# EARTHQUAKE DISASTER MITIGATION ACT OF 1975



## HEARING

BEFORE THE

## SUBCOMMITTEE ON OCEANS AND ATMOSPHERE

OF THE

## COMMITTEE ON COMMERCE
## UNITED STATES SENATE

NINETY-FOURTH CONGRESS

SECOND SESSION

ON

## S. 1174

TO PROVIDE SOUND PHYSICAL BASES AND OPERATIONAL SYSTEMS FOR ACHIEVING MAJOR REDUCTIONS IN THE EARTHQUAKE HAZARDS FACED BY THE POPULATION LIVING IN REGIONS OF THE UNITED STATES OF SIGNIFICANT SEISMIC RISK AND TO AMEND THE NATIONAL SCIENCE FOUNDATION ACT OF 1950 SO AS TO PROVIDE FOR A RESEARCH PROGRAM RELATING TO EARTHQUAKE MITIGATION, AND FOR OTHER PURPOSES

FEBRUARY 19, 1976

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# EARTHQUAKE DISASTER MITIGATION ACT OF 1975

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**THURSDAY, FEBRUARY 19, 1976**

U.S. SENATE,
COMMITTEE ON COMMERCE,
SUBCOMMITTEE ON OCEANS AND ATMOSPHERE,
*Washington, D.C.*

The subcommittee met at 1:30 p.m., in room 5110, Dirksen Senate Office Building, Hon. Frank E. Moss presiding.

## OPENING STATEMENT BY SENATOR MOSS

Senator MOSS. The subcommittee will come to order.

Senator Hollings will be here in a few minutes and will take over as chairman when he arrives. I will proceed as chairman until that time.

This is to make a record and hold hearings on S. 1174, a bill to provide sound physical bases and operational systems for achieving major reductions in an earthquake catastrophe. It would authorize the appropriation of $25 million a year for 10 years to the Geological Survey, and there would be also $15 million the first year, and $25 million in the remaining 9 years to the National Science Foundation.

This hearing is for the purpose of developing a national capability to minimize the hazards of earthquakes. The major earthquake in Guatamela 2 weeks ago dramatically reminds us about the devastating effects of earthquakes: Some 20,000 people were killed, and 1 million people were left homeless, which is one-sixth of Guatamela's entire population.

In the United States there is a long history of earthquakes causing loss of lives and human misery and economic damage. I need mention only Alaska in 1964, Seattle in 1965, Los Angeles in 1971.

I am glad that I could appear to present this statement. The subject under consideration today is of great importance to several million people in this Nation. We have in the past failed to recognize the importance of earthquakes as a natural disaster. For too many years we have done nothing to counter the damage caused by earthquakes.

Our inaction has probably been caused by lack of recognition—our failure to recognize two facts: One, that earthquakes can and will occur in densely populated areas, and we need only look to Guatemala for the most recent evidence of that fact, and two, that modern technology can minimize the dangers of earthquakes both to life and property.

Staff member assigned to this hearing: Steven H. Flajser.

We would be grossly negligent if we waited until a disaster has occurred in Los Angeles, Boston, or Seattle before we take action to mitigate the potential dangers of earthquake. There are many preventive measures which can be taken by those communities which are susceptible to earthquake damage, and S. 1174 has provision for the initial steps in that direction.

As a Senator from Utah I have been interested in reducing the hazards of earthquake since I was a young man, long before I was elected to the Senate. The major portion of my home State lies over many geological faults, and the State of Utah suffers minor earthquake tremors continuously.

It was only in April of last year that a major earthquake occurred along the Utah-Idaho border. We were fortunate that the epicenter of the earthquake was in an area largely uninhabited. Such has been the case in most of the major earthquakes which have struck the United States in recent years.

However, everyone remembers the devastation in San Francisco in 1906 where more than 700 lives were lost and where the damage exceeded $500 million. From 1865 to 1971 there occurred in the United States 36 major earthquakes which caused in excess of $1.8 billion in damage. More than 85 percent of that damage was caused by only three of those quakes that occurred in populated areas; these were: San Francisco, Alaska, and the San Fernando earthquake, each of which caused more than $500 million damage.

We have been fortunate in years past because earthquakes occurred in less populated areas. However, the extensive growth of population in the United States in recent years, which will surely increase in future, means that we can no longer ignore protection against earthquakes. Just as we have recognized the need for protection against disasters of flood and abnormal weather, we must recognize the need for mitigation of earthquake damage.

A natural disaster can strike at any time and with severe intensity, such intensity, in fact, that in the last 500 years it has caused more than two million deaths throughout the world. We are fortunate in the United States that we have not had a catastrophic loss of life from earthquake, but that certainly does not mean that we are immune from such a possibility.

The science of earthquake study is relatively new, both in the physical and social sciences. Only during this century has any real scientific understanding of the phenomenon of earthquakes been forthcoming, and it really had not taken great strides until the last 15 years or so; but we can now take some steps for protection.

After the earthquake that occurred in Utah in April of last year, I conducted hearings in Salt Lake City, as chairman of the Aeronautical and Space Sciences Committee. Those hearings were on the present state of the art of earthquake research and the present ability to mitigate damage caused by earthquakes.

Rather than presenting here today extensive testimony, I would like to submit for the record selected excerpts of testimony presented before the Committee on Aeronautical and Space Sciences, and ask that it be inserted in the record. This testimony represents the best-informed views of Government, industry, and academia regarding the occurrence and mitigation of earthquakes. It is directed not only to the structural and economic damage, but also to the social impact.

I understand that one of the witnesses who testified before my committee—Dr. Eugene Hass—will testify here today. Because of that I might suggest that we could avoid duplication by deleting any portions of the excerpts of testimony which presented before the Committee on Aeronautical and Space Sciences by Dr. Hass.

But, before concluding my statement, I would like to bring to the attention of the subcommittee what I consider to be an oversight in the bill, S. 1174. When I became cosponsor of S. 1174, I noticed the provisions for research and thought that they were more than adequate to meet our needs. However, from the testimony presented to the Committee on Aeronautical and Space Sciences by the National Aeronautics and Space Administration, I believe that the most advanced research taking place today in earthquake predictions and monitoring of the Earth's movements might very well come from the National Aeronautics and Space Administration.

In April of this year NASA is scheduled to launch the laser geodynamic satellite, Lageos, which will be used to measure the crustal movements of the tectonic plates covering the Earth's surface, and to monitor those phenomena which cause earthquakes. Next year they will launch the magnetic field satellite, Magsat, which will help the U.S. geological survey to update maps of the Earth's magnetic field declination and enhance our knowledge of the geologic structure of the Earth.

I would suggest that S. 1174 recognize the potential for long term future prediction of the Earth's stress by making use of NASA's capabilities in earthquake research and prediction.

In addition, I think there should be some requirement that private industry be assimilated into the research effort. This is again the result of our April 1975 hearing where we found that there are many among the private groups with the capability to augment the efforts of the USGS and NSF in monitoring Earth stresses.

I offer this statement as part of the record.

[The bill and Agency comments follow:]

94TH CONGRESS
1ST SESSION

# S. 1174

IN THE SENATE OF THE UNITED STATES

MARCH 13 (legislative day, MARCH 12), 1975

MR. CRANSTON (for himself, MR. EAGLETON, MR. GRAVEL, MR. HARTKE, MR. HATFIELD, MR. HOLLINGS, MR. HUMPHREY MR. JAVITS, MR. KENNEDY, MR. MCGEE, MR. MOSS, MR. STEVENS, and MR. TUNNEY) introduced the following bill; which was read twice and, by unanimous consent, referred to the Committee on Commerce then to the Committee on Labor and Public Welfare for not to exceed thirty days, if and when reported by the Committee on Commerce

# A BILL

To provide sound physical bases and operational systems for achieving major reductions in the earthquake hazards faced by the population living in regions of the United States of significant seismic risk and to amend the National Science Foundation Act of 1950 so as to provide for a research program relating to earthquake mitigation, and for other purposes.

*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* That (a) this Act may be cited as the "Earthquake Disaster Mitigation Act of 1975".

(b) The Congress hereby finds and declares that—

(1) thirty-nine States are wholly or partly areas of high and moderate seismic risk, including, but not limited to, Alaska, California, Hawaii, Illinois, Massachusetts, Missouri, Montana, New York, Nevada, South Carolina, Utah, and Washington;

(2) a large portion of the population of the United States lives in such areas of seismic risk;

(3) highly developed urban areas such as Anchorage, Boston, Charleston, Los Angeles, Memphis, Salt Lake City, San Francisco, San Jose, Seattle, and their surrounding areas are especially vulnerable to the hazards of earthquakes;

(4) loss of life, destruction of property, and economic disruption caused by future earthquakes can be substantially reduced by implementing improved construction practices, land use controls, earthquake prediction and warning techniques, emergency preparedness plans, and redevelopment practices;

(5) implementation of earthquake mitigation capabilities requires extensive education of the population regarding earthquake phenomena and measures that can be taken to reduce earthquake hazards to individuals and to communities;

(6) there is a scientific basis for hypothesizing that in at least some seismically active regions of the United

States major earthquake risk can be moderated by earthquake control;

(7) seismological research in the United States has developed to the point where a determined and well-funded research program in earthquake prediction could provide data adequate for the design of an operational prediction capability to predict accurately the time, place, magnitude, and physical effects of earthquakes within ten years; and

(8) earthquake mitigation procedures reduce public exposure to other natural and manmade hazards, such as extreme winds, accidents, explosions, landslides, progressive collapse, and fire, through the implementation of better land use practices, improved construction methods, and emergency preparedness procedures.

(c) The Congress hereby declares that it is the purpose of this Act to—

(1) support a strong and coordinated national program in earthquake mitigation to reduce the loss of life, property destruction, and economic and social disruption resulting from earthquakes and associated phenomena through the development of—

(A) economically feasible design and construction methods for building earthquake resistant structures of all types, and for the identification and repair of existing hazardous structures;

(B) an operational program for predicting damaging earthquakes and their physical effects in the seismically active regions of the United States;

(C) procedures for integrating data and information about seismic risk with on-going land use planning and regulation activities;

(D) procedures for identifying, evaluating, and accurately characterizing seismic hazards in earthquake-prone regions;

(E) improved understanding of the social and economic consequences of individual and community decisions on earthquake-related issues, emphasizing risk control, pre-event planning, issuance of warnings, provision of emergency services, rescue, recovery, and redevelopment; and

(F) methods and procedures for the control or alteration of seismic phenomena and their effects on existing structures; and

(2) implement the earthquake disaster mitigation program by educating the population of the United States about earthquake phenomena and measures to mitigate their effects, assist public officials in develop-

ing sound regulations, and assist the professions in developing sound technical procedures.

SEC. 2. (a) The Director of the Geological Survey, in consultation with the National Science Foundation, shall develop and carry out a program of research and implementation in the areas of tectonics, seismology, and geology necessary to achieve the purposes of this Act. Such program shall include, but not be limited to—

(1) development of an operational system for predicting damaging earthquakes in the seismically active regions of the United States;

(2) development and placement of instruments and networks of instruments necessary to collect appropriate data;

(3) seismicity studies throughout the United States;

(4) evaluation of methods that may lead to the development of a capability to modify or control earthquakes in selected regions of the United States;

(5) zonation and microzonation for seismic risk of the entire United States—considering tectonic environment; seismicity; fault location; intensity, location, and return time of expectable earthquakes; and

(6) preparation of seismic risk analyses useful for emergency planning and community preparedness.

(b) In carrying out that part of such program related to research purposes, and in expending a significant portion of the funds appropriated pursuant to this Act for such purposes, the Director shall utilize the services of qualified personnel in institutions of higher education and public entities or organizations (other than the Geological Survey) and private entities or organizations concerned with seismic risk and seismic mitigation research.

SEC. 3. The Director of the National Science Foundation, in consultation with the Geological Survey, shall develop and carry out a program of research and implementation in the areas of engineering, planning and social sciences necessary to achieve the purposes of this Act, which shall include, but not be limited to—

(1) advancing basic earthquake engineering and earthquake mitigation research;

(2) developing information in engineering seismology as it relates to destructive ground motion and hazards to urban communities;

(3) developing more accurate and reliable methods of earthquake engineering analysis for all types of structures and for a variety of ground conditions;

(4) developing improved methods, based upon the seismological and geotechnical characteristics of the re-

gion, of assessing the earthquake risk at all types of locations, especially densely populated areas;

(5) developing more reliable and economical methods of earthquake-resistant design and improved criteria for earthquake-resistant construction, measuring the cost of protection against the benefit of prevented damage and loss of life, with priority given to dams, hospitals, schools, public utility and public safety structures, high occupancy buildings, buildings necessary for emergency operations, and other structures especially needed in times of disaster;

(6) developing methods that enhance community preparedness for earthquakes; and

(7) developing procedures for the rehabilitation of damaged areas through—

(A) the restoration of individual physical and emotional health, employment, and standard of living;

(B) the maintenance and restoration of a functioning community; and

(C) the application of such procedures and methods that can decrease community vulnerability to future earthquakes.

SEC. 4. The Director of the Geological Survey and the Director of the National Science Foundation, jointly, shall—

(1) establish an advisory committee composed of representatives of the research community (including the design professions), and Federal, State, and private users of the products of this program to review periodically the progress, implementation, and coordination of the earthquake mitigation program and to recommend to the Directors, through periodic written reports, appropriate modifications in the conduct or emphasis of the program authorized by this Act;

(2) establish an information dissemination mechanism to make available in a timely manner information developed pursuant to this Act, including instrumental data which may be of interest to other researchers, design and analysis data and procedures which may be of interest to the design professions and to the construction industry, and to report periodically to the Congress, Governors in States of significant seismic risk, and other interested Federal, State, and local officials;

(3) prepare and submit within ninety days of the end of each fiscal year an annual report to the Congress describing the progress of the program and achievements in earthquake mitigation;

(4) establish a joint program to evaluate, synthesize, and present, through appropriate educational programs, the knowledge developed pursuant to this Act to decrease vulnerability to earthquakes as well as to other natural and manmade hazards in a manner suitable for use by public officials and interested professionals engaged in earthquake disaster mitigation activities; and

(5) assist the States in carrying out their responsibilities under section 201 of the Disaster Relief Act of 1974 by making readily available the results of research conducted pursuant to this Act.

SEC. 5. The Director of the Geological Survey and the Director of the National Science Foundation, or their designees, shall meet periodically and shall take such other steps as may be necessary to insure that the programs authorized pursuant to this Act are fully coordinated, complementary, and responsive to user needs and requirements.

SEC. 6. For the purposes of this Act, the term "United States" when used in a geographical sense means the States. the District of Columbia, the Commonweatlh of Puerto Rico, and all the territories and possessions of the United States.

SEC. 7. (a) To carry out the purposes of section 2 of this Act, there is authorized to be appropriated for the fiscal year ending June 30, 1976, the sum of $25,000,000, and for each of the following nine fiscal years, the sum of $25,000,000.

(b) Section 16 of the National Science Foundation Act of 1950 is amended by adding at the end thereof the following:

"(c) To enable the Foundation to carry out its powers and duties under section 3 of the Earthquake Disaster Mitigation Act, there are authorized to be appropriated to the Foundation for the fiscal year ending June 30, 1976, the sum of $15,000,000, and for each of the following nine fiscal years, the sum of $25,000,000.".

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UNITED STATES DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
*Washington, D.C., February 18, 1976.*

Hon. WARREN G. MAGNUSON,
*Chairman, Committee on Commerce,*
*U.S. Senate, Washington, D.C.*

DEAR MR. CHAIRMAN: This responds to your request for this Department's views on S. 1174, a bill "To provide sound physical bases and operational systems for achieving major reductions in the earthquake hazards faced by the population living in regions of the United States of significant seismic risk and to amend the National Science Foundation Act of 1950 so as to provide for a research program relating to earthquake mitigation, and for other purposes."

S. 1174 would establish a new coordinating structure for review and implementation of a national earthquake hazards mitigation program, specifying the responsibilities for the Geological Survey and the National Science Foundation.

S. 1174 would also establish a joint GS–NSF advisory committee composed of representatives of the research community (including the design professions), and Federal, State, and private users of the products of this program.

To carry out its provisions, the legislation would authorize $25,000,000 per year for 10 years for the Survey beginning in fiscal year 1976. NSF would be authorized $15,000,000 in fiscal year 1976, and $25,000,000 in each of the subsequent 9 years.

We recommend against enactment of S. 1174.

The Federal program in earthquake research and the Disaster Relief Act Amendments of 1974 were the result of the growing recognition that earthquakes are not only capable of causing enormous losses to life and property, but that the risk of such losses is increasing with urban growth in high risk areas. The Nation's annualized loss due to earthquakes is estimated to be $630 million.

The Geological Survey now has the principal Federal responsibility for earth science aspects of earthquake hazards reduction. Its present program has evolved over the past decades under the administrative guidance of several agencies, including the U.S. Coast and Geodetic Survey and its successors under the Environmental Science and Services Administration, and the National Oceanic and Atmospheric Administration (NOAA). In 1973, the earthquake programs of NOAA were merged with those of the Geological Survey and the Survey was given the responsibility for Federal earth-science earthquake research. The USGS also undertakes seismic engineering data-gathering and research on behalf of the National Science Foundation, which has the principal Federal responsibility for earthquake engineering research. As a result of a recent redelegation of authority under the Disaster Relief Act of 1974, the Survey also has the responsibility for issuing warnings of earthquakes and certain other kinds of geological disasters such as volcanic eruptions and landslides, to the extent that they are predictable.

An effective national earthquake hazard reduction program can be accomplished under the existing authorities already available to the Federal agencies and no new legislative authority is necessary. We are working closely with the NSF to develop proposals for further earthquake research for consideration in the 1978 budget. However, we would emphasize that a true hazard reduction program must include building codes, zoning ordinances, and warning systems which are the responsibilities of State and local governments as well as research on predicting earthquakes.

The Office of Management and Budget has advised that there is no objection to the presentation of this report from the standpoint of the Administration's program.

Sincerely yours,

NATHANIEL P. REED,
*Assistant Secretary of the Interior.*

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GENERAL COUNSEL OF THE DEPARTMENT OF COMMERCE,
*Washington, D.C., February 24, 1976.*

Hon. WARREN G. MAGNUSON,
*Chairman, Committee on Commerce, U.S. Senate,*
*Washington, D.C.*

DEAR MR. CHAIRMAN: This is in response to your request for the Department of Commerce to furnish you its views on S. 1174, a bill—

"To provide sound physical bases and operational systems for achieving major reductions in the earthquake hazards faced by the population living in regions of the United States of significant seismic risk and to amend the National Science Foundation Act of 1950 so as to provide for a research program relating to earthquake mitigation, and for other purposes."

The bill would assign individual and joint responsibilities to the Directors of the Geological Survey (USGS) and the National Science Foundation (NSF) for comprehensive coordinated research and operational programs to mitigate the impact of earthquakes in our Nation. The bill would authorize the appropriation of $25,000,000 a year for ten years starting in FY 1976 for the Geological Survey and $15,000,000 in FY 1976 with $25,000,000 in each of the following nine fiscal years for the National Science Foundation. The program would include, but not be limited to, earthquake prediction, engineering research, seismicity studies, risk mapping and analyses, instrumentation, observation, and community preparedness.

The Department of Commerce defers to the Department of the Interior and the National Science Foundation views on this proposed legislation.

The Department of Commerce has developed certain expertise in the area that may be useful to the Geological Survey and the National Science Foundation in their continuing research on earthquake hazard reduction under existing authorities. The National Bureau of Standards conducts disaster mitigation research on a reimbursable basis. This includes research into the procedures for evaluating the hazard potential of existing buildings, improved design criteria and standards for a variety of natural hazards (e.g., earthquakes, hurricanes, and winds), post disaster investigations, and the development of more reliable measures of the effects of natural forces on buildings. In carrying out this program, the National Bureau of Standards has established contacts with the numerous sectors affected; specifically, the building regulatory agencies, State and local governments, the professional design community, the research community, and other Federal agencies, such as the Department of Housing and Urban Development (HUD), the General Services Administration (GSA), the Veterans Administration (VA), the Federal Disaster Administration (FDAA), the Defense Civil Preparedness Agency (DCPA), United States Geological Survey (USGS), the National Science Foundation (NSF), and the Department of Defense (DOD). Consequently, the Department assumes that the National Bureau of Standards will be considered by the lead agencies for earthquake mitigation research and consultation on a reimbursable basis.

The Department of Commerce is further interested in research on the basic science of earthquakes because of the potential relationship of an earthquake prediction capability to tsunamis for which the National Oceanic and Atmospheric Administration (NOAA) has warning responsibility. Also, if earthquake prediction techniques are developed and public warnings are issued, there is a possibility that NOAA disaster warning systems could be used for their dissemination.

We have been advised by the Office of Management and Budget that there would be no objection to the submission of our report to the Congress from the standpoint of the Administration's program.

Sincerely,

ROBERT B. ELLERT,
*Acting General Counsel.*

Senator MOSS. There is a vote now underway on the floor of the Senate, and I must go to make that vote; but as soon as I can return, or if Senator Hollings can get here sooner, we will hear from Dr. Eugene Haas, Institute of Behavioral Science, University of Colorado at Boulder; and Dr. Ralph Turner, professor, Department of Sociology, University of California at Los Angeles.

If those two gentlemen could come to the table and be ready, we will start just as soon as the chairman returns.

[Recess.]

Statement of Hon. Ernest F. Hollings, U.S. Senator From South Carolina

The hearing today has been called to discuss S. 1174 for the purpose of developing a national capability to minimize the hazards from earthquakes. The major earthquake in Guatemala two weeks ago dramatically reminds us about the devasting effects of earthquakes. Some 20,000 people were killed and 1 million people were left homeless—one-sixth of Guatemala's entire population.

In the United States there has been a long history of earthquakes causing loss of life, human misery and economic damage. Alaska had an earthquake in 1964, Seattle in 1965, and Los Angeles in 1971. Though the popular conception is that the earthquake hazard is limited to the Pacific Coast, we've had earthquakes in South Carolina, Utah, Missouri, and other states. If a 7.5 magnitude earthquake such as the one in Guatemala occurred in a heavily populated area of our country, it would be a disaster of catastrophic proportions. As a Nation we must see to it that we do everything possible to minimize the human and economic loss resulting from future earthquakes.

In the United States and other countries, scientists have made some real progress in understanding earthquake phenomena. The Committee is aware that the science of earthquake prediction is on the brink of major advances. An early warning capability could go a long way toward reducing human and economic losses. Although the capability to predict certain earthquakes seems to be within our reach, we still have no coordinated national program in this country to develop this capability expeditiously and wisely.

Prediction would be just one part of a needed research program in earthquake mitigation. We must develop and incorporate the best engineering knowledge when constructing schools, hospitals, dams, office buildings, and other structures. And we need to address the legal, economic, political, social, and human issues involved as we develop the technology to predict and possibly someday modify earthquakes.

S. 1174 would provide for a national research and operational program to achieve reductions in earthquakes hazards. This bill is a product of efforts by Senator Cranston, myself and others over the past several years to develop a national earthquake hazard protection plan, and to develop the necessary scientific and technical knowledge. We have had hearings on related bills in 1972 and 1973. It is now time to move forward with necessary legislation, and I am delighted to have such a distinguished group of witnesses to help us with this bill.

## OPENING STATEMENT BY SENATOR CRANSTON

Senator Cranston [presiding]. The hearing will reconvene.

I want to express my appreciation for scheduling this hearing on S. 1174, the Earthquake Disaster Mitigation Act. As the author of S. 1174, I am hopeful that this hearing will lead toward quick enactment of this important legislation.

The recent tragic earthquake in Guatemala could be the harbinger of our own future if the Federal Government—indeed government at all levels—does not begin to take preventive, lifesaving measures now.

It is unfortunate that it takes a tragedy of the magnitude of Guatemala's to shake us out of our complacence. But we all suffer from that peculiar earthquake mentality which chooses not to think about the destructive earthquake that could mar our future. Perhaps it is just human nature to avoid unpleasant thoughts. But in siding with the fatalists, we are courting certain disaster.

I do not intend to make a lengthy statement today since we have here the experts who can tell the tale better than I. But I would touch on a few points that need emphasis.

First, the threat of future destructive earthquakes is a national problem. Certainly, the Pacific Coast States—principally Alaska and California—are especially vulnerable to earthquakes and related disasters. Yet nearly every State in the Nation faces some degree of risk from future earthquakes, and some 70 million people live in the 39 States that are wholly or partly in areas facing a risk of moderate to major damage from future earthquakes. Earthquakes have occurred in our history all over the United States, with major earthquakes in Charleston, S.C. (1886), New Madrid, Mo. (1811–1812), Cape Ann, Mass. (1755), Seattle, Wash. (1949) and Hebgen Lake, Mont. (1959), and the terrible "Good Friday" earthquake in Alaska (1964).

Second, we must remember that despite a considerable seismic history, the United States has been extraordinarily lucky. Less than 1,200 people have lost their lives in U.S. earthquakes so far. Compare this to the more than 20,000 Guatemalans, who died earlier this month in a major earthquake and its aftershocks. Throughout history somewhere in the neighborhood of 74 million people have died in earthquakes. And in just the second quarter of the 20th century, 350,000 people worldwide have lost their lives in earthquakes and related disasters.

Third, the United States today faces the greatest potential danger from earthquakes that we have ever faced before. It is only in the last decade or so that our population has become concentrated in major cities and along our coastal regions, and major construction has occurred on land-fill and other unstable soils. Thus, it is only recently that the potential for great earthquake destruction in this country has existed. Indeed, if the San Andreas Fault were to give us an encore of the 1906 San Francisco earthquake, the deaths could number in the tens of thousands and the property damage could exceed $20 billion. On top of this, we must consider the incalculable losses resulting from the loss of economic and social functioning. Such an earthquake would have a major impact on our national economy and our national psyche.

In 1974, according to the Bureau of the Census, the value of new construction put in place in the United States totalled $134.8 billion. Approximately one-third of this new construction occurred in the high and moderate earthquake risk regions of the United States. Thus, new construction valued at approximately $45 billion in 1974 was put in place in areas with a high expectation of future earthquake damage. The annual expenditure authorized by my legislation is thus but 1 percent of the annual value of new construction in high risk zones. I believe that this is but a small price to pay to protect our massive annual expenditure on new construction.

I believe that S. 1174 could take major strides toward mitigating the hazards of future earthquakes. It would pump a total of $50 million a year for 10 years into a major Federal effort to understand earthquakes and to mitigate against their destructive impact on people, their lives, communities, property and economic well-being.

The major goals of this program would be:

1. to develop the ability to predict accurately the time, place and magnitude of future earthquakes;

2. to issue earthquake warnings in a way which avoids panic and promotes the safest possible human response during and after an earthquake;

3. to improve our understanding of earthquake-resistant design and construction so that future dams, bridges, homes and high-rises will be able to withstand the impact of an earthquake;

4. to undertake research into the social and psychological consequences of earthquakes and earthquake warnings;

5. to investigate the feasibility of modifying or controlling future earthquakes;

6. to assist local officials with the essential task of implementing the knowledge gained from this federally-supported research—to improve land use planning, building codes, and disaster preparedness;

7. to increase the likelihood that emergency facilities, such as hospitals, electrical generating plants, police stations, etc. will remain functional in the aftermath of a destructive earthquake;

8. to develop methods for the identification of existing hazardous structures and to assist local jurisdictions with the renovation or removal of such structures; and

9. to improve earthquake risk assessment for regions and localities. Even those areas not likely to suffer the direct impact of an earthquake can nevertheless suffer damage from earthquake shaking due to the character of the underlying soil. Cities along coastal and inland waterways must be prepared for earthquake-induced tidal waves and flooding. Cities in the floodplain of dams must be prepared for flash flooding which can result from an earthquake-induced dam failure. It is thus of critical importance to make a better assessment of the actual risks faced by various localities and regions, which in turn can lead to improved land use planning and construction practices.

In closing, Mr. Chairman, I would like to say that you and I and many others have been supporting this legislation for nearly 4 years now. We have been repeatedly told by the administration that this legislation is unnecessary because adequate authority exists now to implement an appropriate Federal earthquake program. Indeed, I am advised that the Office of Management and Budget is again recommending against enactment of S. 1174.

Yet we just have to examine the President's recommended budget for fiscal year 1977 to see that this administration's commitment to earthquake research is nil. The actual budgets for both Federal agencies conducting vital earthquake studies have been cut. The National Science Foundation, which for several years was operating an $8 million a year engineering research program, has been forced by the budget cutters to operate within about a $6 million program. Yet, as I just indicated, we are spending $45 billion every year on new construction in high-risk regions.

The U.S. Geological Survey has also not been spared the OMB's radical surgery. This year's program is at $12 million. The proposed 1977 budget would be $10.5 million, a cut which in the face of inflation is even more serious than first glance. In short, I am absolutely convinced that S. 1174 is necessary to provide our citizens with some measure of protection from future earthquakes.

Mr. Chairman, it is foolhardy—even irresponsible—to pretend that destructive earthquakes will not happen again. We know they will. Let us make every effort to be better prepared for them when they do strike.

I am delighted at this time to welcome Dr. Eugene Hass, Institute of Behavioral Science, University of Colorado at Boulder; and Dr. Ralph Turner, professor, Department of Sociology, University of California at Los Angeles.

We welcome you and appreciate very much your presence. You can briefly summarize whatever prepared statement you have, and place the full statement in the record, to expedite our proceedings. The full statements will go in the record.

## STATEMENT OF DR. J. EUGENE HAAS, INSTITUTE OF BEHAVIORAL SCIENCES, UNIVERSITY OF COLORADO

Dr. Haas. Thank you for this opportunity. I will attempt to summarize my testimony.

Let me first give just a brief bit of background: With Federal research funds I have been conducting research on the social and economic aspects of natural hazards and disasters for more than a decade now. This work included research on the human aspects of earthquakes in the United States, Japan, Italy, Chile, El Salvador, and most recently, Nicaragua, where we conducted research on the reconstruction process following the large earthquake in Managua. At the present time we are conducting research on the "Socioeconomic and Political Consequences of Earthquake Prediction".

The earthquake hazard should be viewed in a broad context which includes consideration of other geophysical hazards as well. In a recent multidisciplinary research effort, with the help of Federal and academic scientists and administrators from the Federal and State level, we examined each of 15 geophysical hazards, including earthquakes, within a common analytical framework designed to answer the basic question: What, if anything, should the United States be doing differently to reduce the economic losses and social disruption flowing from each hazard? Much of what I am about to present reflects the findings and recommendations growing out of that comprehensive 3-year effort which was funded by the NSF.

From one perspective, earthquakes are relatively unimportant in the United States; at least eight other hazards, for example, floods, hurricanes, drought, frost, tornadoes, inflict larger mean annual property losses than do earthquakes, and seven other hazards result in a greater annual death toll.

But from a different perspective, however, the great earthquake is the ultimate natural hazard. Its potential for death and destruction greatly exceeds that of any other natural hazard. It ranks first in catastrophe potential. It can produce in a matter of a few minutes, even in a modern American city, deaths in the tens of thousands, injuries in the hundreds of thousands, direct economic losses in the billions, and indirect losses of equal magnitude.

And I have as an example, figure 3–10, which shows estimated losses for a repeat of the 1906 San Francisco earthquake. While the pain, emotional impact, and incredible social and economic disruption resulting from such an event cannot be easily quantified, its overwhelming magnitude is beyond dispute.

And when a great earthquake strikes one of our major cities, the consequences will flow far beyond that one metropolitan area. An earthquake-crippled city such as Boston, Memphis, Los Angeles or Seattle, will produce extensive disruption in the commerce, transportation and communications of the whole region.

The threat of very large earthquake disasters grows rapidly, the relatively low-recorded losses in recent years notwithstanding. Tropical Storm Agnes, the Nation's worst disaster did $4 billion in damage; a repeat of the 1811–12 Mississippi Valley earthquake could cost over $100 billion. More than 70 million Americans live in the two highest of four seismic risk zones. Thirty-nine States are entirely or partly in areas of high or moderate seismic risk. Despite popular belief to the contrary—and if you will look at the map on display here—it is not just the West Coast States that are earthquake country. In fact, of the 18 States currently represented on the U.S. Senate Committee on Commerce, only two States lie entirely outside of the area of moderate or high seismic risk zone. Earthquakes are indeed a national problem.

Floods and hurricanes occur with greater frequency than earthquakes and thereby force us to be more aware of their threat. The infrequency of earthquakes should not be permitted to lull Congress and the American people into a false and dangerous sense of security. Earthquakes, more than any other geophysical hazard, can produce almost complete social disruption in modern urban areas because all life-supporting technologies, both above and below ground, may be shattered and rapid repair of below ground lifelines is almost impossible.

Earthquakes often result in compound disasters in which the major event triggers a second associated event. Fires are the most common but tsunamis, landslides, and flash floods from ruptured dams or reservoirs also occur.

The mechanisms used in the United States to cope with the consequences of earthquakes and tsunamis include: (1) attempts at reduction/prevention of earthquakes, per se; (2) earthquake and tsunami-resistant construction; (3) land-use management; (4) attempts to forecast, predict, and disseminate earthquake and tsunami warnings; (5) insuring structures against earthquake and tsunami damage; (6) efforts to prevent or minimize associated hazards such as floods, fire, and landslide; and (7) efforts to prepare the community to respond promptly and adequately when disaster does strike.

Public investment in research related to earthquakes has been focused primarily on geophysical, seismological, and engineering research. Only nominal amounts have been invested in research on insurance, community preparedness and the utilization of existing scientific knowledge and skills.

An analysis of significant research needs suggests that the emphasis should be shifted if economic loss and social disruption are to be reduced.

Mr. Chairman and members of the Subcommittee on Oceans and Atmosphere, a careful examination of S. 1174 shows that it is a necessary measure. It comes to grips with the everpresent threat of catastrophe. The bill offers no magic that will make the threat evaporate, but it represents an eminently wise and approximately balanced approach to the gradual but certain recuction of casulaties, destroyed structures, economic dislocation, social disruption, and psychological trauma which earthquakes produce. It recognizes that a single earthquake cannot only destroy a major city, but cripple the economy of a region for a considerable period.

The major merit of the bill is its recognition that a balanced set of mitigation measures will bring the most rapid progress. We can't move all of our cities out of areas of seismic risk, but with the application of improved microzonation information the risk of loss can be reduced through improved land-use controls.

We can't build all of our buildings to withstand the largest earthquake without damage, but we can, within the limits of economic feasibility, move toward a time when most buildings can be inhabited without any reasonable fear of their collapsing in an earthquake.

We can't at this time prevent earthquakes, but with a concerted effort we can, before many years, warn of a coming earthquake in such a manner as to bring casualties to near zero. Landslides following earthquakes may be inevitable, but ruptured dams and extensive fires need not be. All damage from earth shaking can't be prevented, but the massive economic and social disruption that follows widespread destruction can be dampened considerably.

This bill provides a much needed basis for a potentially balanced national earthquake hazard mitigation program. My concern is with funding. If this multifaceted program is authorized but given inadequate funding, the public will have been deceived. Some 70 million U.S. citizens in 39 States have a right to lowered risk from earthquakes. It will take adequate funding to make that right a reality.

Let me be more specific about the funding of a balanced program. In tables 1–1 and 1–2 of my testimony submitted for the record are some of the findings from a systematic, 3-year assessment of research on natural hazards in the United States. The assessment found that needed research funding for earthquake mitigation was second only to that of floods.

In table 1–2, we should note the current annual funding levels for each earthquake research area. Those figures represent the current balance in our national investment in earthquake-related research. The adoption and utilization aspects of the various mitigation measures are now essentially unsupported. Land-use management, insurance, community preparedness, and relief and rehabilitation measures receive only marginal attention.

The center column in table 1–2 expresses in person years of effort the additional investment, if any, which is required for a balanced national effort. Note that work on earthquake-resistant construction still receives heavy emphasis overall but would be more balanced. Land-use management would receive considerably greater emphasis as would all research related to adoption and implementation of the various mitigation measures.

Only if there is adequate funding can a balanced, effective program be developed.

In conclusion, the following points need reiteration:

One: The earthquake hazard is a significant national problem.

Two: There is a range of hazard mitigation measures now being used. The current emphasis is on the scientific and technological approach to reduction of earthquake losses.

Three: The nontechnological measures, generally undersupported currently, are the key to an improved effectiveness of the total mitigation program for the United States.

Four: The proposed bill, S. 1174, if adequately funded, provides for the development of a balanced and therefore effective program of earthquake hazard mitigation.

I thank the chairman and members of the subcommittee for the opportunity to present my views.

[The statement follows:]

STATEMENT OF J. EUGENE HAAS,[1] INSTITUTE OF BEHAVIORAL SCIENCE, UNIVERSITY OF COLORADO

Mr. Chairman, members and staff of the Senate Subcommittee on Oceans and Atmosphere. It is indeed a privilege to present testimony on the earthquake hazard in the United States.

In my testimony I will discuss the nature and extent of the earthquake hazard in the United States, outline the range of coping mechanisms or adjustments which could be used or are being applied to the earthquake hazard in the United States, and conclude by pointing to the balanced research and education effort called for by the current situation and the threat of earthquakes in the future.

But first some background information is relevant.

With Federal research funds I have been conducting research on the social and economic aspects of natural hazards and disasters for more than a decade. This work included research on the human aspects of earthquakes in the United States, Japan, Italy, Chile, El Salvador, and most recently, Nicaragua, where we conducted research on the reconstruction process following the Managua earthquake (National Science Foundation Grant #GI-39246). At the present time we are conducting research on the "Socioeconomic and Political Consequences of Earthquake Prediction" (National Science Foundation Grant #AEN-74-24079).

The earthquake hazard should be viewed in a broad context which includes consideration of other geophysical hazards as well. In a recent multidisiplinary research effort, with the help of Federal and academic scientists and administrators from the state and Federal level, we examined each of 15 geophysical hazards, including earthquakes, within a common analytical framework designed to answer the basic question: What, if anything, should the United States be doing differently to reduce the economic losses and social disruption flowing from each hazard? Much of what I am about to present reflects the findings and recommendations growing out of that comprehensive three-year effort funded by the National Science Foundation (Gilbert F. White and J. Eugene Haas, *Assessment of Research on Natural Hazards*, MIT Press, 1975).

From one perspective, earthquakes are a relatively unimportant threat in the United States. At least eight other hazards, e.g., floods, hurricanes, drought, frost, tornadoes, inflict larger mean annual property losses than do earthquakes, and seven other hazards result in a greater annual death toll.

From a different perspective, however, the great earthquake is the ultimate natural hazard. Its potential for death and destruction greatly exceeds that of any other natural hazard. It ranks *first* in catastrophe potential. It can produce in a matter of a few minutes, even in a modern American city, deaths in the tens of thousands, injuries in the hundreds of thousands, direct economic losses in the billions, and indirect losses of equal magnitude (see, for example, Figure 3-10, which shows estimated losses for a repeat of the 1906 San Francisco earthquake). The pain, emotional impact and incredible social and economic disruption resulting from such an event cannot be quantified for its overwhelming magnitude is beyond dispute.

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[1] J. Eugene Hass, Ph.D., Progessor of Sociology and head, Research Program on Technology, Environment and Man, Institute of Behavioral Science, University of Colorado, Boulder, Colorado.

And when a great earthquake strikes one of our major cities, the consequences will flow far beyond that one metropolitan area. An earthquake-crippled city such as Boston, Memphis, Los Angeles or Seattle, will produce extensive disruption in the commerce, transportation and communications of the whole region.

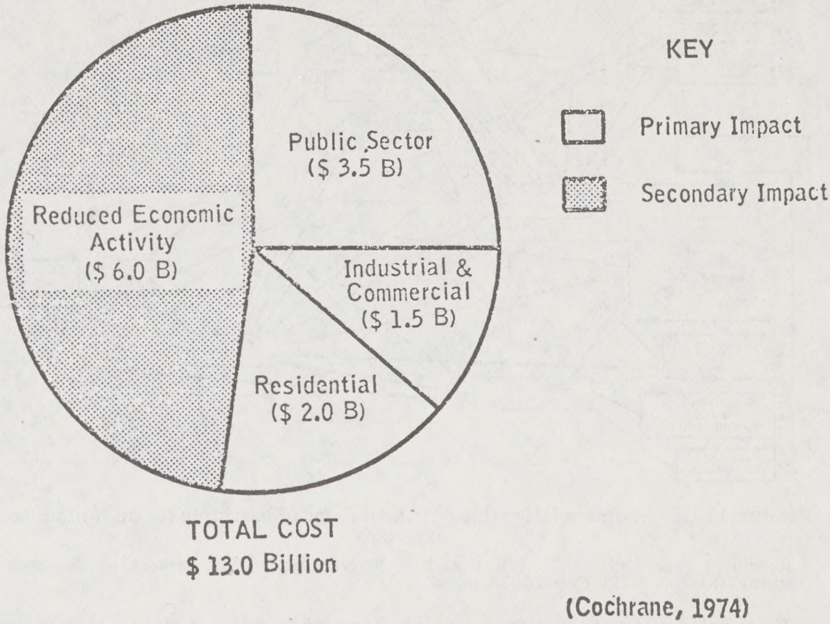



FIGURE 3–10.—Breakdown of losses from a repetition of an earthquake in San Francisco of the same magnitude of that in 1906

Reprinted from Gilbert F. White and J. Eugene Haas, "Assessment of Research on Natural Hazards," MIT Press, 1975, p. 80.

The threat of very large earthquake disasters grows rapidly, the relatively low-recorded losses in recent years notwithstanding. (Tropical Storm Agnes, the nation's worst disaster, did $4 billion in damage; a repeat of the 1811 Mississippi Valley earthquake could cost over $100 billion). More than 70 million Americans live in the two highest (of four) seismic risk zones. Thirty-nine states are entirely or partly in areas of high or moderate seismic risk. Despite popular belief to the contrary, it is not just the west coast states that are "earthquake country". In fact, of the eighteen (18) states currently represented on the United States Senate, Committee on Commerce, only two states lie entirely outside moderate or high seismic risk zones. Earthquakes are a national problem!

Floods and hurricanes occur with greater frequency than earthquakes and thereby force us to be more aware of their threat. The infrequency of damaging earthquakes should not be permitted to lull Congress and the American people into a false and dangerous sense of security. Earthquakes, more than any other geophysical hazard, can produce almost complete social disruption in modern urban areas because all life-supporting technologies, both above and below ground, may be shattered and rapid repair of below ground lifelines is almost impossible.

Earthquakes often result in compound disasters in which the major event triggers a secondary associated event. The secondary event may be natural, may result from the failure of some man-made system, or may be a combination of both. In some cases, the secondary event may overshadow the major triggering event in casualties and damage (see Figure 11–12).

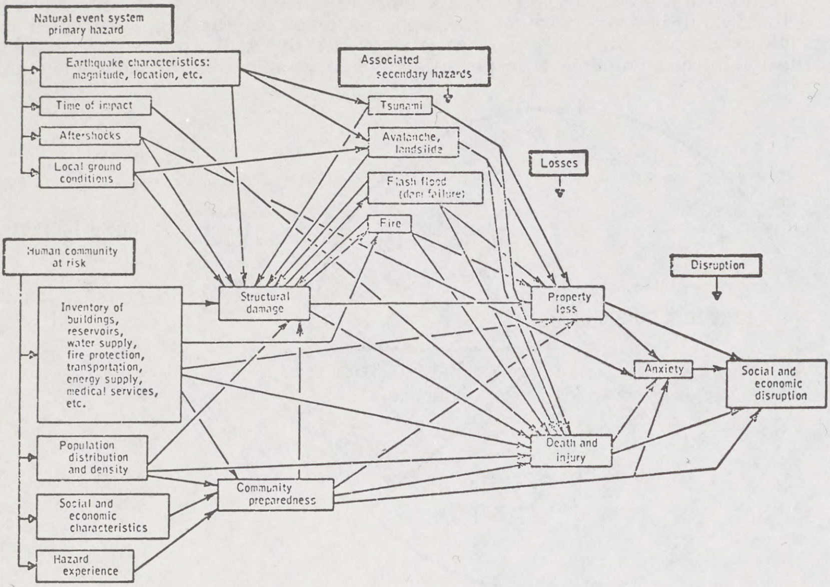



FIGURE 11–12.—Some relationships of the impact of earthquakes on human social systems

Reprinted from Gilbert F. White and J. Eugene Haas, "Assessment of Research on Natural Hazards," MIT Press, 1975, p. 322.

Fire is the greatest secondary hazard. More than 80% of the total damage in San Francisco during the disaster of 1906 has been attributed to fire, and the Managua disaster in 1972 also involved devastating fires. The greatest disaster in this century due to the compounding of earthquake and fire was undoubtedly that at Tokyo in 1923, in which some 100,000 lives were lost.

The compound disaster of an earthquake and a resulting tsunami has been rare on this continent, but the event in Alaska in 1964 indicates that it can occur in the United States.

A flash flood may result from an earthquake-caused dam failure. Flooding was narrowly averted in the partial failure of earth dams at the Van Norman Lakes during the San Fernando earthquake of 1971. A massive slope failure occurred in the lower dam, and the fact that the reservoir behind it was only about one-half full probably prevented a disastrous flash flood. The potential for disaster resulted in the evacuation of an estimated 80,000 people.

Other associated hazards which are often triggered by earthquakes are landslides and avalanches, as was the case at Hebgen Lake, Montana, and in Alaska in 1964. The most recent major disaster of this sort which occurred in Peru in 1970, resulted in about 70,000 fatalities. Disasters combining erathquakes and landslides could occur in localized areas of overdevelopment on the coast of California.

