly summaries of hypocenter locations are published with a lag time of only 3 months. The primary needs in this program are to lessen the lag time for publication, to fill gaps in worldwide coverage, and to improve the relative and absolute accuracies of the earthquake hypocenters.

The USGS also supplies a wide range of information services to the public in answer to direct inquiry and publishes seismicity maps, annual earthquake summaries, popular brochures, and list of earthquakes and station locations.

SPECIFIC TASKS

- Expand the telemetric network to provide better real-time coverage in the Central and Eastern United States.
- Consolidate the USGS seismic- and tsunami-warning station services by telemetry to the National Earthquake Information Service.
- Publish preliminary hypocenters on a time frame of a few days after the occurrence of earthquakes.
- Reduce the errors in hypocenter determinations through use of better station coverage and relative location techniques.
- Lower the thresholds of detection and location for earthquakes that occur within the United States.
- Incorporate improved methods of describing earthquake focal parameters, such as magnitude, depth, seismic moment, effective stress, displacement, and length of faulting.
- Improve techniques for presenting regional seismicity data.

POSTEARTHQUAKE STUDIES

GOALS

- Observe the causes and effects of the particular earthquake.
- Check geological and geophysical theory against actual behavior of the natural system.
- Observe previously unrecorded effects that will guide the extension of current theories.

APPROACH

Postearthquake examinations depend in large measure on the particular set of effects that reveal themselves in a given earthquake. Of special scientific interest will be the fault that produced the earthquake, whether or not it broke the ground surface, and what the patterns and amounts of offset are. The position of the fault plane in three dimensions can be determined by analysis of *P*-, *S*-, and surface-wave data from stations recording the earthquakes throughout the world. The relationship of aftershock activity to the fault rupture during the main shock can be determined from data obtained from a network of portable seismograph stations installed as rapidly as possible after the main shock. The seismographs in this network should be designed to cover as wide a dynamic range as possible since, if the main shock is large, aftershocks will occur over a wide range of magnitudes, often very close to the seismographs.

Landsliding and other ground failures will be mapped, and their relation to geologic factors analyzed. Portable strong-motion seismographs will be used to record major aftershocks and thus develop data on the free-field ground motions. Studies of strain accompanying the earthquake will be made by geodetic methods, and gravity changes will be made where appropriate.

Effects on water, both surface and underground, will be studied.

The period after some large earthquakes is an especially opportune time in which to study jointly with engineers and planners the interrelation of Earth-science factors of earthquakes and human activities. The relation of ground motion and fault displacement to damage of structures, for example, should be analyzed.

Effort should be planned to accomodate the needs of emergency-response activities. Inventories of critical facilities should be assembled for seismic regions. The rapid determination of the hypocenter and magnitude of major earthquakes by the NEIS would then permit the application of theoretical isoseismal maps from which lists of potentially damaged facilities could be printed and provided to emergency response activities within a matter of hours. Data also should be provided regarding emergency water supply, least hazardous areas for relocation, and the likelihood and magnitude of aftershocks to be expected. The general public should be informed by the Earth scientists through the press, radio, and television about the nature of earthquakes so that it may respond intelligently and without panic.

SPECIFIC TASKS

- Map the causative fault by photogeologic and ground examination.
- Determine the offsets along the fault and any evidence of past movements.
- Determine the parameters of the fault plane by analysis of *P*- and *S*-waves and surface waves recorded at stations throughout the world.
- Determine the three-dimensional position of the causative fault by microearthquake studies of aftershocks employing portable seismographs. In doing this, also determine the space-time-magnitude history of the aftershock sequence.
- Determine strains in the Earth's crust by geodetic methods, tiltmeters, or other instrumental means.
- Determine gravity changes.
- Map areas of landsliding and other ground failures and determine the cause of instability.
- Determine the effects on water, both surface and underground.
- Determine free-field ground response of different geologic units by deploying portable strong-motion instruments to record strong aftershocks.
- For State and Federal disaster-relief agencies, develop estimates of the magnitude and nature of probable losses in future earthquakes.

APPLICATION AND DEMONSTRATION PROJECTS

GOALS

- Develop administrative, economic, and social techniques by which the Earth sciences may have direct impact on reducing the hazard of earthquakes.
- Demonstrate through application the feasibility of the administrative, economic, and social techniques in reducing the hazard of earthquakes.