When an earthquake hits a community, individuals suffer physical deprivation, psychological trauma, pain, and death. Family life patterns are altered for weeks, or even months, as the economic loss and physical dislocation take their toll on the social web into which each family was embedded.

A few business organizations profit from an earthquake or tsunami-produced disaster, but many more businesses suffer economic loss. Many other organizations are seriously disrupted. Loss and disruption at the family and organization level take their toll on the community as a total system. Needs for most governmental services increase drastically while the tax base is reduced and perhaps decimated. Many of the usual concerns and activities that make a community a humane place have to be set aside during the emergency and early restoration periods. Reconstructing an earthquake devastated area is a slow, costly and conflict-laden process (J. Eugene Haas, Robert W. Kates, and Martyn J. Bowden, *Reconstruction Following Disaster*, MIT Press, forthcoming).

## RANGE OF ADJUSTMENTS

Mechanisms used in the United States to cope with the consequences of earthquakes and tsunamis include: (1) attempts at reduction/prevention of earthquakes per se; (2) earthquake and tsunami-resistant construction; (3) land use management; (4) attempts to forecast and disseminate earthquake and tsunami warnings; (5) insuring structures against earthquake and tsunami damage; (6) efforts to prevent or minimize associated hazards such as fire and landslide; and (7) efforts to prepare the community to respond promptly and adequately when disaster does strike.

Public investment in research related to earthquakes and tsunamis has been focused primarily on geophysical, seismological, and engineering research. Only nominal amounts have been invested in research on insurance, community preparedness and the utilization of existing scientific knowledge and skills.

An analysis of significant research needs suggests that the emphasis should be shifted if economic loss and social disruption are to be reduced.

### *Land use management*

Of all the potential mechanisms to cope with earthquakes, the simplest and most direct would be the avoidance of high-risk areas wherever economically practicable. However, cities cannot be relocated, and many undeveloped high-risk areas may be potentially very valuable. The degree of risk is not always obvious. Several courses of action are indicated: (1) risk zoning of critical parts of the already developed areas to turn them into park land or other nonhazardous use as opportunity arises; (2) risk zoning of high-risk undeveloped areas to prevent future hazardous development; and (3) development of systematic techniques for collection and evaluation of data for use in microzoning (zoning of comparatively small areas), and the establishment of criteria for microzone levels of risk.

Research should be done on microzoning procedures with some detailed case studies, collection of local seismicity data and local fault mapping as needed, and the identification of especially hazardous areas, including potential landslides and soil liquefaction.

But all that information on the location and character of risk areas is of little value unless it results in lowered damages. Research designed to point out ways in which restriction of building in fault zones might be encouraged and adopted is also required. Land use decisions are local decisions and very little is known about how and why some communities come to adopt and enforce land use practices that significantly reduce expected losses.

It is important to learn what incentives lead to improved zoning practices, especially for structures and facilities of vital importance. Social, political and economic constraints to improved land use management need to be assessed, as well as the longer-term consequences of such changed practices.

Research on zoning and subdivision regulation can be combined, in certain instances at least, with experimental research on building code adoption. Undeveloped areas subject to high seismic activity could be used for certain economically feasible purposes if improved building codes were first adopted and used as a basis for seismic-resistant design.

### *Earthquake-resistant structures*

Few structures can be made completely earthquake-proof, especially against the shaking produced by giant earthquakes. Most buildings can be designed and constructed to resist significant structural damage, the possibility of total collapse. Loss of life and injury can be greatly reduced.

Most of the research attention to date, the largest single program in the natural hazards field, has been applied to the more spectacular and analytically interesting types of structures; for example, many-storied buildings, large dams, nuclear power palnts, and storage tanks. Relatively little attention has been paid to lesser structures, including the ordinary single-family dwelling.

Engineering research is needed on: (1) development of continuity in structural systems; (2) earthquake resistance of low buildings; (3) overall safety of multistoried buildings, including structural integrity, safe evacuation routes and fire resistance; and (4) overall safety of dams and the valley below, and restrictions on land use in areas subject to flooding. Research is also needed for greater understanding of foundation conditions.

The upgrading of building codes should be studied in light of the fact that estimates of increased costs to *new* construction rarely exceed 6% of the total cost of the structure. Building codes for all classes and structures and the political, social and economic constraints to their adoption and enforcement should be considered.

Some high-risk cities appear to be significantly more progressive in the upgrading of building codes than other cities. If this is true, a series of comparative case studies would provide answers on how this upgrading takes place, and what the secondary consequences are. Experimental efforts should be made to provide incentives to the local powers who could influence building code upgrading. For example, communities could be identified where the mortgage lenders are somewhat progressive. A small team of professionals (economists, structural engineers) could carry out a careful effort to demonstrate to the lenders why supporting an improved building code would be in their own best interest. Other approaches could be tried in other cities to see which approach was most effective in producing the desired change.

Old buildings probably present the most difficult problem of all. They may be lucrative rental property or tax write-offs for the owners, homes and community foci for a great number of persons who cannot or will not live anywhere else, and may also be potential death traps due to the danger of collapse or fire. The two general classes of problems concern the physical condition of the structures and the social and economic constraints on doing anything about the conditions.

Research is needed which will contribute to quicker adoption of policies that will sharply reduce the risk from old buildings. Economic constraints to the phasing out of dangerous structures include not only costs to the individual owner, community, state, or Federal subsidies, but also shifts in the tax base. Social costs include the disruption of established neighborhoods, a possible rise in social instability associated with urban renewal, and the problems inherent in the relocation of families and businesses.

It is difficult to estimate how dangerous a threat older buildings pose to lives and property. Study is needed to determine the risk they present, as well as how this risk might be lessened. Such work might start by determining how many old buildings exist in hazardous areas, as well as their conditions and use patterns. Of those that are dwelling units, knowledge of their inhabitant density would clarify the degree of risk they present. Research should be designed to determine how the risk might be reduced. Determination of their natural rate of abandonment could be followed by an investigation of how that rate might be affected and what would be the cost of remodeling appropriate structures to some level of acceptable safety. All alternatives should be examined. In addition to alternatives for reducing the risk, the research should address the social, economic, and political constraints to the adoption of each alternative.

*Earthquake prediction and its consequences*

Specific forecasts of damaging earthquakes may be available in less than a decade, and possibly next year. Specific forecasts of damaging earthquakes will have lead times on the order of a few months to ten years, and will be relatively specific as to location and magnitude. Such forecasts are qualitatively different from those used in other hazard warning systems because the extended lead times allow a variety of developments to occur between warning and impact.

A reliable method of reasonably precise prediction, with a low false alarm rate, could significantly reduce earthquake casualties, greatly reduce psychological trauma and permit modest reductions in property losses. Research underway suggest that earthquake prediction will have additional large-scale impacts, some of which will be positive and others negative.

Earthquake prediction will be no panacea. A reliable method of reasonably precise prediction will permit only modest reductions in property losses. It will not be feasible to strengthen most structures after a prediction is out. There are three significant justifications for earthquake prediction, however. The saving of life and the reduction of injuries is by far the most important. Recently in the People's Republic of China, tens of thousands of lives were saved as a result of a successful prediction. Second is the avoidance of the social disruption and psychological trauma of living through a damaging earthquake. Finally, an earthquake prediction with extended lead time allows for the orderly planning for the reconstruction of the earthquake-stricken city.

A great deal is yet to be learned about how public officials, legislative bodies, private organizations and average citizens will respond to a scientifically based earthquake prediction. It is clear, however, that there will be large negative economic impacts on the area for which the prediction applies. The availability or unavailability of earthquake insurance appears to be the key factor determining whether there will be a large local economic recession in the face of an earthquake prediction. There will be enormous legal problems centering on liability.

The potential benefits from an earthquake prediction are very great, but so, apparently, are the disbenefits. Research to improve the predictive capability should be stepped up but only if there is also increased emphasis on research and education in how best to utilize that predictive capacity while minimizing the negative impacts. It is possible that without adequate preparation the economic losses from an earthquake prediction may be as large as the economic losses from the earthquake itself.

*Insurance*

While insurance against earthquake damage is generally available, relatively few policies are sold. In California less than 5% of the property insured against fire is also insured against earthquakes, and the percentage is even smaller in Alaska.

The reasons for this low rate of adoption should be analyzed. Insurance companies are concerned about the possibility of severe losses. The industry now is handicapped by lack of a sound reinsurance program. The low rate of adoption may also result from insufficient awareness of the earthquake hazard, or misinformation on the availability of coverage and the rates.

Insurance could be the most important economic stabilizer in a community to which an earthquake prediction applies. New earthquake insurance policies will not be available at that time. Research is needed now into the economic and political feasibility of policies and programs to make some sort of financial back-up available to property owners who face an impending predicted earthquake.

So long as the insurance adoption rate remains below a socially desirable rate, these issues will require probing.

*Community preparedness*

Community preparedness for earthquake disasters is vital for adequate community response, especially since secondary hazards such as fire require immediate attention after an earthquake. In most communities, however, present levels of preparedness fail to provide for all the eventualities of an earthquake disaster. Research should be conducted on how emergency planning and levels of preparedness could be improved. Research should also be conducted on the long-range social costs of relief and rehabilitation programs in which costs are defined more broadly than those involving administrative organizations. It would examine the extent to which present loan and grant practices are successful in aiding individual recovery and which aid programs retard the adoption of other adjustments, thereby possibly increasing the hazard potential in an area. It should be possible to restructure present programs to improve the character of the services offered. In selected communities relief efforts could be assessed for long-term social and economic costs and interaction with the adoption of other adjustments. The study would also determine the major policy issues involved in implementing the adjustment and their effects on economic costs, social disruption, and the speed of recovery.

More specific case studies of earthquake impact could contribute needed baseline data that would be relevant to many of the adjustments to earthquakes, as well as to other lines of hazard research. The most efficient and fruitful way to perform the studies is through the organization of interdisciplinary postdisaster field teams. Such a comprehensive effort should also: 1) develop a methodology for estimating earthquake loss (social, economic and political); 2) document comprehensive interdisciplinary field observations; 3) maximize information flow to responsible officials; and 4) develop comprehensive field research techniques.

*Earthquake reduction*

The general aim of earthquake reduction is to release by physical means the energy in relatively small steps to bring about many small earthquakes, rather than one or a few major earthquakes. There are unevaluated risks in attempting to reorder the forces of nature; there is no certainty that attempts to trigger small earthquakes will not release a large one, nor is it known to what extent the results of experiments conducted in one geological area can be applied to another.

Earthquake reduction is an ongoing field of geophysical and engineering research which may have potential long-term benefits, but its ultimate success can not be predicted at this time. Such research should be done with provision for an interdisciplinary research program, including investigation of the social and economic consequences of earthquake reduction. If and when techniques for earthquake reduction become feasible, knowledge will be needed on how those techniques might be implemented. If many small earthquakes cost less socially and economically than one or a few large ones, questions of implementation become paramount.

Research should focus on the constraints operating to thwart implementation, and the means by which these may be overcome. The economic consequences should be addressed. If an area were to shut down temporarily in order to accommodate a series of artificially triggered, small earthquakes, what would the costs and effects be? It would be desirable to analyze how conflict between special interest groups might be resolved, the amount and cost of any resultant social disruption, and the level and structure of necessary community preparedness. The political implications of implementation and liability for damages should also be addressed. It should also look into the means for implementation, to indicate who would decide when such an event would occur.

## CONCLUSIONS

Mr. Chairman and members of the Subcommittee on Oceans and Atmosphere, a careful examination of S. 1174 shows that it is a necessary measure. It comes to grips with the ever-present threat of catastrophe. The bill offers no magic that will make the threat evaporate, but it represents an eminently wise and approximately balanced approach to the gradual but certain reduction of casualties, destroyed structures, economic dislocation, social disruption and psychological trauma which earthquakes produce. It recognizes that a single earthquake cannot only destroy a major city, but cripple the economy of a region for a considerable period.

The major merit of the bill is its recognition that a balanced set of mitigation measures will bring the most rapid progress. We can't move all of our cities out of areas of seismic risk, but with the application of improved microzonation information the risk of loss can be reduced through improved land use controls. We can't build all of our buildings to withstand the largest earthquake without damage, but we can, within the limits of economic feasibility, move toward a time when most buildings can be inhabited without any reasonable fear of their collapsing. We can't, at this time, prevent earthquakes, but with a concerted effort we can, before many years, warn of a coming earthquake in such a manner as to bring casualties to near zero. Landslides following earthquakes may be inevitable, but ruptured dams and extensive fires need not be. All damage from earth shaking can't be prevented, but the massive economic and social disruption that follows widespread destruction can be dampened considerably.

This bill provides a much needed basis for a potentially balanced national earthquake hazard mitigation program. My concern is with funding. If this multifacited program is authorized but given inadequate funding, the public will have been deceived. Seventy million U.S. citizens in 39 states have a right to lowered risk from earthquakes. It will take adequate funding to make that right a reality.

Let me be more specific about the funding of a balanced program. Here in Tables 1–1 and 1–2 are some of the findings from a systematic, three-year assessment of research on natural hazards in the United States. The assessment found that needed research funding for earthquake mitigation was second only to that of floods.

TABLE 1–1.—*Summary of needed research expenditures:*[1] *Recommended levels of U.S. research effort for 15 geophysical hazards*

[Estimated professional person-years of effort over 10-year period]

| | |
|---|---|
| Geophysical hazard: | |
| Flood | 893 |
| Earthquake and tsunami | 815 |
| Drought | 547 |
| Volcano | 381 |
| Hurricane | 293 |
| Tornado | 260 |
| Coastal erosion | 238 |
| Hail | 175 |
| Landslide | 158 |
| Frost | 140 |
| Snow avalanches | 100 |
| Lightning | 85 |
| Windstorm | 62 |
| Urban snow | 15 |
| Total | 4, 162 |

[1] Extracted from Gilbert F. White and J. Eugene Haas, "Assessment of research on Natural Hazards," MIT Press, 1975, p. 27.

TABLE 1-2.—SUMMARY OF RESEARCH OPPORTUNITIES IN RELATION TO CURRENT (1974) LEVELS OF FUNDING[1]

| Hazard and research opportunities sets | Current annual funding level[2] | Suggested additional person-years total[3] | Time horizon in years |
|---|---|---|---|
| Earthquake: | | | |
| Earthquake reduction: | | | |
| Geophysical and engineering | 3 | (4) | 10 |
| Adoption processes for new techniques | 0 | 25 | 5 |
| Earthquake-resistant construction: | | | |
| Analysis, design of building codes | 4 | 200 | 10 |
| Code implementation | 0 | 25 | 5 |
| Old building treatment | 0 | 100 | 10 |
| Code adoption processes | 0 | 30 | 5 |
| Land use management: | | | |
| Seismic risk zoning studies | 1 | 200 | 10 |
| Zoning adoption processes | 0 | 40 | 5 |
| Prediction and warning: | | | |
| Geophysical aspects | 4 | P | 10 |
| Warning system implementation | 0 | 50 | 5 |
| Insurance: | | | |
| Adoption processes | 1 | 10 | 5 |
| All-risk insurance | 0 | 20 | 5 |
| Community preparedness, relief and rehabilitation: | | | |
| Microstudies of vulnerability | 1 | 30 | 5 |
| Preparedness studies | 1 | 25 | 5 |
| Processes and socioeconomic effects | 0 | 25 | 5 |
| Total | | 780 | |

[1] Extracted from Gilbert F. White and J. Eugene Haas, "Assessment of Research on Natural Hazards," MIT Press, 1975, pp. 419–420.
[2] 0=No expenditure or less than $10,000; 1=$10,000 to $100,000; 2=$100,000 to $1,000,000; 3=$1,000,000 to $2,000,000; 4=Greater than $2,000,000.
[3] Estimates are for the total number of person-years over a period of 10 years: some projects may run only 1 year, others as long as 10 years.
[4] Program underway could include suggested work.

In Table 1–2, note the current annual funding levels for each earthquake research area. Those figures represent the current balance in our national investment in earthquake-related research. The adoption and utilization aspects of the various mitigation measures are essentially unsupported. Land use management, insurance, community preparedness and relief and rehabilitation measures receive only marginal attention.

The center column expresses in person years of effort the additional investment, if any, which is required for a balanced national effort. Note that work on earthquake-resistant construction still receives heavy emphasis overall but would be more balanced. Land use management would receive considerably greater emphasis as would all research related to adoption and implementation of the various mitigation measures.

Only if there is adequate funding can a balanced, effective program be developed.

In conclusion, the following points need reiteration:

1. The earthquake hazard is a significant national problem.

2. There is a range of hazard mitigation measures now being used. The current emphasis is on the scientific and technological approach to reduction of earthquake losses.

3. The nontechnological measures, generally undersupported currently, are the key to an improved effectiveness of the total mitigation program for the United States.

4. The proposed bill, S. 1174, if adequately funded, provides for the development of a balanced and therefore effective program of earthquake hazard mitigation.

I thank the Chairman and members of the Subcommittee for the opportunity to present my views.

TABLE 11-11.—RESEARCH OPPORTUNITIES—EARTHQUAKE

| Research opportunity | National aims | | | | | | | | Research findings | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Economic efficiency, reduction of net losses, benefits-costs | | Enhancement of human health, reduction of casualties | | Avoidance of social disruption | | Environment, protection or enhancement | Equity, distribution of costs and benefits | Expected success of research | Likelihood of adoption |
| | Average | Catastrophic | Average | Catastrophic | Average | Catastrophic | | | | |
| Earthquake reduction: Geophysical and engineering; adoption of techniques. | Medium | Low to negative. | Medium | Low to negative. | Low | Low to negative. | Not available | Not available | Low | Low. |
| Earthquake-resistant construction: analysis, design of building codes; code implementation and adoption; old building treatment. | High | High | High | High | High | High | do | Low | High | Medium. |
| Forecast and warning: geophysical aspects; detection, dissemination and response. | Low | Medium to high. | do | do | Low to high | Low to high | do | Negative to low. | Medium | High. |
| Land use management: Seismic risk zoning studies; zoning adoption. | Medium to high. | do | Medium | Medium | Medium | Medium | Medium | Not available | do | Low. |
| Insurance: Adoption processes; all-risk insurance. | Low to medium. | do | Low | Low | do | Low | Not available | Medium | do | Medium. |
| Relief and rehabilitation: Microstudies of vulnerability; community preparedness studies; relief processes and socioeconomic effects. | Low | Low | Medium | Medium | do | do | do | High | High | Do. |

Source: Reprinted from Gilbert F. White and J. Eugene Haas, "Assessment of Research on Natural Hazards," MIT Press, 1975, p. 337.

Senator Cranston. May I interrupt for a moment? We have the same problem again: There is a rollcall. I will be back and please wait, because I want to ask you some questions.

Mr. Flajser. Senator Cranston has requested that we continue with Dr. Turner's testimony, and shortly the chairman will be back to pose questions.

## STATEMENT OF RALPH H. TURNER, PROFESSOR OF SOCIOLOGY, UNIVERSITY OF CALIFORNIA, LOS ANGELES

Dr. Turner. Mine is some direct reading and some summary of my testimony.

When the prospect of an earthquake prediction capability became credible and imminent in 1973, seismologists and others quickly recognized that the usefulness of predictions will depend upon how the community receives and acts upon them. What kinds of individual and community response to the published prediction of a potentially destructive earthquake might be expected, and how a community could be organized so as to reduce the death and destruction when the quake occurred are distinctively problems for social scientists.

Accordingly, a panel on the public policy implications of earthquake prediction was established within the National Academy of Sciences to complement the work of seismologists, geologists, and earthquake engineers. Sociologists, economists, and political scientists worked with officials experienced in emergency preparedness programs, and with lawyers and earthquake scientists to prepare tne report that you may have seen, entitled "Earthquake Prediction and Public Policy." I shall not attempt to summarize the report's many conclusions and recommendations for action. But I shall outline a few of the most significant and urgent items of unfinished business that we now face as a consequence of the new earthquake prediction capability.

It is important to realize that we cannot simply apply experience already gained in dealing with warnings of tornadoes, hurricanes, and floods, because of several unique features of earthquake prediction. The anticipated period of weeks, months, or years of advance warning for an earthquake creates both opportunities and perils that are lacking when warning times are briefer.

The absence of external signs by which people can personally confirm the scientists' prediction—like the funnel cloud or the rising water level in a river—will make it more difficult for people to believe and act on the prediction. The usual period of decades between dsetructive quakes in any locality will prevent the accumulation of personal experience as a guide to action, such as we find when there is an annual season—for tornadoes, hurricanes, forest fires, or similar threats.

The difference between effective and ineffective response to prediction can be great. The panel estimates that—

> Under the worst combination of an inaccurate prediction and an inappropriate public response, the prediction and quake together might even be more costly than an unpredicted quake would have been.

On the other hand, a well-considered response could save several thousand lives in a serious quake. To reap maximum benefits from earthquake prediction we must develop plans now so that they can be put into effect immediately when a significant prediction is issued. In order to plan wisely, we need to plug the crucial gaps in our understanding of the potential social and economic consequences of an earthquake prediction. I shall discuss a few of the areas in which coordinated planning and research are urgently needed.

The first area includes releasing the prediction and issuing the warning to the public. Evidence before the panel convincingly disposed of the specter of mass panic as a gross misconception. But three realistic problems of credibility, mobilization and timely information flow require attention. People often disbelieve even scientifically generated forecasts of danger, especially when they are stated as probabilities rather than absolutes, when the danger seems remote in time, and when they are confused by deliberate efforts to discredit the forecast.

Experience with diverse hazards to human well-being has also documented a familiar pattern of inaction in the face of threat, a disposition to cling to "life as usual."

Panel investigations also reveal that the problem is complicated by a tendency at every stage to delay informing the public of danger and to suppress the most troubling information, which leads to information leaks that distort the truth and create widespread distrust. If we are to combat the problems of credibility, the problems of inaction, and the problems of delay and distortion of information, we are going to require a concerted program of study of the social factors that account for these difficulties.

Closely related to this is the problem that some call "acceptable risk." People routinely accept high levels of risk in some activities while demanding that risk be minimized in others. Safety campaigns often fail because they are uninformed about public willingness to accept certain risks. There has been no systematic study of public acceptance of earthquake risk.

The second crucial area for planning in advance of the first serious earthquake prediction is the economic impact of the prediction on the community. Economists consulted by the panel agreed that long periods of advance warning will probably trigger substantial economic readjustments in threatened communities. It is reasonable to speculate that the issuance of new mortgages, the sale of insurance, and capital investment in the threatened area would be curtailed, and some outmigration and decline of tourist trade might occur. These and similar developments would lead to rising unemployment and declining property values, which, in turn, mean lost tax revenue just when the burdens of local governments are becoming heavier.

My associated witness here, Professor Haas, has made one of the first concrete attacks on the problem of estimating what these economic effects would be. We need, however, to go on beyond Professor Haas' work, in particular to explore the potential impact of various countermeasures that might be useful in stabilizing the local economy or in saving the individual wage earner or businessman from economic disaster.

For example, to what extent could a program of low-cost Federal loans and outright grants for reinforcing or demolishing unsafe structures compensate for declining building activity brought on by the earthquake warning? Are there practical incentives that would motivate business officials to accept temporary losses in order to sustain their position in the postquake era?

Legal aspects of earthquake prediction constitute a third, urgent field for planning and investigation. In the opinion of the lawyer serving on the panel, litigation might well stall efforts to apply hazard-reduction measures until too late, even with several years of advance warning. Because of the unique features of earthquake prediction, applicable precedents in law are often unclear.

Since the greatest danger in earthquakes is from the collapse of human structures, hazard mitigation is largely a matter of condemning or otherwise interfering with normal use of buildings, many of which are privately owned. Hence the relative claims of public safety and private ownership are often in contention.

It is plain that all our efforts to develop the earthquake prediction capability may go for naught if we do not promptly organize a careful study of relevant legislation, identifying the points at which clarifying legislation is needed, and enacting new legislation as appropriate.

Inequitable effects of prediction constitute a fourth area of urgent concern. We already know that disasters often strike the poor, the disabled, and the otherwise disadvantaged more severely than other populations.

Studies of other forms of natural disaster have shown that some population segments, by virtue of social isolation or language barriers, often fail to receive warnings at all. Past experience of neglect or exploitation has disposed some poor and ethnic population groups to be suspicious of all efforts to bring their housing up to acceptable safety standards or to relocate them to safer parts of the community.

Only through careful study and planning before the emergency actually confronts us can we hope to develop guidelines that will assist public and private leaders to avoid creating new inequities in the course of responding to an earthquake warning.

A fifth set of problems concerns the feasibility of various hazard-reduction strategies and measures. We have already noted that some measures may not be legally feasible. Some measures will be infeasible because of cost or because of social implications. Evacuation is one obvious measure to explore as a response to earthquake prediction.

We believe that large-scale evacuation is usually impractical, but that discriminating use of evacuation on a limited scale can result in substantial saving of lives. However, in order to deal with the social difficulties created by evacuation, public officials will need carefully developed guidelines concerning feasibility.

When the warning comes a few years before the quake, revised and accelerated land-use planning, strict enforcement of building codes, and selective demolition and upgrading of hazardous structures offer great promise for hazard reduction. But costs may be astronomical. Here we need accurate estimates of probable cost under various conditions, determination of resources that might be available, and consideration of possibilities for amortizing costs over the years of land stability that usually follow the quake and its aftershocks.

A critical question here is the extent to which aid that would normally be available to a community for relief and rehabilitation after a disaster can be made available for hazard-reduction activities before the disaster, on the basis of an authenticated prediction.

In spite of all that can be accomplished in these five crucial areas of planning and research, much will still remain to be learned from the first few experiences with actual prediction of a potentially destructive earthquake. But we must be prepared to learn the most from each experience.

We should already be recording baseline social and economic data in communities where predictions are most likely to be made, and developing standby plans for research to be activated when the first prediction begins to materialize. In order to make up for the fortunate infrequency of destructive earthquakes in the United States, we must also monitor the experience with prediction in other countries such as China, Japan, and the Soviet Union.

The main thrust of my testimony has been to indicate the weight of social and economic planning and investigation that should be undertaken as promptly as possible if we are to reap the full benefit from the new earthquake prediction capability. With this kind of advance preparation, an earthquake prediction should enable us to save many lives and reduce property loss when the earthquake strikes.

Thank you.

[The statement follows:]

Statement of Ralph H. Turner, Professor of Sociology, U.C.L.A.; and Chairman, Panel on Public Policy Implications of Earthquake Prediction, National Academy of Sciences

When the prospect of an earthquake prediction capability became credible and imminent in 1973, seismologists and others quickly recognized that the usefulness of predictions will depend upon how the community receives and acts upon them. What kinds of individual and community response to the published prediction of a potentially destructive earthquake might be expected, and how a community could be organized so as to reduce the death and destruction when the quake occurred are distinctively problems for social scientists. Accordingly, a Panel on the Public Policy Implications of Earthquake Prediction was established within the National Academy of Sciences to complement the work of seismologists, geologists, and earthquake engineers. Sociologists, economists, and political scientists worked with officials experienced in emergency preparedness programs, and with lawyers and earthquake scientists to prepare the report that you may have seen, entitled *Earthquake Prediction and Public Policy*. I shall not attempt to summarize the Report's many conclusions and recommendations for action. But I shall outline a few of the most significant and urgent items of unfinished business that we now face as a consequence of the new earthquake prediction capability.

It is important to realize that we cannot simply apply experience already gained in dealing with warnings of tornadoes, hurricanes, and floods, because of several unique features of earthquake prediction. The anticipated period of weeks, months, or years of advance warning for an earthquake creates both opportunities and perils that are lacking when warning times are briefer. The absence of external signs by which people can personally confirm the scientists' prediction—like the funnel cloud or the rising water level in a river—will make it more difficult for people to believe and act on the prediction. The usual period of decades between destructive quakes in any locality will prevent the accumulation of personal experience such as guides people who live where there is an annual season for tornadoes, hurricanes, forest fires, or similar threats.

The difference between effective and ineffective response to prediction can be great. The Panel estimates that "Under the worst combination of an inaccurate prediction and an inappropriate public response, the prediction and quake together might even be more costly than an unpredicted quake would have been" (p. 3). On the other hand, a well considered response could save several thousand lives in a serious quake. To reap maximum benefits from earthquake prediction, we must develop plans now so that they can be put into effect immediately when a significant prediction is issued. In order to plan wisely, we need to plug the crucial gaps in our understanding of the potential social and economic consequences of an earthquake prediction. I shall discuss a few of the areas in which coordinated planning and research are urgently needed.

The first area includes releasing the prediction and issuing the warning to the public. Evidence before the Panel convincingly disposed of the spectre of mass panic as a gross misconception. But three realistic problems of credibility, mobilization, and timely information flow require attention. People often disbelieve even scientifically generated forecasts of danger, especially when they are stated as probabilities rather than absolutes, when the danger seems remote in time, and when they are confused by deliberate efforts to discredit the forecast. But there are ways to make predictions more credible than otherwise, and we urgently need to explore alternative procedures. Experience with diverse hazards to human well-being has also documented a familiar pattern of inaction in the face of threat, a disposition to cling to life-as-usual. Again, there are more and less effective ways to mobilize communities into action. The sources of resistance to action must be understood so that each can be dealt with constructively. Sometimes the problem is distrust of public leaders or scientists. Often past experience leads to a conviction that others will benefit at the expense of those who cooperate. Frequently inaction results from the absence of alternatives that are realistic from the standpoint of the populations affected. Action strengthens belief: inaction fosters disbelief! We must work to facilitate both belief and action.

Panel investigations also reveal that the problem is complicated by a tendency at every stage to delay informing the public of danger and to suppress the most troubling information. Delay and suppression inevitably mean information-leaks that distort the truth and create wisespread distrust. They also lessen the time available for taking hazard-reducing steps, and often permit people with inside information to benefit at the expense of the uninformed. If we are to combat this ubiquitous tendency, we must understand the sources of reluctance to release information and weigh the merits of alernative strategies in dealing with it.

Closely related to the problems of securing belief and active cooperation with disaster warnings is the familiar question of *acceptable risk*. People routinely accept high levels of risk in some activities while demanding that risk be minimized in others. Safety campaigns often fail because they are uninformed about public willingness to accept certain risks. There has been no systematic study of public acceptance of earthquake risk.

The second crucial area for planning in advance of the first serious earthquake prediction is the economic impact of the prediction on the community. Economists consulted by the Panel agreed that long periods of advance warning will probably trigger substantial economic readjustments in threatened communities. Financial panic was judged unlikely: local economic recessions were considered quite probable. It is reasonable to speculate that the issuance of new mortgages, the sale of insurance, and capital investment in the threatened area would be curtailed, and that some outmigration and decline of tourist trade might occur. These and similar developments would lead to rising unemployment and declining property values, which in turn mean lost tax revenue just when the burdens on local governments are becoming heavier. But such economic readjustments as these will only come as a result of complex chains of interdependent decisions, made at all levels from national corporation headquarters to local private households. Economists are loath to predict the pattern of economic response until these decision-making patterns have been explored in detail in the context of earthquake prediction.

One of the first concrete attacks on this problem is being made by Professor Eugene Haas of the University of Colorado, who is interviewing business and financial leaders in selected California communities. Their serious judgments of how their own business establishments would respond in case an earthquake of specified magnitude were predicted have been extrapolated to create some preliminary estimates of the extent of economic decline that could be anticipated. In order to refine these estimates and supply more useful information for officials who must guide communities through the earthquake warning period, we must employ a variety of investigative strategies. In particular, we must explore the potential impact of various counter-measures that might be useful in stabilizing the local economy or in saving the individual wage earner or businessman from economic disaster. To what extent could a program of low-cost federal loans and outright grants for reinforcing or demolishing unsafe structures compensate for declining building activity brought on by the earthquake warning? Are there practical incentives that would motivate business officials to accept temporary losses in order to sustain their position in the post-quake era?

Legal aspects of earthquake prediction constitute a third urgent field for planning and investigation. In the opinion of the lawyer serving on the Panel, litigation might well stall efforts to apply hazard-reduction measures until too late, even with several years of advance warning. Because of the unique features of earthquake prediction, applicable precedents in law are often unclear. The Panel could not even secure a confident determination of whether the prediction of a potentially destructive earthquake would constitute an emergency under the terms of the Disaster Relief Act of 1974 (PL 93-288). The relatively long periods of advance warning, coupled with probablistic rather than absolute prediction, make the sense in which a prediction constitutes an emergency unclear.

Since the greatest danger in earthquakes is from the collapse of human structures, hazard mitigation is largely a matter of condemning or otherwise interfering with normal use of buildings, many of which are privately owned. Hence the relative claims of public safety and private ownership are often in contention. It is plain that all our efforts to develop the earthquake prediction capability may go for nought if we do not promptly organize a careful study of relevant legislation, identifying the points at which clarifying legislation is needed, and enacting new legislation as appropriate.

Closely related are problems of jurisdiction and coordination among government units. An earthquake of destructive magnitude will usually affect dozens of local government units, besides state or federal jurisdictions. There are different views concerning the responsibilities of state and federal officials in issuing warnings. The United States Geological Survey made a good beginning by bringing together selected state and local officials from the most earthquake-prone states last November. But much careful investigation and planning is required if we are to clear the way for prompt and decisive action when a prediction is first released.

Inequitable effects of prediction constitute a fourth area of urgent concern. We already know that disasters often strike the poor, the disabled, and the otherwise disadvantaged more severely than other populations. In San Francisco today there is a disproportionate concentration of the poor and elderly in the "Tenderloin" district, where earthquake danger is especially high and where many buildings are of an outdated, unreenforced brick construction. Studies of other forms of natural disaster have shown that some population segments, by virtue of social isolation or language barriers, often fail to receive warnings at all. Past experience of neglect or exploitation has disposed some poor and ethnic population groups to be suspicious of all efforts to bring their housing up to acceptable safety standards or to relocate them to safer parts of the community. In the rush to foster the general welfare once a prediction is at hand, it will be easy to overlook these inequities. Only through careful study and planning before the emergency actually confronts us can we hope to develop guidelines that will assist public and private leaders to avoid creating new inequities in the course of responding to an earthquake warning.

A fifth set or problems concerns the *feasibility* of various hazard-reduction strategies and measures. We have already noted that some hazard-reduction measures may not be legally feasible. Some measures will be lnfeasible because of cost or because of social implications. Evacuation is one obvious measure to judgment that large-scale evacuation will usually be impractical for a variety of reasons, but that discriminating use of evacuation on a limited scale can result in substantial saving of lives. But previous experience has indicated that evacuation can have adverse effects when family members are separated, when the people moved are emotionally rooted to their homes, when evacuees are preoccupied with pressing responsibilities they have left behind, and when evacuation is disruptive to the host communities. Structures will often have to be vacated, but can sometimes become even more hazardous when they are unused. Public officials will need carefully developed guidelines concerning evacuation feasibility and the care of vacated buildings that are left standing.

When the warning comes a few years before the quake, revised and accelerated land use planning, strict enforcement of building codes, and selective demolition and upgrading of hazardous structures offer great promise for hazard reduction. But costs may be astronomical. Here we need accurate estimates of probable cost under various conditions, determination of resources that might be available, and possibilities for amortizing costs over the years of land stability that usually follow the quake and its aftershocks.

A critical question is the extent to which aid that would normally be available to a community for relief and rehabilitation after a disaster can be made available for hazard-reduction activities before the disaster, on the basis of an authenticated prediction. Besides legal and economic considerations, there are social and psychological aspects to this question. It is doubtful that the spontaneous outpouring of altruistic concern and self-sacrifice that follows most natural disasters will be evoked by the *prediction* of disaster. Loans with forgiveness provisions might offend the popular sense of justice less than outright gifts before there is tangible loss and injury. These imponderable community attitudes must be better understood if we are to devise hazard-reduction programs that stand a chance of working as they are intended.

In spite of all that can be accomplished in these five crucial areas of planning and research, much will still remain to be learned from the first few experiences with actual prediction of a potentially destructive earthquake. But we must be prepared to learn the most from each experience. We should already be recording baseline social and economic data in communities where predictions are most likely to be made, and developing standby plans for research to be activated when the first prediction begins to materialize. In order to make up for the fortunate infrequency of destructive earthquakes in the United States, we must also monitor the experience with prediction in other countries such as China, Japan, and the Soviet Union.

The main thrust of my testimony has been to indicate the weight of social and economic planning and investigation that should be undertaken as promptly as possible if we are to reap the full benefit from the new earthquake prediction capability. With this kind of advance preparation, an earthquake prediction should enable us to save many lives and reduce property loss when the earthquake strikes.

Mr. FLAJSER. Thank you. Senator Cranston will be right back, and we will recess until his return.

[Recess.]

Senator CRANSTON. Forgive the in-and-out.

You have each characteriezd quite dramatically as I understand it the total earthquake hazard we feel here in the United States. In view of this very great risk, how adequate do you think the current role of the Federal Government is?

Is there a lot left to be done, and therefore the sort of program we are proposing here—is it a realistic one in your view?

Dr. HAAS. As I suggested, Senator, the effort to date I think could be characterized as minimumly adequate but only with respect to certain aspects. I suggested, and I would reaffirm, that what is needed is not entirely an increase in funding; but an increase in the balance, so that there is an overall comprehensive and balanced program.

I guess the major point I would like to make is that yes, we need additional development in seismology and earthquake engineering; but it is the application side that we should not overlook, for the best knowledge, and the best technique—until applied—is of little value in actually mitigating the earthquake hazard.

This bill does, at least to a reasonable extent, indicate that a balanced attack is needed; and therefore, I am much in support of the bill for that reason.

Senator CRANSTON. You touched on a matter of earthquate insurance; what role, if any, should the Federal Government play, in your opinion, in promoting earthquake insurance?

Dr. Haas. In the absence of earthquake prediction, you can make a strong case either way for saying that earthquake insurance at the present time is adequate, or that it is inadequate.

I am principally concerned with the role of earthquake insurance once a scientifically based prediction becomes available. Our tentative research suggests that the availability of insurance or something comparable in function is probably going to be the key factor in whether or not you have a very great downturn, perhaps a very great depression in the local area, in the local economy. The bankers, people in the savings and loans, people in real estate, people in investment and construction, say, that some basis for insuring the owner, that all is not lost with respect to the property, is important.

And it would seem to me that very soon careful investigation ought to be made as to how it would be possible to provide that function; perhaps through a program comparable to the national flood insurance program, or whether it's something different is a matter that should be investigated soon.

Senator Cranston. What light can you shed on the national aspects of the problem? Some people think of California and Alaska as areas that are more likely to have bad quakes. As I understand, the experts believe there are 39 States presently that face some danger from some point of seismic quake?

Dr. Turner. Let me suggest a couple of points on that: First of all: The fact that destructive earthquakes come at infrequent intervals at any one location means that if you are going to accumulate experiences from sources dealing with quakes, it almost has to be done on a national basis. It is not like a situation in which you have an annual disaster season.

Second: The principal problem with earthquakes is the collapse of human structures, and the costs, involved in correcting faulty structures, replacing them, getting new patterns of construction underway, are such that again there is going to have to be support from outside of the local area.

Senator Cranston. We haven't had a really severe quake strike in a major city since 1906, when it happened in our State, my State; is there not a likelihood of far greater damage if a major quake strikes, with so many more people concentrated in that problem area?

Dr. Turner. I think everyone who has studied the problem would agree that the probability of death and destruction is many times greater than the previous quake.

Senator Cranston. Dr. Turner, would you submit for the record whatever thoughts you can express to us on the needs for legal, economic, and social impact research, in addition to the research on physical activities on quakes themselves? It would help very much if you could submit that in writing to us.

Dr. Turner. Yes, I have comments on that in my prepared statement, also, which you have; and I am sure, Senator, your office has our National Academy of Science Panel Report on Earthquake Prediction and Public Policy, which goes into that in considerable detail.

Senator Cranston. Fine.

Thank you both very much. This is very helpful of you. We appreciate your coming.

Our next witness is Dr. Carl Kisslinger, director, Cooperative Institute for Research in Environmental Science, University of Colorado.

Thank you very much for being present, Doctor. If you could briefly summarize your statement, the full statement will be included in the record.

## STATEMENT OF DR. CARL KISSLINGER, DIRECTOR, COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCE, UNIVERSITY OF COLORADO, BOULDER, COLO.

Dr. KISSLINGER. Yes. I think I can briefly summarize the remarks I have prepared under three major headings: (1), That the risk due to earthquakes is great; (2), the competence to make substantial progress toward the solution of the technical problems of disaster mitigation exists, and is not being fully utilized because of insufficient funding; and (3), the scientific problems which are to be solved are fairly well defined.

The statistics on earthquake risks are so well known there is no need to repeat them in any detail; but I think we all recognize that the history of our Nation is short, and the time during which the most seismically active parts of our country have supported a large population is even shorter, so the actual exposure to earthquakes has been limited.

Generally the Nation has been lucky that the circumstances during our great earthquakes have been such that the number of deaths has been small, some 1,600, with property losses of a few billions of dollars. In my opinion it would be irresponsible for the Nation to depend on luck to protect the large population at risk from future earthquakes that will certainly occur.

There is no doubt that the overall technical competence to make substantial progress toward the solution of these problems exists today in the United States. Seismologists and other geophysicists, geologists, and engineers in universities, Government laboratories, and privately supported research organizations are at work on these tasks; but today they work within severe constraints imposed by the limitations of available resources.

My concern about the impediments to progress imposed by insufficient funding was greatly enhanced by my experience in April of last year as a member of the review panel advising the Geological Survey on the external contracts part of the present earthquake hazards reduction program.

I have served on many review panels, advisory to a variety of Federal agencies, but I have never had an experience more depressing and frustrating than this exercise in attempting to stretch totally inadequate funds in order to keep a minimum research effort alive, with some semblance of balance among the various essential tasks.

After the panel eliminated those proposals that were either deficient in scientific merit, or were not immediately relevant to the goals of the program, the remaining requests, all judged to be meritorious and highly relevant, still called for about twice the money that was available. The factor of two is itself somewhat misleading, because most of the proposal writers knew on the basis of the experience of the first year of the program—the previous year—that there was no hope of support for more than a minimum effort, and most of the proposals were already cut to the bone.

I judge that at least four times the available funds could have been used wisely and effectively in the external contracts program alone during the current year. It was obvious to me that the rate of progress toward the goals of reducing the hazards due to earthquakes during 1975 and 1976 would be much lower than we are capable of.

The scientific problems to be addressed, as I stated, are well defined, and I have provided with my written statement a kind of a flow diagram of the interrelation of the research problems in seismology. I will just touch very quickly on some of the points I think are most important:

The first question is: What is the ultimate cause of earthquakes? As a matter of fact, we have made great progress in recent years on this question, at least in terms of understanding why the great earthquake belts of the world exist, where they go, and where the energy released from these earthquakes comes from. The seismicity on the west coast and Alaska is understood in this sense. But we do not understand at all the causes and the reasons for the localization of earthquakes that occur within the interior of the plates; for example, the great earthquakes around Charleston, S.C., or in Boston, or in the Missouri-Tennessee-southern Illinois region. The nature of these so-called intraplate earthquakes is a subject of great current interest, especially among seismologists in the Eastern United States.

The next major study area is based on the question: What actually goes on in the earth during an earthquake? That is, what are the physics of an earthquake. We have had good qualitative models of earthquakes since 1910, but we are still trying to get quantitative understanding of the details of the operative process.

The study of earthquake physics is a broadly interdisciplinary activity, and requires the efforts of not only seismologists and geologists, who have the data on what happens in the field, but also specialists in rock mechanics and materials science.

A great need for progress in this subject is measurements by a variety of instruments in the region very close to the fault during rupture. Just as our theoretical understanding of the seismic effects of underground explosions developed rapidly after reliable measurements within the zone of very high pressures around the shop became available for analysis, so future progress on the earthquake problems will be based on measurements within the poorly understood zone of inelastic, nonreversible behavior at the fault and in the close-in region of strong ground motion.

The acquisition of the earthquake data is more difficult and requires more patience, first because earthquakes occur at considerable depth within the Earth, and then because we do not yet enjoy the benefit of knowing when and where an earthquake will occur, as we do for explosions.

Once we have a good model of an earthquake, there are a number of useful things we can do, including the prediction of the ground motion that will be produced by future earthquakes, after we have postulated the location and the orientation and depth of the fault, and the expected amounts of slip and change in strain in the rocks. Every assessment of the seismic hazard at a location is based in some sense on a prediction of the maximum ground motion to be expected at that site.

The more accurately we can predict the motion, the more reliable the hazard assessment becomes. If an operational capability to predict specific earthquakes is achieved, the prediction of the distribution of ground motion expected to accompany that earthquake will be a necessary step in fully utilizing the foreknowledge of the event to reduce losses of life and property.

And that brings us, then, to the topic of earthquake prediction, which is one of the most promising and exciting areas of seismological research today. Investigations in a number of countries, including Japan, the U.S.S.R., People's Republic of China, and the United States, have demonstrated that at least some earthquakes are preceded by detectable phenomena that are diagnostic of the impending event.

It is this discovery that provides the basis for our confidence that at least some earthquakes in some geological settings are predictable on the basis of readily observed precursors. We do not know that the problem is generally solvable, that is, that all earthquakes are predictable, and we do not know to what extent prediction methods that work in one geological situation are transferable to another.

Only a few earthquakes have been predicted in the whole world, where prediction means a statement of the time and place and magnitude of the event. The most important of these, because it was a major, destructive event, is the Haicheng earthquake in Liaoning Province, China, February 4, 1975. Although we are still trying to gather more specific information on the methods of prediction used, the evidence is overwhelming that the Chinese accurately predicted this major event and were able to reduce the loss of life tremendously by acting on that prediction.