APPROACH

The hazard of earthquakes can be reduced through two general avenues: by proper land use and by proper engineering design and construction. The hazard of earthquakes can be modified or the risk can be spread through insurance, by proper disaster preparedness, and by proper disaster response.

Proper land use can be developed through long-range plans, zoning ordinances, grading or building codes, and consideration of earthquake risk by insurance companies and financial institutions. Proper engineering can be developed through building codes and guidelines for the theoretical and practicing engineer. The USGS will collaborate with other Federal agencies such as the National Bureau of Standards, the States, and local communities and organizations such as the Structural Engineers Association of California and the International Association of Building Officials to develop model ordinances, codes, and guidelines most suitable in light of Earth-science factors. The States or local communities will be primarily responsible for applying the ordinances or codes and for evaluating their effectiveness.

SPECIFIC TASKS

- In collaboration with State agencies, develop model State legislation for earthquake hazard reduction.
- In collaboration with State agencies, develop mechanisms for dissemination of guidelines on earthquake hazard reduction to local communities.
- In collaboration with selected local communities, develop and test model ordinances, codes, and guidelines for earthquake hazard reduction.
- In collaboration with engineers, develop improved codes and standards that will most suitably accommodate Earth-science factors.
- Prepare information leaflets, booklets or manuals, and films for dissemination of information to the general public.

EXTRAMURAL GRANTS AND CONTRACTS

The Earthquake Hazard Reduction Program of the USGS is being implemented by utilizing the capabilities of the USGS and universities, States, and the private sector. Proposals are solicited through such publications as the Commerce Business Daily, Geotimes, and E⊕S. A grants review panel made up of outstanding non-USGS scientists assists the USGS in selecting the projects to be supported. The projects are judged according to:

1. The capability of the individual scientists making the proposal,
2. The capability of the scientist's institution to carry out a project serving the missions of the program,
3. The appropriateness of the proposed project as it may serve, mesh with, supplement, or broaden the inhouse research of the USGS program, and
4. The proposed budget for the project in balance with that of other extramural and inhouse project budgets and the total funds available.

GEOGRAPHIC DISTRIBUTION OF EFFORT

The geographic distribution of the proposed program within the next few years and the nature of the program in each area will be as follows:

1. San Francisco Bay region.—For the San Francisco Bay region, a multifaceted program of geologic-hazard evaluation and mapping is underway in which the basis for predicting ground motion and ground failure is being developed. Techniques of predicting slope stability under seismic shaking are being developed, and the relative hazards of different slopes are being mapped. Changes in vertical elevation that may occur during an earthquake will be analyzed. Additional work will be done on fault mapping and evaluation.

2. Greater Los Angeles region.—A multifaceted program of geologic-hazard evaluation and mapping for the greater Los Angeles region will emphasize mapping and evaluation of active faults and slope-stability and liquefaction studies. Priority will be given to those areas considered most likely for development in the near future.

3. Central San Andreas fault.—The central San Andreas fault will be a major field laboratory for intensive instrumentation aimed at developing predictive capabilities and fundamental understanding of tectonics. An attempt will be made to monitor this area fully for stress and strain changes.

4. Northern and southern San Andreas fault.—The northern and southern San Andreas fault will be studied by selected techniques to provide an overview of the behavior of the San Andreas fault system. Seismic nets for microearthquake study will be combined with strain measurements and analyses of the tectonic style of the regions.

5. Northwest Washington.—A disaster-relief planning study and development of a regional risk map are underway. Northwest Washington will be studied by a minimum deployment of seismic instruments and by a reconnaissance of geologic hazards.

6. Central Nevada.—Central Nevada has potential as a future test site for earthquake modification and control experiments. Geologic mapping and background studies of the seismicity, tectonics, and fault behavior will be carried out in search of a suitable test site. In addition a regional risk map will be completed for the entire State.

7. Rocky Mountain region.—In the Rocky Mountain region, the emphasis will be on an analysis of faulting, its distribution, and its mechanisms. For this purpose a combination of seismic nets and photogeologic and ground studies of faults will be employed. A regional risk map has been completed for Utah. Regional risk maps for Idaho and Montana are under development. A disaster-relief planning study for the Salt Lake area is planned.