If a similar good prediction had been available in Guatemala——

Senator Cranston. How close did they come to the time of the quake?

Dr. Kisslinger. They place very accurately, an actual warning to the people to leave their homes, was a matter of a few hours before the earthquake occurred.

Senator Cranston. Was that the main thrust?

Dr. Kisslinger. I understand they actually set up movies in the town squares so people would come out and look at the films and get out of their houses.

If a similar good prediction had been available in Guatemala prior to the disaster that struck 1 year later to the day, there is no question that thousands of deaths and injuries suffered in collapsed adobe houses could have been prevented by the simple measure of having the people stay outdoors until after the event. Of course, adequate plans for food, water, medical and other emergency services could have been made and would have been necessary for reducing the impact of the earthquake.

I think I shall not review here the actual techniques that we are studying as ways to predict earthquakes. They are mentioned in the statement I have prepared for the record; but I would like to point out that among the various kinds of precursors that have been observed, there are some that occur or begin to occur quite a long time before the earthquake, and will offer hope of warnings in the order of several years before a major event; and then there seem to be other short-term precursors that begin some hours or perhaps a day or so before the event, and if they prove to be reliable indicators, they will give a basis for concerted action just before the event—but all of this has to be tested.

I would like to point out that even complete success in the development of technique for reliably predicting earthquakes—and there is no assurance that such success can be achieved—but even achieving that success would not in any way lessen the need for vigorous application of other, proven methods of mitigating earthquake disasters.

Good engineering of earthquake-resistant structures, combined with accurate mapping of seismic hazards, and assessment of seismic risks, and wise planning for the use of land will lessen the impact of earthquakes. If bad buildings have been put up in dangerous places, some useful actions based on accurate prediction can be taken to reduce deaths and injuries. Such buildings, in the absence of prediction, represent disasters waiting to happen, as we have seen repeatedly and most recently in Guatemala.

The accurate determination of the locations of earthquake-prone sites and of the maximum earthquake and expected recurrence of earthquakes at those sites is one of our great needs. We know that we cannot depend on our very short history for knowledge of where earthquakes will not happen in the future. On the other hand, there are ways of identifying and establishing approximate dates of prehistoric fault movements, and these can be used to extend the historical record. A program of detailed structural mapping in suspected seismic areas combined with analysis, including dating of movements on faults that show evidence of movements during the last few hundred thousand years should be pursued.

I would now like to come to the final topic of earthquake control, which, if ever achieved, would represent an ultimate step in eliminating earthquake disasters. The very limited experience gained in connection with the waste disposal well at the Rocky Mountain Arsenal and the series of experiments at Rangely, Colo., as well as laboratory experiments, has established a rational basis for approaching the problems.

In my opinion, a series of control experiments in a remote area in which events in the magnitude range 5 to 6 could be anticipated should be initiated.

Even if control techniques should prove to not be feasible as a means of eliminating disastrous earthquakes, the knowledge of the earthquake processes gained in these experiments would be of great value for other aspects of disaster mitigation. For example, such experiments would give us a unique opportunity to instrument the region around the event in advance so that our theories on fault mechanics and the prediction of strong ground motion could be tested.

And one last point is that seismology is a science that is heavily dependent on observations over the entire globe. Our progress has gone hand-in-hand with the development and widespread deployment of better seismographs. I cannot urge too strongly that legislation providing for seismological research must include provisions for maintaining and extending as needed the observatory and data management systems.

Thank you.

Senator CRANSTON. Thank you very much.

Let me ask you first if you are satisfied with the level of funding on the bill, the $50 million a year? Or what do you feel is the sum that would be wisely spent and should be spent?

Dr. KISSLINGER. I think that is an adequate sum to work from. Some of the kinds of experiments, for example, I call for here, such as a serious set of experiments in earthquake control will indeed be expensive to carry out.

Senator CRANSTON. Are you confident that with adequate investigation we can develop a reliable prediction capability soon?

Dr. KISSLINGER. I am confident some earthquakes are predictable. We simply do not yet have the basis for knowing whether all major earthquakes can be predicted on the basis of precursors that we can measure.

I am actively engaged in research on this subject, myself; I am confident that, certainly, we can make great progress toward establishing earthquake prediction capability.

One of the problems of setting a time limit as to when we would know we have a prediction capability is the fact that we don't get very large earthquakes all that often; and whether there would be one within any time frame specified, a big event, that would provide a test of the methods is questionable.

Senator CRANSTON. Do you concur with the estimate that at least 39 States, according to figures we have been given, with a population of around 70 million, are in regions characterized as facing risk of major to moderate earthquake?

Dr. KISSLINGER. Yes, that is clearly true.

Senator CRANSTON. You also concur the destruction level would be far worse now than it would have been years ago?

Dr. KISSLINGER. No question about that, especially when one considers how totally dependent we have become on complex life suport systems to keep our system going; we are very vulnerable.

Senator CRANSTON. Thank you very much, you have been most helpful.

[The statement follows:]

STATEMENT OF CARL KISSLINGER, PROFESSOR OF GEOLOGICAL SCIENCES AND DIRECTOR, COOPERATIVE INSTITUTE FOR RESEARCH IN ENVIRONMENTAL SCIENCES, UNIVERSITY OF COLORADO, BOULDER, COLO.

Mr. Chairman and members of the committee, the scientific study of earthquakes evolved from mankind's need and desire to understand, and perhaps thereby be able to mitigate, a major cause of natural disasters. Of course, a great deal of basic knowledge of the internal structure, composition, and dynamic processes that characterize the planet Earth has been gained also during these investigations and the results of the studies of earthquakes and the waves they send through the earth are the basis of a major part of our current understanding of the earth.

Today we can readily identify a number of problem areas in which seismological research has an opportunity to contribute further to the well-being of the nation. High among these areas of opportunity is the entire field of earthquake hazards mitigation, and it is to this subject that these remarks are primarily addressed.

The statistics on the earthquake risk to the American population have become well-known and need not be repeated here in detail. About one-third of our population, roughly 70 million people, live in places where the likelihood of significant losses from earthquakes is high, and fewer than one-tenth of all Americans can be considered to be free of this hazard. The history of our nation is short, and the time during which the most seismically active parts of our country have supported a large population is even shorter, so our exposure to earthquakes has been limited. Generally, the nation has been lucky that the circumstances during our great historical earthquakes have been such that the number of deaths has been small, some 1,600, with property losses of a few billions of dollars. In my opinion, it would be irresponsible for the nation to depend on luck to protect the large population at risk from future earthquakes that will certainly occur. This opinion is reinforced when we realize that trivial changes in the circumstances of recent earthquakes, for example, if the San Fernando earthquake of 1971 had occurred only a few hours later, might well have resulted in truly major disasters.

There is no doubt that the overall technical competence to make substantial progress toward the solutions of these problems exists today in the United States. Seismologists and other geophysicists, geologists and engineers, in universities, government laboratories, and privately supported research organizations are at work on these tasks, but today they work within severe constraints imposed by the limitations of available resources. My concern about the impediments to progress imposed by insufficient funding was greatly enhanced by my experience in April, 1975, as a member of the review panel advising the Geological Survey on the external contracts part of the present Earthquake Hazards Reduction program. I have served on many review panels, advisory to a variety of Federal agencies, but I have never had an experience more depressing and frustrating than this exercise in attempting to stretch totally inadequate funds in order to keep a minimum research effort alive, with some semblance of balance among the various essential tasks. After the panel eliminated those proposals that were either deficient in scientific merit or were not immediately relevant to the goals of the program, the remaining requests, all judged to be meritorious and highly relevant, still called for about twice the money that was available. The factor of two is itself somewhat misleading, because most proposal writers knew on the basis of the experience of the first year of the program that there was no hope of support for more than a minimum effort, and most of the proposals were already cut to the bone. I judge that at least four times the available funds could have been used wisely and effectively in the external contracts program alone during the current year. It was obvious that the rate of progress toward the goals of reducing the hazards due to earthquakes during 1975 and 1976 would be much lower than we are capable of.

The present high level of competence in seismology in the United States is largely the result of the support given by the Department of Defense to research directed to the detection and identification of underground nuclear explosions, and the steady, if modest, funding of basic research provided by the National Science Foundation. In the past 15 years, seismologists have been given the tools to bring their field up to a level appropriate for a modern physical science. This powerful assemblage of personnel, instrumentation, computational facilities and advanced knowledge is available to the nation to help with the vexing problem of earthquake catastrophes.

The scientific problems can be organized under a number of major headings. The Figure displays a flow diagram, showing the inter-relations of these problem areas. First, what is the ultimate cause of earthquakes? Why do they occur, what is the source of the energy that drives them, why are they located where they are? These are questions concerning which we have made much progress in recent years. In terms of the plate tectonics model of geological processes we do understand the major distributions of earthquakes along well-defined belts associated with the boundaries between the great plates that make up the outer portion of the Earth. The seismicity on the West Coast and Alaska is in this category. In a general way at least, we understand the source of the energy released in these earthquakes. But we do not understand at all the causes and the reasons for the localization of earthquakes that occur within the interior of the plates, for example the great earthquakes around Charleston, S.C., Boston, or in the Missouri-Tennessee-southern Illinois region. The nature of these so-called intra-plate earthquakes is a subject of great current interest, especially among seismologists in the eastern United States.

Another major study area is the nature of the processes that go on durinn ga earthquake, in other words, the physics of an earthquake. Although we have had a good qualitative model of earthquakes since 1910, we are still struggling, by means of theoretical investigations, field observations, and laboratory studies, to gain quantitative understanding of the details of the operative processes. This kind of understanding is not only something we seek in order to satisfy our desire as scientists for comprehensive knowledge, but it is essential to progress in the development of techniques for prediction, and perhaps, eventually, even control, of earthquake occurrences. The study of earthquake physics is a broadly interdisciplinary activity, and requires the efforts of not only seismologists and geologists, who have the data on what happens in the field, but also specialists in rock mechanics and materials science, who know about the nature of crack formation and propagation in general. A great need for progress in this subject is measurements by a variety of instruments in the region very close to the fault during rupture. Just as our theoretical understanding of the seismic effects of underground explosions developed rapidly after reliable measurements within the zone of very high pressures around the shot became available for analysis, so future progress on the earthquake problems will be based on measurements within the poorly understood zone of inelastic, non-reversible behavior at the fault and in the close-in region of strong ground motion. The acquisition of the earthquake data is more difficult and requires more patience, first because most earthquakes occur at considerable depth within the earth, and then because we do not yet enjoy the benefit of knowing where and when an earthquake will occur, as we do for explosions.

Once we have developed a quantitative model of an earthquake, we can proceed to do a number of useful things. The closer to reality the model, the more meaningful will be the results of these next few steps. One is to calculate the ground motion to be expected in the neighborhood of a future earthquake, after postulating the location, orientation and depth of the fault, and the expected amounts of slip and change in strain in the rocks. Every assessment of the seismic hazard at a location is based in some sense on a prediction of the maximum ground motion to be expected at that site. The more accurately we can predict the motion generated by the earthquake, the more reliable the hazard assessment becomes. If an operational capability to predict specific earthquakes is achieved, the prediction of the distribution of ground motion expected to accompany that earthquake will be a necessary step in fully utilizing the foreknowledge of the event to reduce losses of life and property.

That thought brings us to the topic of earthquake prediction, one of the most promising and exciting areas of seismological research today. Investigations in several countries, Japan, U.S.S.R., People's Republic of China, and the United States, have demonstrated that at least some earthquakes are preceded by detectable phenomena that are diagnostic of the impending event. It is this discovery that provides the basis for our confidence that at least some earthquakes in some geological settings are predictable on the basis of readily observed precursors. We do not know that the problem is generally solvable, that is, that all earthquakes are predictable, and we do not know to what extent prediction methods that work in one geological situation are transferable to others.

A prediction implies a statement of the time, place, and magnitude (or other measures of strength) of a future event. Only a few earthquakes have been predicted in this sense in the whole world. The most important of these because it was a major, destructive event, is the Haicheng earthquake, in Liaoning Province, China, February 4, 1975. Although we are still trying to gather more specific information on the methods of prediction used, the evidence is overwhelming that the Chinese accurately predicted this major event and were able to reduce the loss of life tremendously by acting on that prediction. If a similar good prediction had been available in Guatemala prior to the disaster that struck one year later, to the day, there is no question that thousands of deaths and injuries suffered in collapsed adobe houses could have been prevented by the simple measure of having the people stay outdoors until after the event. Of course, adequate plans for food, water, medical and other emergency services could have been made and would have been necessary for reducing the impact of the earthquake.

Scientific predictions of earthquakes will be based on observations of combinations of premonitory phenomena. Anomalous changes in the elevation of points on the surface above the impending earthquake, tilts of the surface at places around the future epicenter, changes in rates of occurrence of microearthquakes, changes in the physical properties of the rocks, such as earthquake wave velocities and electrical conductivity, have all been detected, in various combinations or alone, for different earthquakes. Changes in the chemistry, as well as the level of water in wells have been reported, especially by the Chinese.

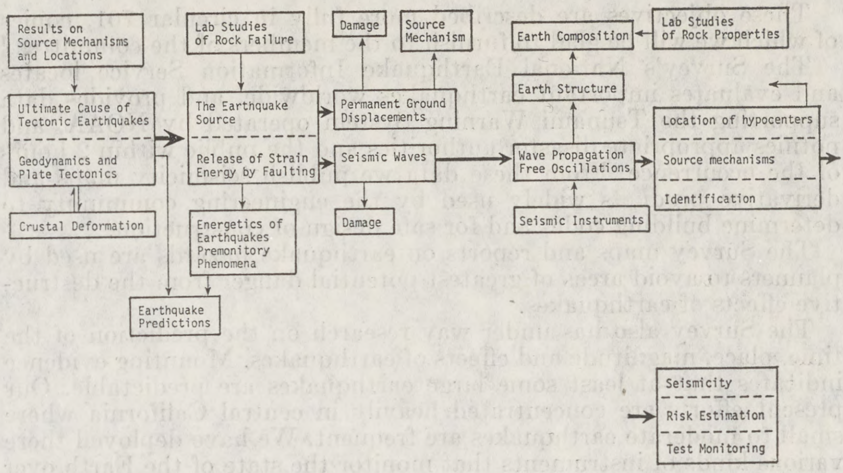
Anomalous precursory behavior seems to fall into two populations. One group begins a long time before the event, the interval increasing with increasing magnitude. These long-term precursors offer the hope of establishing a warning time of several years before a major earthquake. The short-term precursors have been observed some hours, or perhaps a day or two before moderate to large events, and if they prove to be reliable indicators, they will give a basis for concerted action just before the event. All of the proposed diagnostic phenomena must be fully tested to determine first the reality of the previous claims, then the reliability as a predictor, including the false alarm rate.

Even complete success in the development of techniques for reliably predicting earthquakes, and there is no assurance that such success can be achieved, would not in any way lessen the need for vigorous application of other, proven methods of mitigating earthquake disasters. Good engineering of earthquake-resistant structures, combined with accurate mapping of seismic hazards, and assessment of seismic risks, and wise planning for the use of land will lessen the impact of earthquakes. If bad buildings have been put up in dangerous places, some useful actions based on an accurate prediction can be taken to reduce deaths and injuries, but the property damage will be great. Such buildings, in the absence of prediction, represent disasters waiting to happen, as we have seen repeatedly and most recently in Guatemala.

The accurate determination of the locations of earthquake-prone sites and of the maximum earthquake and the expected rates of recurrence of earthquakes at these places is one of the great needs. We know that we cannot depend on our very short history for knowledge of where earthquakes will not happen in the future. On the other hand there are ways of identifying and establishing approximate dates of prehistoric fault movements, and these can be used to extend the historical record. A program of detailed structural mapping in suspected seismic areas combined with analysis, including dating, of movement on faults that show evidence of movements during the last few hundred thousand years should be pursued.

Earthquake control, if ever achieved, would represent an ultimate step in eliminating earthquake disasters. The very limited experience gained in connection with the waste disposal well at the Rocky Mountain Arsenal and the series of experiments at Rangely, Colorado, as well as laboratory experiments, has established a rational basis for approaching the problems. In my opinion, a series of control experiments in a remote area, in which events in the magnitude range 5 to 6 could be anticipated, should be initiated. Even if control techniques should prove to not be feasible as a means of eliminating disastrous earthquakes, the knowledge of the earthquake processes gained in these experiments would be of great value for other aspects of disaster mitigation. Such experiments would give us a unique opportunity to instrument the region around the event in advance, so that our theories on fault mechanics and the prediction of strong-ground motion could be tested.

Finally, I wish to point out that seismology is a science that is heavily dependent on observations over the entire globe. Our progress has gone hand-in-hand with the development and widespread deployment of better seismographs. Today we have available through a smoothly functioning data exchange system seismograms of uniformly good quality from hundreds of observatories. It is essential that the data acquisition network and the data archiving and distribution systems be maintained at a high level. Advanced technology for data transmission via satellites now makes routine observations from remote places feasible. Devices for storage and distribution of large amounts of data exist and are well-suited for seismological applications. Stable support of conventional observatory systems, as well as the applications of this advanced technology is imperative for the continued health of the science. The primary data-gathering system within the United States has been a cooperative effort of universities and government agencies, while the global monitoring systems has been supported and managed as a joint effort of the Department of Defense, Department of Commerce, Department of Interior, and National Science Foundation. I cannot urge too strongly that legislation providing for the support of seismological research must include provisions for maintaining and extending as needed the observatory and data management systems.




Flow diagram for seismological investigations.

Senator CRANSTON. Our next witness is Dr. Vincent E. McKelvey, Director, U.S. Geological Survey, and Dr. Barry Raleigh.

I thank you very much for your presence. I would like to request you hold your verbal presentation to not more than 10 minutes; we have a tough time problem. The whole statement will go into the record.

## STATEMENT OF DR. V. E. McKELVEY, DIRECTOR, U.S. GEOLOGICAL SURVEY; ACCOMPANIED BY DR. BARRY RALEIGH, EARTHQUAKE RESEARCH CENTER, MENLO PARK, CALIF.; AND DR. JACK EVERNDEN

Dr. McKELVEY. I have with me Dr. Barry Raleigh and Dr. Jack Evernden of our Earthquake Research Center, and we have some charts which at this time I will try to show you.

Mr. Chairman, I thank the committee for this opportunity to discuss the role of the Geological Survey in the earthquake hazards reduction program. The Survey now has the principal Federal responsibility for earth science aspects of earthquake hazards reduction, and as a result of a recent redelegation of authority under the Disaster Relief Act of 1974, the Survey also now has the responsibility for issuing warnings of earthquakes and certain other kinds of geologic disasters, such as volcanic eruptions and landslides, to the extent they are predictable.

We share responsibilities for the overall earthquake hazard reduction effort with NSF and other scientific organizations and other Federal organizations, and in particular, State and local civil authorities. But the Survey's part in earthquake hazard reduction is critical. Its major program objectives include first the acquisition and dissemination of information on earthquake occurrences; second, mapping and evaluation of earthquake hazards; and third, development of earthquake capability to predict time, place, magnitude, and effects of earthquakes.

These objectives are described more fully in circular 701, copies of which we will be glad to furnish to the members of the committee.[1]

The Survey's National Earthquake Information Service locates and evaluates important earthquakes worldwide, and provides data supporting the Tsunami Warning System operated by NOAA, and notifies appropriate disaster authorities and the public within 2 hours of the occurrence. From these data we publish seismicity maps and derivative products widely used by the engineering community to determine building codes and for safe design of construction.

The Survey maps and reports on earthquake hazards are used by planners to avoid areas of greatest potential danger from the destructive effects of earthquakes.

The Survey also has under way research on the prediction of the time, place, magnitude and effects of earthquakes. Mounting evidence indicates that at least some large earthquakes are predictable. Our present efforts are concentrated heavily in central California where small to moderate earthquakes are frequent. We have deployed there various kinds of instruments that monitor the state of the Earth over this seismically-active region continuously. Reconnaissance networks of seismographs and other instruments are located in southern California and the Bay area, but the density is sparse.

Recently analysis of data from precise leveling has shown that a large uplift has occurred in the last 15 years in the vicinity of the San Andreas fault in the Mohave Desert just north of Los Angeles, with the land surface rising nearly a foot in the central part of the uplift.

Senator CRANSTON. How far north of Los Angeles is that?

Dr. McKELVEY. About 50 miles. The significance of this uplift in relation to a forthcoming earthquake is not understood but there is clearly cause for concern. Such uplifts have preceded some earthquakes in the past; but in this very area one occurred earlier in this century with no following earthquake.

There is a critical need for an assessment of this problem and I am glad to report that the President has recently—in the last few days—authorized an increase in our fiscal 1977 budget request to expand our observations and analysis of this uplift.

Senator CRANSTON. How much of an augmentation is that?

Dr. McKELVEY. $2.6 million, sir.

Senator CRANSTON. On top of what figure?

Mr. McKELVEY. $10,522,000 for the total earthquake hazards reduction program.

Senator CRANSTON. Yes.

Dr. McKELVEY. I mentioned earlier the responsibility recently redelegated to the Survey with respect to the issuance of warnings of impending disasters of geologic origin. Frankly, however, no one currently has the capability to carry out this responsibility simply because we do not know enough, particularly with respect to predictions as to the time an event will occur. As an initial step in responding to this expanded responsibility, however, the Survey currently is reviewing its capabilities for prediction of natural disasters and is developing procedures for issuance of the predictions we are able to make so that they can be effectively used by local authorities.

[1]See p. 117.

The framework of the plan we have developed is indicated by a chart accompanying my testimony. It provides for careful review of scientific data and transmittal to the appropriate State and Federal officials. It assures that the scientific data will be publicly available, that a prediction will be reviewed and authenticated by a council of experts, and that an official prediction will be accompanied by recommendations from local authorities for appropriate action by the public. This plan was generally well received by State and local officials at the San Francisco conference held in November, the proceedings of which have just been published as Survey Circular 729, also furnished to the committee.[1]

In carrying out the responsibilities under the Disaster Relief Act, we will be in a difficult position while an earthquake prediction capability is being developed. The impact of incorrect predictions, a subject presently under review, will be socially and economically adverse. Prediction research is a complex and difficult program, and the period of uncertain and inaccurate predictions could well stretch over the next few decades. We are looking at possible ways to reduce this period of uncertainty.

The bill under review today, S. 1174, would provide an acceleration in earthquake hazards reduction research and would establish earthquake disaster mitigation as a national objective. It would also provide a new coordinating structure for a national earthquake program.

A true national earthquake hazard reduction program can be accomplished under the existing authorities already available to the Federal agencies. We are working closely with the NSF to develop proposals for further earthquake research for consideration in the 1978 budget. Let me emphasize, however, that a true hazard reduction program must include building codes, zoning ordinances and warning systems—which are the responsibilities of State and local governments—as well as research on predicting earthquakes.

I believe there is still a little time left, Mr. Chairman, and with your permission, I will ask Dr. Raleigh to at least identify the charts we have.

Dr. RALEIGH. I have only a brief statement to make. In California at the present time we need to have a large number of instruments in a place where an earthquake of a magnitude of possibly 5 or greater might occur to provide us with observations of precursory phenomena to develop a physical basis for earthquakes. At the present rate of occurrence of magnitude 4.5 to 5 earthquakes in California, it may very well be as long as 10 years before we collect enough such observations to understand the physics of the precursory phenomena of earthquakes.

With this bill I would imagine that the necessary observations would be obtained in something like 3 years' time. It would provide considerable acceleration in the program.

The charts we brought along, which I can identify quickly, show, first, the uplift in the region of the San Andreas Fault north of Los Angeles, extending from the Mojave Desert to the Garlock Fault. Its maximum height, which is centered around Palmdale, is about 1 foot; it falls to something like half that amount to a distance of about 50 to 100 miles on either side of Palmdale, and in fact covers

[1] See p. 79.

most of the area of the great quake in 1857 that occurred on that section of the San Andreas Fault.

As Dr. McKelvey said, we don't understand entirely what is going on. There are physcial models which might explain the observations, and they do give some cause for concern.

The next diagram which I will just show very briefly is simply a diagram showing precursory phenomena to some earthquakes in central California where the survey now has a dense network of observation points. And there are clear precursory signals on a couple of instruments which happen to be fairly close to the epicenter of a magnitude 5 earthquake. A change in the magnetic field of a substantial amount over a month or so prior to a magnitude of 5 earthquake, and a large tilt on a tiltmeter which happened to be close by.

Well, since our time is running out, I think I will leave my comments to that.

Senator CRANSTON. Thank you very much. That is very helpful.

As I understand it the basic position as stated by the Secretary of Interior on this legislation, presumably with the guidance of Office of Management and Budget, is that the basic authorities already exist and are moving in these directions, and that the questions raised about the initial funding we propose—without getting into whether you may be able to move faster towards the objective if you had greater funding—would you be able to move more rapidly toward achieving the goal of a high degree of accuracy in predicting quakes if you had further funding?

Dr. MCKELVEY. Without question.

Senator CRANSTON. What funding would it take to bring this capacity into reality?

Dr. MCKELVEY. I am not sure funding alone will do it in that time.

Senator CRANSTON. How much could be done with adequate funding?

Mr. MCKELVEY. Well, we have thought quite a bit about this and have suggested several levels of increased funding recently to the Baker committee, i.e., the President's Advisory Panel on Anticipated Advances in Science and Technology; and we suggested that for a 10-year effort toward achieving a prediction capability, an increase of about $16 million, I believe——

Senator CRANSTON. $16 million what—per year?

Dr. MCKELVEY. With an increase of $16 million our total program would be funded at $27 million a year.

Senator CRANSTON. Do you believe in 10 years you will have the capacity?

Dr. MCKELVEY. Our scientists are very confident that at least for many kinds of earthquakes—those associated with plate boundaries, where we have some understanding of the mechanism involved, of the origin of earthquakes—we think that that is a reasonable goal.

Senator CRANSTON. Roughly, what was the magnitude of the San Francisco quake?

Dr. MCKELVEY. A little over 8.3.

Senator CRANSTON. If this struck, say, Los Angeles, right now, roughly what would be the property damage?

Dr. MCKELVEY. Well, I believe——

Dr. RALEIGH. Numbers like $10 billion have been quoted.

Senator CRANSTON. $10 billion.

What would the cost of a system like you presently have in California be in some other State, like Massachusetts, or South Carolina?

Dr. McKelvey. I'll ask Dr. Raleigh to speak to that.

Dr. Raleigh. Presumably by the time we were able to implement the system—and I don't mean to minimize the amount of work to get there—the system would be tailored more to actual prediction; we're doing a lot of experiments now, so the expense in California is much greater than, presumably, would be required by Massachusetts. And, you know, it's hard to estimate, but a few million seems to be reasonable.

Dr. Evernden. I don't want you to take that answer as meaning we are doing an adequate job in California.

Senator Cranston. I understand that. I am well aware of that.

What fractions of the earthquakes at sites in the United States are now being monitored by U.S.G.S.?

Dr. McKelvey. We were working to a degree in nearly all of the most earthquake prone areas.

Senator Cranston. How many is that?

Dr. McKelvey. Well, by that I would include Hawaii, Alaska, the Pacific and Inter-Mountain States, the Central United States.

Senator Cranston. Would you submit for the record a list of the States and the amount of actvity?

Forgive my being in such a hurry. There's another vote going on, and I didn't want to keep you sitting here. If you would submit that for the record.

[The following information was subsequently received for the record:]

*U.S. Geological Survey earthquake hazard reduction program, Estimated Funding Activity, fiscal year 1976*

| Nationwide activities: | *Thousands* |
|---|---|
| Earthquake information and worldwide seismicity | $1,608 |
| Analysis of seismic risk | 376 |
| Topical studies in earthquake hazard evaluation | 376 |
| Laboratory, theoretical and topic studies in earthquake prediction | 1,342 |
| Socioeconomic studies of earthquake prediction | 25 |
| Other (National Academy of Science committees, Advisory Panel, grants and contract management, etc.) | 120 |

[In thousands of dollars]

| Regional activities | Evaluation of eq hazard | Field studies for eq prediction |
|---|---|---|
| Alaska | $442 | $145 |
| California | 2,245 | 2,970 |
| Hawaii | 76 | 76 |
| Idaho | 31 | |
| Mississippi Valley (Illinois, Missouri, Kentucky, Tennessee, Arkansas) | 156 | 42 |
| Montana | 9 | |
| Nevada | 266 | 131 |
| New Mexico | 57 | |
| New York | 31 | 31 |
| Northeastern United States (Connecticut, Delaware, Massachusetts, Maine, Maryland, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont) | 50 | |
| Oregon | 30 | |
| South Carolina | 17 | 17 |
| Utah | 225 | 44 |
| Washington | 108 | 37 |
| Worldwide | | 39 |
| Joint studies with U.S.S.R | | 100 |
| Total | 3,743 | 3,632 |
| | 11,222K | |

Is it true there are about 39 States in areas facing something like moderate to major earthquakes?

Dr. McKelvey. Yes, there is.

Senator Cranston. What fraction of the faults capable of 6 or greater are being monitored in California?

Dr. McKelvey. Only a very small fraction, and we are monitoring with dense instrumentation, using real-time data processing only in the Hollister area.

Dr. Raleigh. It would be generous to say about 10 percent of the faults capable of magnitude 6 or greater shocks, I would say.

Senator Cranston. What budget request has USGS made originally for this coming fiscal year?

Dr. McKelvey. We requested, I think it was an increase of about $1 million.

Senator Cranston. Knowing what you face, you didn't request what you could use?

Dr. McKelvey. We had to do that of course within the balance of priorities within the Department of the Interior.

Senator Cranston. Yes.

I would like to ask if you would answer three questions for the record while I go vote, and then I will come back and we will carry on.

And following the answers to those three questions if Dr. Albert Eggers and Dr. Charles Thiel would start their testimony, I will be right back as fast as I can.

The questions I would like you to answer relate to the coordination of earthquake research in the Federal Government, whether there were any problems over that, or whether it has been well handled?

A comparison of the China program to ours; how many people involved, equipment used, number of seismic stations? What would it take to get us to their level?

And, finally, what about Russia? What are they doing? Do we have any arrangements with either China or Russia, and should we? If you would touch on those, and then the next witnesses carry on—thank you.

Dr. McKelvey. The coordination of the Federal program is well in hand as of about 3 years ago. The administration working with the Geological Survey, NOAA and NSF reached an agreement about the distribution of responsibilities and activities within the Federal research program.

Geological Survey under that agreement has responsibility for Earth science related research, and NSF for studies in seismic design and engineering; and NOAA maintains responsibility for the tsunami warning system.

And I think that the cooperation—and coordination—within the Federal program has followed those lines very closely, and gone beyond that to evolve I think in a highly satisfactory way up until now. And the interest of other agencies, such as NRC and ERDA, Veterans' Administration, Bureau of Reclamation, and so on, in earthquake hazards reduction have helped.

We have an advisory panel of which Dr. Frank Press of MIT is chairman that meets twice a year, and has been working out well as a forum for the exchange of information in this general area. It is attended not only by our own specialists but by representatives of other Federal agencies, and some State agencies.

With respect to the second question, a comparison of the Chinese and United States efforts in this area, I will ask Barry Raleigh to speak briefly on that. I suspect that any statistics that we may have on that would have to be submitted later for the record.

Dr. RALEIGH. The Chinese have a very large program in earthquake prediction principally because of the tremendous rate of damage in a given earthquake in China; the construction practices are such that many of their houses and buildings are of pounded earth construction.

The size of the program is orders of magnitude, probably 50 times or so, larger in numbers of people. There certainly is less capability in China for automatic processing of data, using large computers, as we have in the United States.

Other than that their program is technically equal to the U.S. program in all ways.

[The following information was subsequently received for the record:]

Several hundred scientists are involved, and, in addition, 10,000 trained workers and 100,000 amateurs. All sorts of sophisticated equipment is used. There are 17 complex observatories and 250 regional stations. Appropriations at approximately the level of $25,000,000 would be required as proposed in S. 1174.

Dr. McKELVEY. With respect to the last question, cooperative programs with the U.S.S.R. and other countries, we do have a very active cooperative program with the Soviet Union under the Environmental Protection Agreement reached a few years ago. And I have in fact here a synopsis of the status of that work as of the most recent meeting of the joint committee—about three pages long, a memorandum jointly prepared by Administrator Train and Dr. Israel, the Chairman of the Soviet side.

If you would like I could submit that for the record.

[The following information was subsequently received for the record:]

In Russia, a few hundred scientists are involved, and, in addition, several hundred to a thousand trained workers. About 140 permanent, three-component seismograph stations, many with additional equipment, are in operation. The Russians use all the same types of equipment that we do.

## AREA IX—EARTHQUAKE PREDICTION

### 1. EARTHQUAKE HAZARD REDUCTION PROGRAM

Dr. R. E. Wallace, Dr. R. Hamilton (both of the US Geological Survey), and Dr. C. Thiel of the National Science Foundation met in Moscow in August with Academician M. A. Sadovskiy, Dr. I. L. Nersesov, and Dr. V. I. Myachkin to finalize plans for joint work in 1976. In addition, Dr. Wallace visited field projects in Garm and Dushanbe, Tadzhik SSR.

Arrangements were completed for a special session at the Fall National Meeting of the American Geophysical Union entitled "Preliminary Results from the US-USSR Working Groups in Earthquake Prediction," to be held in San Francisco December 8–12, 1975. At the special session 12 papers, all with joint US-Soviet authorship, will be presented.

*Project IX–1.1, Field Research on Earthquake Prediction*

Joint observations of earthquakes in the area of Garm, Tadzhik SSR, begun in 1974 were expanded. Equipment used in 1974 was renovated, supplemented, and reinstalled in July to provide a network of ten three-component seismograph stations in the Peter the First Range. Preparations were completed to operate this network through rather severe winter weather conditions and to begin year-round observations. Analysis of data obtained to date is being carried out in Garm by Dr. R. Wesson and F. Fischer of the US Geological Survey in collaboration with Dr. I. Nersesov and others of the Institute of Physics of the Earth, USSR.

Observations of seismic spectra using a field digital recording system were also begun in the area of Garm in July by Dr. B. Tucker, G. Self, and Soviet colleagues. The data collected are currently being processed and analyzed using a US mini-computer in Garm and compared with the results of concurrent observations using the Soviet frequency selecting seismograph "CHISS."

Dr. A. Nikolayev of the Institute of Physics of the Earth, USSR, and J. Scheimer of MIT worked in Garm and Moscow in July-August 1975 on data collected from seismic arrays in the USSR and the USA to study the properties of scattered seismic waves. This is a continuation of work begun by Dr. Nikolayev and Dr. Keiiti Aki of MIT in Cambridge in 1974. Dr. P. Molnar, also of MIT, spent one month in Garm in August and September to complete manuscripts of papers with Drs. V. Khalturin and T. Rautian on work done in 1974 on seismic spectra.

Dr. D. Simpson and T. Koczynski of Columbia University, working with S. Negmatullayev and others of the Institute of Seismically Stable Construction and Seismology (ISSCS), of the Academy of Sciences of the Tadzhik SSR in Dushanbe, established a network of six seismograph stations around the reservoir of the Nurek hydroelectric station to search for possible relations between the filling of the reservoir and seismicity. Analysis of the data being collected is underway in Dushanbe and at the Lamont-Doherty Geological Observatory of Columbia University.

K. Mirzoyev of ISSCS spent September and October 1975 in the USA to conduct joint work at Lamont-Doherty, at the USGS in Menlo Park, and to visit other seismological research facilities. A. Sultankhodzhayev of the Institute of Seismology, Uzbek SSR, spent one month in the USA during September and October to consult on geochemical possibilities for earthquake prediction. He worked in Menlo Park, San Diego, and Yellowstone National Park.

Dr. R. E. Wallace, US Geological Survey, spent two weeks in the Kirghiz SSR and Tadzhik SSR investigating the feasibility of joint geologic work on the Talas-Ferghana fault system in Kirghizia and on the Vaksh and related fault systems of Tadzhikistan.

The Project Leaders were Dr. J. P. Eaton of the US Geological Survey (USA) and Dr. I. L. Nersesov, Deputy Director, Institute of Physics of the Earth, USSR Academy of Sciences (USSR).

*Project IX–1.2, Laboratory and Theoretical Investigations of the Physics of the Earthquake Source*

Analysis of joint experiments on seismic velocity variations and crack development in simulated fault gouge carried out in Menlo Park in 1974 by Drs. J. Dieterich, L. Peselnik, and J. Byerlee of the US Geological Survey and Drs. V. Myachkin and G. Sobolev of the Institute of Physics of the Earth (USSR) were carried out in Menlo Park and Moscow. Preparations were completed for a new set of joint experiments in October and November 1975 in Menlo Park and at the University of Colorado in Boulder.

The Project Leaders were Dr. W. Brace, MIT (USA), and Dr. V. Myachkin, Deputy Chief, Seismology Section, Institute of Physics of the Earth (USSR).

*Project IX–1.3, Mathematical and Computational Prediction of Places Where Large Earthquakes Occur and Evaluation of Seismic Risk*

In August 1975, Professors F. Press, MIT, and L. Knopoff, UCLA, worked in Moscow with Professor V. Keilis-Borok and others of the Institute of Physics of the Earth, comparing algorithms for the mathematical prediction of eathquakes and the computation of seismic risk. These algorithms were applied to sets of geophysical and gelogic data assembled to cover parts of the western USA and seismically active parts of the USSR.

The Project Leaders were Prof. L. Knopoff, UCLA (USA), and Prof V. Keilis-Borok, Institute of Physics of the Earth, USSR Academy of Sciences (USSR).

*Project IX–1.4, Engineering-Seismological Investigations*

Dr. C. Rojahn and P. Mork of the US Geological Survey, working with Dr. S. Negmatullayev and others of the ISSCS, installed a network of 18 strong motion accelerographs in various parts of the Tadzhik SSR. These instruments will provide material of significance to both US and Soviet structural engineers and engineering seismologists of ground motions during strong earthquakes. Plans were also completed for experimental work on the seismic resistance of typical California and Tadzhik dwellings to be carried out jointly in California and Tadzhikistan.

The Project Leaders were Dr. C. Thiel, Deputy Division Director, National Science Foundation (USA), and Dr. S. Negmatullayev, Director, Institute of Seismically Stable Construction and Seismology, Academy of Sciences, Tadzhik SSR (USSR).

Dr. McKelvey. It has been an effective program involving work on the part of our scientists in the Soviet Union, and Soviet scientists here, working along with us.

With respect to both China and Japan, we have had exchanges. I don't believe we have any actual agreement with them of a formal character; but the exchange with both has been fruitful. We have been working recently in trying to develop another exchange with China because we are most anxious to hear firsthand and in detail about the prediction they made last February—just what it was based on, and so on.

And we are hopeful that we will be able to arrange such an exchange.

[The statement follows:]

### Statement of V. E. McKelvey, Director, U.S. Geological Survey

Mr. Chairman, I thank the Committee for this opportunity to discuss the role of the U.S. Geological Survey in earthquake hazards reduction. The Geological Survey now has the principal Federal responsibility for earth science aspects of earthquake hazards reduction. Our present program has evolved over the past decades under the administrative guidance of several agencies, including the U.S. Coast and Geodetic Survey and its successors under the Environmental Science and Services Administration, and the National Oceanic and Atmospheric Administration (NOAA). In 1973, the earthquake programs of NOAA were merged with those of the Geological Survey and the Survey was given the responsibility for Federal earth-science earthquake research. The USGS also undertakes seismic engineering data-gathering and research on behalf of the National Science Foundation, which has the principal Federal responsibility for earthquake engineering research. As a result of a recent redelegation of authority under the Disaster Relief Act of 1974, the Survey also has the responsibility for issuing warnings of earthquakes and certain other kinds of geologic disasters such as volcanic eruptions and landslides, to the extent that they are predictable.

The Federal program in earthquake research and the Disaster Relief Act Amendments of 1974 were the result of the growing recognition that earthquakes are not only capable of causing enormous losses to life and property, but that the risk of such losses is increasing with urban growth in high risk areas. The Nation's annualized loss due to earthquakes is estimated to be $630 million. A single great earthquake in a metropolitan area such as Los Angeles could cause property losses approaching $50 billion and deaths and hospitalized injuries in the tens of thousands.

All 50 states are subject to some earthquake-related hazard and 39 states, containing nearly 35 percent of the U.S. population, are in zones where moderate to major damage from earthquake shaking can occur. For example, Charleston, South Carolina, was struck with a disastrous earthquake in 1886. The destructive earthquakes near New Madrid, Missouri, in 1811 and 1812, were felt throughout the Midwest and Eastern United States, and Boston suffered a large earthquake in 1755. Other states experiencing damaging earthquakes more recently include Alaska, California, Montana, Nevada, Hawaii, Utah, and Washington. Potential losses are increasing tremendously because of accelerated urbanization of earthquake-prone regions. Earthquakes in areas of rapid population growth, particularly in the Western United States, pose a growing threat to large numbers of people and to major industrial facilities that are important to the national economy.

It is useful to think of the consequences of a major earthquake in terms of primary, secondary, and perhaps even tertiary effects—not in the sense of importance but in the sense of the sequence in which they develop. Primary effects are those directly involved in the crustal movement—strong ground shaking; warping of the earth's crust; and vertical or horizontal movement along a fault at the earth's surface. Strong ground shaking is the principal cause of damage during earthquakes. Rupture of the ground surface, although rarely the major cause of destruction, can destroy even the largest and best engineered structures that are located on the lines of rupture. Permanent warping of the earth's surface also can have profound and long-term impact, resulting either in the flooding or draining of facilities along the coast.

These primary effects, of course, can be devastating in their immediate impact on man-made structures. In large earthquakes, however, the principal damage often results from the secondary and tertiary effects—the forces set in motion by the primary shaking and tectonic movement. Transient stresses generated by earthquake waves commonly trigger landslides, differential settlement, and liquefaction and lateral spreading of the ground.

Among the most terrifying secondary effects of some earthquakes are tsunamis. These large ocean waves, as much as tens of feet high, are generated by sudden vertical movement of the ocean floor. The waves can travel thousands of miles and devastate coastal communities within their reach.

Other secondary effects include destructive seiches or oscillations of the surface of lakes or bays, caused by crustal tilting or major landslides. Flooding resulting from earthquake-induced dam or levee failure may be a greater threat to life and property in heavily populated areas than the primary effects of an earthquake.

Tertiary effects can also be highly devastating. They include fire storms—turbulent blasts of scorching air—resulting from the large fires that may develop after the earthquake, the consequences of the panic of people under the stress of a terrifying disaster, and possibly disease and hunger resulting from the disruption of food and water supplies and the destruction of transportation systems. These latter effects were of great concern in the areas in Guatemala struck by the 7.5 magnitude earthquake on February 5 and its aftershocks.

If appropriate measures are taken, damage from these effects can be much reduced and some of the secondary and tertiary effects—such as catastrophic floods from breeched reservoirs and large fires and fire storms—can be avoided altogether. The capability for earthquake hazard reduction is already in hand to some degree and the results of research already achieved indicate that it can be much advanced by a combination of continued research and the determination to apply the knowledge already in hand. The strategy for earthquake hazard reduction involves several components: (a) improved design of man-made structures to increase their resistance to earthquakes; (b) identification of active faults and areas subject to strong ground motion, landslides and other forms of ground instability as a basis both for improved construction design and engineering and for land use planning and zoning: (c) development of the capability to predict the time, place, magnitude, and effects of earthquakes; (d) earthquake insurance to spread the economic losses; and (e) emergency preparedness, to utilize most effectively earthquake predictions and to have essential defensive measures at hand even for unexpected disasters. Responsibilities for implementing these components of the strategy for earthquake hazards reduction are shared not only by the research organizations such as the Survey, NSF, and academic institutions, but by other Federal agencies such as the Federal Disaster Assistance Administration and the Defense Civil Preparedness Agency and especially by State and local civil authorities.

The Geological Survey's part in earthquake hazard reduction is a critical one, however, and its major program objectives include: (1) acquisition and dissemination of information on earthquake occurrences; (2) mapping and evaluation of earthquake hazards; and (3) development of the capability to predict the time, place, and magnitude of earthquakes. These objectives and goals are described more fully in Geological Survey Circular 701, copies of which we are glad to furnish the Committee. I will briefly describe here some of our activities in these areas.

The Survey's National Earthquake Information Service locates and rapidly evaluates important earthquakes worldwide, provides data supporting the Tsunami Warning System operated by the National Oceanic and Atmospheric Administration, and notifies appropriate disaster authorities and the public within two hours of the occurrence. From these data, the Geological Survey publishes seismicity maps and derivative products such as regional and national seismic risk maps that indicate expectable values of earthquake frequency and levels of shaking; these are widely used by the engineering community to determine building codes and for the safe design of structures.

Geological Survey maps and reports on earthquake hazards are used by planners to avoid areas of greatest potential danger from the destructive effects of earthquakes. Active faults are identified on the basis of seismologic and geologic evaluations. Areas are delineated that could be subject to surface faulting, strong shaking, ground failure, tectonic elevation changes, or earthquake-induced flooding from seismic sea waves or from dam failure. Methods for assessing these various earthquake hazards also are published to enable scientists in the academic community, state agencies, and the private sector to analyze the origin, distribution, and effects of earthquakes.

The Geological Survey also has under way research on the prediction of the time, place, magnitude and effects of earthquakes. Mounting evidence from the United States and from China, Japan, and the Soviet Union indicates that at least some large earthquakes are predictable. Our present efforts are concentrated heavily in central California near the town of Hollister where small to moderate earthquakes are frequent. We have deployed there various kinds of instruments that monitor the state of the earth over this seismically active region continuously. The data are analyzed at our center in Menlo Park, California, to which they are telemetered. Reconnaissance networks of seismographs and other instruments are located in southern California and the Bay area but the density is sparse.

Recently, analysis of data from precise levelling has shown that a large uplift has occurred in the last 15 years in the vicinity of the San Andreas fault in the Mojave Desert just north of Los Angeles, with the land surface rising nearly a foot in the central part of the uplift. The origin of this uplift and its possible relation to a forthcoming earthquake is not understood but there is clearly cause for concern. Such uplifts have preceded some earthquakes in the past; but in this very area one occurred earlier this century with no following earthquakes. There is a critical need for an assessment of this problem and I am glad to report that the President has recently authorized an increase in our fiscal 1977 budget request to expand our observations and analysis of the uplift. Copies of our February 13 press release describing the uplift will be provided for the Committee.

I mentioned earlier the responsibility recently redelegated to the Survey with respect to the issuance of warnings of impending disasters of geologic origin. Frankly, however, no one currently has the capability to carry out this responsibility because we do not know enough, particularly with respect to predictions as to the time an event will occur. As an initial step in responding to this expanded responsibility, however, the Geological Survey currently is reviewing its capabilities for prediction of natural disasters and is developing procedures for issuance of the predictions we are able to make so that they can be used most effectively by local authorities. At a recent conference we held in San Francisco with Federal, State, and local officials concerned with disaster warning and response, we proposed a preliminary plan for the issuance of earthquake predictions and warnings. The framework of this proposal is indicated on the accompanying chart. The plan provides for careful review of the scientific data and transmittal of a prediction to the appropriate State and Federal officials. It assures that the scientific data will be publicly available, that a prediction will be reviewed and authenticated by a council of experts, and that an official prediction will be accompanied by recommendations from local authorities for appropriate action by the public. This plan was generally well received by State and local officials at the San Francisco conference, the proceedings of which have just been published as Geological Survey Circular 729. Copies will be furnished to the Committee.

In carrying out the responsibilities under the Disaster Relief Act, we will be in a difficult position while an earthquake prediction capability is being developed. The impact of incorrect predictions, a subject presently under review, will be socially and economically adverse. Prediction research is a complex and difficult program and the period of uncertain and inaccurate predictions could well stretch over the next few decades. We are looking at possible ways to reduce this period of uncertainty.

The bill under review today, S. 1174, would provide an acceleration in earthquake hazards reduction research and would establish earthquake disaster mitigation as a national objective. It also would provide a new coordinating structure for a national earthquake program.

A true National Earthquake Hazard Reduction Program can be accomplished under the existing authorities already available to the Federal agencies. We are working closely with the NSF to develop proposals for further earthquake research for consideration in the 1978 budget. Let me emphasize, however, that a true hazard reduction program must include building codes, zoning ordinances, and warning systems which are the responsibilities of State and local Governments, as well as research on predicting earthquakes.

That concludes my testimony, Mr. Chairman. My colleague here, Dr. Barry Raleigh, has some charts with which to illustrate briefly the scientific basis of earthquake prediction if the Committee so desires.[1]

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[1] See p. 92.

Mr. Flajser. As Senator Cranston requested, we will proceed with the next witnesses, Dr. Alfred Eggers, and Dr. Charles Thiel.

## STATEMENT OF DR. ALFRED J. EGGERS, JR., ASSISTANT DIRECTOR FOR RESEARCH APPLICATIONS, NATIONAL SCIENCE FOUNDATION; ACCOMPANIED BY DR. CHARLES C. THIEL, DEPUTY DIRECTOR, DIVISION OF ADVANCED ENVIRONMENTAL RESEARCH AND TECHNOLOGY

Dr. Eggers. Thank you, Mr. Chairman. It is a pleasure for me to be able to describe to you the National Science Foundation's earthquake research and how it relates to Senate bill 1174, The Earthquake Disaster Mitigation Act of 1975.

My discussion will touch briefly on the nature of the national earthquake problem, the possibilities for adjustments to reduce earthquake impacts, and the NSF research program as it relates to the objectives of the Senate bill under consideration.

First, in the area of the national earthquake problem, the popular conception of the earthquake hazard in the United States often limits it to the Pacific coast, especially California, and to such well known disasters as San Francisco in 1906, Long Beach in 1933, the Alaskan coast in 1964, and San Fernando in 1971.

Major earthquakes are of course by no means unknown to the rest of the country with occurrences in the St. Lawrence River region on several occasions from 1650 to 1928; the vicinity of Boston in 1755, the Central Mississippi Valley, specifically New Madrid, Mo. in 1811 and 1812; Charleston, S.C. in 1866, and Hebgen Lake, Mont. in 1959.

While the San Francisco quake was felt over a 400,000-square-mile area, eastern quakes at Charleston, New Madrid, and along the St. Lawrence were felt over an area of 2 million square miles. In 1973, quakes were felt in 34 States.

This last figure may be more indicative of the overall extent of the earthquake hazard in the United States. A recent study indicates that there are, in fact, some 39 States wholly or partially in regions of major and moderate risk, with a combined population in 1970 of over 70 million people, as is noted in attachment 1. And that has been discussed already in these hearings.

A damaging earthquake at a given site is fortunately a relatively rare event in the United States. In the past as a result the estimated loss per year from earthquakes over the last century averages about $30 million. Historic data can be misleading, however, since major urban and suburban development of dense populations in seismically hazardous regions is a relatively recent phenomenon in the United States. If these trends continue it is estimated as we move into the next century, the average loss per year due to earthquakes could exceed $1 billion, and specific events, like a recurrence of the San Francisco earthquake, could cause us losses in the tens of billions of dollars. Clearly, earthquakes pose an increasingly costly threat to the local and national community that cannot be ignored.

Let me turn now to adjustments to decrease earthquake vulnerability: The occurrence of an earthquake, or any other natural event, is important to the degree that it affects man and his works in an unacceptable way, through life loss, injury, property damage, economic disruption, and social dislocation.

The general objective of any individual or group that is attempting to deal with a potential earthquake is to control the consequences of the event through adjusting its impacts. As adjustments, one may seek either to change the phenomena or to alter the response of man and his works to the phenomena. Possible adjustments the decisionmaker may seek to accomplish are:

Control the event by prevention or modification of the event.

Construct facilities so as to perform acceptably during and after the event.

Plan for the warning, response, and recovery from the event.

Distribute the economic risk, for example, through insurance and redevelopment loans.

Generate and select alternative physical development plans.

Adopt and enforce effective zoning, construction, and management standards.

Clearly, these adjustments are both physical and social in nature and they depend critically on each other. Moreover a balanced combination of adjustments will undoubtedly yield the maximum benefit in relation to social and economic costs over a period of time. Some estimated benefits due to such adjustments are as follows:

The restriction of population growth in high damage potential areas in the San Francisco Bay area could reduce the impact of a recurrence of the 1906 earthquake early in the next century by one-one-quarter if adopted now, something like one-quarter, and it would correspond to the neighborhood of a $5 billion reduction in damage due to the earthquake.

Another example—reinforcement of hazardous structures in the highest hazard counties in the United States could reduce losses by one-quarter per year.

Replacement of hazardous buildings 10 years earlier than normal could reduce the Nation's loss from 5 to 10 percent by the turn of the century.

Finally, as an example, improvement of building codes by the doubling of lateral force requirements for new construction could reduce the annual national loss by some 10 percent by the turn of the century.

The impacts of these adjustments illustrate the potentials for reduction of major national earthquake damage by the implementation of policies that change the nature of the constructed environment and the response of its institutions to earthquake hazards.

I think I will skip some of my prepared testimony, Mr. Chairman, in the interests of saving time, if you agree, sir?

Senator CRANSTON. I certainly do.

Dr. EGGERS. And move directly if I may now to the National Science Foundation's earthquake research program.

Since its inception, the NSF has supported research on earthquakes and their effects. Our program has two major thrusts:

First, basic research in the Earth sciences, and, second, applied research in earthquake engineering and public policy.

Our research, Mr. Chairman, in the Earth sciences area, is fundamentally a highly complementary program to the program that was described by Dr. McKelvey of the USGS, and therefore, I will not go into that.

Again, applied research is centered in the Foundation's research applied to national needs program—or RANN program. Earthquake engineering research has been supported by RANN since its inception. Following the occurrence of the 1971 San Fernando earthquake, RANN broadened the scope of the program to include all those—essentially all those aspects of problem-focused research that could potentially reduce the public's exposure to earthquake losses.

The general objective of the RANN earthquake engineering program is to develop methods that will allow decision-makers to control the consequences of earthquake occurrences. The specific objectives of the program are as follows—and again, I will abbreviate my remarks by pointing out they focus in the area of improved design, improved land use; fuller, more effective consideration of socioeconomic factors; and utilization is a special area of the program; there we focus on presentation of program results in forms most suitable for the user communities.

The RANN program does not include the topics of the scientific basis for earthquake prediction and control. Those are the responsibility of USGS.

I would like to take a few minutes to discuss two specific initiatives that we have undertaken. The first is the cooperative Federal program on building practices for disaster mitigation, which is a major utilization effort. The purpose of this work is to develop comprehensive, nationally applicable seismic design provisions for buildings through the integration of activities and resources in Federal agencies, professional organizations, private practitioners, State, and local governments and researchers.

It involves a concentrated effort to update, expand, and substantially revise present seismic design provisions to incorporate the latest state of the art research results. The public relies heavily on building codes to foster a constructed environment that protects life and limb from the hazards of fire, wind, and earthquake, among others.

For the most part, the seismic provisions adopted throughout the country are based on documents prepared in the 1950's. Thus the products of the joint cooperative Federal program will fill a vital public need, we believe. The draft provisions are now out for review. The publication of the final provisions and associated commentaries will take place in about 1 year.

At that time they will be available for incorporation into building codes throughout the country. I am sure you can appreciate the size and complexity of this special effort to collect, evaluate, and synthesize the products of two decades of research into an economically realistic set of building provisions applicable on a national scale.

The second initiative involves research on the public consequences of earthquake mitigation. As part of a comprehensive assessment of natural hazards, a major examination was made of the mix of policies and procedures that are available. This effort to a considerable degree has already been discussed by Dr. Haas, and also by Dr. Turner, and others, and I will therefore not go into that.

The possibility of predictions of events to take place 10 years hence I should note greatly complicates the public policy decisions that must be made. It is important to note that the multiplicity of issues presented by such a prediction are at an early stage of investigation, at this point, certainly.

Let me turn, now, sir, to the proposed legislation: I am speaking, of course, of S. 1174. This bill would establish objectives in the areas of structural design and construction, earthquake prediction, seismic hazard identification, community preparedness, earthquake control, and public education.

As I have explained, NSF already has the legislative authority needed to accomplish many of the objectives the bill sets forth for the Foundation. Indeed, we are proceeding along the lines of the bill's objectives. The NSF proposed fiscal 1977 budget currently before Congress, would expand out basic research support applicable to earthquake prediction by approximately $1 million, to a total of $3.5 million. It would also maintain out support of earthquake engineering research at $6.8 million in the RANN program.

These programs are entirely consistent with section 3 of the proposed bill that pertains to the Foundation.

Section 6(2) of the bill proposes the establishment of an information dissemination mechanism, which the RANN program has already initiated.

Section 5 specifies the formation of coordinating mechanisms between the USGS and the Foundation which is indeed presently ongoing at an informal level, in some areas at a formalized level, but which we agree should be further formalized. That activity as it currently is ongoing is also discussed by Dr. McKelvey, and I will not go into it further.

There are certain objectives of the bill that would extend the Foundation's responsibilities well beyond those of supporting basic and applied research and education in the sciences. Specifically, section 3 would greatly enlarge and extend the functions of NSF by calling for an implementation program. We will continue to do all we can to make the benefits of our research support available to all those who have need, and we will continue to cooperate closely with agencies, such as the USGS and Federal Disaster Assistance Administration, that have responsibilities for implementation.

But we feel that the Foundation's role should be limited to its mainline functions of supporting research and science education; and it should not be extended to include implementation per se. Such an extension could seriously impair the Foundation's ability to discharge its mainline functions.

In closing, there are two major points with respect to any pending legislation on earthquake mitigation that should be kept in mind, we believe:

First, it is vitally important that any Federal program in earthquake research maintain a balance between the geophysical and social sciences and engineering. To do otherwise will seriously impair the public's ability to implement in a sound, economic way the fruits of research.

Second, it is highly unlikely that research performed over the next few years will appreciably decrease losses from earthquakes in the near term. The payoff of research performed now will be in reduced

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losses over the long term. For the next decade or so, the earthquake vulnerability, it is most probable, of virtually all this Nation's cities will be dominated by those older structures now standing that cannot be expected to withstand a major quake or shake.

The biggest challenge to the public official is to develop economically and politically realistic procedures and policies for the condemnation of substandard structures, and for their reinforcement, replacement, or abandonment.

This concludes my statement, Mr. Chairman, and I will be pleased to answer any questions you may have.

I have with me, my colleague, Dr. Thiel.

Senator CRANSTON. Thank you very much.

Do you concur in the view expressed by others that there are at least 39 States that are earthquake prone to one degree or another, where there could be reasonably significant amounts of damage done by quakes?

Dr. EGGERS. Yes, sir.

Senator CRANSTON. A recent California report, "Urban Geology: Master Plan for California," Bulletin 198, Division of Mines and Geology, 1973, estimates California will suffer $21 billion in losses as a result of earthquakes between 1970 and the year 2000.

Assuming that that may be a reasonably accurate prediction, would you consider this Federal research effort might minimize that loss?

Dr. EGGERS. Mr. Chairman, as I indicated in my testimony I think in terms of between now and the turn of the century, the research effort is probably not the weak link in the chain.

Senator CRANSTON. Is what?

Dr. EGGERS. Not the weak link.

I think where the major challenge lies is as I have stated in my last paragraph, the challenge to the decisionmakers to take economically and politically effective action to take out of use these earthquake-unworthy buildings, if you will: condemn them, replace them, or some other effective action. That is where the great hazard is. And of course we have very dramatic evidence of that sort of thing.

Senator CRANSTON. In addition to that, what is your feeling about what would be an adequate level of funding for the research program?

Dr. EGGERS. I believe, Mr. Chairman, that all factors considered, including the financial constraints that we face in terms of total expenditures, the Federal program as currently put before the Congress is a very soundly conceived program.

Senator CRANSTON. Do you feel that more money could be spent well if it was available?

Dr. EGGERS. Yes, sir. I believe this is the case, but if steps of that type are taken at the expense of other parts of the program. I think we can find ourselves in a state of imbalance that would not be to the net advantage of the country.

Senator CRANSTON. I am not suggesting that. I am suggesting this: taken by itself—or by investing more, I gather you do feel there could be benefit from additional funds?

Dr. EGGERS. Yes.

Senator CRANSTON. Thank you very much.

[The statement follows:]

STATEMENT OF DR. ALFRED J. EGGERS, JR., ASSISTANT DIRECTOR FOR RESEARCH APPLICATIONS, NATIONAL SCIENCE FOUNDATION

Mr. Chairman, Members of the Committee, it is a pleasure for me to be able to describe to you the National Science Foundation's earthquake research and how it relates to Senate Bill 1174, The Earthquake Disaster Mitigation Act of 1975. My discussion will touch briefly on the topics of the nature of the national earthquake problem, the possibilities for adjustments to reduce earthquake impacts, and the NSF research program as it relates to the objectives of the Senate Bill under consideration.

## NATIONAL EARTHQUAKE PROBLEM

The popular conception of the earthquake hazard in the United States often limits it to the Pacific Coast, especially California, and to such well known disasters as San Francisco in 1906, Long Beach in 1933, the Alaskan Coast in 1964, and San Fernando in 1971. Major earthquakes are by no means unknown to the rest of the country with occurrences in the St. Lawrence River region on several occasions, the vicinity of Boston in 1755, the Central Mississippi valley (New Madrid, Missouri) in 1811 and 1812, Charleston, South Carolina in 1866, and Hebgen Lake, Montana in 1959. While the San Francisco quake was felt over a 400,000 square mile area, eastern quakes at Charleston, New Madrid, and along the St. Lawrence were felt over an area of 2 million square miles. In 1973, quakes were felt in 34 states.

This last figure may be more indicative of the overall extent of the earthquake hazard in the United States. A recent study indicates that there are, in fact, some 39 states wholly or partially in regions of major and moderate risk, with a combined population in 1970 of over 70 million people as may be noted in Attachment 1.

A damaging earthquake at a given site is fortunately a relatively rare event. The estimated loss per year from earthquakes over the last century averages about $30 million. Historic data can be misleading, however, since major urban and suburban development of dense populations in seismically hazardous regions is a relatively recent phenomenon in the United States. Thus, it is estimated that as we move into the next century the average loss per year due to earthquakes could exceed $1 billion, and specific events, like a recurrence of the San Francisco earthquake, could cause losses in the tens of billions of dollars. Clearly earthquakes pose an increasingly costly threat to the local and national community that cannot be ignored.

## ADJUSTMENTS TO DECREASE EARTHQUAKE VULNERABILITY

The occurrence of an earthquake, or any other natural event, is important to the degree that it affects man and his works in an unacceptable way, through life loss, injury, property damage, economic disruption, and social dislocation. The general objective of any individual or group that is attempting to deal with a potential earthquake is to control the consequences of the event through adjusting its impacts. As adjustments, one may seek either to change the phenomena or to alter the response of man and his works to the phenomena. Possible adjustments the decisionmaker may seek to accomplish are:

Control the event by prevention or modification of the event.

Construct facilities so as to perform acceptably during and after the event.

Plan for the warning, response and recovery from the event.

Distribute the economic risk, for example, through insurance and redevelopment loans.

Generate and select alternative physical development plans.

Adopt and enforce zoning, construction and management standards.

Clearly these adjustments are both physical and social in nature and they depend critically on each other. Moreover, a balanced combination of adjustments will undoubtedly yield the maximum benefit in relation to social and economic costs over a period of time. Some estimated benefits due to such adjustments are as follows:

The restriction of population growth in high damage potential areas in the San Francisco Bay area could reduce the impact of a recurrence of the 1906 Earthquake early in the next century by one quarter if adopted now.

Reinforcement of hazardous structures in the 42 highest hazard counties in the United States could reduce losses by one quarter per year.

Replacement of hazardous buildings 10 years earlier than normal could reduce the Nation's loss from 5 to 10 percent by the turn of the century.

Improvement of building codes by the doubling of lateral force requirements for new construction could reduce the national annual loss by some 10 percent by the turn of the century.

The impacts of these adjustments illustrate the potentials for reduction of major national earthquake damage by the implementation of policies that change the nature of the constructed environment and the response of its institutions to earthquake hazards. The impacts of these adjustments are preliminary but indicative, and do not make allowance for the cost of achieving the adjustment. It is important to note, however, that better earthquake disaster policies will reduce the impact of other hazards such as accidents, explosions, and extreme winds, and in addition, many of the benefits that accrue will benefit the public at large as well as those directly affected. Public Law 93–288, the Disaster Relief Act of 1974, established a broad program of relief and rehabilitation for disaster struck communities. Thus a reduction in an earthquake's impact translates directly into reduced Federal expenditures under this act to aid the victims and restore the community.

At this time, there is a crucial need to determine the full costs associated with achieving these beneficial adjustments. The development of effective methods to estimate these costs requires joint effort in the application of research, experience and good judgement.

### THE NATIONAL SCIENCE FOUNDATION EARTHQUAKE RESEARCH PROGRAM

Since its inception, the National Science Foundation has supported research on earthquakes and their effects. Our program has two major thrusts. First, basic research in the Earth Sciences, and, second, applied research in earthquake engineering and public policy.

Basic research is focused in the Division of Earth Sciences programs on Geophysics and Ocean Sediment Coring. The later program supports drilling in the central Atlantic which has provided widely accepted evidence for the plate tectonic theory of the earth's crust. This theory has greatly enhanced our understanding of the mechanisms of earthquake generation and has provided an explanation for the general location of most earthquakes along plate boundaries. The Geophysics Program has supported over the past two decades the Nation's principal academic activity in seismology, geophysics, and geology as they relate to earthquakes. The basic knowledge developed under its support forms both the foundation for the advancements discussed earlier by Drs. Kisslinger, McKelvey, and Raleigh, and sets the limits on that which can be expected to be accomplished in the near future.

Applied research is centered in the Foundation's Research Applied to National Needs Program (RANN). Earthquake Engineering research has been supported by RANN since its inception. Following the occurrence of the 1971 San Fernando Earthquake, RANN broadened the scope of the program to include all those aspects of problem-focused research that could potentially reduce the public's exposure to earthquake losses.

The general objective of the Earthquake Engineering program is to develop methods that allow decisionmakers to control the consequences of earthquake occurrences. The specific objectives of the program are as follows:

*Design.*—Development of economically feasible design and construction methods for building earthquake resistant structures of all types.

*Land use.*—Development of procedures for integrating information on seismic risk with ongoing land use planning processes.

*Socioeconomics.*—Development of an improved understanding of socioeconomic consequence of individual and community decisions on earthquake related issues.

*Utilization.*—Presentation of program results in forms most suitable for the user communities.

The RANN program does not include the topics of the scientific basis for earthquake prediction and control. Basic and applied research in these areas are respectively supported by the NSF Earth Sciences Division and the USGS.

I would like to take a few minutes to discuss two specific initiatives that we have undertaken. The first is the Cooperative Federal Program on Building Practices for Disaster Mitigation which is a major utilization effort. The purpose of this work is to develop comprehensive, nationally applicable seismic design provisions for buildings through the integration of activities and resources in

Federal agencies, professional organizations, private practioners, State and local governments, and researchers. It involves a concentrated effort to update, expand, and substantially revise present seismic design provisions to incorporate the latest state-of-the-art research results. The public relies heavily on building codes to foster a constructed environment that protects life and limb from the hazards of fire, wind and earthquake, among others. For the most part the seismic provisions adopted throughout the country are based on documents prepared in the 1950's. Thus the products of the Joint Federal Program will fill a vital public need. The draft provisions are now out for review. The publication of the final provisions and associated commentaries will take place in about one year. At that time they will be available for incorporation into building codes. I am sure that you can appreciate the size and complexity of this unique effort to collect, evaluate, and synthesize the products of two decades into an economically realistic set of building provisions applicable in a national context.

The second initiative involves research on the public consequences of earthquake mitigation. As part of a comprehensive assessment of Natural Hazards, a major examination was made of the mix of policies and procedures that are available. This has formed in part the basis for future program development. In addition, we have supported a major effort under Dr. Haas, who spoke earlier, to investigate the "Socioeconomic and Political Consequences of Earthquake Prediction." Earthquake prediction presents a number of problems that have not been encountered in the warning programs associated with other hazards.

The possibility of predictions of events to take place ten years hence greatly complicates the public policy decisions that must be made. It is important to note that the multiplicity of issues presented by such a prediction are at an early state of investigation. I believe that Dr. Turner will explore this topic in some detail.

## PROPOSED LEGISLATION

I will now turn briefly to the specific Bill under consideration, S. 1174. This Bill would establish objectives in the areas of structural design and construction, earthquake prediction, seismic hazard identification, community preparedness, earthquake control and public education.

As I have explained, NSF already has the legislative authority needed to accomplish many of the objectives the Bill sets forth for the Foundation. Indeed we are proceeding along the lines of the Bill's objectives. The NSF proposed fiscal 1977 budget, currently before Congress, would expand our basic support applicable to earthquake prediction by approximately $1 million to a total of $3.5 million; it would also hold about constant our support of Earthquake Engineering Research at $6.8 million. These programs as described above are entirely consistent with Section 3 of the proposed Bill that pertains to the Foundation. Section 6(2) of the Bill proposes the establishment of an information dissemination mechanism, which the RANN program has already initiated. Section 5 specifies the formation of coordinating mechanisms between the USGS and the Foundation which is indeed presently ongoing at an informal level but which might well be formalized.

There are certain objectives of the Bill that would extend the Foundation's responsibilities well beyond those of supporting basic and applied research, and education in the sciences. Specifically, Section 3 would greatly enlarge and extend the functions of NSF by calling for an implementation program. We will continue to do all we can to make the benefits of our research support available to all those who have need, and we will continue to cooperate closely with agencies, such as the USGS and the Federal Disaster Assistance Administration, that have responsibilities for implementation. But we feel that the Foundation's role should be limited to its mainline functions of supporting research and science education and should not be extended to include implementation per se. Such an extension could seriously impair the Foundation's ability to discharge its mainline functions.

In closing, there are two major points with respect to any pending legislation on earthquake mitigation that should be kept in mind.

I. It is vitally important that any Federal program in earthquake research maintain a balance between the geophysical and social sciences and engineering. To do otherwise will seriously impair the public's ability to implement in a sound, economic way the fruits of research.

II. It is highly unlikely that research performed over the next few years will appreciably decrease losses from earthquakes in the near term. The payoff of research performed now will be in reduced losses over the long term. For the next decade or so the earthquake vulnerability of virtually all this Nation's cities will be dominated by those older structures now standing that cannot be expected to withstand a major shake. The biddest challenge to the public official is to develop economically and politically realistic procedures and policies for the condemnation of substandard structures, and for their reinforcement, replacement, or abandonment.

This concludes my statement, Mr. Chairman, and I will be pleased to answer any questions you may have.

U.S. POPULATION RESIDENT IN VARIOUS EARTHQUAKE RISK ZONES

| | Estimated population at risk (1970) | Number of affected States |
|---|---|---|
| Seismic risk zone: | | |
| 3 (high) | 30,943,000 | 213 |
| 2 | 40,472,000 | 39 |
| 1 | 115,091,000 | 42 |
| 0 (low) | 16,717,000 | 5 |

Senator CRANSTON. Our final witnesses are Mr. Henry J. Degenkolb of the Earthquake Engineering Research Institute, Oakland, Calif., and Mr. Elmer E. Botsai, vice president, the American Institute of Architects.

I appreciate very much your presence and your patience. I would like to reverse the normal procedure and ask you a few questions, because I have to go, and then you may summarize your prepared statements.

In relationship to the damage Japan has suffered in quakes, have they not had a reasonable strong earthquake building code, and yet suffered considerable damage despite that fact?

## STATEMENT OF HENRY J. DEGENKOLB, EARTHQUAKE ENGINEERING RESEARCH INSTITUTE, OAKLAND, CALIF.; ACCOMPANIED BY ELMER E. BOTSAI, VICE PRESIDENT, THE AMERICAN INSTITUTE OF ARCHITECTS

Mr. DEGENKOLB. Yes; they have. I really do not feel their code applies to the majority of buildings, one-, two-, and three-story buildings, where our codes do apply across the board.

Senator CRANSTON. Are the Federal research programs a benefit to you as a practicing engineer?

Mr. DEBENKOLB. Yes, they are.

Senator CRANSTON. Can they be improved?

Mr. DEGENKOLB. Yes; I might amplify on both of those. Mr. Botsai is an architect, and I am a structural engineer. Of the witnesses present this afternoon, we are the only ones that are users of the codes, of the research, on behalf of the public, and we realize the shortcomings that we have.

Senator CRANSTON. I would like to ask you, Mr. Botsai, it seems the current research effort is directed primarily toward engineering and geophysics; what Federal assistance would be helpful to you as an architect to improve buildings and community development?

Mr. BOTSAI. A tremendous increase in that activity; right now there is practically none. The architectural profession is living in the dark ages for seismic design, and it is something we cannot tolerate.

Senator CRANSTON. Who is responsible for incorporating earthquake considerations in buildings? Is it entirely local? How much does the State get into it, the Federal get into it? Have adequate safety standards been set, or are we moving toward that?

Mr. DEGENKOLB. We are moving toward it. It is a mixed bag, dependent upon which area is being covered. Certainly the Federal Government is involved with such things as where they supply the funding; State governments have some control, and in other areas it is local government.

Senator CRANSTON. Thank you very much. If you would now proceed with your prepared statements, and forgive me for departing. I have another responsibility I have to meet. Thank you very much.

Mr. DEGENKOLB. I will shorten my statement in the interests of time. I am pleased to be here and to have an opportunity to speak on behalf of the Earthquake Engineering Research Institute, the chairman of the Seismic Safety Commission of the State of California, and for myself both as a commissioner and as a consulting structural engineer concerned with earthquake hazard reduction.

There is a critical need for research in all aspects of earthquake engineering and seismology. It is gratifying to find that recognition of this need extends to most parts of the country and has resulted in the introduction of S. 1174.

As I say, this afternoon I believe that Mr. Botsai and I represent the users of the research as compared to the producers of it. As a structural engineer, trying to design buildings and structures that will be safe for the public to occupy, I consider three general areas of research to be the most critical of all the various facets of the problem.

The first area concerns the acqusition of the records of motion due to strong ground shaking. All earthquake engineering research has to be based on just how the ground shakes or moves in a strong earthquake. Without that knowledge, everything following is subject to uncertainty or error. We do not get many opportunities to measure this ground motion—it cannot be produced in the laboratory nor can it be purchased for any amount of money.

In the recent Guatemalan earthquake we again lost the opportunity to obtain adequate strong motion records just as we lost it in Alaska and Caracas.

The second area of research is not really research, but Dr. Eggers has referred to it briefly as the application of known, existing, research findings to engineering practices and codes in a form that can be used by practicing engineers. There is much that's already known from past and current research that is not available to the average engineer. This research has to be translated into practical form so it can be used in the average design office, and administered.

The NSF has recently funded experiments in this field of using practicing engineers through a mix of different disciplines in trying bring our codes up to date. And also they are utilizing the efforts of all the engineers, both public and private, rather than sticking to just the research labs and universities.

The third area of research is the determination of material behavior at high stresses that are associated with earthquakes and the development of adequate tools of engineering analysis. Since most materials are usually tested for performance only in the service range, too little is known about their performance when high ductility is required. Our whole engineering approach at present is quite rudimentary because of the lack of past research and the translation of that research into practice.

One of the ways of improving this is through the use of large-scale shaking tables where we can actually combine all these effects and see what we are missing. We have found out in the past earthquakes in our engineering designs that every earthquake brings out illustrations of where we have missed something; and we need an encompassing-whole to test the whole process all the way through design and construction and analysis.

In the absence of large enough facilities, some engineers and earth scientists have been visiting the scene of major earthquakes to observe their damaging effects so that we can incorporate those empirical findings into building codes and practices. Our observations, in the absence of more definitive and reliable research, have led to some changes and improvements in our codes. They have been productive insofar as new construction is involved.

However, the United States has a very large inventory of older buildings that have not been designed to resist earthquakes—as has been mentioned before. Little research has been done to test the methods that we currently use to reinforce these structures. It is generally conceded that the largest numbers of casualties in a future major earthquake in California will be in these old, dangerous, unreinforced masonry structures, just as happened in San Fernando in 1971.

California is not alone in this problem. It is often stated that the largest earthquake to strike the North American Continent was in Missouri in 1811 and 1912. Boston suffered a destructive earthquake in 1755. About 100 persons were killed in Charleston, S.C. in the earthquake of 1866.

As mentioned earlier, 39 of our 50 States are subject to high or moderate risk from earthquakes, and it is almost inevitable that where earthquakes have occurred in the past, they will occur in the future. One has only to look at the unreinforced masonry construction prevalent in most parts of the country and in our older buildings to anticipate the number of casualties that would occur should a strong earthquake strike. While the impact will not be as large as in Managua with about 10,000 deaths, nor as in Guatemala, with over 20,000, it will still be considerable. Some studies have indicated that a major earthquake in San Francisco or Los Angeles may have casualties that approach these figures.

Another aspect of the materials and design problem relates to the functioning after a disaster of certain critical facilities such as hospitals. As you know, four hospitals failed in San Fernando. Four failed in Managua; and while my written statement says four failed in Guatemala City, I later understand it is really three.

But they had to evacuate three hospitals that we know of, and move the beds to warehouses, which, incidentally, were not designed for earthquakes but stood up, nevertheless.

In all the cases that I have mentioned some of these damaged buildings were designed and constructed to modern engineering standards for earthquake resistance. This probably illustrates, better than any other single statement, the low degree of our available practical knowledge about earthquake hazard. Only research and education can improve this situation.

S. 1174 is a means to enhance public safety by increasing the knowledge available to engineers.

Since the Alaska earthquake in 1964 there has been increasing concern about the earthquake hazard that has resulted in a moderate increase in earthquake engineering research and a greatly increased level of instrumentation. However, if funds are now reduced and important research programs eliminated before they can be translated into practical forms that the buildings industry can use, much of the anticipated benefits will be lost and a large portion of the previous investments in research will have been useless.

Earthquake research is now in a critical period. If the present impetus is lost, many of our important projects will have to start over in the future. We will have lost the opportunities to learn from earthquakes that may occur in the near future as we have missed many opportunities to learn from past earthquakes.

Speaking on behalf of the groups I mentioned earlier, we respectfully request that this committee does everything in its power to expedite the passage of Senate bill 1174.

Thank you.

Mr. BOTSAI. Good afternoon, Mr. Chairman. I am Elmer E. Botsai, FAIA, vice president of the American Institute of Architects. I am here today in behalf of the AIA, the national society for the architectural profession, and the Joint Commission on Hazardous Buildings, a joint activity of the California Council/AIA and the structural engineers of California.

Basically I wish to point out we endorse strongly the balance in the bill, and we are particularly happy that dissemination of information is incorporated in the charges to the National Science Foundation under section 3.

We have four basic concerns:

The first one is the need for supplying this information at the design level for utilization by the whole profession, and the architectural profession is particularly in need of additional research information in nonstructural areas.

Some examples from the recent horrible earthquakes are in Nicaragua a major building remained intact but suffered a 70-percent loss of value through nonstructural damage.

In Oroville, Calif., several firehouses were out of operation because the overhead door tracks were not properly anchored, and the doors collapsed on top of the equipment, rendering the trucks inaccessible.

Also, there is strong evidence to suggest that the current test criteria for fire safety of many building components are in conflict with the best known practice of seismic safety, and visa versa.

The second area of concern is for the unreinforced or minimally reinforced masonry construction in our existing building stock.

The third area is the lack of knowledge in large-scale problems in much of the country: What would happen if any of the past quakes took place—New Madrid, Charleston, Boston—some of those areas could have mass liquefaction of the soils.

The last area I am concerned about is the economic and social consequences of a major quake in a metropolitan area. We are already faced with a projected $600 to $800 billion shortage of capital improvement funds in the near future, and if any major metropolitan area was subject to a major quake, I don't know whether the States could survive.

In closing, I would ask the authors of this bill consider the ramifications that our property tax base for local government financing: The whole concept of this method of taxation is contrary to what this bill is trying to do. I think it is an area that needs to be examined further if we are truly to mitigate the hazards of earthquakes.

It is an excellent bill. I would like to read this one statement:

S. 1174 is an outstanding proposal that offers great potential benefits to the public in both life safety and fiscal soundness. We therefore offer our support in its behalf and recommend that this committee approve S. 1174 without delay.

Thank you.

Mr. FLAJSER. Thank you both for your statements.

[The statements follow:]

STATEMENT OF HENRY J. DEGENKOLB, PRESIDENT, EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

I am very pleased to be here and to have the opportunity to speak on behalf of the Earthquake Engineering Research Institute, the Chairman of the Seismic Safety Commission of the State of California and for myself both as a Commissioner and as a Consulting Structural Engineer concerned with earthquake hazard reduction.

There is a critical need for research in all aspects of earthquake engineering and seismology. It is gratifying to find that recognition of this need extends to most parts of the country and has resulted in the introoduction of Senate Bill 1174. It is disturbing that the deliberations on the adoption of this legislation has been so long delayed. This delay has already resulted in the loss of valuable data which cannot be replaced.

As a structural engineer, trying to design buildings and structures that will be safe for the public to occupy, I consider three general areas of research to be the most critical of all the various facets of the problem.

The first area concerns the acquisition of the records of motion due to strong ground shaking. All earthquake engineering research has to be based on just how the ground shakes or moves in a strong earthquake. Without that certain knowledge, everything following is subject to uncertainty or error. We do not get many opportunities to measure this ground motion—it cannot be produced in the laboratory nor can it be purchased for any amount of money. The only way to obtain these records is to set out enough instruments so that when a major earthquake occurs some instruments will be close enough to obtain meaningful records. Because the public has not furnished adequate resources in the past, most opportunities to obtain these records have been lost. We have no strong motion records of really major earthquakes, we have only a few of strong earthquakes and they are so few that many inferences have to be drawn regarding the effects of distance, geology, depth to rock, etc. We have just lost the opportunity to obtain adequate strong motion records from the Guatemala Earthquake because a sufficient number of instruments were not installed. This repeats the sad experience in Alaska in 1964 where no instruments were installed in areas of major shaking and in Caracas, Venezuela where the instrument that was potentially available was not adequately serviced. In the past, the few records we do have were obtained through the Coast and Geodetic Survey of the U.S. Department of Commerce, a group that has now been transferred to the U.S. Geological Survey. They have been doing an excellent job with the resources available, but past budgetary restrictions has hampered their progress regarding the installation and servicing of the necessary instruments.

The State of California has started a program within the state and this is excellent as far as it goes—but earthquakes occur world-wide and we have missed and are continuing to miss many opportunities of obtaining absolutely vital information at a very minor cost. Despite its low cost and the lack of glamour associated with its acquisition, the strong motion program is the cornerstone of *all* succeeding research.

The second area of critical need is not really research, but is the application of known existing research findings to engineering practice and codes in a form where it can be used by practicing engineers. There is much already known from past and current research that is not available to the average engineer.

The results of highly theoretical research must be translated into design rules and formulae that can be used in practice. In recent months there has been a concentrated attempt by the National Science Foundation to encourage projects to provide this translation but again, due to restricted resources, the program was late and with projected budget cuts, may be reduced. This past delay means that a year and a half of construction eventually will not have been benefited by existing research. This whole area of translation requires the use of practicing engineers who know the research and use the results daily—not the research people themselves. And, this type of translator will not be found in the universities or the research laboratory or even some government office.

The National Science Foundation has recognized this fact and has inaugurated a unique project using the services of a group of private practicing engineers to interpret present research knowledge into a practical form for use in design and construction standards. At present this aspect of the program promises to be highly successful.

Senate Bill 1174 also recognizes this situation and provides for the use of all professional and technical talent available, both public and private.

The third area of critical research need is the necessity of determining material behavior at the high stresses that are associated with earthquakes and the development of adequate tools of engineering analysis. Since most materials are usually tested for performance in the service range of stresses, too little is known about their performance when high ductility is required. I need not bore you with details, but the entire engineering design of structures to resist earthquakes is in a very elementary stage and the methods of analysis available are crude and costly. In addition to the very many facets of engineering materials and analysis research that are needed is some method of correlation of all the various theoretical items of importance into one encompassing whole. This is best done through actual physical dynamic testing where large scale models can actually be shaken. A pilot shaking table has been constructed at the University of California and has been in operation for some time. A larger one is planned and I hope it can be built in the near future. When a large scale model can be tested, by actually shaking it with the various components of expected ground motion, all of the theories of dynamic response, material behavior, details of connection, interaction of vertical and horizontal motion components, etc., can be tested as a whole with all of their effects on each other accounted for. If our theories have overlooked some important item the actual dynamic testing of complete assemblies should discover these discrepancy and provide an overall check on proposed design procedures.

In the absence of large enough facilities, some engineers and earth scientists have been visiting the scene of major earthquakes to observe their damaging effects so that we can incorporate our empirical findings into building codes and practices Our observations, in the absence of more definitive and reliable research, have led to some changes and improvements in our codes. This has been productive insofar as they relate to newer construction.

However, the United States has a very large inventory of older buildings that have not been designed to resist earthquakes. Little research has been done to test methods currently used to reinforce these structures. It is generally conceded that the largest number of casualties in a future major earthquake in California will be in these old dangerous unreinforced masonry structures just as happened in San Fernando in 1971. California is not alone in this problem. It is often stated that one of the largest earthquakes to strike the North American Continent was in Missouri in 1811–1812. Boston suffered a destructive earthquake in 1755. About 100 persons were reported killed in the Charleston, South Carolina earthquake of 1966. Thirty-nine of our Fifty states are subject to high or moderate risk from earthquakes and it is almost inevitable that where earthquakes have occurred in the past, they will occur in the future. One has only to look at the unreinforced masonry construction prevalent in most parts of the country and in our older buildings to anticipate the number of casualties that would occur when a strong earthquake strikes. While the impact will not be as large as in Managua with 10,000 deaths nor as in Guatemala with over 20,000 deaths, it will still be considerable. Some studies have indicated that a major earthquake in San Francisco or Los Angeles may have casualties that approach these figures.

Another aspect of the materials and design problem relates to the functioning after a disaster of certain critical facilities such as hospitals. In the San Fernando earthquake, four major hospitals had to be evacuated immediately. One collapsed with over 40 deaths. In the Managua, Nicaragua earthquake, four hospitals also had to be evacuated with collapses in portions of the buildings. In the recent Guatemala earthquake, again four hospitals had to be evacuated immediately. One is reported to have collapsed, but I do not know the details at this time. In *all* cases, some of these damaged buildings were designed and constructed to modern engineering standards for earthquake resistance. This probably illustrates, better than any other single statement, the low degree of our available practical knowledge about earthquake hazard. Only research and education can improve this situation. Senate Bill 1174 is a means to enahance public safety by increasing the knowledge available to engineers.

Wherever the next major earthquake will occur in the United States, the loss of these older dangerous buildings will have an enormous economic impact on the local community—not only from direct losses to the private and governmental sector—but also in the great reduction of the local tax base.

Since the Alaska earthquake of 1964, there has been increasing concern about the earthquake hazard that has resulted in a moderate increase in earthquake engineering research and a greatly increased level of instrumentation. However, if funds are now reduced and important research programs eliminated before they can be translated into practical forms that the building industry can use, much of the anticipated benefits will be lost and a large portion of the previous investments in research will have been useless. Earthquake research is now in a critical period. If the present impetus is lost, many of our important projects will have to start over in the future. We will have lost the opportunities to learn from earthquakes that may occur in the near future as we have missed many opportunities to learn from past earthquakes.

We respectfully request that this committee does everything in its power to expedite the passage of Senate Bill 1174—the Earthquake Disaster Mitigation Act of 1975.

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## Statement of Elmer E. Botsai, FAIA, Vice President, The American Institute of Architects

Good afternoon, Mr. Chairman. I am Elmer E. Botsai, FAIA, Vice President of the American Institute of Architects. I am here today on behalf of the AIA, the national society for the architectural profession, and the Joint Commission on Hazardous Buildings, a joint activity of the California Council/AIA and the structural engineers of California.

As evidenced by my appearance on behalf of the AIA, I would like to state that the architectural community is becoming—belatedly—increasingly concerned with the seismic exposure risk of the public and the many ramifications thereof. At the outset, we wish to commend the sponsors of S. 1174, the Earthquake Disaster Mitigation Act, for their comprehensive analysis of the earthquake hazard and their breadth and scope of interest and detail toward the alleviation of this problem. We are particularly pleased to see the balance of effort between the potential long-range life safety issue of prediction and the equally important long- and short-range protection of both public and property in basic building performance development.

In our evaluation of this bill, we have assumed that the purpose of the legislation as specifically stated in Sections c(1)(A) concerning hazardous buildings, and c(1)(C), dissemination of information, is incorporated in the charges to the National Science Foundation under Section 3.

In our support of this legislation, we would like to especially reinforce four particular components of the bill.

(1) The whole practicing design profession, and particularly the architects, who generally establish the basic parameters of our man-built environment, are in desperate need of the knowledge that currently exists in the cloistered halls of the research community. As we become more and more sophisticated in our

technology, we will need faster and better methods of communication of additional new knowledge. The architectural profession strongly recommends a greater emphasis on the development of research in the non-structural areas. Three examples of the need for this research are:

(a) In the recent Nicaraguan earthquake, a major building remained intact, but suffered a 70 percent loss of value through non-structural damage.

(b) In the recent Oroville, California earthquake, several fire houses were out of operation because the overhead door tracks were not properly anchored and the doors collapsed on top of the equipment, thus rendering the trucks inaccessible.

(c) There is strong evidence to suggest that the current test criteria for fire safety of many building components are in conflict with the best known practice of seismic safety, and visa versa.

(2) As the results of earthquakes around the world are examined, we are experiencing a growing concern for our existing building stock, particularly the unreinforced or minimally reinforced masonry construction. It is my personal opinion that, excluding single family wood framed construction, approximately 50 percent of the total population in this country is living or working in seismically hazardous buildings. The real tragedy of this is that we do not know the true magnitude of this problem. Recently, the Joint Commission conducted a survey of every governmental body in the State of California and we are convinced by the results that even in California, the majority of public officials have no idea of what constitutes a hazardous building, let alone the magnitude of the problem.

(3) There is an almost total void in the knowledge of large scale soil problems in much of the country, including such heavily populated seismic risk areas as New Madrid, Missouri, Charleston, South Carolina and Boston, Massachusetts. How are we to adequately plan for the future under these conditions?

(4) Assuming that we will develop the necessary expertise to predict earthquakes in not only the shallow western faults but also the more difficult, deep-seated eastern faults, what about the economic and social consequences of a major quake in any populated area? We are already faced with a projected $600 to $800 billion dollar shortage of capital improvement funds in the near future. What happens to these already short funds if the majority of Los Angeles, St. Louis, or Boston is wiped out in 20 to 40 seconds of tremor? Without question, it would bankrupt the cities involved and perhaps even the states. How would the quake survivors survive?