8. Mississippi Valley.—A preliminary risk map for the Mississippi Valley has been completed. Seismic instrumentation and geologic analysis aimed at defining the recurrence, mechanisms, and distribution of earthquakes of the New Madrid type will be the principal goals.

9. Alaska.—The earthquake problems of Alaska must be approached selectively because of the size and complexity of the area. Attention will first be given to the region bordering the Gulf of Alaska and will consist of expanding seismic networks and geologic and tectonic analysis of major faults such as the Fairweather and Denali.

10. Eastern United States.—Although the seismicity and earthquake hazards are poorly defined for much of the Eastern United States, sufficient data are now available to develop generalized risk maps. Selected seismic networks in South Carolina, New York, and New England are expected to provide new data from which hazard investigations and risk analyses can be developed.

11. Puerto Rico.—A modest effort involving deployment of a minimal seismic net is proposed to help define and evaluate the seismic hazard in Puerto Rico, particularly with reference to nuclear powerplant site selection. Active faults are to be mapped and evaluated. Maps of seismic risk will be developed.

INTERNATIONAL PROGRAMS AND COOPERATION

A rational program of earthquake hazard reduction cannot be based upon a limited, provincial view of a natural process that involves the reactions of the Earth's crust and interior as a whole. Some parts of the Earth's crust are far better suited for studying certain basic physical processes than are others. Furthermore, for the most rapid evolution of ideas and concepts, the program of the USGS should make a strong effort to keep fully abreast of, and participate in, the science as it develops in other countries.

THE WORLDWIDE NETWORK OF STANDARD SEISMOGRAPHS

One of the most important international cooperative efforts involves the Worldwide Network of Standard Seismographs (known as WWNSS), which was created during the early 1960's to enhance the coverage of seismic events with instruments that have similar response characteristics. This network presently consists of 29 continuously recording stations in the United States and 86 stations distributed in 68 other countries and territories throughout the world. Each station is equipped with north-south, east-west, and vertically oriented long- and short-period seismometers, correctable timing systems, and photographic-paper recorders. The station records are sent monthly to the Seismology Data Center in Asheville, N.C., where they are copied on 70-millimeter film and can be duplicated on film or paper for applied purposes and for research. The successful operation of the WWNSS system depends upon widespread voluntary cooperation among individuals, institutions, and nations. It has become the essential source of observational seismological data for locating earthquakes, determining focal mechanisms, investigating wave propagation, and developing concepts of global and regional tectonics.

The WWNSS has played a vital part in fostering the investigations of the solid Earth by seismologists and earthquake engineers. Less than 1,000 epicenters per year were routinely located previously, whereas 5,000 or more epicenters per year are now located—mainly as a result of data from the WWNSS. These epicenters, when plotted on maps, provide the facts for delineation of plate boundaries and for development of seismic risk maps. Determination of earthquake focal mechanisms from the particle motions of *P*- and *S*-waves indicated on the WWNSS records has led to an improved understanding of the orientation of fault systems throughout the world. Wave-propagation studies with WWNSS data have led to the development of improved traveltime tables and increased greatly the understanding of the attenuation characteristics at the surface and in the interior of the Earth. The knowledge of the attenuation characteristics is an important contribution to the identification of seismic hazards and the estimation of seismic risk.

The responsibility for maintenance of equipment for and supply of materials to the WWNSS stations was transferred from NOAA to the USGS in September 1973. During the next 5 years the USGS hopes to improve the output of the WWNSS by replacement of timing systems and addition of multiple-level recording capability at many of the stations.

The Advanced Research Projects Agency of the U.S. Department of Defense is assisting some of the countries in upgrading the instrument capabilities of selected stations.

USA-USSR COOPERATIVE PROGRAM IN EARTHQUAKE PREDICTION

As a result of President Nixon's visit to Moscow in May 1972, an Agreement for the Protection of the Environment was developed and placed under the overall supervision of the Council on Environmental Quality. A program for earthquake prediction was included among the topics for study.