In closing, I cannot resist asking you to go beyond this bill and consider the ramifications that our property tax base for local government financing has on the necessary upgrading of our existing physical plant. The very nature of this tax and its enforcement deter some of the major goals of this bill and therefore warrant your additional evaluation.

S. 1174 is an outstanding proposal that offers great potential benefits to the public in both life safety and fiscal soundness. We therefore offer our support in its behalf and recommend that this Committee approve S. 1174 without delay.

Thank you.

[Whereupon, at 4 p.m., the hearing was adjourned.]

[illegible] we will need to demand better methods of [illegible] knowledge. [illegible]

[illegible] buildings remained [illegible] but suffered [illegible] structural damage. [illegible]

[illegible]

[Whereupon, at [illegible] p.m., the hearing was adjourned.]

# ADDITIONAL ARTICLES, LETTERS, AND STATEMENTS

STATEMENT OF CARL L. MONISMITH, CHAIRMAN, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY

The purpose of these remarks is to strongly support Senate Bill 1174 and urge its expeditious passage. Specifically my comments are directed to support of the engineering research and education aspects of the Bill.

Urgent need for recognition and reduction of earthquake hazards to the works of man has been graphically demonstrated by the continuing sequence of earthquake-produced disasters in many parts of the world. The recent tragic event in Guatemala is only the latest in the current sequence which includes Haicheng, China in 1974, Managua, Nicaragua in 1972 and San Fernando, California in 1971.

Research has not advanced sufficiently far to demonstrate clearly that earthquake hazards can be reduced in the United States. The possibility that earthquake prediction can lead to significant reductions in loss of life was demonstrated by the Chinese with the 1974 Haicheng earthquake, and there is no doubt that intensive efforts should be made in this country to develop prediction capabilities. However, even if and when such techniques are perfected, the need for improved earthquake engineering practices will remain. Prediction capabilities cannot alter the fact that earthquakes will occur in our populated regions; the destruction or severe damage to dams, power plants, hospitals, office and apartment buildings, transport systems etc, could deal a severe blow to our economy even if it were possible to minimize loss of life by evacuating people in advance of the earthquake. Thus these remarks are intended to complement those already presented by emphasizing the importance of achieving a significant mitigation of the earthquake hazard by means of earthquake engineering research.

Improved understanding of the behavior of structure during earthquakes which has resulted from engineering research in recent years has led to significant advances in design of earthquake resistant structures. Each recent earthquake, including the Guatemala disaster, has provided numerous examples of the generally superior performance of structures designed with the aid of recently-developed knowledge. Failures have been observed, however, in new structures designed by current code procedures, such as the Olive View Hospital in San Fernando and the Four Seasons Apartment Building in Anchorage, Alaska; these clearly demonstrate that additional research must be accomplished before reliable as well as economical solutions to the seismic hazard problem can be achieved.

Although many government agencies participate in earthquake engineering research, and although many professional engineers are concerned with the need for improved design procedures, a significant part of the research effort must be accomplished by academic institutions. Meaningful contributions from these institutions have been and will continue to be associated with two areas, namely: (1) developing better understanding of earthquake ground motions which are the essential source of the problem; and (2) developing improved understanding of the behavior of structures of all types which are subjected to the earthquake motions.

The first need in the study of earthquake ground motions is an expanded network of strong motion seismograph stations which will provide data on the nature of the earthquake input in a variety of soil and geologic conditions. Installation and maintenance of this network should be the responsibility of a government agency. However, it is important to emphasize that the acquisition of these records alone does not provide the solution to the problem of designing structures providing an adequate degree of seismic safety. The records must be analyzed, the factors influencing the characteristics of the ground motions must be determined, and finally methods must be developed for utilizing the characteristics of past records to predict the nature of ground motions from earthquakes which may occur in the future, in different tectonic regions, for different source mechanisms, with different magnitudes, for different site conditions, and at different distances from the source of the earthquake. In addition, relationships must be developed between the probability of damage to various kinds of structures and the intensity of ground shaking. This involves detailed damage surveys, studies of the observed performance of structures of all kinds (buildings, earth dams, port facilities, etc.) in relation to the intensity of shaking to which they were subjected, the development of the analytical procedures required to anticipate the stresses and deformation likely to be produced in these structures by various types of earthquake motions, and thus the ultimate development of a reliable capability to predict potential damage patterns in advance of any anticipated earthquake occurrence. By this means critical structures can be designed to remain functional, hazardous structures can be recognized and appropriate precautions taken for the safety of their occupants, and all structures can be checked to ensure an adequate level of seismic safety.

Attention must also be given to damages resulting from ground failure and settlement, sometimes leading to serious settling and tilting of buildings and land areas, inundation of low-lying areas, to the loss of support for otherwise well-designed structures leading to failure or collapse, or the complete covering of developed areas with landslide debris—all phenomena observed in earthquakes during the past 12 years.

Understanding the behavior of structures when subjected to any specified earthquake motions is an essential step in the design of safe and economical structures for seismic regions. Significant advances in the mathematical procedures for calculating the response of structures to earthquake motions have been made during the past 20 years, since it became possible to use digital computers in the analysis. The application of these mathematical procedures is necessarily seriously limited, however, unless they are supplemented by extensive experimental studies which determine the behavior of typical structural materials and structural systems when subjected to severe dynamic loads. Such experimental data is an essential part of the information which must be provided to the computers in order that the refined methods of analysis may be applied.

A large program of experimental research directed toward study of the behavior of structures subjected to severe earthquakes has been funded by the National Science Foundation at the Earthquake Engineering Research Center of the University of California during the past 10 years, and this work has contributed significantly to current earthquake resistant structural design capabilities. The 20 ft square earthquake simulator funded by NSF and operated by the EERC is the world's most advanced facility for study of the earthquake behavior of structures. However, the relatively small size of this facility limits the types of tests that can be made, and the time required to conduct such tests makes it impossible to study the full range of structural systems which must be considered within a reasonable number of years. Thus it is imperative that additional research facilities including larger earthquake simulators be provided to maintain an adequate rate of progress toward the ultimate objective.

While we tend to think primarily of building damage during earthquakes it is imperative that research also be directed to problems associated with "life line" systems, i.e., transportation and water and energy transmission systems. Seismic effects on and seismic design of structures such as highways and railway bridges, port and harbor facilities, airport control towers, dams electricity transmission systems, buried and above-ground pipelines for the transmission of petroleum and natural gas, and fuel storage facilities must be considered. It is not difficult to imagine the disastrous consequences of disruption of services brought about by a destructive earthquake. For example, in the San Fernando earthquake of 1971 a number of major bridge structures were completely destroyed. Similarly in a study of 120 bridges after the Anchorage earthquake, 30 structures (25 percent) either collapsed or were determined to be unserviceable. Such disruption could preclude the transmission of needed emergency supplies, the prevention of fire fighting equipment from access to fires, etc. In the Niigata earthquake of 1964 complete destruction of a refinery by fire resulted because of failure of bridges on the roadway system leading to the refinery.

It should be emphasized that the earthquake engineering side of earthquake disaster mitigation is not limited to the development of improved procedures for the design of new structures. By far the greater hazard is represented by the vast number of older structures, e.g., buildings, which were designed according to less restrictive codes or to no code at all. Intensive research efforts will be required to develop techniques for assessing the adequacy of existing construction, and to provide economical systems for strengthening structures which are not up to standard.

The conduct of fundamental research studies to provide a deeper understanding of all these phenomena would be a major contributing factor to the development of engineering design procedures for evaluating the safety of existing structures and designing new structures to safely withstand the effects of earthquakes with a reasonable balance between safety and economy. Academic institutions play a strong role in the development of such studies. Translation of the results of this research into engineering design practice is a critical part of this effort. Without this, the most sophisticated studies are of little social or public value and potentially invaluable results lie dormant and unused. To insure this research implementation, well-trained practitioners are required; here also academic institutions have an important role.

In general, to achieve the desired objectives of mitigating the destructive effects of earthquakes, an adequate supply of highly trained design engineers and researchers must be forthcoming on a continuing basis since requirements for solutions are extensive. Universities play a significant role in these educational and research efforts. Reference has already been made to the Earthquake Research Center at the University of California. Faculty and student research in this center has contributed to the knowledge required to improve our design capabilities while the educational activities of the Department of Civil Engineering coupled with the research program of the Center have provided some of the required engineers and researchers. Similarly other universities such as the California Institute of Technology, Stanford University, the University of Illinois, Massachusetts Institute of Technology and others ave also been developing needed research and the necessary people to work in the field. These efforts have received substantial support from the National Science Foundation. Passage of this Bill will assure continued support of these engineering programs through NSF which will in turn continue to provide needed basic engineering research and trained design and research engineers. Thus I urge that this Bill be expeditiously passed by the Congress.

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STRUCTURAL ENGINEERS ASSOCIATION OF CALIFORNIA,
*San Francisco, Calif., February 12, 1976*

Hon. ERNEST HOLLINGS,
*U.S. Senate,*
*Washington, D.C.*

DEAR SENATOR HOLLINGS: The Structural Engineers Association of California is an organization of California Structural Engineering Societies. A primary activity of our group has been to develop building code recommendations towards improving building design and construction techniques and strengthening existing construction as needed, to reduce earthquake hazards to the public.

Senator Cranston has introduced Senate Bill 1174, "The Earthquake Disaster Mitigation Act of 1975", which we understand has been referred to your Committee on Oceans and Atmosphere. Although earthquakes are a problem primarily associated with the Pacific Coast and Rocky Mountain States, major earthquakes have occurred in the past in New England, the Central Plain States, and along the South Atlantic States. The earthquake hazard truly is a major threat to major areas of the country.

The intent of Senator Cranston's Bill is to establish a continuing comprehensive program of research and development on the earthquake problems.

We cannot prevent earthquakes, nor can we move our cities or centers of industry or commerce from seismically active areas. The need, therefore, is to increase earthquake engineering research so that we can improve our knowledge on how to identify and strengthen existing sub-standard buildings and how to construct new buildings, economically, to be earthquake resistant.

We, therefore, urge favorable consideration by your Committee on the Earthquake Disaster Mitigation Act of 1975 (SB 1174).

Very truly yours,

H. S. (PETE) KELLAM,
*President, SEAOC.*

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STATE OF CALIFORNIA,
SEISMIC SAFETY COMMISSION,
*Sacramento, Calif., February 17, 1976.*

Hon. ERNEST F. HOLLINGS,
*U.S. Senator, New Senate Office Building,*
*Washington, D.C.*

DEAR SENATOR HOLLINGS: I understand S. 1174, regarding an earthquake hazard reduction program, will be heard before your subcommittee on Thursday, February 19.

The Seismic Safety Commission is aware of the legislation, and I have had a chance to review it in detail. As Chairman of the Commission I strongly endorse the bill and urge passage out of committee. This program will do a great deal to support work in a number of areas needing critical attention if we are to do a better job of reducing earthquake hazards in the U.S.

Sincerely,

KARL V. STEINBRUGGE, *Chairman.*

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AMERICAN SOCIETY OF CIVIL ENGINEERS,
*New York, N.Y., March 9, 1976.*

The Hon. WARREN G. MAGNUSON,
*Chairman, Committee on Commerce, U.S. Senate, Washington, D.C.*

DEAR MR. CHAIRMAN: I am writing to you with reference to the Earthquake Mitigation Act (S–1174) on which hearings were held by your committee on February 19. The Commerce Committee release on the hearings was made on February 9.

This provided simply no time to consider this bill with sufficient care for the American Society of Civil Engineers (ASCE) to endorse it or to prepare detailed comments.

In connection with the bill I would, however, observe that ASCE supports in principle a national program to achieve reductions in earthquake hazards through control of earthquake risks, improved earthquake prediction, and public understanding of earthquake phenomena and measures to mitigate their effects. This, your committee advises, is the purpose of the bill.

Further I might comment that ASCE is quite concerned that sufficient funds are not being directed by NSF towards all engineering research, including of course that necessary to achieve the purposes of S–1174. Also, the Society wonders if the number of engineers serving on the National Science Board (NSB) are proportionately represented. NSB should be shouldering at least part of the load, at this time, envisioned in S–1174 for an advisory committee. NSB does not now have adequate representation from the design professions to do this.

These matters are of concern to ASCE and the engineering profession.

If the American Society of Civil Engineers can assist further in this matter, please feel free to call upon us.

Sincerely yours,

ARTHUR J. FOX, Jr., *President.*

# Earthquake Prediction— Opportunity to Avert Disaster

**A conference on earthquake warning and response held in San Francisco, California, on November 7, 1975**

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GEOLOGICAL SURVEY CIRCULAR 729

*Contributions from:*

*City of San Francisco, Director of Emergency Services*
*National Science Foundation, Research Applications Directorate*
*State of California*
*Office of Emergency Services*
*Seismic Safety Commission*
*U.S. Department of the Interior*
*Assistant Secretary for Energy and Minerals*
*Geological Survey*
*University of California at Los Angeles, Department of Sociology*

*1976*

# Foreword

The past several years have witnessed rapid progress toward a capability to forecast the time, place, and size of impending earthquakes. Advances in understanding of earthquake occurrence—together with an ever-growing number of observations of earthquake premonitory signals in the United States, the Soviet Union, the People's Republic of China, Japan, and elsewhere—suggest that the scientific prediction of potentially destructive earthquakes is an attainable goal.

The U.S. Geological Survey has supported a major research effort into earthquake prediction as part of its Earthquake Hazard Reduction Program. Theoretical and experimental studies of earthquake mechanisms and possible geophysical precursors are being carried out, in large measure with the cooperation of university scientists through a grants and contracts program. Seismically active zones in many parts of the United States are being monitored by seismograph networks. Crustal-strain accumulation in the Western United States is being investigated through a variety of geodetic techniques. In central California, the U.S. Geological Survey is conducting an ongoing earthquake-prediction experiment using dense arrays of various geophysical sensors astride a highly seismic part of the San Andreas fault.

Although operational earthquake-prediction systems are not likely to be deployed for a number of years, the prediction capability is achieving significant progress. It must be anticipated that predictions of some potentially damaging earthquakes will be forthcoming during the present research and development stage. Consequently, serious consideration of how predictions will be used by society should accompany the research. Procedures for evaluating the scientific data and issuing predictions must be established, and the responsibilities of Federal, State, and local agencies with respect to disaster warning must be agreed upon. It is important to anticipate public reaction to a prediction and to evaluate the possible responses that can be taken to reduce loss of life, injury, and property damage. Earth and social scientists, engineers, and public officials all have vital roles to play in determining how society will use earthquake predictions.

With these factors in mind, the Assistant Secretary of the Interior for Energy and Minerals convened a conference on earthquake warning and response on November 7, 1975, in San Francisco, California. Federal, State, and local officials responsible for disaster response were invited, together with representatives from the business and labor communities. The purpose of the meeting was to review the status of and prospects for earthquake prediction in the United States, to present for consideration a proposed Federal plan for issuance of earthquake predictions, and to consider the public policy implications of earthquake forecasts. The ramifications of these issues were explored in a panel discussion that followed the briefing. It is expected that the concepts and viewpoints presented at the conference will help stimulate development of plans and procedures for effectively utilizing earthquake predictions to save lives and reduce property damage.

V. E. McKelvey
Director

# Welcoming Remarks

**By Edward P. Joyce,**
*Director of Emergency Services, City of San Francisco*

It is a great privilege for me to welcome you to the great city of San Francisco on behalf of Mayor Joseph L. Alioto.

For many years as Director of Emergency Services for San Francisco, my concern has been to develop a viable response to earthquake disaster. Thanks to meaningful assistance from the State Office of Emergency Services, the Federal Defense Civil Preparedness Agency, and the Federal Disaster Assistance Administration, we have an earthquake response plan that has been approved unanimously by our Emergency Planning Committee and our Disaster Council here in San Francisco.

Of course, this plan has been directed to mitigation of the effects that a major earthquake can pose after the fact. I am, therefore, most anxious to hear the status of earthquake prediction in the United States because the reality of earthquake prediction will require a whole new approach to emergency planning. It appears to me that the public policy implications of earthquake predictions are somewhat similar to those for tsunami warnings, although the implications of the latter are of a much lesser degree. At least for tsunamis, we have developed experience with regard to reaction by political jurisdictions that have been in receipt of warnings over many years. I hope that when earthquake predictions are a reality, there will be a shared responsibility by Federal, State, and local officials in prediction announcements and in the actions to be taken.

I am, of course, also interested in hearing about other factors relating to predictions, such as length of advance warning time, reliability of data, ability to predict magnitudes within acceptable limits, likelihood of evacuation and guarantees for property left behind, and other important socioeconomic and political implications of earthquake forecasting.

On behalf of Mayor Alioto, I wish you a most enjoyable stay in San Francisco and hope that your participation in this conference is as profitable to you as I know it will be to me.

EARTHQUAKE PREDICTION—OPPORTUNITY TO AVERT DISASTER

# Earthquake Forecasting: An Opportunity

**By Jack W. Carlson,**
*Assistant Secretary of the Interior for Energy and Minerals*

It is appropriate that we meet today in San Francisco. Since 1906, the name San Francisco has been associated, rightly or wrongly, with the terrible destruction that an earthquake can bring upon an urbanized society. Furthermore, our scientists tell us that major damaging earthquakes will continue to strike the San Francisco region in the years ahead.

However, to single out San Francisco as "the city that waits to die" is both unfair and inaccurate. San Francisco is only one of a number of urban areas that face a significant threat from earthquakes. Damaging quakes have hit and will continue to strike the Los Angeles region, California, Seattle, Wash., and Anchorage, Alaska. Salt Lake City, Utah, although it has not yet experienced a major destructive shock, lies astride a large and active fault system that someday will produce a potentially devastating magnitude-6 or -7 quake. Scientists caution us that some important cities in the Eastern United States, including Memphis, Tenn., Charleston, S.C., and Boston, Mass., also are exposed to major damage from future earthquakes. In fact, 15 percent of the U.S. population—more than 31 million Americans—reside in Seismic Risk Zone 3, the zone of greatest earthquake danger. Thus, the earthquake threat is of national concern.

If a 1906-sized event hits any of our major cities, potential losses could be as high as tens of thousands dead, hundreds of thousands seriously injured, and property damage measured in the tens of billions of dollars. A catastrophe of this scale would seriously affect the economy of the whole country, yet it is an event that most earthquake scientists expect to occur sooner or later. Even moderate-sized earthquakes bring death and destruction to urban areas, as we learned at San Fernando, Calif., in 1971. And earthquakes of this size occur relatively frequently, for example, striking California on the average of once every 6 years.

Our earthquake-prone cities do not have to "wait to die." Increasingly, the earthquake threat is being recognized and dealt with at all levels of government. Government and the private sector are following several mutually supportive paths that can reduce the effects of earthquakes: land-use planning, earthquake-resistant engineering, and emergency-preparedness actions. Areas of potential earthquake hazards are being mapped and evaluated so that planners can site future construction away from the most dangerous ground within earthquake-prone regions. The frequency and level of earthquake shaking are being assessed for areas subject to damaging earthquakes, and the data derived are providing the basis for building codes and for earthquake-resistant design of structures by engineers and architects. Research into the mechanisms of earthquake occurrence and possible premonitory signals of impending quakes is being intensified. Earthquake prediction and its practical application are our subjects today.

Within the past 3 years, seismologists and geophysicists in government laboratories and the universities have made remarkable progress toward an astounding goal: the ability to forecast reliably the place, the time, and the size of future earthquakes. The scientific progress has been truly remarkable because just a decade ago, prediction was considered to be only remotely possible. Today, many scientists are confident that potentially damaging earthquakes can be predicted from precursory changes in the Earth's crust, provided that systems of geophysical instruments are deployed.

Earthquake forecasting will give us an opportunity to help alleviate the ravages of earthquakes by a number of possible actions in anticipation of a destructive event. Emergency service groups can plan and coordinate their responses to the potential disaster. Hazardous structures can be evacuated. The water level behind large dams can be lowered to reduce their susceptibility to earthquake-induced failure. Supplies and materials for postearthquake relief and reconstruction can be stockpiled. Critical facilities such as nuclear reactors and pipelines can be shut down temporarily. The public can be informed of what measures individual households could take to reduce the effects of an earthquake.

Actions such as these, taken in advance of a large earthquake, could substantially reduce the casualties and damage that might otherwise occur.

Society, however, must prepare itself fully to derive the greatest benefit from knowing when and where an earthquake will occur. It is important to evaluate the various possible actions that might follow an earthquake prediction and to assess the impact on all segments of the community. Earth scientists, engineers, sociologists, economists, and public officials all have a role to play in deciding how to best use the capability to forecast earthquakes.

Handled in the proper way, earthquake prediction can be a great blessing to mankind. Our purpose in this conference is to bring you up to date on the prospects for prediction in the United States and the possible implications to society, and to have you consider how earthquake predictions and warnings ought to be disseminated and how an effective public response to prediction should be marshalled.

EARTHQUAKE PREDICTION—OPPORTUNITY TO AVERT DISASTER

# Role of State Government in Earthquake Warning

**By Charles Manfred,**
*Director, Office of Emergency Services, State of California*

State government has a responsibility, which it shares with city and county governments, to be prepared to mitigate the effects of earthquakes that threaten life, property, and the resources of California.

The California Emergency Services Act confers emergency powers on chief executives of the State, including the Governor, chairmen of county boards of supervisors, and city mayors, in order to meet that responsibility. We have an excellent State Emergency Plan, which serves as a basis for the conduct of emergency operations by all jurisdictions throughout the State, and we have established a Seismic Safety Commission which has just begun to initiate programs to reduce earthquake hazards in our State.

Damaging earthquakes have been and will continue to be part of California's natural environment. California's experience with earthquakes has taught us that measures can be taken to preserve life and property during and after an earthquake, that our buildings can be made earthquake resistant, and that appropriate actions by individual citizens can prevent loss of life. Local governments that maintain realistic plans and trained emergency staffs capable of providing the facilities, information, and resources needed by their chief executive for the direction and control of emergency operations do an effective job in the postearthquake environment, caring for distressed people and restoring and maintaining essential services.

The California State government is monitoring the development of earthquake-forecasting techniques and is preparing to modify our emergency-preparedness efforts in the light of new scientific information that might become available.

The Office of Emergency Services has established two advisory committees to deal with problems related to the development of earthquake-prediction technology. One is composed of eminent scientists qualified to evaluate the credibility of earthquake predictions; the other is composed of members representing social, economic, and government disciplines qualified to make recommendations on State government response to earthquake prediction.

In addition, we are cooperating with two research projects being conducted in this area by the University of Colorado and the California Institute of Technology.

The California Emergency Council will consider and discuss the public-policy implications of earthquake prediction at its next meeting on December 10, 1975. The California Legislature Assembly Committee on Finance, Insurance, and Commerce will hold a 1-day hearing on the subject of insurance aspects of earthquake prediction on Wednesday, December 17, 1975.

The technology to predict earthquakes is in the research and development stage—there can be no doubt about that—but questions need to be answered about these research activities and their eventual effects:

- How rapid is the development of earthquake-prediction technology?
- How reliable is the technology?
- Will the Federal Government be able to establish an operational earthquake-prediction system comparable to the Tsunami Warning Service? If so, when?
- How are earthquake predictions to be communicated to the public?
- Will the cost of the social and economic dislocations resulting from the prediction of the time, location, and magnitude be greater than the cost of the physical destruction during and after the earthquake? In this regard, which is the more acceptable risk?
- How will people and their government organizations respond to earthquake predictions? How *should* they respond?

In California, we not only have the problem of what to do once an operational earthquake-prediction system is established, but we have the more immediate problem of dealing with new information about seismic activity in our State—information that has resulted from the various studies and research projects seeking answers to the questions posed above.

These difficult questions demand carefully considered responsible answers from scientists and public officials. Perhaps this conference will provide some of them.

# The Status of Earthquake Prediction

**By Robert M. Hamilton,**
*Chief, Office of Earthquake Studies, U.S. Geological Survey*

The September 1, 1975, issue of "Time" magazine focused national attention on the rapid progress that has been made in recent years toward earthquake prediction. The "Time" cover story accurately reflects the mood of optimism that currently pervades the scientific community. It also highlights the many scientific problems that remain to be solved before, and the many socioeconomic problems that must be dealt with after, earthquake prediction becomes a reality. The main purpose of this meeting is to call attention to the nature of the problems and to initiate a national dialogue leading to their resolution. My contribution to this conference will be to assess the status of earthquake prediction and to consider the outlook for the future.

One of the reasons for the current optimism about prediction is that some very startling news has been received in recent months from the People's Republic of China. A strong earthquake, measuring about 7.3 on the Richter scale, took place there in February 1975. Apparently the shock was predicted, and actions were taken that saved many lives—perhaps tens of thousands.

The prediction was made by a gradual refining, or homing in, on the place, time, and magnitude of the upcoming shock by using a variety of techniques. As early as 1970, the area of Liaoning Province in northeast China, where the shock took place, was identified as an area of possible risk, apparently on the basis of long-term variations in seismicity. This concern was reaffirmed in June 1974 when the State Seismological Bureau called for increased vigilance in the area. This warning was based on a combination of observations, including migrations of seismic activity, tilting of the ground surface, changes in the water level in wells, changes in electric currents in the ground, and strange animal behavior. These observations prompted the Chinese to move more seismographs and tiltmeters into the area. On December 20, 1974, the local government was warned to expect a large earthquake. Apparently this warning resulted in a false alarm on the part of local officials, and people slept outside in the snow for 2 days. In mid-January 1975, the State Seismological Bureau met again, concluded that an earthquake was imminent, and on January 28, the villages were warned to be prepared. Extra seismographs were set up. On February 1, anomalous earthquake activity began, which was interpreted as foreshocks, and it increased markedly on February 3. At 2 pm on February 4, people were told to expect a major quake within 2 days. Shops were shut in the town of Yingkow, and general evacuation of buildings was ordered in Yingkow and Haicheng Counties. The quake came at 7:36 pm that evening.

This all sounds like the fantasy of a science-fiction writer. If the reports we have received accurately describe the events that transpired, then the Chinese achievement represents a milestone in the quest for earthquake prediction.

Earthquake prediction has long been a lively topic of after-dinner conversation, a proclaimed capability of mystics and soothsayers, and an elusive goal of scientists. The fascination with earthquakes derives mainly from their mysterious nature and their awesome power—the ability to level cities within seconds.

Historical accounts are rich with reports of strange events before earthquakes: dogs howling, strange lights in the night sky, weird sounds, withdrawal of the sea from a harbor, and so on. The significance of these reports has been discounted in many cases, but many of the observations have been sufficiently good to keep alive the hope that earthquakes can be predicted.

Many of the reports of earthquake precursors have come from Japan. A particularly impressive anomaly was observed for the magnitude-7.5 earthquake that caused heavy damage in the city of Niigata in 1964. Level surveys and a tide-gage station revealed anomalous land uplift starting 10 years before the shock. Reports such as this one led Japan in 1965 to establish a formal program to predict earthquakes.

A serious attempt to predict earthquakes is also underway in the Soviet Union. Near the village of Garm, in the seismically active Republic of Tadzhikistan, scientists have been working on prediction for more than 25 years. The fruit of these labors was revealed in the late 1960's; some results were truly electrifying. The Soviet scientists reported that prior to some earthquakes, the speed with which vibrations or waves travel through rocks deep in the Earth showed a distinctive variation. Until then, seismic-wave velocity was thought to be constant. This startling finding opened a new realm of scientific investigation. Incidentally, American scientists are now working at Garm with the Soviet scientists under a long-term program of scientific exchange. The activities of this exchange program were reported to President Ford October 31, 1975, by Russell Train, head of the Environmental Protection Agency, and Academician Israel of the Soviet Union.

Variation in seismic-wave velocity was but one of a variety of phenomena reported from the Soviet Union as earthquake precursors. Radon gas in well water increased anomalously before an earthquake at Tashkent in 1966. Electrical resistivity of the Earth behaved unusually before earthquakes near Garm and in Kamchatka. Migration of centers of seismic activity and reorientation of earthquake-causing rock stress were also observed. Taken together, these findings presented an impressive case that earthquakes indeed have precursors.

These observations have an explanation. It is widely believed that earthquakes are caused by a gradual buildup of stress in rock to the point at which the rock can no longer withstand the forces, and it fails suddenly along a preexisting plane of weakness, or a fault. This, of course, takes place on a large scale in the Earth, the larger earthquakes involving areas of hundreds of square miles. The stresses are created by large plates of the Earth's crust scraping past each other or colliding in a process called by a variety of names: continental drift, sea-floor spreading, or plate tectonics.

The failure process can be simulated in the laboratory by squeezing a rock specimen only inches across. As the stress builds up and the rock nears failure, tiny cracks form that actually cause the rock to expand in volume. Laboratory measurements show variations in seismic-wave velocity, electrical resistivity, and other properties of a rock undergoing such expansion that are similar to the anomalies observed before earthquakes.

American results have by and large confirmed the Soviet findings. In hindsight, it appears that the magnitude-6.5 earthquake near San Fernando, Calif., in 1971 was preceded by a velocity anomaly, as was a smaller shock of magnitude 5.0 in central California in 1972. In the Adirondack Mountains region of New York State, a small earthquake was successfully forecast on this basis in 1973. A resistivity anomaly preceded a magnitude-3.9 earthquake in central California in 1973.

The most encouraging new results in the United States came in November 1974 for a magnitude-5.2 earthquake that struck on Thanksgiving Day near Hollister, Calif. Just south of Hollister, the Geological Survey operates a dense network of instrumentation in an experimental earthquake-prediction system. Strong precursors to the shock were observed in the Earth's magnetic field—the first such anomaly recorded—and in the tilting of the land surface. At a lower level of certainty, anomalies were also observed in the length of survey lines. Such a variety of precursory phenomena had not been previously observed for a single earthquake.

Thus, by 1974, the Soviet Union, Japan, and the United States had taken on earthquake prediction as a national goal and had convincingly established that earthquakes have precursors. At that time, the Chinese effort was virtually unknown to us, but word reached the West that a major prediction program was underway. The opportunity to find out about it came when former President Nixon's visit there led to an exchange of earthquake specialists. The Chinese came to the United States in spring 1974. They gave little information on their program, saying that they were here to learn of our activities, but they dropped enough hints about their own program to alert American scientists that they had some surprises in store when the U.S. delegation, of which I was a member, visited China in October 1974.

What we found was a well-organized, large-scale effort of research specifically aimed at earthquake prediction. The program began soon after two very destructive earthquakes hit Hopeh Province of China in 1966. China's leaders, including Premier Chou En-lai, visited the stricken area and proclaimed that a serious effort would be undertaken to reduce the dreadful impact that earthquakes have had on the Chinese people. More than 800,000 people were killed in 1556 from a shock near Sian, in central China, and about 180,000 were killed in 1920 near Kansu.

The biggest surprise we found in China was that roughly 10,000 people, including several hundred scientists, were working very hard to predict earthquakes, using a wide variety of instrumentation that includes some of the best in use anywhere in the world today. Virtually every technique that has ever been suggested as a basis for prediction is being studied to some degree. Many precursors have been observed, ranging from reports of unusual animal behavior to well-documented anomalies recorded on the finest instruments. About 10 earthquakes have been successfully predicted, and warnings have been issued, but the Chinese readily acknowledge that many predictions have not been successful.

The Chinese success in predicting the Liaoning earthquake signals that the age of earthquake prediction may be upon us. The laboratory studies show that earthquake precursors should exist, and the many field observations seem to confirm that they are observable. The big questions now are whether all earthquakes have precursors—and whether these precursors are sufficiently regular or uniform in nature to be reliable as predictors. These questions can be answered only through continued studies.

The one area in the United States that has a comprehensive prediction system, mentioned before with regard to the Thanksgiving Day earthquake, is in central California astride the San Andreas fault south of the town of Hollister. This area was chosen for intensive study by the Geological Survey because of its high seismicity. The instrumentation system used there is very much in the experimental phase of development, but at the same time it is a prototype of what could be installed elsewhere in the future.

As is the case with most new technological developments, progress can be a mixed blessing. Earthquake predictions undoubtedly can save lives, as has already been demonstrated in China, but in the finely balanced socioeconomic structure of the United States, a prediction can also cause serious problems; much of our discussion today will focus on these problems. One can imagine, among other things, that prediction of a shock near a major city could lead to a drop in tourism, nonrenewal of earthquake insurance policies, fleeing of the area by the panic stricken, and convergence on the area by the thrill seekers. Failure of the earthquake to occur could result in recriminations, lawsuits, and loss of confidence in the scientists who made the prediction. Unlike a hurricane that veered off course, there would be no way to convince people that they had had a near miss. The fallout of legal, political, social, and economic problems could be serious.

Predictions, however, have the potential to provide enormous benefits. Tens of thousands of lives were saved in 1971 because the lower Van Norman Reservoir was lowered before the earthquake struck at San Fernando, Calif., and caused near-collapse of the dam. Although the action was based on general concern for the dam, rather than on an earthquake prediction, the lesson is clear. Many critical facilities are of necessity sited in regions that will experience strong earthquakes. A warning could avert serious consequences from damage to pipelines, storage tanks, and nuclear reactors.

Much remains to be accomplished before earthquake prediction becomes as useful as weather forecasting. Nevertheless, hopes are high that progress will be rapid. The greatest need is for additional observations of earthquake precursors. Observations are needed from a variety of geologic settings to assure that each area will not be a special case. The current level of effort will permit progress toward meeting these needs; however, it does not provide for establishment of any prototype earthquake-prediction system. As a result, the transition to a reliable prediction capability will not be very rapid. Even in the areas that are now under study, the development phase for prediction may stretch over the next decade. In the meantime, we can expect to see many scientific predictions based on only fragmentary data, and we must develop a system for reporting these predictions and for responding to them effectively.

EARTHQUAKE PREDICTION—OPPORTUNITY TO AVERT DISASTER

# A Federal Plan for the Issuance of Earthquake Predictions and Warnings

**By V. E. McKelvey,**
*Director, U.S. Geological Survey*

As Dr. Hamilton showed, we are now entering an age when scientific instruments are detecting signals that can be interpreted to forecast earthquake occurrence. We have not advanced to the stage of full-scale deployment of earthquake-prediction systems. In fact, we now have in operation only an experimental system covering a small area of central California. However, advance indications of a coming earthquake can be detected on fairly inexpensive instruments that would give a scientific basis for making a prediction.

With the increased deployment of geophysical sensors the number of scientifically based predictions is increasing. Scientists recognize that the data are difficult to interpret at this stage, but nevertheless it is clear that the observations must be reported to the public, and the best interpretation possible must be attempted. Developing a plan to issue predictions may appear to be premature when the capability is not really operational, but the impact that a prediction can have requires that even the most fragmentary data be processed in a careful and responsible manner.

The plan we are presenting today is tentative and is intended as a basis for discussion. We expect it to change as a result of this meeting, and we also expect it to evolve as progress is made in prediction research and as experience is gained in issuing predictions.

Before I discuss the plan, I would like to call your attention to a very important point, namely, the difference between a *prediction* and a *warning*. A *prediction*, as we are using the term here, is a forecast that an earthquake will occur at a certain time and place and will have a certain magnitude capable of causing certain kinds of effects. A *warning* is a recommendation or an order to take some defensive action, such as to reduce the water level in a reservoir or to evacuate a building. As you will see in the plan, the U.S. Geological Survey (USGS) has the responsibility for issuing a predicition, but State and local officials have the responsibility for issuing a warning. The plan deals with formulating the prediction and transmitting it to the local officials for issuance of a warning to the public.

The steps in this plan are shown in figure 1. The starting point is with the scientists who are receiving data from field instruments and interpreting them. This is also the starting point of contact with the public, for it is our policy that the raw data be made available to the public. The scientific interpretation of data will be reported through talks at scientific meetings, publications, and information releases. Care will be taken, however, to distinguish between an individual scientist's interpretation of data and the interpretation of his data and other relevant data by his peers that might result in a USGS prediction.

Peer review will be provided by the USGS Earthquake Prediction Council composed of 5 to 10 USGS scientists and scientists from outside the USGS whose experience covers all aspects of earthquake-prediction technology. The purpose of this review is to assure the public that, in the judgment of scientific experts, the basis for the prediction is sound. The role of the

# EARTHQUAKE PREDICTION AND WARNING
## Proposed Information Flow

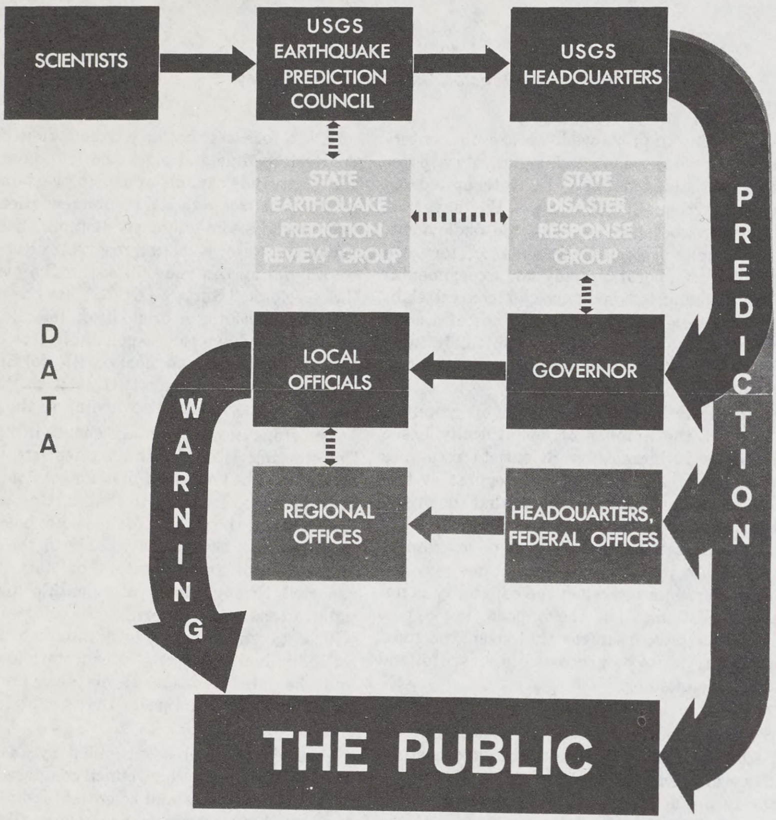


FIGURE 1.—Proposed Federal plan for the issuance of earthquake predictions and warnings. It provides for continual public release of scientific data but ensures that there are firm bases for an official prediction. In the plan, the Geological Survey has the responsibility for issuing a prediction (statement that an earthquake will occur), whereas State and local officials have the responsibility for issuing a warning (recommendation or order to take defensive action).

Council is to review all relevant data and to report its conclusions. The report need not be a consensus report, and it might not agree with the conclusion of the scientist presenting the data. He, of course, could continue to argue his case, but he must make clear that his is not a USGS position.

The report of the Earthquake Prediction Council would go to USGS headquarters, where a decision would be made whether and how to issue a prediction. If the case is not sufficiently strong, a decision could be made to issue an advisory notice, stating, for example, that possible precursors have been detected in a certain area and that that area is under intensive study. The nature of the headquarters action would be tailored to the particular situation.

The statement issued by the USGS headquarters would be communicated to the Governor of the State potentially affected, to Federal agencies with responsibilities for disaster preparedness and response, for example, the Federal Disaster Assistance Administration and the Defense Civil Preparedness Agency, and to the public. This does not necessarily mean that the public would be notified simultaneously with the others, but any delay should be short. It may be judged that the negative impact of a prediction could be lessened if responsibile State and Federal officials received prior notice. A strong case can be made that a warning should be issued with a prediction, so that the public is not left without any recommendation for appropriate action.

Upon receipt of a prediction, we anticipate that the Governor's office would refer the prediction to the State office concerned with disaster response, and the Governor may choose to call together his own group of experts to evaluate the evidence for the prediction. In California, for example, the prediction would probably be referred to the Office of Emergency Services (OES) and then to the Governor's/OES Earthquake Prediction Review Group. USGS scientists would certainly be available for discussion with State personnel, as indicated on the chart by the dashed line.

The Governor's decision about the prediction would be transmitted to local officials and a warning issued. USGS personnel would be available for consultation at every stage of this process. The procedures adopted will surely vary from State to State, so I will let clarification of this part of the chart develop from our discussions today.

The prediction going to the headquarters of other Federal agencies would be transmitted to their regional offices, where coordination would be effected with State personnel.

Scientists not funded by the USGS who find evidence of an earthquake precursor are not specifically considered in this plan. We believe, however, that given the mechanisms I have described, other scientists would be willing to enter the system, by discussing their data with either the USGS Earthquake Prediction Council or the State Earthquake Prediction Review Group. In either way, the findings would be evaluated as a basis for issuing a prediction.

Perhaps this is sufficient discussion of the plan on my part. As I mentioned earlier, this is only a proposal, and we are here to receive your suggestions for improvements. We want a procedure that assures responsible, open, and credible treatment of earthquake-prediction information. We realize that the transition to the age of earthquake prediction will be difficult, but a carefully developed prediction and warning plan can ease the difficulties and yield great savings in both life and property.



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# Possible Loss-Reduction Actions Following an Earthquake Prediction

By Charles C. Thiel,
*Research Applications Directorate, National Science Foundation*

Dr. Hamilton has given us a review of the technical aspects of earthquake prediction, and Dr. McKelvey has detailed a proposed plan whereby a prediction will be evaluated and disseminated. I propose to discuss what can be done—what mitigating public and private actions can be taken in anticipation of the event —when a prediction is of such scientific validity that it constitutes an official warning. Whether one agrees with the proposition that earthquake prediction is good (as I do) or not (and there is some dispute) is really a moot point. There are going to be predictions, some scientifically based and others from seers and fortunetellers. It will be the responsibility of the public official, the engineer, the applied scientist, and the entrepreneur to take the information that an earthquake will occur and turn this into public and private policies and actions that allow the individual and the community to reduce the net impact of the earthquake in terms of loss of life, injury, economic cost, and social disruption.

A natural tendency is to think in terms of earthquakes posing a major risk only to the Western States. Without delving into the specifics, 70 million people in 39 States live in regions of major and moderate earthquake risk. This conference is directed at the representatives of the nine Western States at principal risk, each having a major vulnerability to loss of life and property destruction.

I have summarized the extent of the vulnerability of these States in the West by listing in table 1 the population residing in major- and moderate-damage-potential zones and the projected State property values. Although California clearly has the largest number of people at risk, each of the other States have large parts of their population exposed. There is some likelihood that earthquakes will be predicted in the future in each of these States.

It would be nice if, in dealing with earthquake prediction, we could merely decide to leave the area, wait for the earthquake to take place, and

TABLE 1.—*Population and property at high earthquake risk in the Western United States*

| State | Population (thousands, 1970) | | State's property value (billion dollars, 1980 est.) |
|---|---|---|---|
| | Major risk | Moderate risk | |
| Alaska | 270 | 25 | 2.9 |
| California | 17,317 | 2,636 | 292.1 |
| Hawaii | 63 | 39 | 19.2 |
| Idaho | 200 | 513 | 8.1 |
| Montana | 142 | 313 | 7.0 |
| Nevada | 189 | 300 | 8.2 |
| Utah | 972 | 48 | 9.0 |
| Washington | 2,169 | 1,240 | 46.4 |
| Wyoming | 5 | 19 | 7.4 |

then go back and pick up the pieces. Unfortunately, this is impractical. As an example, if the 1906 San Francisco earthquake were to recur in the year 2000, it could cause about $20 billion in damage, 9,000 deaths, and 400,000 injuries. Even so, this does not represent the destruction of the Bay area—it represents the loss of less than 25 percent of the value of structures in the region. The damage would be widely distributed, and those persons in San Jose could not seek refuge in Oakland, San Francisco, or even Marin County. I could just as well show you similar losses for Seattle, Salt Lake City, or Los Angeles. Obviously we cannot count on mass evacuation as a means of protecting the public when the population of the area affected is large; we must seek other means to protect life and property. We cannot run away from the problem.

An earthquake can cause damage in several ways. First, I want you to understand that it is not the fault rupture but the shaking of the ground that causes most of the damage. Extensive ground shaking can cause the disruption of a building's contents and its collapse, the collapse of a dam, the rupture of a pipeline, and many other types of structural damage. Ground shaking can cause soils to lose their capacity to support buildings, causing them to fail. The damage can be from secondary sources—the ruptured dam can cause downstream inundation, toxic chemicals can be released from an industrial facility, or a falling parapet can strike a pedestrian. Old unreinforced buildings are generally the most vulnerable to collapse, and there are lots of them, even in Los Angeles and San Francisco where a long-term attempt has been made to build earthquake-resistant structures. Finally there is fire. Conflagration can be a companion to earthquakes, and the resulting devastation can be nearly total.

Given that an earthquake is going to take place, a variety of actions and procedures can be undertaken to reduce its direct impacts and hasten the restoration of the community.

We can evacuate hazardous buildings or sites. We can reinforce or replace structures that will not perform adequately. Note this last word, "adequately," because we want a hospital to remain operational but may not care if a shed collapses. We can remove the contents of a structure so that they will not be damaged. We can change the pattern of use of a facility or area—for instance, not use a theater, or move a clinic to a "better" building. We can activate emergency-preparedness plans and distribute emergency materials. We can review insurance options. We can adopt tax policies that benefit owners who upgrade their facilities. Finally, we can provide for the relief of the victims and rehabilitation of the community. This list is far from complete. It is meant to show that many methods are available to decrease earthquake impacts.

The actual nature of the specific response to an earthquake prediction will be determined by the size of the predicted earthquake, how long until the event is to take place, the time of year, and whether the earthquake will occur in an urban, suburban, or rural region. It will also depend on the technical and managerial skills of the resident population and its economic and material capabilities. Generally, the longer the period of forewarning, the more the community will be able to do to decrease the impact on the community. As a caution, please remember that, in most cases, it is unrealistic to expend more than can be expected in losses. We must always be careful to balance social and economic costs and resultant benefits in reduced human suffering and property damage.

From an engineering point of view, there seem to be four basic time spans that should be discussed when considering the types of specific actions to be taken. These are 3, 30, 300, and 3,000 days. Table 2 lists a group of actions that could be initiated according to the various stated lead times. I have assumed that we are dealing with an urban event of major magnitude, and have distinguished the actions that could be taken in the time allowed to protect buildings, their contents, lifeline facilities (for example, bridges, communications, water, and hospitals), and special structures (for example, dams, nuclear reactors, and pipelines). If the prediction is a few days in advance, say three, the options are limited to the somewhat obvious. We can evacuate previously identified hazardous buildings and selectively remove contents. Special facilities such as reactors can be closed down. Petroleum pipelines can be emptied and shut down. We can deploy emergency materials and identify staging areas. Use of mass-assembly buildings such as theaters and schools can be restricted.

TABLE 2.—*Engineering responses to an earthquake prediction*

| LEAD TIME | BUILDINGS | CONTENTS | LIFELINES | SPECIAL STRUCTURES |
|---|---|---|---|---|
| 3 Days | Evacuate previously identified hazards | Remove selected contents | Deploy emergency materials | Shut down reactors, petroleum products pipelines |
| 30 Days | Inspect and identify potential hazards | Selectively harden (brace and strengthen) contents | Shift hospital patients; alter use of facilities | Draw down reservoirs, remove toxic materials |
| 300 Days | Selectively reinforce | | Develop response capability | Replace hazardous storage |
| 3,000 Days | Revise building codes and land-use regulations: enforce condemnation and reinforcement | | | Remove hazardous dams from service |

When there is a 30-day warning period, building inspections can be performed to identify hazardous buildings and conditions. In most cases there will be neither the professional expertise, skilled labor, or materials available to reinforce hazardous buildings in this short time. Reservoirs can be emptied within this time but not much faster. Hospital patients and prisoners can be moved to facilities beyond the area to be affected. Clinics, emergency communications, and emergency response and relief personnel and materials can be moved to less vulnerable sites. Some toxic, incendiary, and explosive materials can be removed from industrial facilities to places where they pose no major hazards.

Only when the period of warning is of the order of 300 days is it realistic to expect that substantial numbers of structures can be upgraded to reduce their vulnerability. During this period an earthquake-prediction response plan can be formulated. Unfortunately it is unlikely that such a plan, which responds to more than obvious opportunities, can be formulated and put into operation in a much shorter time.

Beyond these time periods, in the 3,000-day or about 10-year range, the potential to reduce the vulnerability of the community is great. Building codes can be adopted and enforced that protect the occupants from unacceptable risks of injury. Land-use policies can be adopted that decrease the density of occupations in hazardous landslide areas or filled areas that are likely to be subject to soil failure. These procedures, although useful and obvious, are not the ones that will yield the greatest benefit. *For the next decades the earthquake vulnerability of virtually all this Nation's cities will be dominated by those older structures now standing that cannot be expected to withstand a major shake. The biggest challenge to the public official is to develop economically and politically realistic procedures and policies for the condemnation of substandard structures, and for their reinforcement, replacement, or abandonment.* I wish to call to your attention that these are the same major policies and procedures that we in the engineering profession urge you to take when a specific earthquake has not been predicted but can be expected to occur in the not-too-distant future.

It is logical to ask what the potential impact of all these adjustments during the warning period might be. When the period is but a few days, the major benefit will be in the saving of lives. Property damage will be essentially unchanged. When 30-days warning is available, the damage might be reduced by 20 percent. In 300 days, we might be capable of reducing impacts by 40 percent, and in 10 years, the reduction could be 60 percent or more. These reductions do not consider economic costs incurred in improving physical performance and presume that all available technology is applied.

I would be remiss in my professional responsibilities if I did not point out to all of you that many of the procedures that an engineer or architect might use to design or reinforce a structure economically are yet to be formulated. The same lack of clear-cut procedure is even more true for public-policy matters. Just as a substantial effort must be expended to achieve earthquake prediction, there must be a significant companion research, development, and educational program in the engineering, economic, and social sciences. They must all be pursued together.

In summary, I wish to highlight a few of the public-policy problems, or should I say challenges, that will present themselves:

1. Within the built environment, a particular building or piece of land may be within the jurisdiction of any of a large number of groups, often having overlapping responsibilities. The point is that the control of the physical structures in a community is vested in a vast maze of generally unknown groups.
2. You must start to plan now how you will respond to a prediction, and formulate the basic plans and procedures that you intend to pursue while there is time to rationally contemplate objectives, rather than be forced to respond to the need for immediate action.
3. During the warning period you will have to mobilize trained personnel and materials and protect the public from unscrupulous practitioners pretending to possess capability in the professions dealing with earthquakes.
4. The public will need information on how they can protect themselves and their property. It is logical to assume that they will look to government officials for this information.
5. Finally, there will be the problems of equity. We must formulate and carry out public programs that do not overly benefit some at the expense of others.

# Social, Economic, and Political Implications of Earthquake Prediction

By Ralph H. Turner,
*Department of Sociology, University of California at Los Angeles*

My remarks are based chiefly on a new report, "Earthquake Prediction and Public Policy," prepared by the Panel on the Public Policy Implications of Earthquake Prediction, National Academy of Sciences. This report is available directly from the National Academy of Sciences, Washington, D.C.[1]

In exploring public-policy implications of earthquake prediction, the National Academy of Sciences panel assumed that prediction is inescapably at hand, that it will be fallible throughout the foreseeable future, that we shall have the benefit of warning times ranging from weeks to years, and that we shall be plagued initially with a fairly extended prediction-time window. Lacking experience in the prediction of potentially destructive earthquakes, we must be tentative in everything we say. As far as possible, our analysis and recommendations are based upon research findings from the study of other kinds of public disaster and disaster warning, and upon established principles in the behavioral sciences.

## GENERAL CONSIDERATIONS

Earthquake prediction will have its disadvantages as well as its advantages. Under the worst combination of inaccurate prediction and an ill-conceived public response, the prediction and quake might even be more costly than an unpredicted quake would have been. However, it was the considered judgment of our panel that earthquake prediction can be a means for substantially reducing the losses from earthquakes if appropriate social, economic, engineering, and legal actions are taken prior to the quake. Even in case of a false alarm, some of the costs of a well-planned hazard reduction program will contribute to the seismic safety of the community.

There is danger that preoccupation with the costs and difficulties in launching a constructive response may lead public officials to lose sight of the greatest potential benefit from earthquake prediction, which is *the saving of human lives*. Good fortune has kept the loss of life down in recent United States earthquakes, but the toll in case of new earthquakes in San Francisco and Los Angeles could run as high as 8,000 and 20,000 lives, respectively, according to recent estimates. The saving consideration is that earthquakes—unlike hurricanes, tornadoes, and floods—kill few people directly. People die from the collapse of manmade structures, such as buildings, bridges, and dams; from fires ignited when gas and powerlines rupture; and sometimes from tsunamis and landslides. If people are protected from fire and collapsing structures, and evacuated short distances from low-lying coastal areas, very few lives need be lost in even a strong earthquake.

A complete program to save lives and minimize property loss and disruption on the basis of an earthquake prediction will include four kinds of tasks:

1. Authenticating and issuing predictions and warnings;

[1] Copies of the report, "Earthquake Prediction and Public Policy," can be ordered from the National Academy of Sciences, Printing and Publishing Office, 2101 Constitution Avenue, Washington, D.C. 20418, for $6.50 each.

2. Readying emergency services to deal with the situation after the quake has occurred;
3. Implementing a hazard reduction program to minimize loss and disruption when the quake occurs; and
4. Dealing with potentially counterproductive consequences of prediction.

I shall take up these tasks, in turn.

### ISSUING PREDICTIONS AND WARNINGS

Many scientists and community leaders are fearful concerning the release of uncertain and imprecise predictions, citing the prospect that a false alarm might diminish response to a later valid prediction, that mass panic might result, and that essential business and political activity might be disrupted. Actually the usual interval of years between serious earthquakes in United States localities is too great to sustain a "crying wolf" effect, and we have abundant evidence from studies of public response to disaster warnings that mass panic is mostly a figment of the imagination. Even a careful reading of reports on the famous 1938 "War of the Worlds" broadcast fails to confirm that any great number of people actually took to the highways or engaged in other extreme actions. Studies repeatedly show that denial of danger and efforts to continue with life as usual, rather than mass panic, are the prevalent responses to warnings of imminent disaster.

The justifiable fear of economic and political turmoil must be balanced by two considerations. If news of a prediction is initially suppressed but property values drop when the prediction is eventually released, persons with inside information stand to gain unfairly at the expense of persons who are not informed. As the recent incident in Kawasaki, Japan, confirms, suppressed information inevitably leaks out, and the ensuing confrontations weaken the credibility of scientists and public officials responsible for withholding information. Only the prompt release of all predictions can forestall these undesirable developments.

*Predictions* should be prepared, assessed, and issued to the public by scientists, promptly and without respect to policy considerations. Public officials must then exercise their discretion in issuing *warnings* when they judge that the situation warrants action and are prepared to launch an appropriate community response. A panel of scientists should be established on a standby basis to assist public officials in evaluating predictions. The responsibilities of local, State, and Federal officials for issuing warnings should be clarified at once through meetings of concerned parties. Both predictions and warnings must be constantly revised, and public officials must have the benefit of a constant flow of information about the beliefs, attitudes, and actions of the public in response to a warning.

### READYING EMERGENCY SERVICES

Earthquake prediction creates new opportunities to place both public and private emergency services in readiness to perform their postdisaster tasks of rescue, relief, and rehabilitation. Emergency plans should now be revised accordingly. Long-term standby civilian organization is not recommended, because activities soon lose their meaning in the absence of imminent threat. Citizen involvement in emergency preparations after a warning has been issued, however, should be a useful way of imparting a realistic understanding of the nature of prediction and the problems of preparing for an earthquake to a wide spectrum of community representatives.

### IMPLEMENTING A HAZARD REDUCTION PROGRAM

Because of Mr. Thiel's informative review of hazard reduction measures, our comments here can be limited to a few broad conclusions. First, *large-scale* evacuation will usually be neither practical nor necessary. Second, the prospect of substantially reducing earthquake hazard will be greatest when the prediction response builds on a continuing program of hazard reduction. Where standards for earthquake-resistant construction are already strictly enforced, where some continuing identification of safe and unsafe structures is maintained, and where land-use management has systematically taken seismic risk into account, the response to earthquake prediction will be largely a selective acceleration of existing programs.

Third, long periods of advance warning and the central importance of land-use planning and structural design and maintenance programs require a different allocation of authority than we find in most emergency planning. Departments of planning, building, and safety, engineering and public works, and the like must be given as central a role as police and civil defense agencies in responding to earthquake prediction.

Fourth, depending upon the period of advance warning and other considerations, the ability of the local communities and the region to bear a substantial part of the cost of hazard reduction measures will vary. Careful advance planning and some Federal assistance will be essential.

Finally, because we lack exact precedents and analogies, all phases of earthquake prediction and response will be plagued initially by legal uncertainties. These uncertainties must be clarified and legal obstacles to needed actions must be overcome as quickly as possible, with new legislation when necessary.

### DEALING WITH COUNTERPRODUCTIVE CONSEQUENCES

Although most inhabitants of a prediction area will attempt to continue life as usual, regional and national business and financial establishments will likely consider limiting mortgages, insurance, and investment in the threatened area. Combined with a possible net outmigration and reduced tourist trade, these conditions could provoke rising unemployment, falling property values, and reduced tax revenue. The panel recommends that upon issuance of an earthquake warning, a joint governmental and private-sector commission be established to monitor the economy in the threatened area to insure early detection of changes and to make recommendations to government, business, and labor organizations as needed. Representatives of insurance and investment organizations should play an integral part in the commission's work.

Proposals will be made in some quarters to respond to the warning by encouraging an orderly outflow of capital and population, but political realities and the long-term view will favor sustaining the community. Two strategies may be important in pursuing the latter objective. First, many of the short-term costs during the prediction period can be handled as investments in the postquake development of the community, if appropriate planning is undertaken. Second, steps should be taken now to gain acceptance for a policy that much of the outside financial assistance normally available to a community from public and private sources should be made available as needed for hazard reduction measures taken in response to the authenticated prediction of a potentially destructive earthquake. As the fate of the local economy will be largely determined by decisions made outside the local area, it is essential that national support for the threatened community begin when the warning is first issued and not be delayed until the earthquake has struck.

In these brief remarks I could only touch on a few of the problems explored and recommendations offered in the panel's report. I believe the full report merits your careful attention, not for any final answers, but as a starting point in meeting the challenge of earthquake prediction. The new-found opportunity to save thousands of human lives is the reward for dealing effectively with this challenge.

EARTHQUAKE PREDICTION—OPPORTUNITY TO AVERT DIASTER

# Earthquake Prediction is the Beginning of Problems—Not the Answer

**By Karl V. Steinbrugge,**

*Chairman, Seismic Safety Commission, State of California*

San Francisco's Chinatown area typifies the problems associated with the prediction of damaging earthquakes in California, and no realistic answers yet exist to help us deal with such problems.

A great many of the older unreinforced brick and similar buildings in Chinatown are potential collapse hazards in the event of a major earthquake. From such collapses, we can expect large life losses. The narrow congested streets and resulting debris and fires will make evacuation, search and rescue, and fire suppression difficult.

When a disastrous earthquake is predicted, critical public-policy questions will demand answers. Should the seriously deficient buildings be immediately strengthened? If so, who pays if the owner cannot? If buildings are closed, where do the residents go and who supports them? Unemployment? Taxes? Rents? Loss of business? Real estate values? Realistic answers to the foregoing must include historic, cultural, and economic considerations in addition to the obvious life-safety problems. Clearly, an earthquake prediction is the *beginning* of many real problems and not the answer for many public and private organizations and citizens. The policy questions involved in such negative consequences of earthquake prediction are of vital concern to California's newly created Seismic Safety Commission.

Concern for these problems is not new. In 1968, a Commissioner wrote:

"Suppose, for example, that the public were told that there was a 50–50 chance of a destructive earthquake occurring within three years of the announcement. What might be the response? In many cases, major industrial and commercial construction would probably be postponed until after the anticipated event, or relocated elsewhere, thus resulting in a major dislocation for large segments of the local economy. Painting and other maintenance work on dwellings, as well as other buildings, would probably be postponed until after the predicted earthquake, if possible. In many instances, inventories subject to damage would be reduced or relocated elsewhere, in anticipation of the earthquake."

The State Office of Emergency Services (OES) already has taken steps to deal with problems posed by earthquake prediction in its areas of responsibility. OES has established a scientific advisory panel to advise it on the credibility of earthquake predictions and a committee on State government preparedness to strengthen the response posture of several State agencies.

Now that prediction is seemingly imminent, solutions to these problems are mandatory. Practically speaking, what then can the commission do?

Its first role is to examine in detail the problems to be faced by the public, including the human aspects (such as safety, evacuation, temporary housing) and the financial aspects (such as unemployment, insurance, mortgage loans, property damage, and taxes) to see where adequate assistance may not be available. On the basis of its findings, the commission's actions *may* be:

1. To see that local, State, and Federal agencies are not letting the problems go by default by ensuring that the problems are addressed by the responsible agencies, recommending executive actions to the Governor, advocating necessary changes in Federal laws and programs, and other measures.
2. To recommend needed legislation to inaugurate new and expand existing programs to minimize the negative effects of prediction.

The Seismic Safety Commission is headquartered in Sacramento. It is directly responsible to the Legislature and to the Governor for seismic safety policy in California. The commission includes in its membership scientists and engineers, planners, and local governmental policymakers. The members were appointed in June 1975 as a result of recommendations by the Legislature's Joint Committee on Seismic Safety and the Governor's Earthquake Council. It has replaced both bodies. The Seismic Safety Commission is now beginning to take decisive actions to continue the work of minimizing earthquake hazards in the State.

# Earthquake Warning and Response—A Panel Discussion

Moderator:

Jack W. Carlson, Assistant Secretary for Energy and Minerals, United States Department of the Interior

Panelists:

Richard Courter, Department of Emergency Services, State of Washington

Charles R. Ford, Assistant Vice President, Home Office Research Department, Fireman's Fund American Insurance Companies

Robert J. Gregory, Director, Civil Defense and Disaster Agency, State of Nevada

Robert M. Hamilton, Chief, Office of Earthquake Studies, U.S. Geological Survey

Edward P. Joyce, Director of Emergency Services, City of San Francisco, California

James S. Lee, President, State Building and Construction Trades Council of California

Charles Manfred, Director, Office of Emergency Services, State of California

Dale Marr, Business Manager, International Union of Operating Engineers —Local No. 3

V. E. McKelvey, Director, U.S. Geological Survey

Donald T. McMillan, Director, Utah Geological and Mineralogical Survey, State of Utah

Terry Nidiffer, Alaska Disaster Office, State of Alaska

Honorable John H. Reading, Mayor of Oakland, California

Major General Valentine A. Siefermann, The Adjutant General and Director of Civil Defense, State of Hawaii

Karl V. Steinbrugge, Chairman, Seismic Safety Commission, State of California

Robert Stevens, Federal Disaster Assistance Administration

Honorable George Sullivan, Mayor of Anchorage, Alaska

Charles C. Thiel, Research Applications Directorate, National Science Foundation

Professor Ralph H. Turner, Department of Sociology, University of California at Los Angeles

Darrell Waller, Staff of Adjutant General of Idaho

Seymour Wengrovitz, Defense Civil Preparedness Agency

MR. CARLSON: I propose to go back to our keynote speaker, Charles Manfred, and refer to the questions that he raised, because these seem to encapsulate the main problems. So let me start off with those questions and see if we tend to agree with the person who presented the paper as to the dimensions of the problem in each area.

First, how rapid is the development of earthquake prediction technology? I gather from the comments presented by Mr. Hamilton that the full development will take a long period of time. However, there has been rather rapid advance during just the last 2 or 3 years. Also, that it is clearly worth trying to predict, and clearly worth passing on predictions to the public and private sector.

Are there any members of the panel who feel they would like to discuss this aspect?

MAYOR SULLIVAN: Do I understand from your comments that the Chinese are much, much further ahead than we are in predicting? And if so, when do we catch up, if possible?

MR. HAMILTON: The Chinese are ahead in the sense that they have already issued earthquake predictions and have taken action that has saved lives.

They readily concede that they have made many mistakes in their predictions. They have issued warnings for earthquakes that did not come. It seems that the Chinese are not as concerned about this as I think we would be in the United States.

MR. CARLSON: Were the benefits commensurate with the fact that they had at least one false alarm?

MR. HAMILTON: The benefits appear to outweigh the adverse effects because tens of thousands of lives were saved. That is just my opinion. We don't have any details from China.

MR. CARLSON: Mayor Sullivan?

MAYOR SULLIVAN: I just have one follow-up question. About 2 weeks ago, on the car radio, driving to work, I heard a statement, from either A.P. or U.P.I., that I think could have come from your office, about a prediction for an earthquake in the Cordova area of Alaska.

I searched very carefully in the newspapers the next 2 or 3 days, and there was nothing in the papers about this. Are you familiar with this?

MR. HAMILTON: No, I am not. As far as I know, we have no predictions that are pending.

MR. CARLSON: Mayor Reading of Oakland?

MAYOR READING: Yes. Maybe I can pose the question in a little different way. What is the state of the art in terms of your ability to predict? How long will it be before you estimate you will be able to predict?

Putting it another way, how long will it be before I can expect to get a call from the Governor saying "there is going to be a major earthquake in Oakland in 3 days?"

MR. CARLSON: That goes to the second question brought up by our keynote speaker—how accurate is the technology?

MR. HAMILTON: We are in a very difficult situation. We have instrumentation deployed in the San Francisco Bay region that could provide a basis for predictions. So, it would be conceivable that within the next year we could acquire some data that might lead us to believe that there would be an earthquake in this area.

Now, the big problem is that we do not have any experience with having made predictions in the area. We mainly have seismographs in this area. We don't have many of the other types of instrumentation that would support seismic evidence.

So, in answer to your question, it would be conceivable that within the next year we might have evidence that we feel we should pass along. We would have to admit that that evidence was fragmentary.

MAYOR READING: So, it's a question of the degree of accuracy. Are you talking about a 10 percent degree of accuracy, or a 50 percent degree of accuracy? Can you predict in that way?

MR. CARLSON: There are two questions in that. One is you may not have the best equipment existing in the Oakland area, and that is the first problem. You may just be dealing with half of the necessary equipment. And if you have all of the equipment, your predictive efficiency may be higher.

The second is: If you have optimal equipment available, what is the probability of a prediction? Maybe you can respond to the latter question instead of the former one?

MR. HAMILTON: I think the ability to assign a percentage, or a judgment of reliability to a prediction, will have to come from experience.

The Earth is a very complicated system. If we move into a new area with new instrumentation, we cannot be sure, until we have observed at least one or two earthquakes, that we really know that the same prediction techniques are going to work there that work elsewhere.

I should point out that even in the central California area, south of Hollister, we have only observed several earthquakes of magnitude 5, and so far no magnitude 6's. So, we really haven't been able to test fully our ideas in that area.

Reliability, at the outset, will be very difficult to assess. As an example, before the Thanksgiving Day earthquake, we saw a magnetic anomaly, the first observed so far in central California. Now, the next time we see a large magnetic anomaly in central California, we will be inclined to think there is another earthquake coming. If it occurs, the reliability of magnetic anomalies for prediction will go up. This is very much an empirical approach.

MAYOR READING: What was the lead time on that magnetic anomaly in central California?

MR. HAMILTON: It was a matter of weeks.

MAYOR READING: So, it would be in the 30-day category?

MR. HAMILTON: That's right.

Mr. Carlson: I think to summarize, we're not anywhere near the reliability of weather forecasting, and we all know the reliability there.

But, the key thing is that it is better than a table of random numbers. And the fact that you can start identifying earthquakes with some probability of success, even though it tends to be low until we develop the confidence, makes it worthwhile doing.

Mayor Reading: Well, you know, I think there is a responsibility, as pointed out here, for the public officials to pass on this information if they get it. It would seem to me necessary to do this in order to maintain the credibility of not only the people who are making the forecasting, but also the officials, and also to inform the people themselves so we can determine what they're going to do, based on that information. It would be helpful if a public official could say: "There is a 10 percent chance that there may be an earthquake in the next 30 days." It would be better if you could give an idea of the reliability of the prediction.

Mr. Carlson: Yes. I think that you should do that like weather forecasting, giving the probability as opposed to whether it's going to happen or not happen. And I agree with you regarding the information.

Mr. Thiel?

Mr. Thiel: There is an assumption in your question that the predictions are going to be issued to you through the Governor's office, or through some political process. I think that is an assumption that is not warranted.

Mayor Reading: That is what the information flow chart shows.

Mr. McKelvey: It is a proposal.

Mr. Thiel: That is only for predictions coming out of the USGS system.

A number of the predictions that were referred to by Mr. Hamilton were not made by USGS scientists. One was made in the State of New York by scientists at Columbia University. The post-prediction of the San Fernando earthquake was made by Caltech scientists. And right at your own doorstep, there is a large university, operated by non-USGS funds, engaged in earthquake prediction activity.

So, it is likely that predictions would be issued from non-USGS sources that are not subject to the Federal Government's program for evaluating and disseminating predictions arising from its own staff.

Mayor Reading: Well, what are your lines of communication and coordination with these other facilities?

Mr. Carlson: Before we get to that, may we just make sure we have completely explored the reliability aspect and the state of the art?

Mr. Courter: Yes. Let me clarify the question. Are we talking about an earthquake prediction reliability for only those kinds of earthquakes that have some kind of surface breakage or visibility?

In the Puget Sound area, through a study of the USGS, we found that most of the earthquake activity is deeply seated and results chiefly in ground shaking. And because of the large amount of water in our area, there are many areas of weak soil. We would, therefore, be vulnerable to ground shaking. Now, are you also including this kind of earthquake in your predictions, and how reliable are they? It is hard to build up an awareness by public officials if they can't see any visible cracks in the surface of the Earth.

Mr. Hamilton: The idea is to include all earthquakes that could cause damage, and not limit it to those that could cause surface faulting. Incidentally, the study in the Puget Sound area is funded by the USGS, although it is done by University of Washington scientists.

General Siefermann: Speaking of predictions of volcanic eruptions rather than earthquakes, I think that Drs. Tilling and Lockwood of the Geological Survey's Hawaiian Volcano Observatory have done a remarkable job predicting the last one almost to a T. Their forecasting is such that we pretty much believe them. There was an earthquake associated with that eruption, but it was localized. And there was one just a few days ago at Mauna Loa. So, we are expecting an earthquake and eruption within 2 weeks to 2 years.

We think we can pretty well determine where the eruptions would occur, that there would be minor damage, and what control we would have. We are even making studies to determine what action we would take to divert a lava flow.

Predictions, I feel, in the case of Hawaii, as far as eruptions are concerned, have come a long way.

MAYOR SULLIVAN: Do I get the understanding that some universities are predicting earthquakes?

MR. HAMILTON: The science writer for the Los Angeles Times pointed out recently that there have been 2½ successful earthquake predictions in the United States, and one failure. The two successes belong to the universities; a half success belongs to the Geological Survey, mainly because its prediction was made informally; and the failure belongs to the Geological Survey.

MR. CARLSON: As Mr. Thiel brought out, there is no attempt at fragmentation in the scientific community. If the community remains together, we can make sure we have no pluralism of predictions.

MR. THIEL: There also are private individuals who are issuing predictions.

MAYOR SULLIVAN: Mr. Hamilton and Mr. McKelvey were speaking of deployment of instrumentation in California. Are the systems going to be nationwide, or is it just going to protect California?

MR. CARLSON: Can you give us an idea, so everybody will know, what kind of initial costs and operating costs would be required for a city like Anchorage, or a city like San Francisco, so people will have an idea of the range?

MR. HAMILTON: Well, we prepared a proposal for developing what we could call a prototype earthquake-prediction system in the two most active seismic areas of California, that is, the central California area and the San Jacinto fault area. The purpose of the two prototype systems would be to confirm our present findings with respect to earthquake precursors and try to show whether it is justified to expand that system further, and then, if things work out, also to expand that system into the two major urban areas of Los Angeles and San Francisco. We estimate we can do that on a budget of about $5 million a year.

In Alaska there are more difficult operational problems, so the costs would be higher. But I think that gives us a feeling for the kind of money that is involved.

Now I would like to say again, at this point we are still in the experimental phase, and I don't think we know just exactly what we would recommend for large-scale deployment. We still have to do quite a lot of research before we would recommend that instrumentation be deployed on a really large scale.

MR. CARLSON: You're talking about a pinpointed area like Anchorage, or Reno, or Salt Lake City. You may be talking about $2 million for the capital investment and about $1 million for operating. Then, for larger areas such as Los Angeles and San Francisco, would you go up to a higher figure?

MR. HAMILTON: You have to approach prediction on a regional basis. You can't approach it on a pinpointed basis, because the volume of rock that is involved in storing the stresses of the earthquake extends over hundreds of miles, and you have to cover that whole area in order to recognize the precursor signals.

Part of the evidence as to the size of earthquakes, we think, will be the size of the area involved in the premonitory signals. So, a prediction system must be established on a regional basis.

I think for southern Alaska, we are talking about something like $10 million.

MR. CARLSON: For the whole region?

MR. HAMILTON: Yes, including Anchorage.

MR. CARLSON: But, it's not entirely a lump sum. You can talk about a closer net, or more instrumentation and less instrumentation. So it is not an all-or-nothing type of investment, is it?

MR. HAMILTON: That's right.

MR. CARLSON: Does that answer your question, Mayor Reading?

MAYOR READING: Can you tell us what is the status of instrumentation in San Francisco, Oakland, and along the San Andreas fault?

MR. HAMILTON: The main instrumentation that now exists in the San Francisco Bay area is a network of seismograph stations. The additional instrumentation that could be installed would be tiltmeters, magnetometers, and sensors for monitoring the electrical resistivity of the ground.

At the present time, such a blend of instrumentation exists only in the region south of Hollister, in what we call the experimental system. In addition, in the Bay region we carry on what are called trilateration surveys, which are surveys to detect changes in the length of lines to look for horizontal deformations in the Earth. But the main type of instrumentation in the Bay region is the seismograph network.

MR. CARLSON: We do not have funds in our budget to go ahead and instrument San Francisco, Los Angeles, Anchorage, or other communities at this time. In fact, I was hopeful that this conference would help us to see if we should move in that direction.

MR. GREGORY: Mr. Secretary, I have a question of Mr. Hamilton.

This instrumentation that is in the Hayward and San Andreas fault area, would Reno be in a region that such instrumentation covers?

MR. HAMILTON: No, although the University of Nevada operates some instruments in the Reno area. We are operating networks of seismographs in a number of areas in the United States. If I may briefly list those regions, we are operating a network of seismograph stations in the Puget Sound region through the University of Washington; there is a network in southern Alaska (partially concerned with environmental monitoring for the Trans-Alaska pipeline); in western Nevada through the University of Nevada at Reno; in Salt Lake City through the University of Utah; in southern Missouri through the University of St. Louis; and we are beginning to fund some work in the Northeastern United States.

MR. WENGROVITZ: Mr. Hamilton, you have stated that your instrumentation was placed in a somewhat large geographic area. What I am wondering about is the ability to be able to predict exactly where an earthquake is liable to occur with respect to a smaller sized area.

For example, if you're talking about an area that extended from Los Angeles to San Francisco, would you be able to say that both areas are likely to be subjected to an earthquake, or can you be more precise than that and say the Oakland area would be subject to it, but not the Los Angeles area, and perhaps not San Francisco?

MR. HAMILTON: We anticipate that the predictions would be specific as to the area involved. So, it would not be a general prediction for the whole State of California. However, a magnitude-8 earthquake could have precursory signals that extend over a fairly large area.

MR. MANFRED: I just have one more point. What are the prospects of increasing, in money and time, these research activities in the next couple of years to change the rate of progress? Would the prediction capability develop faster? What are the prospects?

MR. CARLSON: Obviously, there are several options as to how fast we can proceed. It will be important to us, from the Federal viewpoint, to gain some insight from you as to what would be appropriate. It also requires an assessment of the benefits we can expect from this new technology.

Let me see if I can summarize. Although we have seen fairly rapid advances in recent years, we believe that the development of a prediction technology will continue for many more years—that it isn't going to be attained overnight. However, I judge from the suggestions in the presentations we've heard at this conference that it is worthwhile pursuing. And, if we do pursue prediction, we must consider its utilization aspects, which I would like to talk about now. That is, how does a State government, a local government, or the private sector use this information when it is available? I would like to consider the outline that Mr. McKelvey proposed for the flow of predictions from the scientific community to the public. It is obvious that some sort of process for handling predictions would have to be established.

Let me turn this topic over to Mr. McKelvey.

MR. MCKELVEY: Could I just say something with respect to Mr. Thiel's point regarding the earthquake-prediction flow chart?

We talked about the Geological Survey predictions and the way in which they would be handled. But as I mentioned during my talk, I think it's likely—if we are successful in setting up the system I've described with the Earthquake Prediction Council as the review mechanism, and if the States are successful in setting up a similar kind of mechanism, such as California has already done—that the responsible scientists in the academic community will want to enter that system. They will want to have their predictions understood and reviewed.

So, I think that would follow if we set up the kind of system that we're talking about.

MAYOR READING: I would like to comment on that. I think it's imperative that you get cooperation and coordination. We know about other reporting agencies and what has been brought out here very emphatically today is that there is a multitude of problems attached to any announcements of this sort, and that there ought to be an orderly plan for the distribution of that information. If you have someone who holds a press conference and all of a sudden announces publicly that next week he thinks there is going to be an earthquake, then it completely disrupts the orderly government process.

MR. CARLSON: I think the essence of your statement, Mayor Reading, is that first, we have freedom of speech. Obviously, anybody can speak on any topic they wish. However, it may be useful to identify an agency, so that if somebody does have information, they know where they can take it. And that agency would put the data into a system of screening and verification so the people may judge how reliable that prediction may be.

MAYOR READING: Well, it seems to me that the responsibility is one that belongs in the Federal Government, for example, in the Geological Survey, or with someone who can go to these various agencies and say, "Look, are you willing to cooperate with us and to run through the normal screening processes if you have such a prediction?"

MR. CARLSON: In terms of the Federal family, the Geological Survey would be the appropriate place. But you're talking also about academic communities that are not under the jurisdiction of the Federal Government. You would want to have some sort of comprehensive policy that would enable the Federal Government to process information from other sources.

I do think it is important to be careful how this information flows, and to have responsible people who provide moderation to statements that might come out of the blue.

MAYOR READING: That is the point I am trying to make, it should go through an appropriate channel.

MR. MCKELVEY: At the present time we don't have the authority to require one. We don't have the system established fully, either. But I would think that if we do have the Earthquake Prediction Council that I've described set up and operating, it would be entirely within its purview, if it learns of a prediction that is being developed, to invite the person to submit his data. And the State Council could act similarly.

MAYOR READING: I fully understand that you don't have the authority to direct a person to do that. But I think that you could develop a plan—which you've done—and then persuade the scientific community that it's to their best interest as well as everyone else's that they go through approved channels.

MR. MCKELVEY: Scientists are going to feel that responsibility.

PROFESSOR TURNER: I think we have come to this crucial problem: We are tempted to solve our problems by restricting the flow of information. The moment we start doing that, we create all sorts of complications which tend to make a bad situation worse. And I think we must distinguish between the matters of releasing predictions, authenticating predictions, and issuing warnings. These are three different things.

Now, I understand that the proposal presented by Mr. McKelvey has to do very largely with the authentication of predictions and with steps toward issuing warnings.

But just think what is involved in trying to prevent people who think they have evidence that there is going to be an earthquake from making a public statement. Is that going to include astrologers, or are you only going to restrict legitimate scientists?

You simply have an absolutely unmanageable and uncontrollable situation if you start trying to prevent people who, for whatever reason, honestly believe that they have evidence, from releasing that information.

And, in any case, I would like to remind you again that information leaks out. The longer we hold it back, the longer we try to deliberate over whether to release it or not, the greater the certainty that the press will get it and it will come out. Then the people who are trying to be responsible about it will be embarrassed.

It is a much better alternative to have the information come out independently and then simply say: Well, we don't know whether this information is valid yet. But we are giving it serious consideration.

Everything we know about public reaction indicates that when people have confidence that the scientists and the officials are seriously considering a question, they don't force precipitate action; it's when they think that something is hidden that then they start to force precipitate action.

MR. CARLSON: I think you can see that the precursors don't start the night before an earthquake. There is a buildup of suggestive data that permits people to say, "Can we interpret it this way or not?"

It's not like something that develops overnight and is hidden from view—indications tend to build up over time. So, we do have time to formulate plans.

An earthquake-prediction review system *can* be built around what Mr. McKelvey has said. Perhaps the geophysical information will flow through those channels for weeks or months while people develop an actual prediction, and have some confidence to give a warning, together with the costs and benefits associated with it.

MR. MARR: This is related to a situation we had recently at Oroville, California. I happened to be in Utah for a meeting the night of the earthquake, and you wouldn't believe the number of phone calls I received. People were just staggered with the idea of an earthquake, because there was a likelihood that the Oroville dam would be affected. And knowing the volume of water behind that dam, if someone had said that the dam might fail, there could have been a real panic of people trying to get out of the way.

It amazed me how many of our members who work near Oroville traced me down and asked what to do. There could have been a really chaotic situation.

So, when officials are handling predictions, there has got to be careful analysis of who is going to be issuing statements.

MR. CARLSON: I'm wondering if Mr. McMillan would like to add to that, because of your familiarity with your part of the country?

MR. MCMILLAN: We, of course, are also on the watch. Salt Lake City lies astride the Wasatch fault and is in a potentially active earthquake zone. But you can't ignore the fact that in 150 years of settlement in the Salt Lake Valley, there has not been a destructive earthquake.

What I would like to ask Mr. Hamilton is: Whether or not there are long-range predictors—or if he thinks there will be long-range predictors—that might give a lead time of 1 or 2 or 3 years, during which time instrumentation can be increased so that the imminence of a potential shock can then be predicted in time intervals of 30 days and on down to a 10-day or 48-hour prediction?

MR. HAMILTON: There is evidence that the bigger the earthquake the longer the lead time in terms of when the signals first begin.

In Japan, before the earthquake in 1964, the first changes in sea level occurred about 10 years before the earthquake. Similarly, for the earthquake that occurred in Tashkent in the Soviet Union about 10 years ago, changes in radon gas had increased in well water about 10 years ahead.

So, for the big earthquakes, there is evidence to indicate that there may be very long lead time—on the order of perhaps as much as 10 years.

We would expect that, as you pick up signals that indicate that something may be developing, you would move additional instrumentation into the area to confirm the early results and to sharpen the prediction.

There have been several occasions in the last few years where we, in our studies, have picked up something that looked suggestive of an anomaly. We followed up with additional instrumentation. But in all cases, the anomaly was not confirmed.

MR. MCMILLAN: And wouldn't this be an avenue worth pursuing in order to bring the art of earthquake prediction into a widespread area, and yet control the rather high cost of closely spaced instrumentation?

MR. HAMILTON: Yes. That would be the approach. But, I should point out that you have to have at least a partial network of instrumentation.

In the Salt Lake City area, we have a rather sparse network of seismograph stations, but no other type of instrumentation. The University of Utah has some instrumentation, but it's not adequate to constitute a prediction system, even of a sparse nature. But you're right. Probably the best approach is to gradually upgrade the instrumentation, and then when you identify a problem, to intensify the efforts.

MR. THIEL: Mr. McMillan, you made a statement that I can't agree with. There have been a number of damaging earthquakes in the Salt Lake City area since the time it has been occupied by European man. There have been no great earthquakes, but please note that a great earthquake, in terms of damage and intensity, in the Salt Lake area, does not have to be the giant titanic process that takes place on the West Coast. The seismic resistance of the structures in the Salt Lake area does not match that of the principal West Coast areas. Therefore, a



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smaller shake can cause the same intensity of damage.

MR. MCMILLAN: You're right. I had no intention of downgrading the potential dangers. For instance, the Pocatello Valley earthquake of last March 29th [1975], had it occurred in Salt Lake City, would have caused major destruction. It was a stronger shock than that which destroyed the City of Managua, Nicaragua, a few years ago. We are well aware of that.

And, you're right. There have been shocks which did cause damage in Salt Lake City. I didn't mean to say that there haven't been. But what I did mean is that there has not been, during that period of time, a major destructive earthquake in the immediate Salt Lake City area.

MR. CARLSON: I gather from our discussion, we are agreeing with the general approach to earthquake warning that has been outlined in Mr. McKelvey's proposal. Even though it is rather general, the process provides for verification and for identifying who is the responsible person. That is something we all support. We would frown on trying to hide the information from the news media. There would have to be a responsible release of information as that information is gathered over a period of time.

That moves us to Mr. Manfred's comments on how our earthquake predictions could be communicated to the public. The question we have yet to talk about is: How do we release this to the public?

Now, we have made some mention of the extent that this might be on a probabilistic basis: "We expect an earthquake of magnitude three to five on the Richter scale in the next 90 days in such and such an area. The probability of this occurring is 10–20 percent, or 40–50 percent, or some range of probability."

Are there comments on how we would release information to the public, no matter who is doing it, whether it's the scientific community or a public body.

And of course, the release has to be tied to what you are going to do about the problem. What is the government to do, and the people who provide the goods and the services? So, you would have to accompany a warning with what steps are expected to be taken. May we talk about that for a minute?

GENERAL SIEFERMANN: With regard to prediction of volcanic eruptions in Hawaii, the scientific community contacts the Governor, and the Governor makes the determination to release the information. It then falls on my office, which handles the emergency and civil defense, to disseminate the information to the public and to direct the action they would take and to coordinate the action we would take. This seems to work really well.

MR MCKELVEY: I wonder if I could ask for a reaction to the idea that an authenticated prediction—and with reference to the system that we've proposed, predictions having been authenticated and released by the Geological Survey—ought to go to the State Governor before it goes to the general public, so that a warning and prediction reaches the public at the same time? So that the public is not given a prediction without also being given something from the State and local authorities as to the defensive reactions that they can take?

GENERAL SIEFERMANN: I think it should go to the Governor so the flow of information can be controlled. You get more factual information disseminated to the public.

MAYOR READING: In view of what you have told us here, I think it is important that there *is* a body that authenticates a prediction. I also think it important that the prediction go through the Governor and the local officials so that when it is announced you also can relate the precautionary measures the public can take.

MR. CARLSON: Then, you will need to have the interpretation following rather quickly, if not simultaneously, the announcement of what could happen. And, the elected officials of the State and Federal Governments are the ones whom we normally trust in our society to carry out that function. So I think you're generally saying that you favor this approach.

MAYOR READING: Absolutely.

MR. COURTER: Not only that, but I think it's also very important that the prediction be presented in language that can be easily understood, not only by the public officials at the State and local level of government, but also by the citizenry who is going to receive this kind of information.

Often times, we get information that can be misinterpreted. If we are going to receive a prediction, it should be stated in understandable terms, and it should be given with a suggested action or alternatives so that we really have something to evaluate at the State and local government levels.

MR. CARLSON: Possible responses were outlined in the paper presented by Mr. Thiel: If you have 3 days, there are some things you do; with 30 days, you do other things; and with 3,000 days, you can respond in other ways.

MR. MANFRED: I think we have to be very realistic about it. There are no secrets; we have a free and open society.

I do think that the Survey should establish a council to authenticate predictions. You should make a special effort to see that responsible officials in the area of concern are notified. But, chances are that the responsible officials and the public are going to be notified at just about the same time. Emergency service organizations have to begin to give this some thought and come up with plans and procedures early in the prediction stage: What are we going to do if the Survey tells us an earthquake is imminent?

MR. CARLSON: It is going to be important for society to know that there is a responsible group that can provide an authoritative appraisal of what is being talked about.

MR. STEINBRUGGE: I certainly agree with the ideas expressed in the proposed plan. I would like, however, to ask a question.

Is there mechanism so we don't have two groups developing diverse answers? Let us say that university seismologists make a prediction and it's in the gray zone, which we all feel may well be the case. Would this prediction be reviewed by the USGS?

I am concerned that there may be substantial differences in the interpretation of the scientific data. We must be sure that we aren't faced with the USGS stating that a prediction is probably true, while some other credible institution states that it is probably not true, or vice versa. I think this can be a disaster in itself.

MR. CARLSON: Well, I think the key thing is: We want to make sure there is a responsible body somewhere to verify a prediction.

MR. STEINBRUGGE: I am not critical of the proposed plan. I only see a problem which might arise. I find no fault with what has been proposed. But I would like to see the plan structured in such a way that a scientific consensus might develop with regard to a prediction.

MR. CARLSON: Mr. McKelvey?

MR. MCKELVEY: The situation that Mr. Steinbrugge is anticipating is one we can expect from time to time. The situation in which the significance of evidence is not agreed to by all specialists in the area is not an unusual one in scientific matters at all. And indeed, it does pose an additional complexity in the problem.

But, as I indicated, we would expect that an Earthquake Prediction Council in the Survey—and I think this would be probably the case in State organizations also—would from time to time issue conclusions that are not agreed to by all members. This may be such that we would evaluate the situation as one of greater uncertainty. Those facts would have to be presented to the State and to the general public, and additional emphasis would have to be placed on the investigative process to try to narrow the range of uncertainty.

We are not facing a problem with easy solutions here. And we can expect to have to cope with difficulties of many kinds. This is only one of them.

MR. CARLSON: Let me throw into our deliberations some of the final points that Mr. Manfred gave us earlier. Will the social and economic costs resulting from prediction exceed the cost of the earthquake destruction? In this regard, which is the more acceptable risk? And how will the people and their government organizations respond to earthquake predictions? Let's consider these points in our discussion.

MR. THIEL: I've a two-part question. There are going to be a number of panel meetings by committees on procedures. How would procedures apply to the Federal level; and are these prediction meetings going to be open to the public and will they include a participation phase?

First, I would like to ask Dr. Turner whether the prediction review meetings *should* be open to the public. And secondly, I would like to ask Mr. Carlson whether they *will* be open to the public.

MR. CARLSON: Professor Turner?

PROFESSOR TURNER: Well, that is a loaded question. I have to answer it as from a personal viewpoint, as this is not something that was discussed in the National Academy of Sciences panel, and therefore I can't shift the responsibility to anybody else for the answer.

I think technical questions and policy discussions are two different things.

Technical questions have to be answered on technical grounds. Any time political considerations and policy considerations enter into the determination of a technical matter, we're in trouble.

Now, I think the point is that when you open up a technical discussion to the public, you invite the intrusion of political policy considerations. So, I would say that insofar as a panel or group is involved in the technical evaluation of evidence to determine whether there is going to be an earthquake or not, it should be a closed meeting of technical people.

The question of policy is another type of question. But I would make that distinction.

MR. CARLSON: Within the Federal Government there is a Freedom of Information Act, and anybody can demand access to that kind of information, and we would be obligated to provide it. In fact, frankly speaking, I see no reason to withhold the technical information, for it is going to be building up over a time. It is going to be available. The interpretations will come more slowly.