In 1973 working groups in earthquake prediction were exchanged, and agreements were reached for the conduct of the first 2 years of the program. The agencies involved are the Schmidt Institute of Earth Physics for the USSR and the USGS, with financial assistance from the National Science Foundation, for the United States. The U.S. program, however, will draw in large part on the universities and private sector for staffing the exchange projects.

OTHER INTERNATIONAL PROGRAMS

An exchange with the Peoples Republic of China has been organized by the National Academy of Sciences to consider earthquake research. Members of the USGS will participate in this program.

The USGS has participated in cooperative programs in tectonics and earthquake problems with Turkey, Iran, and Pakistan through the Central Treaty Organization as well as the individual countries. The North Anatolia fault in Turkey has been far more active in recent decades than the analogous San Andreas fault in California, thus presenting an unusual opportunity to make field experiments applicable to the hazards in California without depending entirely upon seismic events in California.

In seismically active New Zealand, the scientific community has developed many innovative approaches of interest to U.S. colleagues. Exchange of technical personnel has been sporadic, and a continuing exchange should be developed.

Japan and the United States have maintained close communication through a series of meetings held jointly to discuss earthquake prediction. More could be done on a continuing scientific exchange.

A long-term program of earthquake hazard reduction, involving USGS advisors, has been formalized in Nicaragua with financial aid from the U.S. Agency for International Development. In additional studies, seismovolcanic activity is being monitored using satellite communication.

The great seismic belt of western South America is a continuation of the western North American belt, and cooperative programs, which have been short in the past, should be enlarged with such countries as Chile, Peru, and Bolivia.

The seismic belts of the ocean floor are keys to global tectonics and must receive continued major attention. Studies of the structure of the oceanic crust have led to a dramatic revolution in concepts of Earth science. Within the framework of these studies possibly lie major answers to the driving forces for earthquakes.

The USGS should be involved in the Geodynamics Program being developed as an international cooperative program in the Earth sciences.

EARTHQUAKE ENGINEERING

"Earthquake Engineering Research," a report to the National Science Foundation prepared by the Committee on Earthquake Engineering Research, Division of Engineering, National Research Council, National Academy of Engineering, was published in 1969 by the National Academy of Sciences. This report elaborates the requirements of a national earthquake engineering research program, which need not be repeated here. In 1973 a report titled "Strong-Motion Engineering Seismology," prepared by the Panel on Strong-Motion Seismology of the Committee on Seismology, National Academy of Sciences and National Research Council, made recommendations for expanding some critical parts of the overall earthquake engineering effort.

Earthquake engineering research should have as its objective the development of methods of engineering analysis, design, and practice to produce safe and economical earthquake countermeasures in structures. The other currently practical means of reducing earthquake hazards are through proper land use and through effective emergency preparedness and response.

The major capability for the conduct of earthquake engineering has resided in the universities and private sector, although Federal agencies such as the National Bureau of Standards, the U.S. Army Corps of Engineers, and Bureau of Reclamation have made important studies. In addition, some State agencies have conducted earthquake engineering research. Because of the involvement of the universities, the National Science Foundation, in its role as a research-funding agency, has become the major Federal agency responsible for earthquake engineering research programs. As described in the section "Seismic Engineering," the USGS program includes a major effort in strong-motion engineering seismology with the financial support of the National Science Foundation.

Other Federal agencies that require earthquake engineering data in the conduct of their programs have also provided some support for earthquake engineering research. Among these agencies are the Atomic Energy Commission, Veterans Administration, HUD, the Department of Health, Education and Welfare, and the Department of Defense. The USGS program expects to continue to be responsive to these needs.

LAND-USE PLANNING

Land-use planning to serve a variety of environmental, socio-economic, and hazard reduction needs is a relatively new practice. No national land-use plan has yet been enacted, although important programs do include elements of land use. For example, the National Flood Insurance Act requires that local communities develop land-use ordinances and other administrative techniques for reducing flood hazards, but no national program yet applies to the reduction of earthquake hazards through land-use planning.

The USGS, in a program financed partly by the Office of Research and Technology, Department of Housing and Urban Development, is attempting to develop guidelines for land-use planning related to earthquake hazards in the San Francisco Bay region. HUD also has financed studies to assist counties and cities to develop better land-use procedures for reducing earthquake hazards.