On the policy side, I'm sure that the important policy is set prior to the occurrence of the event. What we will do depends on given circumstances. If you have a 3,000-day lead time, then obviously, policy decisions will develop over a long period of time. There may be some brainstorming going on that wouldn't necessarily be public. But, I certainly think that the technical data would be generally available to the public. And we have made a point of making sure that the scientific findings of the Federal Government are separate, as much as possible, from the policy side.

PROFESSOR TURNER: Let me just make sure my answer is clear. It is the *deliberations* of the technical body which should be private. But once the technical body reaches some sort of conclusion, then all that information should be public and none of it should be withheld. There should be no censoring or withholding of the technical information, because the scientist must not decide what is good for the public to know and what is not good for them to know.

MR. CARLSON: Science is too important to society to be left to scientists; is that what you are saying?

GENERAL SIEFERMANN: During the last event that we had in Hawaii, we responded on a local government level just about as you stated. We had a consultation with the scientific community. Then, it was the local government that issued the information.

We are now working with the scientific community and the Geological Survey to set up the basic procedures whereby we can get together and almost immediately develop the information necessary so that it can be disseminated to the public.

Being an optimist, I think that more information is always more useful than less information. There may be occasions when that isn't true, but I would hypothesize that most of us feel it is worthwhile taking action as opposed to not doing so. We would have to look at it on a case-by-case basis to see.

MAYOR READING: Mr. Chairman, I have a question of Mr. Manfred. It's pointed out here that when the dissemination of the prediction is made—and as far as I'm concerned that would only come from my office after it has gone through the review board—we should have a response plan that we would start to implement. And that plan would be announced to the public.

Now, it seems to me that it's rather impractical, and a duplication of effort, if every local municipality developed their own plan. It seems the more realistic approach to this would be for the [California] Office of Emergency Services to develop model emergency plans for the use of the counties and cities in the area of a prediction.

MR. MANFRED: Yes. You can be sure that our Governmental Response Committee, meeting in Oakland, is identifying the problems, and we will be developing a plan in California.

I mentioned in my talk that California is fortunate in terms of our emergency organizations, and particularly our planning. Our plan is based on the consignment of shared responsibilities in a mutual manner. We work closely with the cities and counties in the State, and will continue to do so to meet this problem.

MR. CARLSON: Let me pose two additional questions. And I'm wondering if I could call upon Charles Ford, of the insurance industry, and also Mr. Dale Marr, to suggest: (1) how the public at large, as opposed to the governmental sector, would tend to react towards earthquake predictions; and (2) the benefits that may be associated with prediction from the perspective of the insurance industry.

And after we hear from these two gentlemen, I would like the rest of us to be thinking of the important next steps that we should consider after this meeting is over. Do you feel that we should move in the direction of improving the prediction capability, of authenticating the predictions, of having a warning system tied to it?

MR. FORD: Let me say first that these are personal observations not related to any organization.

I think we must look at insurance response in two parts. The insurance mechanism deals with fortuitous events. In our private organizations, we have earthquake insurance available at reasonable cost. This has been substantiated by Mr. George Bernstein, then Federal Insurance Administrator, before the Congress, and by Mr. Lawrence Baker, then California Chief Deputy Insurance Commissioner, who addressed the same subject before the Senate Investigating Committee on the San Fernando earthquake. There is earthquake insurance and it is available. The problem is that it is not generally purchased. We would like to see earthquake insurance more broadly purchased, but this can't be done without a willing buyer.

Insurance is something that is bought for a price—the premium—for a contractual expenditure under circumstances of fortuitous loss for a specified amount of indemnity. Does prediction based on precursors remove the earthquake event from the fortuitous and does the event become an actuality at that time? If it does, then the purchase of insurance *after* a prediction, as when any loss is imminent, is not a proper involvement for the insurance mechanism.

No one would expect to place insurance on a burning building nor would they expect a life insurance company to insure the man in a hospital bed who has been advised by his doctor that he is terminal. To require the certain loss rather than the fortuitous unexpected loss would put a cost burden on the insurance-buying public which would be unthinkable and an economic disaster.

The problem then is to get people to buy earthquake insurance on a long-range basis. If a person has purchased and holds a policy, the company will stay with it and respond. Witness these circumstances drawn from our experience when Hurricane Betsy lay off the coast of Louisiana. It sat for 3 days and then directed itself at the coast at New Orleans. The insurance industry did a lot of fingernail biting and waited for the roof to fall in.

MR. CARLSON: Did you sell a lot of insurance the day before?

MR. FORD: No. We stayed with the contractual obligations that we had and those prudent people who had insurance.

I think we have a necessity of getting broad acceptance of earthquake insurance coverages. What means this may take—in what way it can be done—I don't know.

After the San Fernando earthquake, a number of companies ran full-page ads in the "Los Angeles Times" advertising earthquake insurance, and cutting the price. They didn't get their bait back. The new premium didn't offset the cost of the advertisements.

We have a lot of thinking to do with regard to capacity should insurance become required or generally accepted. Then you are talking about loss potential in the Los Angeles area on dwelling property alone which could amount to $3 billion dollars. Plus another $5 billion for nondwelling property. Certainly there is no insurance mechanism in the world that could take care of this magnitude of loss.

At the present moment, earthquake insurance is available. We must find some way of getting more people to buy it, whether it be mandated or whatever means. At some point, more capital will be required than is presently available.

At the present moment, we are insuring earthquake loss, we are anxious to provide it, but people won't buy it.

MR. SULLIVAN: Let me respond to the issue of rates. Are you speaking only for the State of California, or are you speaking about the 50 States?

MR. FORD: I'm speaking generally.

MR. SULLIVAN: In Anchorage, we operate our own port. The question is, we have a tremendously hard time trying to get earthquake coverage on the port facility, even partial coverage. The rates on it are another question. They are extremely high rates.

MR. FORD: What is reasonable in the Port of Alaska [Anchorage], I don't know.

I know that the Golden Gate Bridge Authority had trouble filling their insurance requirements a few years ago. There was not capacity in the world market to give them enough policy limit to cover the appreciated value of that bridge. There was no problem when it was built, at the level of costs at that time. But with the escalation of inflation and everything else, they ran out of market.

MR. CARLSON: Mr. Dale Marr?

MR. MARR: Well, Mr. Chairman, the people I represent are pretty practical people.

The question that Dr. Turner raises is the one that I think is the key as to how the general public, at least the public that we represent (some 37,000 members), will react. The problem is: who do you believe and how do you keep the issue out of politics?

We have a prime example of that right here in California today in the nuclear-energy hearings that are going on in Sacramento. If we have the same thing for earthquake prediction, the public is going to take a very jaundiced look at it, I'm afraid.

We are seeing some world-renowned scientists say that nuclear energy is the only way to go, but we also have other equally well-known scientists disputing that.

And so, the public is saying, "Who's paying who to say what."

It is not fair to the scientists, but unfortunately this is what I'm hearing out in the field. I just don't know how you can prevent this, because scientists have to discuss things. How do you get the public to understand that the experts are going to disagree on many subjects for a long time to come?

Now, look at Crescent City. When the people there were told to evacuate because a tidal wave was coming, they didn't get out. And the wave was something that could be tracked and was estimated to be only a few hours away. People just didn't believe it was going to happen. Look at Hilo—it has been wiped out several times in the last century or two by tidal waves, and people move right back in again, and they say, "It isn't going to happen again."

How do you get the general public to really believe the scientists? And when the scientists get into arguments in the press among themselves, I think it further confuses the general public, which doesn't have a scientific background.

MR. LEE: Mr. Secretary, I want to ask one question.

I am the president of the State Building and Construction Trades Council of California, representing 350,000 members.

Now, when you take into consideration the members, plus their families, we are talking about a line of communication that we possess in this State with a million people. My question is: How can organized labor and, in particular the building trades, help? What part can we play in participating fully in an earthquake warning program, particularly as far as disseminating information to the membership is concerned?

MR. CARLSON: That's a good question. And in fact, that could be an item we can consider in terms of follow-up from these deliberations today.

Let me go around the table for any recommendations you'd like to make on the question I posed earlier. And if you don't have any particular recommendations at this time, and you would like to share some with us later, we would appreciate a note.

I will start with Bob Stevens:

MR. STEVENS: I don't think I have any recommendations that haven't already been made, except to say that we certainly endorse all speed in the direction we seem to be headed. And I think it's critical that we have this as fast as reasonably prudent in order to accomplish our goals.

MR. CARLSON: Mr. McMillan?

MR. MCMILLAN: We find, in the Salt Lake region, there is very little interest in earthquake insurance as demonstrated by the fact that the people simply don't buy it. I would be interested in pursuing the insurance angle.

MR. CARLSON: Mayor Reading?

MAYOR READING: We are in the stage of developing some hazard analysis of our own, and we are also interested in the insurance phase.

MR. CARLSON: Mr. Wengrovitz?

MR. WENGROVITZ: Yes. I have two points. The first is reemphasizing the statements made by Mr. Manfred and Mayor Reading, pertaining to the development of emergency operation plans, not only at the State level, but also at the local level for those communities that are involved.

And secondly, you have got a promotional job to do. You've got a selling job to do in the sense of convincing the community that earthquake prediction and warning is valid, is acceptable, and is accurate. That message has to be conveyed to the public. Until then, until you get the message across, you will not get any follow-up action.

MR. CARLSON: Thank you.

Mr. Nidiffer?

MR. NIDIFFER: Well, it seems apparent the funding in this direction will be limited for the next few years.

It seems to be appropriate that the dollars available should be put into the first predictable event and that a pilot program be developed that could be transferred to another locality. That would be my recommendation, rather than each community or each State spending a tremendous amount of time and effort without the benefit of the sensors and the prediction ability.

MR. CARLSON: Mr. Courter?

MR. COURTER: Agreeing with that, I would also emphasize that urban planning or land-use planning efforts be included in our endeavor.

In addition to that, I think we should address the code enforcement and building construction standards aspects.

MR. CARLSON: General Siefermann?

GENERAL SIEFERMANN: I don't have anything further to say, except I would like to make a statement with regard to the ones that have been made—about people moving back into Hilo. There was a land-use program for redevelopment of the city of Hilo that resulted in siting an entirely different government and commercial complex away from the area affected by the last tsunami. So actually, we did have proper land-use development there.

MAYOR SULLIVAN: Following the 1964 earthquake in Alaska, we did upgrade substantially our building codes by working with the architects and engineers in Alaska and from out of State, too.

And secondly, we are working very closely with the Governor's Office of Preparedness and have a very active program of our own in the community.

MR. GREGORY: I would urge the Federal Government to establish a line of communication and coordination with all academic and private agencies that are involved with earthquake prediction systems to try to eliminate predictions going out inadvertently and sporadically and instead to have them all come through one central office, the Governor's office of the State involved.

Also, I would encourage the Federal Government to provide the responsible agency within the community information which the agency could use to educate the public as to the validity and feasibility of earthquake predictions.

For I think once the public is educated, you'll get a better response from them.

MR. CARLSON: Is there anything additional that you would like to add? Mr. McKelvey?

MR. MCKELVEY: I would only add this: An invitation to all of you, including the audience, to send us additional thoughts that you may have. We would welcome them.

PROFESSOR TURNER: Two quick points.

I think we must very quickly establish a policy of treating the issuance of earthquake warnings as emergencies for legislative purposes, and that we should examine current legislation from this point of view.

We will certainly have to make some additions to the Relief Act of 1974, and/or other legislation, to make available in the community as soon as there is a warning, some of the types of assistance that would become available to them after the earthquake is over.

And the other point is to emphasize that most disaster emergency plans focus on the police and other emergency agencies. This is quite appropriate when you're speaking of, say, a warning of a few days. But if it is a relatively longer period of warning that is involved, the major activity will have to do with land-use planning, building improvements, and so on. So most emergency plans need to be modified to put the planning departments, building construction departments, and so on, centrally into the plans.

MR. CARLSON: Thank you, Professor. Mr. Joyce?

MR. JOYCE: I would like to second the statement of Professor Turner. The physical crisis in the cities and the counties, to my mind, requires a great deal more funding to be coming forth from both the Federal and State Governments for emergency preparedness. We should not wait until such time that predictions are available. Because it's too late then. This funding must be looked at, the plans must be prepared, and it must come together before, and not something that comes after, the prediction.

MR. CARLSON: Last but not least, Mr. Manfred?

MR. MANFRED: Well, as I indicated in my opening remarks, I think we can judge the policy in California by our actions.

We will continue to monitor the development of the technology. We are in the process of modifying our emergency-preparedness plan and programs, and we are going to keep the lines of communication open with the Federal Government and will pass on any information we get to the cities and counties.

We'll work together, Mayor Reading, on that model plan.

MR. CARLSON: Well, ladies and gentlemen, I think we've had a full morning. I learned a lot from the formal reports and from our discussions.

Obviously, we will not solve all of our problems today. This conference is just one of many steps in the direction of utilizing a new technology that will permit the forecasting of destructive earthquakes.

We have considered the questions Mr. Manfred raised:

How rapid is the development of earthquake predictions and how reliable are they? They apparently will be of sufficient value to justify continued research.

Will the Federal Government be able to establish an earthquake-prediction system? This will depend on further research progress and additional funding.

And how are earthquake predictions to be communicated to the public? I think we can move in the direction proposed, including an authentication system for the prediction of earthquakes.

How will the people in the Government organizations respond to earthquake predictions? That is reflected, in part, in what we have discussed today.

Judging from your comments here, I think that it is incumbent, on each of us, from various levels of government and the private sector, to give additional consideration to these questions.

The bottom line is: Are the benefits of prediction worth the cost of additional steps in the public policy area? I think most of us here are saying, "Yes!" We will have to proceed with these additional steps, and we would appreciate your help in defining what they should be.

We have greatly appreciated your participation in this conference. I certainly felt it was worthwhile and I look forward to the next occasion to meet with you.

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

By Robert E. Wallace

GEOLOGICAL SURVEY CIRCULAR 701

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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.

Robert E. Wallace

# Goals, Strategy, and Tasks of the Earthquake Hazard Reduction Program of the U.S. Geological Survey

By Robert E. Wallace

## 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

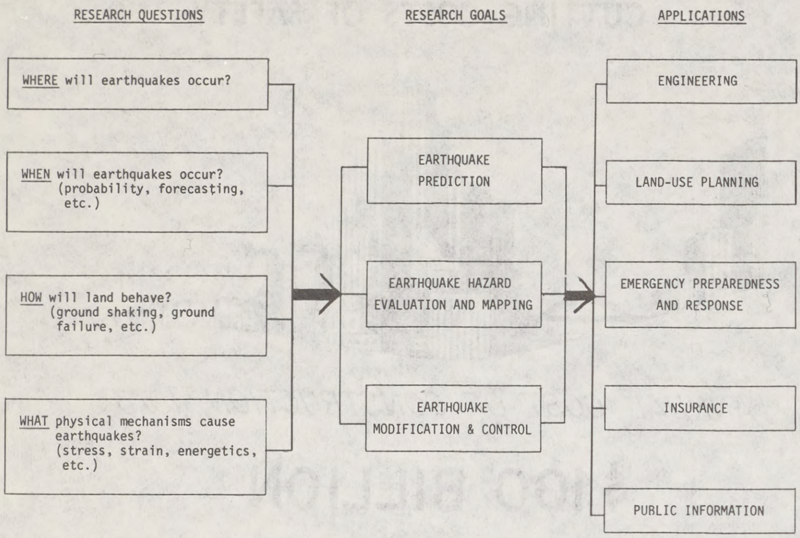


FIGURE 2.—Flow of output from fundamental research in Earth sciences to application in earthquake hazard reduction.

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

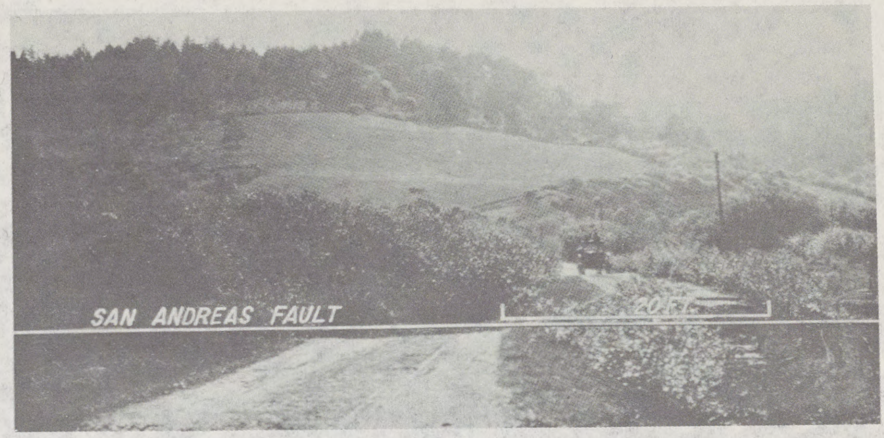


FIGURE 3.—Fault hazard. The hazard of movement on faults can be reduced by prohibiting structures for human occupancy directly astride known active faults. This photograph, taken after the 1906 San Francisco earthquake, shows offset of a road by more than 20 feet along the San Andreas fault, Tomales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

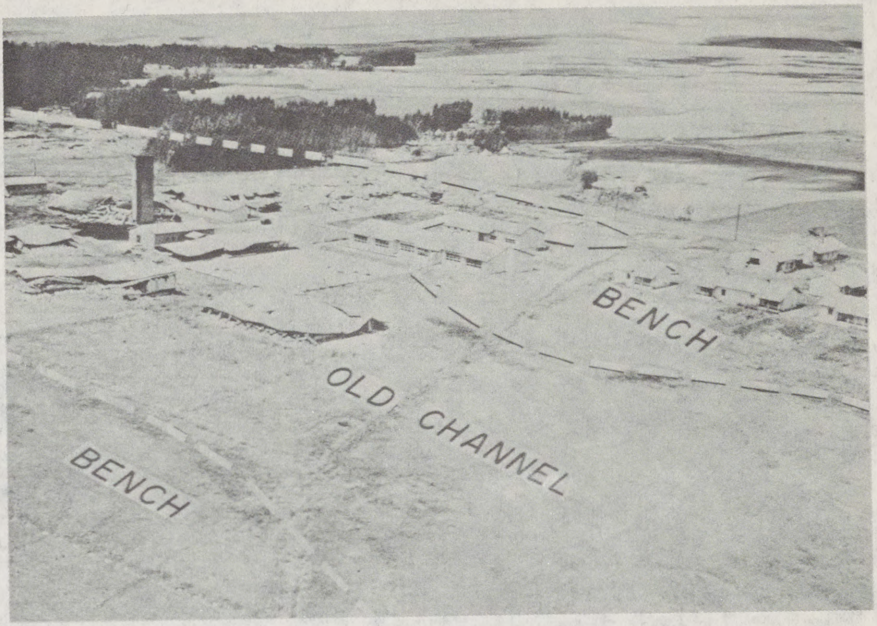


FIGURE 5.—Land-use planning. Damage on different types of ground may be very different. At Varto, Turkey, 12 of 14 buildings on "old channel" material collapsed. On "bench" material no buildings collapsed.

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



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## 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

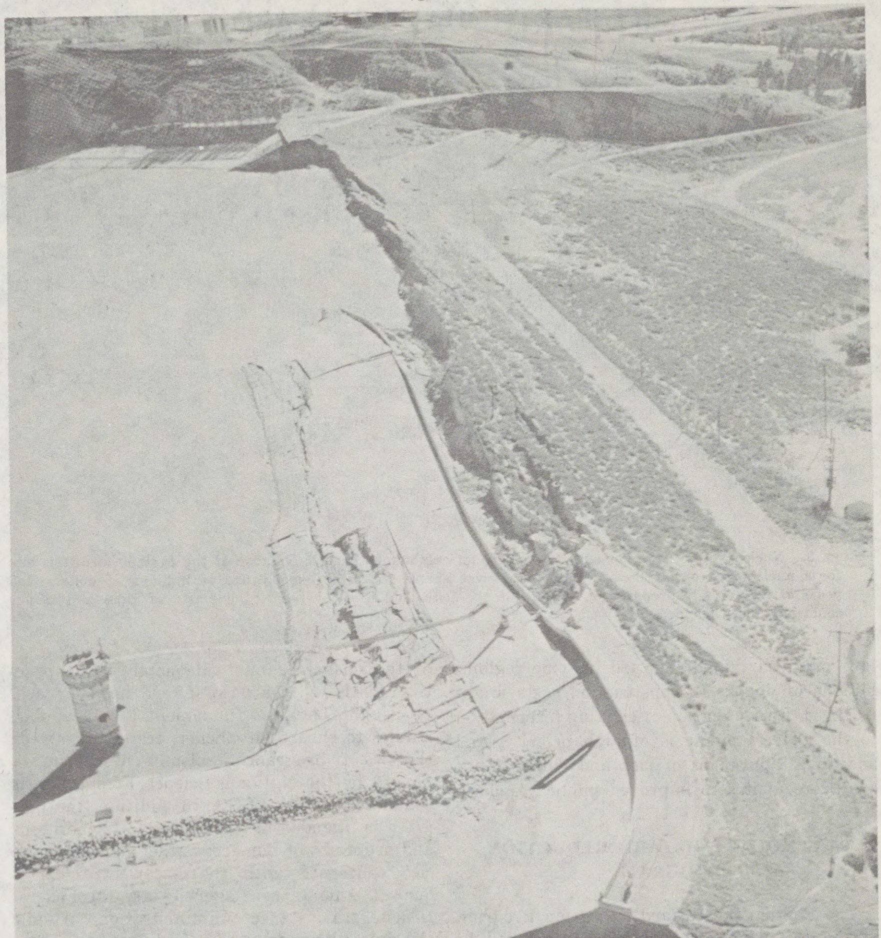

FIGURE 7.—Indirect hazard. Van Norman Dam almost collapsed in the San Fernando earthquake of 1971. If it had, tens of thousands would have drowned.

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

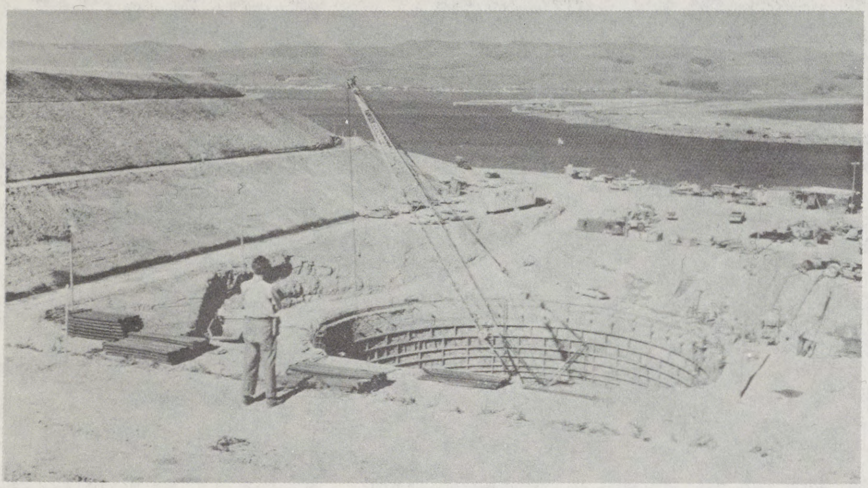

FIGURE 8.—Nuclear power development delayed by an earthquake hazard. Because of the fault hazard, this site for a nuclear reactor at Bodega Bay, Calif., was abandoned after expenditure of millions of dollars and years of time in site preparation. If data on the fault had been available, the waste of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

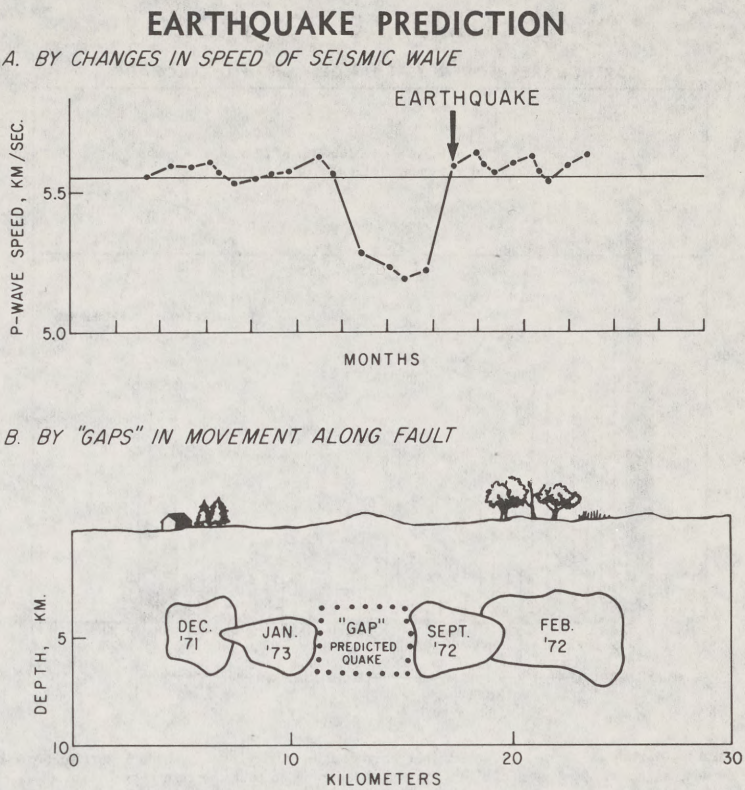


FIGURE 9.—Earthquake prediction. *A*, By changes in speed of seismic wave. Speed of *P*-wave may decrease for months before an earthquake, then rise to normal just before the earthquake. *B*, By "gaps" in movement along fault. Microearthquake mapping identified slip surfaces on the San Andreas fault 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.

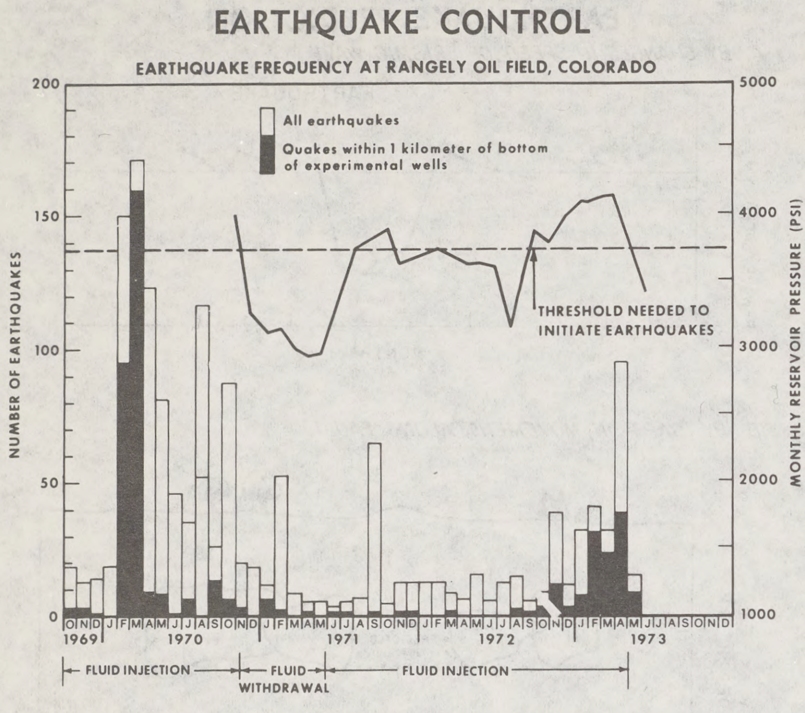


FIGURE 10.—Earthquake control. The level of earthquake activity was controlled at Rangely oilfield, Colorado, as shown in this graph, by controlled pumping so that the reservoir pressure was either above or below a critical threshold level.

### 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 expand-



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ing 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.

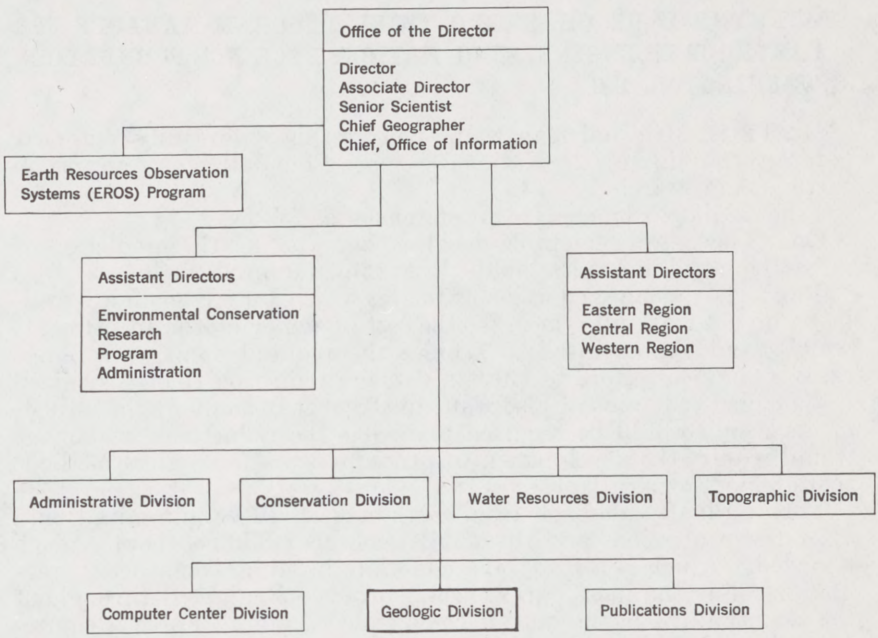
## EMERGENCY PREPAREDNESS AND RESPONSE

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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# Earthquate Research and Knowledge, Selected Excerpts from a Hearing before the Committee on Aeronautical and Space Sciences, United States Senate, April 26, 1975

## STATEMENT OF DR. CHARLES C. THIEL, PROGRAM MANAGER FOR EARTHQUAKE ENGINEERING, NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.

Dr. Thiel. Mr. Chairman, thank you for this opportunity to appear before you to discuss the National Science Foundation's programs on earthquake research.

I should like to summarize my statement as follows:

One: There is considerable debate about whether the prediction of an earthquake leads to less public loss than an unpredicted one.

Two: The damage reduction estimates which I use later in my testimony do not make allowance for the cost of achieving the adjustments which would be required to achieve the reduced damage. In some cases it may cost more to effect a damage reduction than is realized in damaged reduction. I also want to stress that many of the adjustments which would be required to realize the reductions in damage would require the development of procedures and analytical methods that are not now available.

Three: Finally, damage from earthquakes will be minimized only after the professions and the public embrace and incorporate much knowledge which is already available into building construction regulations. For the most part, seismic provisions adapted throughout the country are based on "Recommended Lateral Force Requirements", published by the Structural Engineers Association of California. The last substantial revision of the SEAOC provisions occurred in the 1950's. Thus, current codes are principally based on technology that predates the widespread use of digital computers and the extensive federally supported research conducted since that time.

The earthquake of March 27 on the Utah–Idaho border is a forceful reminder that earthquakes can and do occur outside of California. Indeed parts of 39 States are subject to major and moderate seismic risk; people in these areas account for 35 percent of the total U.S. population. The March 27 event was but one of numerous earthquakes that historically have affected the Wasatch Front. Fortunately this Richter 6.0 magnitude event struck a sparsely populated area. But the historical record indicates that we can indeed expect many more events of equal or greater magnitude in the decades to come, and it is highly doubtful that these future events will be as benign in their location. Earthquakes in urban centers will occur at some future time. Our actions between now and then will determine whether a future quake is benign or is devastating.

The seismic risk map of the United States prepared by the Coast and Geodetic Survey, now incorporated into the U.S. Geological Survey, places parts of Utah in three zones. Zone 3, areas where major damage can be expected, has a Utah population of over 950,000, according to the 1970 census, or 92 percent of the State's inhabitants. Zone 2, moderate damage, and Zone 1, minor damage, have approximately 45,000 inhabitants each. The USGS risk map does not indicate the frequency of damaging earthquakes, but indicates the risk of experiencing an event equaling or exceeding a given intensity during a long period of time. As part of an NSF funded study, John Wiggins, originator of the balanced risk concept in earthquake engineering analysis, has estimated the expected annualized loss from earthquakes for each of the States. This analysis suggests the following losses for Utah over a 30-year period:

| Year: | *Annual loss estimate (1970 dollars in millions)* |
| --- | --- |
| 1970 | $7 |
| 1980 | 10 |
| 1990 | 13 |
| 2000 | 17 |

The annualized loss estimates are based on average seismicity, census series C population growth estimates, which are conservative, of the performance characteristic of the current building inventory, building replacement statistics and similar data.

It is interesting to note that Utah's risk is comparable to several other western States. Looking at suggested annual damage as a percent of the property at risk, Utah currently can expect to lose an annual average about 0.11 percent of its property.

ANNUALIZED LOSSES AS PERCENT OF EXPOSED PROPERTY

Annualized Losses as Percent of Exposed Property

| | 1970 | 2000 |
| --- | --- | --- |
| Washington | 0.31 | 0.29 |
| California | .15 | .13 |
| Alaska | .13 | .12 |
| Utah | .11 | .10 |
| Western United States | .13 | .11 |
| Total United States | 0.039 | .032 |

Utah's risk is comparable as a percent of exposed property to that of California at 0.15 percent and Alaska at 0.13 percent. By way of a footnote it should be noted that expected losses depend upon both the frequency of events and the resistance of affected structures. Although Utah is seismically less active than California, its structures are more vulnerable. Between 1970 and 2000 the Wiggins study suggests that California's annual damage losses will decrease by 14 percent because of the State's new construction regulation, replacement of older structures and the like. In 1973 Salt Lake City adopted the Uniform Building Code with its maximum seismic provisions. Thus Salt Lake City can expect a 6½ percent damage decrease over the next three decades. Hopefully Utah will continue to take similar effective stpes to implement the lastest in seismic design provisions. Net damage expected over the period of the next 30 years to this date is around $350 million in property losses with on the order of 7,000 injuries and 170 deaths.

The impacts of earthquakes in Utah are a microcosm of the national problem. In the year 2000 the Nation could suffer a national annualized earthquake loss of $1.3 billion, about 600 lives lost and 25,000 injuries. For example, a recurrence in the year 2000 of the grade of the 1811–12 New Madrid, Mo., earthquake could cause $5.8 billion in property damage and more than 100,000 injuries. A 1906 San Francisco recurrence in the year 2000 could cost $20.8 billion in property damage, 10,000 lives and 400,000 injuries. Both of these estimates assume that we continue doing things in exactly the same way we do them today and that we make no conscientious effort to decrease our individual and national vulnerability. Clearly, earthquakes pose a serious destructive threat to the local and national communities that cannot be ignored and steps must be taken to minimize their impact.

The occurrence of an earthquake, or any other natural disaster event, is important only insofar as it affects man and his works in an unacceptable manner. It is the disaster potential of earthquakes that forces us individually and collectively to seek adjustments to our physical and social environment in order to decrease our vulnerability. The measurement of vulnerability is related to the potential or realized loss of life and injury, property damage, and/or disruption of function. While each individual or group will apply a different normative combination of these measures in its decisions, the general objective remains the same: To control the consequences of the event.

As adjustments, we may seek either to change the phenomenon or to alter the response of man and his works to the phenomenon. Possible physical adjustments the decisionmaker may seek to accomplish are: Control the event by prevention or modification; anticipate the event so that remedial actions may be taken; identify the seismic potential or apparent risk of areas; and construct facilities so as to perform acceptably during and after the event.

Among the possible social adjustments, the decisionmaker may seek to: Plan for the warning, response and recovery; distribute the economic risk; generate and select alternative physical development plans; and adopt and enforce zoning, construction and management standards.

Clearly, the physical and social adjustments depend critically on each other. It must be remembered that adjustments to earthquakes are not made in vacuo; there are other considerations in making decisions regarding vulnerability reduction that may well be dominant by comparison.

To demonstrate that we are not helpless to affect earthquake losses, I'd like to briefly detail the potential impact of several specific adjustments. The first adjustment involves a land use policy. For example, the State of California or the counties and communities affected could decide to halt population increase in those areas that would have a modified Mercalli intensity 9 or greater shaking recurring of the 1906 earthquake. Assuming that these areas have zero population increase after 1975, the impact of a recurrence of the 1906 San Francisco earthquake in the year 2000 would reduce the damage impact by 24 percent over that which naturally occurred resulting in $5 billion. By then this policy would have caused a reduction of about 7 percent in the normally expected population of these areas.

A second adjustment entails the strengthening of structures. The expected damage to a structure increases exponentially with the Modified Mercalli intensity of its site. An effective method of decreasing the damage to a building is to strengthen it so that it performs better during the event. It would be unrealistic to propose to reinforce all the structures in the United States so that they would be more earthquake resistant. It is realistic, however, to reinforce structures in highly vulnerable areas. Suppose that all the structures in the 42 highest hazard counties in the country—including Salt Lake—were reinforced so that they would perform as if the apparent MMI intensity at the site were decreased by one unit. The national savings from earthquakes would average about 25 percent per year. These 42 highest hazard counties contain about 10 percent of the national construction value [1970] and about 8.0 percent of the national population in 1970.

A third potential adjustment would be the acceleration of structural replacement. Older buildings are generally regarded as presenting the greatest seismic risk, since application of earthquake-resistant design procedures is relatively recent. Many older structures, particularly those built prior to 1933 in California, and most structures outside of the State of California, were designed without consideration for vulnerability to earthquake. These structures generally pose the most serious life and property risk of all the structures in our national inventory. Elimination of these older buildings is clearly economically and socially impractical. It may be practical, however, to adopt a replacement strategy through tax incentives or other means that decrease the useful life of older buildings in hazardous areas. A possible adjustment is to replace buildings 10 years earlier than normal in high and moderate risk areas. This adjustment, starting in 1976, yields a national annualized damage reduction estimate in the year 2000 of 7 percent.

The last adjustment I'd like to discuss is the improvement of seismic building codes. The uniform building code approaches the problem of seismic loads for different regions of the country by assigning a multiplicative factor according to the seismic zones. The factor doubles for each single zone increment. Increasing the coefficient is assumed to improve the performance of buildings during an earthquake. Generally, earthquake forces are the dominant hazard design consideration in zones 2 and 3. Suppose that the current zones 2 and 3 are replaced by zones 3 and a superzone 4, thus effectively doubling the lateral force coefficients, and suppose, further, that these requirements be applicable to all new construction starting in 1976. This adjustment yields on a national basis an annualized loss reduction in the year 2000 of 11 percent. By the year 2000, this adjustment would be required to affect approximately $500 billion in new construction, representing 12.1 percent of the national value. The cumulative savings to that time of the adjustment based on the national annualized loss model would be about $2 billion in property loss.

The impacts of these adjustments illustrate the potentials for reduction of major national earthquake damage by the implementation of policies that change the nature of the constructed environment and the responses of its institutions to earthquake hazards. The impacts of these adjustments are preliminary but indicative. Note the damage reductions do not make allowance for the cost of achieving the adjustment. In some cases it may cost more to effect structural changes than is realized in damage reduction. The scope of these adjustments is limited and representative of only a few. One of the sample adjustments is purely policy oriented in that we can now limit population growth, although the economic, legal and social consequences of doing so are not known. The other adjustments, however, require the development of procedures and analytical methods that are not now available. The development of such methods require a joint effort in the application of research, experience and intuition.

The NSF program of Research Applied to National Needs [RANN] in conjunction with the U.S. Geological Survey has a cooperative research program in earthquake mitigation to reduce the loss of life, property destruction, and economic and social disruption resulting from earthquakes and associated phenomena through the development of—(*a*) Economically feasible design and construction methods for building earthquake resistant structures of all types, and for the identification and repair of existing hazardous structures; (*b*) The technical ability for predicting damaging earthquakes and their physical efforts in the seismically active regions of the United States; (*c*) Procedures for integrating data and information about seismic risk with on-going land use planning and regulation activities; (*d*) Procedures for identifying, evaluating and accurately characterizing seismic hazards in earthquake-prone regions; (*e*) An improved understanding of the social and economic consequences of individual and community decisions on earthquake-related issues, emphasizing risk control, pre-event planning, issuance of warnings, provision of emergency service, rescue, recovery and redevelopment; and (*f*) Methods and procedures for the control or alteration of seismic phenomena and their effects on existing structures.

The National Science Foundation's support of earthquake related research is centered in two programs. The geophysics program in the research directorate has supported over the past two decades the Nation's principal academic activity in seismology, geophysics and geology as they relate to earthquakes. Characteristic of this support of basic research is the long-term support to Professors Cook, Smith, and Ward at the University of Utah. As we heard at this hearing, their most recent award has been for research on "The Regional Seismicity and Tectonics of the Southern Intermountain Seismic Belt with Emphasis on the Wasatch Front." Among other things, their work has involved the placement of seismometers that were instrumental in identifying and locating the recent Utah-Idaho earthquake's characteristics. They and their coworkers have been actively supported by the geophysics program in a variety of scientific areas related to the seismic nature of the Utah Basin, including the interpretation of regional magnetic anomalies, preparation of gravity maps, and geophysical investigations of intermountain lakes. By its very nature the broad range of basic research supported by the geophysics program directly bears on the ability of mission agencies and programs to perform their focused earthquake studies. Basic knowledge, after all, forms both the foundation for advancement and sets limits on that which can be accomplished.

The second major program supporting earthquake research is the RANN earthquake engineering program. (See p. 122.) This is a part of advanced environmental risk management. The program involves a problem-focused research directed at the development of methods that allow decisionmakers to control the consequences of earthquakes. This involves pursuit of research spanning almost every aspect of earthquake mitigation, with the exception of the physical aspects of earthquake prediction, control, and hazard identification. The program entails seven focused-research areas: (1) Ground motion and data services; (2) soils response and analysis; (3) structural response and analysis; (4) systems response, with emphasis on life lines; (5) Tsunami Generation propagation and run-up; (6) technology transfers, a unique program in environment; and (7) social and behavioral studies.

Rather than delve into the specifics of these areas, I'd like to focus on several projects we are pursuing that bear on the ability of Utah to reduce its earthquake vulnerability.

The determination of appropriate structural design and land-use procedures depend in large part on the characterization of the shaking environmnet that can be expected. The RANN program provides the major financial support and programmatic objectives and direction for the National Strong Motion Recording Network. This consists of a nationwide series of instruments that record ground motion and structural response during earthquakes. These are intended to make measurements in the damaging regime, as opposed to seismographs, which we heard of earlier, that record at levels that normally are imperceptible. Immediately after the recent quake, a series of strong motion instruments were installed in the epicentra region. (See fig. 6, p. 63.) It is characteristic of earthquakes in this region to come sometimes in series. Thus we are prepared if such an event reoccurs to obtain strong motion data important to the design professions.

There has been a great deal of public discussion on the subject of earthquake prediction. The Federal Government has invested considerable resources to develop a technical ability to predict individual events. Indeed, much of the USGS program is directed at the achievement of prediction. NSF's applied research does not pursue such studies. We are, however, deeply involved in research to understand the public consequences of the issuance of a prediction and subsequent warning. We have supported a major technology assessment of earthquake prediction with the Stanford Research Institute. We have also initiated a major study with Professor Haas of the University of Colorado to investigate the "socioeconomic and political consequences of earthquake prediction." This research focuses on securing empirically based data on how organizations and citizens in earthquake hazard areas are likely to respond to an early, creditable forecast. Among the objectives of this study that I'm sure Dr. Haas has noted is the evaluation of alternative legislative and administrative actions that may be appropriate to decrease the public's vulnerability after warnings are issued. As an aside, I might point out that there is some considerable debate on whether the prediction of an earthquake leads to less public loss than an unpredicted one. In any case, we must have thorough plans based on the best information, policies, and procedures we can develop.

The public relies heavily on building codes to foster a constructed environment that protects life and limb from the hazards of fire, wind, and earthquake. Codes are generally adopted by local jurisdictions and tailored to their specific needs and aspirations. The codes are often based upon model codes and provisions published by one of several private professional organizations. For the most part, the seismic provisions adopted throughout the country are based on "Recommended Lateral Force Requirements," published by the Structural Engineers Association of California (SEAOC).

The Salt Lake City Building Code is based on the Uniform Building Code published by the International Conference of Building Officials, which in turn incorporates the SEAOC recommendations.

The traditional way in which building safety provisions and criteria are developed is through voluntary associations of professionals meeting at their own expense. The nature of this process leads to long delays between the development of knowledge and its incorporation into codes. The last substantial revision of the SEAOC provisions occurred in the 1950's. Thus, current codes are principally based on technology that predates the widespread use of digital computers, the lessons learned from the Alaskan earthquake in 1964, the San Fernando earthquake of 1971, Managua in 1972 and points in the Orient, and the extensive federally supported research conducted since that time.

The National Science Foundation, in conjunction with the National Bureau of Standards, has initiated a cooperative Federal program on building practices for disaster mitigation. The purpose of this work is to develop comprehensive nationally applicable seismic design provisions through the integration of activities and resources in Federal agencies, professional organizations, private practitioners, State and local governments, and researchers. This will involve a concentrated effort to update, expand, and substantially revise present seismic design provisions so as to incorporate the latest state of the art and research results. The effort covers all aspects of building and geotechnical practices to mitigate the effects of earthquakes. Provisions for architectural, mechanical, and electrical features of construction are included, as are consideration of seismicity, geologic and soil site effects, and soil structure interaction. This extensive program incorporates the efforts of more than 100 nationally known experts. It places particular emphasis on the needs of the potential users of the final recommendations. The final products, a set of design provisions and associated commentaries, will be completed by the summer of 1976, at which time it will be made available for incorporation into building codes. I'm sure that you can appreciate the size and complexity of this unique effort of the professions and government to collect, evaluate, and synthesize the products of two decades of research into an economically realistic set of building provisions.