In large measure, the responsibility for land use is at the State and local government level. The State of California, for example, requires that a seismic safety element be incorporated in the long-range plans of communities. Also, statewide ordinances governing land use near active faults are being developed. Some cities —such as Los Angeles, Hayward, and Portola Valley in California—are in the process of developing land-use ordinances related to earthquake hazards.

The Earthquake Hazard Reduction Program of the USGS, particularly the program element "earthquake hazard mapping and risk evaluation," is aimed at the reduction of the hazards through proper land use. The major users will be State and local governments, but their capabilities must be greatly improved and new administrative techniques related to land-use planning must be developed in order to reach the hazard reduction goals.

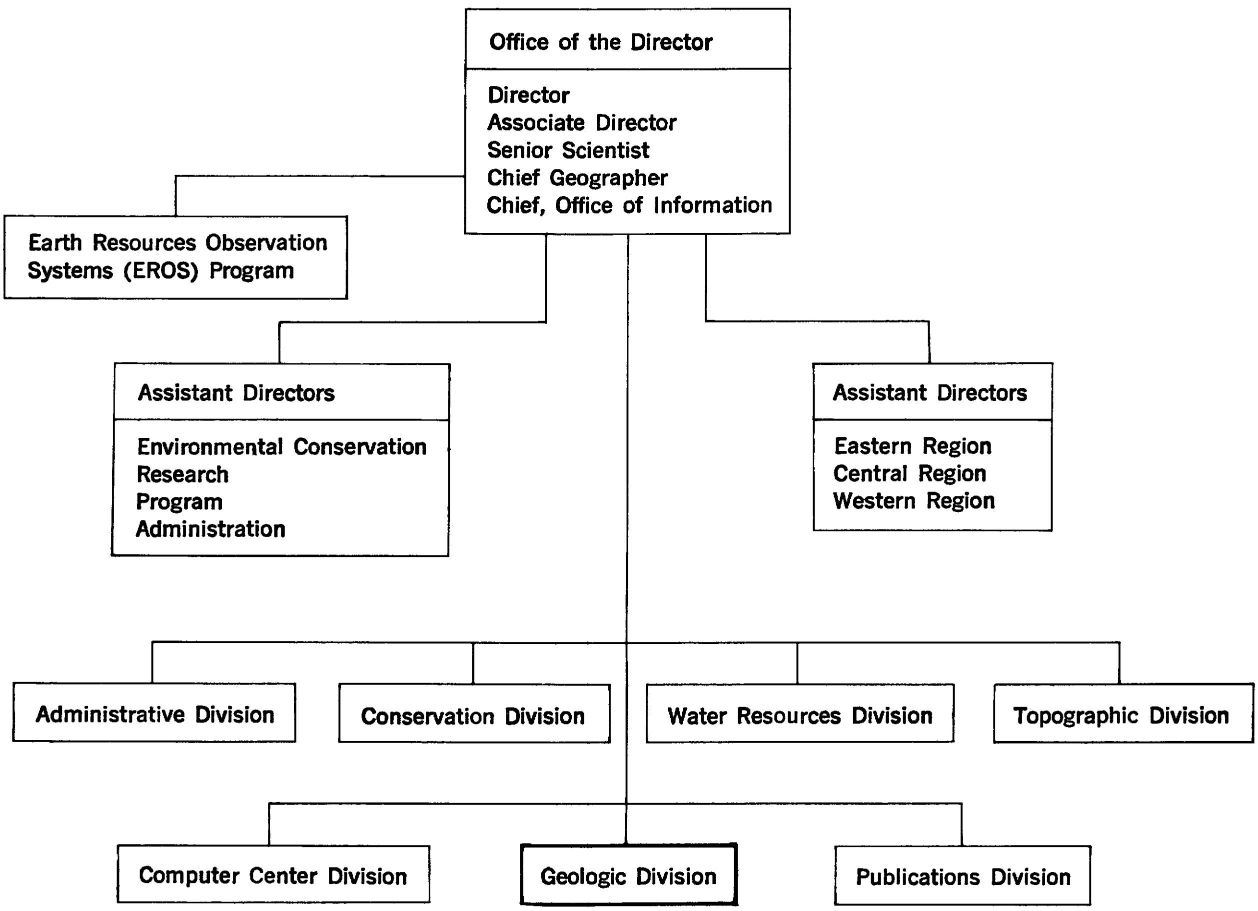
EMERGENCY PREPAREDNESS AND RESPONSE

The report "Disaster Preparedness," a report to Congress by the Office of Emergency Preparedness in 1972, identifies major needs for preparedness for all natural disasters including earthquakes. Emergency preparedness and response constitute one of the major practical actions that can be taken to reduce economic losses, casualties, and suffering after an earthquake.

The Federal Disaster Assistance Administration, HUD (formerly a part of the Office of Emergency Preparedness of the Executive Office of the President), has the major Federal responsibility for emergency preparedness, including funding of research and major reconstruction. The Defense Civil Preparedness Agency of the Department of Defense shares some of the responsibility, and numerous other Federal agencies carry specialized responsibilities. For example, the Small Business Administration provides funds for reconstruction, the U.S. Army Corps of Engineers provides equipment and capability for search and rescue and reconstruction, and the Department of Health, Education, and Welfare is concerned with health problems that follow a disaster. In addition, most States have parallel organizations that are concerned with disaster response.

The aim of the program of the USGS is to provide the necessary basic data for effective emergency preparedness, for example, an accurate scenario of what can be expected and where. The volume "Disaster Preparedness" emphasises the desirability and value of prediction and warning but recognizes that for earthquakes this is not currently feasible. A report on earthquake risk evaluation for the San Francisco Bay region was prepared under the auspices of NOAA, and similar studies for the Los Angeles and Seattle areas begun under NOAA are being completed within the USGS program.

ORGANIZATION OF THE GEOLOGICAL SURVEY



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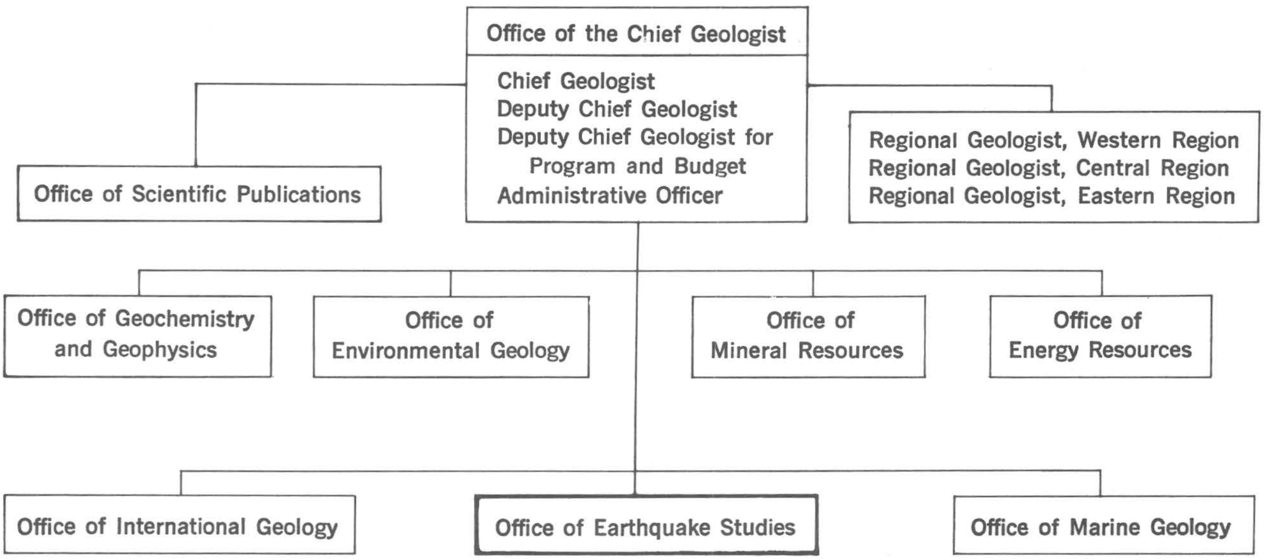
ORGANIZATION OF THE GEOLOGIC DIVISION



ORGANIZATION OF THE OFFICE OF EARTHQUAKE STUDIES