These specific projects are but a sample of the types of activities the NSF is pursuing in both basic and applied earthquake engineering research.

In closing, I would like to highlight the fact that earthquakes are important phenomena only insofar as they affect man and his works in an unacceptable way. Through research in the physical, engineering, and social sciences, we are developing the means for reducing the impact of earthquakes. But damage will be minimized only after the professions and the public embrace and incorporate these means. We believe that much knowledge is now available, and we urge all concerned with building safety to encourage its application.

This concludes my formal statement. I will be happy to answer any questions you may have.

# EARTHQUAKE ENGINEERING RESEARCH SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION

by

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SECTION 1 INTRODUCTION

Numerous recent publications attest to the seriousness of the hazard presented by earthquakes to peoples and economies, both of the United States and of the world (e.g., Refs. 1-6). Thus chapter F [1] asserts, "Earthquakes, of all the natural disasters in this country, can inflict the greatest loss of life and property. Studies have concluded that a repetition of the 1906 San Francisco earthquake would cause billions of dollars of damage, with the potential loss of thousands of lives. /They/ are the most difficult disaster phenomenon to prepare for." Reference 2 reinforces these conclusions by forecasting some $21 billion in earthquake losses for the state of California alone, the period being 1970-2000, under the assumption of no "improvement of existing policies and practices."

The 1969 National Academy of Engineering report [3] has served as a useful basis for recent RANN planning. Its Introduction deserves to be quoted at length: "Earthquakes devastate cities, with heavy loss of life, several times each year. A recent example is the Khorasan, Iran, earthquake of September 1, 1968, with over 10,000 lives lost. The United States has been shaken many times by large earthquakes, for example, 1964 Alaska; 1959 Hebgen Lake, Mont.; 1949 Seattle, Wash.; 1906 San Francisco, Calif.; 1886 Charleston, S. C.; 1857 Fort Tejon, Calif.; 1811-12 New Madrid, Mo.; 1755 Cape Ann, Mass. The history of destructive shocks in the United States is very short compared to other seismic regions such as Japan, the Middle East, and India because the country has been inhabited by urban dwellers for only a short time. The growth of population and the development of cities are so recent that it is only during the past 100 years, or so, that the potential for great earthquake destruction has existed. It is evident, however, from past occurrence of earthquakes that the highly seismic regions of the country have a serious earthquake problem, and even the less seismic regions in the central and eastern parts of the country have an earthquake problem which, although less urgent, should not be ignored."

"Public welfare, in many parts of the country, depends on facing the following questions: What intensity of ground shaking may occur? How will existing buildings respond to the ground shaking? How should new buildings and other works of man be constructed so as to minimize earthquake hazards?"

To illustrate the nation's life risk to earthquakes (and infer its property risk) the following table lists the population at varying risk:

| Seismic Risk | | U. S. Total | California |
|---|---|---|---|
| Zone 0 | (Low | 16.7 M (8%) | 0 |
| 1 | | 115.1 M (57%) | 0 |
| 2 | | 40.5 M (20%) | 2.6 M |
| 3 | (High) | 30.9 M (15%) | 17.3 M |

Zone 0 corresponds to no earthquake damage expected; Zone 1 - minor damage expected; Zone 2 - moderate damage expected; Zone 3 - major damage expected. Thus 35% of the U. S. population (71.4 M) are in risk zones 2 and 3, of which 28% are in California. The extent of development in different regions of the country has led to the conclusion that there will be as much damage to residential type structures in the next 200 years east of the Rocky Mountains as west of the Rockies. The destructive potential posed by earthquakes is indeed a national concern.

Within the United States, Earthquake Engineering is a young field. The great San Francisco Earthquake of 1906 has generally been credited with awakening the nation to the disaster potential of the occurrence of quakes in its urban centers. The primary scientific consequence of the 1906 event was the identification and development of seismology as a research area. It was not until the Santa Barbara earthquake of 1925, however, that serious attention became focused on research into seismic design. Prior to this event, the prevailing attitude was that if adequate information were made available to the designer about the phenomenon, he could cope with it directly. The 1933 Long Beach earthquake established earthquake engineering as a legitimate academic and professional research pursuit and forced the inclusion of earthquake considerations in the building codes of California, and eventually elsewhere.

From NSF's beginning in 1950 to the Great Prince William Sound Alaskan Earthquake of 1964, the Foundation's commitment to the support of earthquake engineering research was limited to a few awards. The Alaskan quake caused extensive damage to modern structures. It caused the NSF to assess its commitment to fund research in the field of engineering. The Engineering Mechanics Program, following this assessment, identified Earthquake Engineering Research as a focused activity within its general disciplinary support of Civil and Mechanical Engineering Research.

One of the new program's first steps was to have a comprehensive report on the state of knowledge and research needs prepared, [3]. A national conference was held to exchange ongoing research information and establish priorities. The Universities Council on Earthquake Engineering Research (UCEER) was formed as a consequence of the latter activity. It acts as a forum for the exchange of ideas in the university community and as a focus for coordination of research.

The first focused program expenditures were in FY 1966. For the next four years, the Mechanics Program maintained an award level of approximately one million dollars annually (see Figure 1). During this period, a major emphasis was placed on developing a research community capable of achieving substantial forward strides in the 1970s. Awards were made to a number of institutions and principal investigators.

The San Fernando Earthquake of February 9, 1971, furnished a major impetus in committing the NSF to vigorous support of Earthquake Engineering Research. About this time, the Foundation initiated its Research Applications Directorate (RANN Program) and included the Earthquake Engineering Program as part of its activities. From its inception to the creation of RANN, Dr. M. P. Gaus was in charge of the Earthquake Engineering Program. Subsequently the program has been under the direction of Dr. Charles C. Thiel.

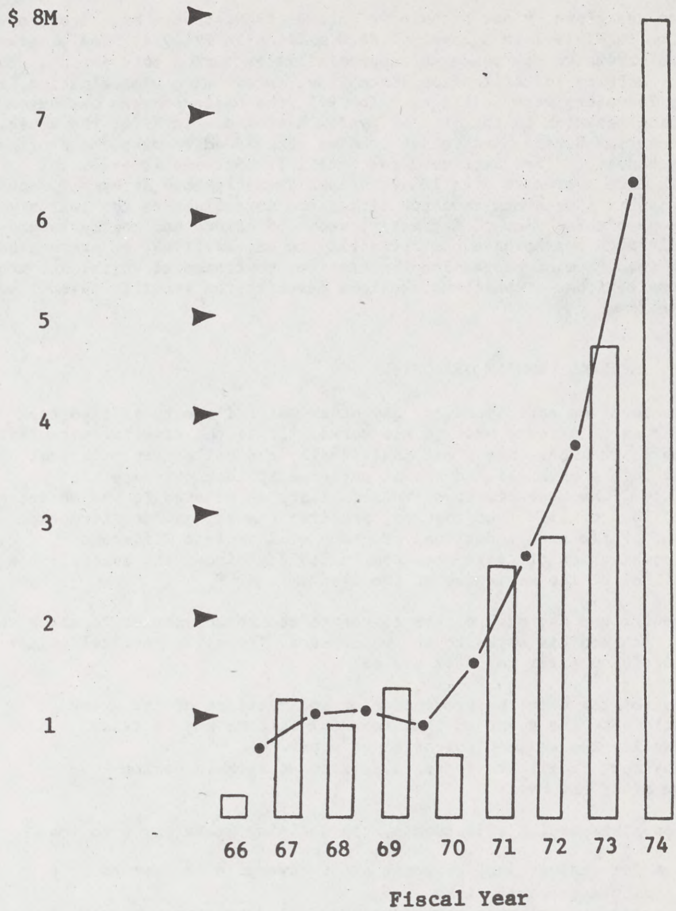


**Figure 1 - Earthquake Engineering Program Expenditures, 1966-1974 with center two year moving average**

The program has grown, since becoming a part of RANN, from a base level of $2.5 million in FY 1971 to a level of $8.0 million in FY 1974. The program has assumed extensive new research responsibilities during this period. In 1972, major efforts in utilization (Data Base, Information Dissemination, and Technology Transfer) were initiated. In 1973, the basic program was augmented by initiating research in the area of System Response. In 1974, the areas of Implementation Studies and Policy Studies were added to make the program more comprehensive. (See Section 3 for details). Between 1966-74, the program has made awards to over 100 principal investigators at over 35 institutions. Appendix A presents research titles and investigators for awards made during the past three years. Currently, about 65 grants and contracts are active. Although awards have been primarily to universities, we are beginning to use the resources of professional societies, governmental units, and profit making organizations. Subsequent sections describe the specific objectives of the NSF program.

## SECTION 2 GENERAL PROGRAM OBJECTIVES

The occurrence of an earthquake, or any other natural event, is important only insofar as it affects man and his works. It is the disaster potential of earthquakes that has caused man individually and collectively to seek adjustments to his physical and social environment that decrease his vulnerability. The measurement of vulnerability is related to the potential or realized loss of life (and injury), property damage, and/or disruption of function. While each individual or group will apply a different normative combination of these measures in its decisions, the general objective remains to control the sequences of the event.

As adjustments, one may seek either to change the phenomenon or to alter the response of man and his works to the phenomenon. Possible physical adjustments the decision maker may seek are to:

- Control the event by prevention or modification of the event.
- Anticipate the event so that remedial actions may be taken.
- Identify the seismic potential of areas.
- Construct facilities so as to perform acceptably during and after the event.

Among the possible social adjustments, the decision maker may seek to:

- Plan for the warning, response and recovery to the event.
- Distribute economic risk.
- Generate and select alternative physical development plans.
- Adopt and enforce zoning, construction and management standards.

Clearly the physical and social adjustments depend critically on each other. It must be remembered that adjustments to earthquakes are not made *in vacuo*; there are other considerations in making decisions regarding vulnerability reduction.

Noting the responsibilities of other Federal agencies to develop techniques for earthquake prediction and control (USGS) and noting the types of adjustments given above, four general objectives have been identified to fulfill the overall program objective. The latter is stated first.

**RANN EARTHQUAKE PROGRAM OBJECTIVE**

**To develop methods that allow decision makers to control the consequences of earthquake occurrences.**

**In furtherance thereof, the RANN Program supports research projects leading to:**

| | | |
|---|---|---|
| **A.** | **Design** | **Development of economically feasible design and construction methods for building earthquake resistant structures of all types.** |
| **B.** | **Land Use** | **Development of procedures for integrating information on seismic risk with on-going land use planning processes.** |
| **C.** | **Social** | **Development of an improved understanding of social and economic consequences of individual and community decisions on earthquake related issues.** |
| **D.** | **Implementation** | **Presentation of program results in forms usable by the affected interest communities to control their vulnerability to earthquakes.** |

SECTION 3 SPECIFIC OBJECTIVES AND PROGRAM ELEMENTS

In order systematically to structure a program overaa period of years aimed at achieving the four general objectives, nine program elements have been identified. With each of these elements are associated several specific objectives, which serve as guidelines for developing that element. In the context of the present report, however, particular project descriptions are inappropriate; rather, the program elements serve as categories into which specific research activities can be divided.

It should be noted that this method of structuring earthquake engineering and related fields owes a debt to the NAE Committee report [3]. The detailed program breakdown and recommendations prepared by NAE have proved very useful in structuring what follows here.

The nine elements have been framed so as to deal with specific problems in the design, analysis and synthesis of engineering and scientific knowledge to contol the consequences of earthquake, measured by life loss, property loss, and/or function loss.

I. Ground Motion/Data Services

Destructive ground motions resulting from earthquake action are of several different types, including heavy ground shaking, slow or rapid fault slip, subsidence and land slides. Fundamental to an understanding of any of these damaging phenomena, however, is an accurate knowledge of the actual earthquake ground motion. Fundamental to the validation of structural design and analysis procedures is the actual structural response generated by the ground motion.

The measurement of destructive ground moticns in the epicentral region of large earthquakes and the associated response of structures is achieved by placing a network of instruments at a variety of sites where earthquakes are likely to occur. These instruments include both passive and active recording devices. The strong motion accelerograph records the time history of acceleration in three component directions. It begins recording after an acceleration threshold has been exceeded. These instruments are the most generally used and find applications in most types of data gathering. Other active recording systems include pore pressure gauges to measure the liquid pressure in saturated soils, earth pressure gauges to measure the inertial effects of soils usually on a foundation wall, strain gauges and displacement meters. Among the passive instruments are the seismoscope, a conic pendulum that records motion on a smoked glass, scratch strain gauges and extensometers.

The measurements obtained are directed at achieving three principal objectives:

A. To support the research program by measuring pertinent quantities to validate, calibrate and/or formulate theories of earthquake response.

B. To support the designer's need for earthquake motion information at varying geological and seismological sites.

C. To obtain a comprehensive data base to perform microregionalization of earthquake risk areas based on events in the area.

These objectives are both research and operational program related. During FY 1973, NSF assumed responsibility for the Seismological Field Survey. SFS is the principal focus for strong motion instrument networks. Using SFS as its principal agent, the RANN Program will: develop criteria for placing an optimal strong motion recording network; begin the placement of this network by new installations and adjustments to the existing network; develop and place specialized instrument networks to answer specific research needs, e.g., down hole soil response arrays, detailed structure response; develop a qualified products list of existent instrumentation, define characteristics for new instrumentation, and ensure steady improvement of instrument quality, sensitivity and reliability.

## II. Soils Response and Analysis

One of the greatest potential sources of property loss is damage to structures that rest on soils or on foundations which, although adequate to support the structures under ordinary circumstances, might fail during an earthquake. A great potential for life loss resides in the possibility of a dam failure. The following areas represent forms of soil failure under consideration by the program: settlement of cohesionless soils; bearing capacity failure; embankment failure; soil liquefaction; and waterfront bulkhead failures, etc.

The dynamic behavior of a structure during an earthquake depends on the shaking transmitted to it by the surrounding soil. These motions are imparted to the structure through the interaction between its foundation and the supporting soil and/or bedrock and include amplification effects.

The objectives of this element are to:

A. Develop methods to evaluate and control soil failure potentials.

B. Develop analysis and design methods to evaluate and control soil amplification.

C. Develop design and analysis methods to characterize the loadings transmitted to structures through soil-foundation interaction.

III. Structural Response and Analysis

The realization of a structure rests on two complementary activities: analysis, and synthesis and design. Analysis forms the basis for design. The ability to analyze a hypothetical structure and determine the stresses and displacements that would be produced by a specified loading is an essential part of the design process. The more accurately this can be done, the more efficient and economical can be the design and the more reliable the design factor of safety. The analysis of a structure can be exceedingly difficult, first, since ordinary structures are exceedingly complex dynamic systems; second, because the ground motions which the structure will be subjected to during its lifetime are probabilistic; and third, because the construction process leads to a structure which is not precisely known. The analysis of structural response requires knowledge of the full system, including foundations, adjacent soils and in some cases the properties of adjacent structures.

The objectives for this program element are to:

A. Determine appropriate models for element (e.g., beam, column, plate, etc.) response to strong motion excitation from analytic and experimental studies.

B. Develop digital computer methods of analysis that predict earthquake response of structural systems comparable in complexity to real structures.

C. Validate and calibrate these models by comparison with earthquake measured motions and damage of structural system and elements.

The basic problem of earthquake design is to synthesize the structural configuration; the size, shape, and materials of the structural elements; and the methods of fabrication, so that the structure will safely and economically withstand the action of earthquake ground motions. The object of design is to control the effects of an earthquake on a structure and keep damage within acceptable bounds. A further series of objectives has been determined for this element:

D. Determine the dynamic properties of structures, elements and materials under conditions of large strains, beyond the yield point and up to failure.

E. Develop reliable, practical and simplified methods of earthquake design for widely used and special important structures: e.g., low rise residential, low rise commercial, school houses, high rise buildings, dams, bridges and industrial structures.

F. Thoroughly study structures that failed during an earthquake, as well as those that did not fail, to refine design principles.

G. Develop design and analysis methods for nonstructural elements and mechanical components of structures.

IV. Systems Response

Previous elements of the research program have dealt almost exclusively with localized structures, that is, a single building, dam, etc. The operation of the community during the emergency and recovery periods is dependent on the functioning of utility and public service facilities that function as a system with elements located at many sites in the affected area. The failure of an element can cause the total system to malfunction or be inoperative. Thus the design of system elements must consider the seismic characteristic requirements of the extended system. Both physically connected and non-connected systems are to be investigated. An example of a connected system is fire water distribution (storage, pumping stations, water mains, etc.) while a non-connected system is represented by emergency health care facilities (hospitals, clinics, laboratories, etc.).

The objectives of the element are to:

A. Develop principles of planning and laying out facilities for minimum disruption of operations due to earthquake ground displacements.

B. Develop design procedures for special structures and equipment of each type of utility and public service facility. Among these, ranked in approximate priority order, are:*

---

*Note that nuclear power plants and related facilities, which would otherwise head such a list, are a responsibility of the Atomic Energy Commission.

1. Fire fighting and emergency transportation

2. Emergency power and communications.

3. Hospitals and emergency agencies

4. General communications

5. Water services and sewage disposal

6. Electrical power and natural gas or fuel supplies

7. General transportation facilities.

C. Evaluate existing methods of land-use control, such as microzonation, that will allow a community to control its earthquake vulnerability.

V. <u>Coastal and Inland Waterways</u>:

An earthquake at sea may generate a tsunami, or tidal wave, that presents a real danger to coastal and island regions of the U. S. The risk posed by tsunamis may best be controlled by land use regulation in vulnerable areas. Verification of the occurrence of a tsunami permits the evacuation of potential affected areas.

If a dam fails, an inundation wave may be generated when the reservoir empties. This wave can cause serious downstream damage. Structuring downstream land use, with this potentiality in mind, can reduce life and property loss. When a reservoir behind a dam is filled, a series of earthquakes often occurs in the vicinity of the impoundment. The incremental risk these quakes cause above the natural risk is at present uncertain.

The objectives of this element are to:

A. Develop methods to verify that an ocean-based earthquake has generated a tsunami.

B. Develop methods to anticipate tsunami run-up in coastal regions.

C. Develop methods to anticipate downstream inundation levels.

D. Determine the incremental seismic risk associated with filling a reservoir and the degree that this risk should be part of the design criteria for the dam.

VI. Technology Transfer:

Within the Earthquake Engineering Program, utilization activities have been centralized and formulated as a specific program thrust, to be conducted by a core series of awards rather than distributed as a component in each individual award.

The objectives in this element are to:

A. Maintain a technical reference collection of published reports and papers and unpublished data available to researchers and professionals; to provide for information dissemination.

B. Maintain a software center to archive, document, validate and distribute computer programs developed for earthquake engineering applications.

C. Consolidate the best knowledge regarding design and analytic methods from current and completed research and professional experience in codes, criteria and standards for use by professionals and regulatory bodies.

D. Conduct regular conferences and workshops to act as foci for dialogues between the research and professional communities.

E. Conduct post earthquake inspections to obtain engineering data and to identify unfulfilled research needs.

VII. Other:

This category includes conference travel, general conference support, advisory committee meetings, program planning and other activities that do not fit conveniently under one of the above classifications.

VIII. Implementation Studies:

Advances in civil engineering methods are implemented through two types of actions: individual professional application; and adoption by regulatory/enforcement agency. The latter process is primarily political, while the former is educational. The structuring of the flow of technological developments from research to implementation is a particularly arduous one, involving a vast complex of institutions, special interest groups and secondary agendas. The way in which this process works is not well understood. An understanding of the process is a first step in structuring a methodology to foreshorten the period from research to practice.

The objectives of this program element are to:

A. Develop an understanding of the implementation process.

B. Develop a methodology to program the education of professionals, using suitable aids, to the best earthquake engineering practice.

C. Develop a strategy of program results to be processed through the community into regulatory and enforcement agency regulations in a timely fashion.

D. Advocate the accomplishment by public and private groups of the developed plan.

The accomplishment of these goals will have far reaching implications on several RANN programs. Indeed, the incorporation of earthquake engineering research results is but a small part of the problem of moving technical innovations into building practices. The same basic methodology is applicable to fire safety, energy conservation, building utilities and novel energy systems such as solar heating and cooling. The program element is beyond the single interests of the Earthquake Engineering Program and, as such, will be considered within the context of the building sciences.

IX. Social and Behavioral Studies

The mitigation of earthquake effects may depend on a variety of actions not directly associated with the assurance of safe structures. The possibilities of earthquake control (or modification) and prediction present different technical methods that may lead to mitigation. Community actions during and following the event may significantly affect the consequences of the quake. Condemnation and redevelopment attitudes, insurance programs and economic assistance may markedly affect the communities' vulnerability to future events. With a view to filling important gaps in our understanding of earthquakes as they impact man and his social environment, research in the social and behavioral sciences, and in economics, will be undertaken to:

A. Develop policy alternatives for the community to provide emergency, rescue, recovery and redevelopment services.

B. Develop policy alternatives for the dissemination of earthquake warnings.

C. Assess the consequences of technical developments and policy alternatives on the achievement of disaster mitigation.

## SECTION 4 SPECIFIC RESEARCH PROGRAMS

The National Science Foundation has supported a wide spectrum of research on earthquake hazard reduction. Rather than detail the specific character of these projects, Appendix A presents the titles, performer and institution for each project initiated in the past three years.

Two recent projects warrent specific highlighting.

These have as their objective the development of improved earthquake design criteria, standards and codes. The first of these projects is a test of the practical design feasibility of new code procedures and assumptions, plus an evaluation of the economic consequences of such a "new code."

The project has four chief objectives:

- draft a set of design rules based on a "design spectrum" type of code;
- apply these rules to the redesign of several types of existing buildings in order to evaluate their applicability by example;
- make a preliminary assessment, as part of a literature survey, of methods by which such a code could include consideration of variations in regional seismicity, proximity of known active faults, and soil amplification and topographic effects of local site conditions; and,
- make a preliminary evaluation of the economic and performance effects of such proposed changes on the example buildings.

The work statement of this project divides the accomplishment of the above objectives into two separate phases. Phase 1 covers the establishment of the design rules and the effect-evaluation procedures. The application of the rules, the literature survey and the actual evaluation of economic and performance effects will be achieved in Phase II. Fortunately, some of the existing buildings to be studied have been subjected to special studies as a result of the 1971 San Fernando earthquake. These special studies will prove useful in the Phase II evaluation of the Phase I design rules.

In this study, the lateral force resistance systems of 11 existing buildings (see Table 1) of varying structural types and heights are to be redesigned for the effects of a dual-earthquake criterion: Specifically, a damaged threshold spectrum, and a collapse threshold spectrum. Current applicable portions of the 1973 Uniform Building Code and the SEAOC Code are to be employed, with the exception that earthquake loading and related deformations are to be computed by the use of the dual spectra. Damping and ductility values have been assigned which are considered to be within certain assumed capabilities of each type of structure being studied. Each of the 11 buildings contains a valid lateral force resisting system within the K-factor categories of the current SEAOC Code. Each is reasonably regular in plan and elevation, therefore the problems of torsional racking, setback response, and soft-story effects will not be significant in the analyses of these particular buildings. (These problems are recognized as important, however).

| | | |
|---|---|---|
| Table | 1 | Building to be redesigned in the Seismic Code Evaluation Study |
| Bldg. | 1 | 5 Stories plus pasement<br>ductile reinforced concrete frame |
| Bldg. | 2 | 19 stories plus 4 levels basement parking<br>steel frame, moment resistant in one direction, braced in the other direction |
| Bldg. | 3 | 10 stories<br>semi-ductile reinforced concrete frame in one direction, shear wall in the other direction |
| Bldg. | 4 | 14 stories<br>shear walls on both major axes of building |
| Bldg. | 5 | 6 stories<br>shear walls are non-load bearing |
| Bldg. | 6 | 2 stories<br>steel frame with vertical bracing system |
| Bldg. | 7 | 2 stories<br>concrete block masonry, bearing and shear walls |
| Bldg. | 8 | 9 stories<br>reinforced concrete, shear wall |
| Bldg. | 9 | 1 story<br>tilt-up, plywood diaphragm, re-entrant corner |
| Bldg. | 10 | 2-story school<br>moment resistant steel frame |
| Bldg. | 11 | 1-story school<br>brick masonry, plywood diaphragm |

The project is nearing completion.

The second project builds upon the first. It is just beginning and will not be completed until late 1975. The objective, simply stated, is to develop a new set of provisions for the SEAOC Lateral Force Requirements. The current criteria are based on the technology of the 1950's with minor updating in subsequent revisions. This study entails carrying out a comprehensive program of updating and revising the present SEAOC seismic requirements so that it will be applicable throughout the United States based upon the latest state-of-the-art of earthquake engineering and construction practices. The format of the seismic provisions will be augmented to include provisions for other natural meteorologically caused phenomena such as hurricanes, tornadoes, and wind storms. The format will follow existing building codes so that it can be codified, adopted and promulgated by various groups writing and implementing code provisions. The new seismic provisions will be comprehensive and written with a national perspective. Provisions concerning the code will include all aspects of building and applicable geotechnical practices for mitigation of losses from earthquakes and earthquake related geologic hazards. The specifications will be based on goals and objectives developed from a performance criteria to be clearly set forth in the provisions so that appropriate regulatory bodies can recognize the level of risk associated with the various code provisions. It will be a balanced statement with proper consideration of low rise (1 to 3 stories), intermediate rise (4 to 6 stories) and high rise (over 6 stories) as well as other nonbuilding type structures. Provisions for nonengineered buildings and engineered buildings will be included. Recognition will be given for different construction practices and different use of materials throughout the United States. The provisions will be stated in simple terms to the fullest extent possible consistent with the goals of the code, the state-of-the-art and practice to produce these objectives, and the complexities of the earthquake phenomenon. The provisions will set forth the loading criteria and performance (resistance) criteria with recommended methods of design and analysis consistent with the seismicity of the site, the importance of the structure, the type of construction and height of the structure.

It will include where feasible, provisions for considering, within the framework of earthquake engineering, various facets such as architectural configurations, contract documents, construction team, quality control, supervision and inspection as well as structural analysis and design.

It will be comprehensive in scope and will be developed after consideration of many provisions not included or adequately covered in the present seismic codes. Evaluation of the state of the knowledge, art and practice relating to each provision will be used to make recommendations for their inclusion in the code. Among such elements are the following:

1. Goals for structural and non-structural damage.

2. Post earthquake factors, importance factors and other socio-economic considerations.

3. Various loading and analysis methodologies and when they should be used: equivalent static force approach, elastic single degree of freedom and multidegree of freedom modal superposition response spectral analysis, elastic and inelastic time history response

analysis and deterministic and probabilistic rock and ground motions.

4. Seismicity, probability consideration of various design earthquakes, seismic risk and seismic zone concepts.

5. Design earthquake criteria based on dual performance for the moderate design earthquake and the severe design earthquake based on maximum credible earthquake.

6. Geologic, topographic, soil and other site condition influences on ground motion.

7. Basic realistic levels of ground motion to represent the design earthquake at a site of average exposure having no unusual soil conditions.

8. Influence of soil conditions on intensity of ground shaking in terms of displacement, velocity and acceleration.

9. Soil structure interaction, including influence of the structure on the ground motion and the influence of ground motion on the structural response.

10. Structural System damping, ductility and stability including P-delta effects.

11. Relative performance criteria of structural systems and materials with particular attention to briftle material behavior and elasto-plastic response.

12. Realistic deterministic ultimate design stresses, load factors, and resistance factors for all materials.

13. Specific criteria to be used for dynamic analysis and design.

14. Drift limitations consistent with realistic response to strong earthquakes.

15. Vertical acceleration criteria.

16. Shear wall frame interaction provisions.

17. Hazardous and earthquake damaged buildings and their rehabilitation and reconstruction.

18. Seismic design requirements for mechanical, electrical elevator and other building "life-safety" systems.

REFERENCES

1). Office of Emergency Preparedness, Executive Office of the President, Disaster Preparedness, 3 vols. Report to the Congress, January 1972, U. S. Govt. Printing Office, Washington, D. C., 1972.

2). Alfors, J. T., J. L. Burnett, and T. E. Gay, Jr., Urban Geology, Master Plan for California, Bulletin 198, California Division of Mines and Geology, Sacramento, 1973.

3). National Academy of Engineering Committee on Earthquake Engineering Research, Earthquake Engineering Research, published by NAS, Washington, D. C., 1969.

4). Seismology: Responsibilities and Requirements of a Growing Science, Parts I and II, National Academy of Sciences, 1969.

5). Federal Council of Science and Technology, Office of Science and Technology, Executive Office of the President, Proposal for a Ten-Year National Earthquake Hazards Program, U.S. Govt. Printing Office, Washington, D. C., 1966.

6). Office of Science and Technology, Executive Office of the President, Earthquake Prediction, a Proposal for a Ten-Year Program of Research, U. S. Govt. Printing Office, Washington, D. C., 1964.

Chairman Moss. Thank you very much, Dr. Thiel. It was a very good statement and you have given us some insight on what is being done by way of research. I noticed at the beginning you cited the projected annual loss estimates in dollars. Is that cumulative or for 10-year intervals?

Dr. THIEL. Those are for 1-year periods.

Chairman Moss. Well, in 1970 it would be $7 million and——

Dr. THIEL. That's correct.

Chairman Moss. And for the year of 19——

Dr. THIEL. For the individual years, there is an increasing exposure on a statistical basis, each successive year has population increases and we continue to accelerate the occupancy of hazardous areas.

Chairman Moss. The projections of course are quite sobering and I was wondering if they were as sizeable as they appear to be. You confirmed that for Zone 3 States, particularly Utah and California. Some States already have and use zoning requirements for construction, but if we adopted the additional suggestions which you made, you say we could expect a risk reduction. How large of a risk reduction could we find?

Dr. THIEL. Let me first say that it's not economically reasonable, justifiable, nor are we capable of reducing the losses from earthquake to zero basis. We'll continue to lose property and lives and have social disruption from earthquakes for the foreseeable centuries. We can act through a variety of methods to bring those losses down through economic means. It's not unrealistic in my view—on the basis of the losses per expected property base—to expect that in three or four decades we will reduce the damage by 50 percent. If the techniques are available.

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## STATEMENT OF DR. ROBERT M. HAMILTON, CHIEF, OFFICE OF EARTHQUAKE STUDIES, U.S. GEOLOGICAL SURVEY, NATIONAL CENTER, WASHINGTON, D.C.

Dr. HAMILTON. First of all, I would like to thank you Senator Moss, for this opportunity to appear at the hearing. In my presentation I will discuss the earthquake threat to Utah.

### EARTHQUAKE THREAT TO UTAH

The earthquake that struck near Malad City, Idaho, on March 27, 1975, occurred in a region that has been classified as Seismic Zone 3—the zone of highest seismic risk (figure 1). A similar earthquake, or even a considerably larger one, could occur near Salt Lake City, and the resulting loss of life and damage would be high. An earthquake the size of the Idaho shock in the Los Angeles area in 1971 caused damage of almost $1 billion and killed 64 people. Loss of life in the tens-of-thousands almost resulted when a dam in the area suffered severe damage and nearly collapsed. Many of the effects experienced in Los Angeles could occur here.

Eighty percent of the Utah population—750,000 people—live within 10 miles of the Wasatch Fault zone, a major geologic structure that runs along the western front of the Wasatch Mountains. Consequently, the future of the State is closely linked with the future behavior of the fault zone. Since 1850, there have been 20 other damaging earthquakes in the region, including a magnitude 6.6 shock in 1934 and a magnitude 5.7 event in 1962. Some seismologists believe that the Salt Lake City area, which has not experienced a large earthquake in recent yaers, lies in a "seismic gap" and thus can be regarded as in an especially dangerous situation. Dr. Smith discussed this point earlier today. Major, destructive earthquakes therefore are expectable and must be planned for within the Wasatch Front urban corridor.

Communities along the Wasatch Front are exceptionally vulnerable to earthquake damage. Potentially active faults lace through urban areas and pose hazards to water, energy, and transportation lifelines. The thick, soft sediments of the valleys where most Utah cities are built can be expected to amplify earthquake motions to hazardously high levels. The ground in some areas may liquefy and fail under earthquake shaking.

Can anything be done to mitigate these potentially destructive effects? The answer to that question is emphatically yes, and during my presentation today I will briefly describe part of the USGS earthquake hazards reduction program that is currently underway, with emphasis on the activities in the Salt Lake City region.

## ORGANIZATION AND FUNDING OF RESEARCH TO REDUCE EARTHQUAKE HAZARDS

In the United States, research to mitigate the effects of earthquakes is largely funded by the Federal Government and is managed at the Federal level. The agencies responsible for the program are the National Science Foundation, which funds studies in earthquake engineering, and the U.S. Geological Survey, which conducts and funds studies on the other topics including mapping of earthquake hazards, evaluation of seismic risk and prediction of earthquakes. In addition, the USGS operates a nationwide network of instruments to record strong ground shaking from earthquakes for NSF.

Justifications for the Federal involvement are that the earthquake threat is nationwide with 39 States exposed to earthquakes and with the national economy vulnerable to a major earthquake disaster, research results from one part of the country are applicable nationwide, and national uniformity is needed in many of the instrumentation systems. Although the Federal Government has the primary responsibility for earthquake research, much of the expertise to carry out the work resides in universities, State geological surveys, and private industry. Federal funds are disbursed to these groups to carry out studies in support of the Federal program.

The funds available to the USGS for the earthquake hazards reduction program in fiscal year 1975 total about $12 million. These funds are distributed about evenly in three main subject areas: (1)

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The mapping and evaluation of earthquake hazards and seismic risk, (2) prediction of earthquakes, and (3) acquisition and dissemination of information on the distribution and occurrence of earthquakes.

PRIMARY GEOGRAPHIC AREAS OF USGS EARTHQUAKE HAZARDS STUDIES

The urban areas in zones of highest seismic risk are the target for much of the effort under the earthquake hazards reduction program. Networks of instrumentation have been established or are planned and geologic studies are underway in at least part of all areas of seismic risk.

[Seismic risk map of the United States shown on the screen.]

Dr. HAMILTON. The zones of seismic risks, three, as you can see cover the western coast of California, the western part of Nevada, the western front of the Wasatch range, the Puget Sound area, the southeastern part of Missouri, Southern Illinois, Western Tennessee, the area around Charleston, S.C., and the area around Boston, Mass.

Chairman MOSS. Three is the most dangerous?

Mr. HAMILTON. That's right. Now this map is based on historical earthquake activity and one of the things that we are a little uneasy about as seismologists is that we don't really understand why the Charleston, S.C., earthquake occurred where it did, and similarly for the one in southeastern Missouri. Without such knowledge and understanding this map could be altered by the next earthquake. We are in a somewhat better position in the Western United States because we can recognize the geologic structures that give rise to the earthquake activity there.

The level of effort by the USGS in fiscal year 1975 to map and evaluate earthquake hazards in the major urban areas that lie within zone 3 in the Western United States is indicated below.

| Area: | *Funding for Earthquake hazards, mapping, and evaluation* |
|---|---|
| 1. Los Angeles | $362, 000 |
| 2. San Francisco | 300, 000 |
| 3. Seattle | 70, 000 |
| 4. Salt Lake City | 50, 000 |
| 5. Reno | 20, 000 |

The results from these studies will provide an information base for decisions on land use. In addition, mapping is underway in most of the zone 3 regions with funding at about $1 million to delineate active faults and determine the tectonic setting of major urban areas.

EARTHQUAKE STUDIES IN THE SALT LAKS CITY REGION CONDUCTED OR FUNDED BY THE USGS

The studies that are currently underway in the Salt Lake City region include:

One: Earthquake hazard study—USGS on behalf of the Federal Disaster Assistance Administration.

Two: Operation of a seismograph network for monitoring earthquake activity—University of Utah.

Three: Evaluation of the feasibility of earthquake prediction—also by University of Utah.

Four: Environmental geologic studies of the Snake River Plain and adjacent areas—USGS.

Five: Earthquake geologic hazards mapping in Salt Lake City—USGS.

Six: Determination of earthquake recurrence—by the Utah Geological and Mineralogical Survey, a USGS project subcontracted to Woodward-Lundgren, Inc.

In fiscal year 1976, the USGS plans to start new projects on the earthquake tectonics of the Wasatch zone, and to expand earthquake hazards mapping and evaluation along the Wasatch Front urban corridor.

EARTHQUAKE PREDICTION

The delineation of active faults and unstable ground permits wise land use, but many of the actions that could save lives during an earthquake depend on knowing in advance when and where the shock will occur and how large it will be. As recently as 5 years ago, earthquake prediction was widely regarded among scientists as only a remote possibility. Major advances have changed that view. It is now generally believed that earthquake prediction is feasible and that useful predictions could be made in well-instrumented areas in the next few years.

National programs to predict earthquakes have been undertaken in the Soviet Union, Japan, and the Peoples' Republic of China. Each of these foreign countries has contributed important findings to the American earthquake prediction effort. Cooperation with Japan has been underway for many years. Within the past 2 years, delegations of American scientists have exchanged visits with their colleagues from the Soviet Union and the Peoples' Republic of China.

Results on earthquake prediction in the United States are extremely encouraging. Already a small earthquake in New York State has been successfully predicted several days in advance. Last Thanksgiving Day, November 28, 1974, a magnitude 5.2 shock in central California showed premonitory signals in several types of geophysical phenomena, including variations in the magnetic field, tilting of the ground surface, and slowing of seismic waves traversing the locus of the impending earthquake. The capability to make such observations exists only in a small area of central California that has been selected on the basis of its high seismicity for development of an experimental earthquake prediction system. The recent successes require that we seriously consider deployment of instrumentation in other hazardous areas to confirm the recent findings and to upgrade prediction systems from the experimental to the prototype phase of development.

It is recognized that the capability to predict earthquakes is a mixed blessing. The opportunity to save lives and reduce injuries demands that the earthquake prediction effort proceed. But the forecast of a major shock for an urban area could cause economic stagnation, social disruption, and in some cases, panic. Studies are now underway to anticipate the social, legal, economic, and political problems associated with earthquake prediction, and to plan for the most effective utilization of the new capability.

In view of the earlier comments, I would like to insert one item. Several speakers here today, have questioned whether earthquake prediction should be developed. I think it's important to realize that unreliable prediction are already being made. In addition, progress in prediction is an unavoidable product of progress in understanding earthquakes. The real question is whether we should try to develop reliable predictions, not whether prediction should occur.

## CONCLUSION

Earthquakes pose a serious threat to the people and the economy of Utah. However, casualties and damage can be reduced substantially by the wise use of land and by appropriate building practices. Modest programs are underway to provide information that will assist in mitigating the effects of earthquakes. Although much of this information is being developed under Federal auspices, the utilization of the information in zoning land and establishing adequate building codes is the responsibility of State and local governments. I strongly urge that increased efforts be undertaken now in Utah to deal with the earthquake threat.

Chairman Moss. Thank you very much, Dr. Hamilton. On these exchanges with the Japanese, Chinese, and Soviet Union have there been noticeable contributions from all of the countries involved?

Dr. Hamilton. Yes, there have been. The observations of a slowdown in seismic waves before an earthquake that I referred to, and that Dr. Smith referred to earlier, originated in the Soviet Union. These observations have international importance. Similarly there have been important observations in Japan and China that have given us leads as to observations we should make in our own country.

Chairman Moss. And this collaboration is on a continuing basis now?

Dr. Hamilton. Yes, it is. The basis for the exchange grew out of President Nixon's visits to the Soviet Union and China. At the present time we have an agreement with Russia, under which we are exchanging about 20 man-months of expertice each year. In the case of China, an exchange of delegations was negotiated. The Chinese sent 10 scientists over here about a year ago, and then 10 American scientists returned that visit last October. As it stands now that's the end of the presently negotiated activities, although I think the scientists on both sides would like to see a continuation.

Chairman Moss. You spoke about the expanded mapping of the Wasatch Front. Are you using any of the LANDSAT imagery we were talking about in this seismic mapping?

Dr. Hamilton. The project you are referring to on the expanded mapping will begin in 1976. The initial stages of that will be compilations of known lineaments and geologic faults from existing literature and I'm sure they will make use of the satellite photographs. However, I don't really anticipate that there will be anything too unexpected that will come out because there already has been a lot of geological work done in Utah.

Chairman Moss. On these No. 3 zones of high-seismic risk, are they all instrumented now and are you monitoring all of these zones nationally?

Dr. Hamilton. The zones are not completely instrumented, not by a long shot. There are instruments in each of those areas but, for example, the only area that is instrumented in the Wasatch zone extends from the Utah-Idaho border to just south of Salt Lake City. So there are large areas in seismic risk 3 zones that are not instrumented at this time.

Chairman Moss. Is that from choice or from lack of resources?

Dr. Hamilton. Lack of resources.

Chairman Moss. You referred to the studies made by two private industry groups, one Woodward-Lundgren and the other Terra Tek. We are going to hear from Terra Tek today, but how far has the Woodward-Lundgren study advanced?

Dr. Hamilton. There have been reports from the Woodward-Lundgren study released. The State geologist mentioned earlier this morning that the Utah Geological and Mineralogical Survey has released some reports. I believe that Lloyd Cluff of Woodward-Lundgren has submitted a statement for the record, so some of the results from that work will appear in the record.

Chairman Moss. Fine, we'll have a chance to look at that. I have a newspaper clipping here, from today's Salt Lake Tribune, that said the U.S. Geological Survey has devised an earthquake prediction system that can anticipate major seismic events up to a year ahead of occurrence and minor events up to a week. Is that an accurate statement?

Dr. Hamilton. No, I suspect that something got lost in translation. More accurately, the scientists working on earthquake prediction feel that we have now established that earthquake prediction is feasible and we feel that in the areas we have instrumented that we do have a limited prediction capability. There are results from the Soviet Union, from China, from Japan and elsewhere in the United States that indicate that such leadtimes as are referred to in the article should be possible, but I don't think we could state in such strong terms that the capability exists at this particular time. But we feel that the next step is to expand the instrumentation in order to prove out the current results from overseas are directly applicable to the United States.

## STATEMENT OF DR. DAVID E. SMITH, GEODYNAMICS BRANCH OF APPLICATIONS DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, GODDARD SPACE FLIGHT CENTER

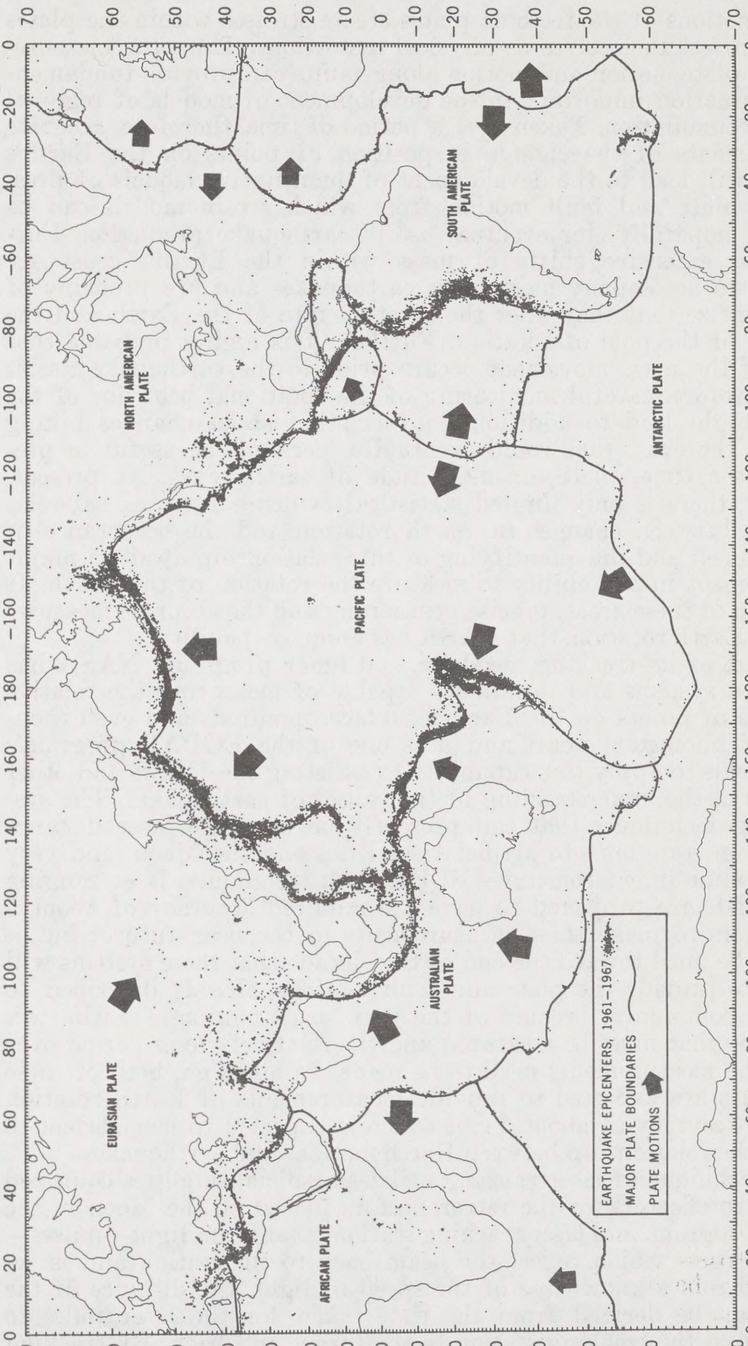
Dr. Smith. Mr. Chairman, it is a pleasure to appear before you today to discuss the work being done by the National Aeronautics and Space Administration, in cooperation with other Federal agencies, in the broad area of earth dynamics and specifically in attempting to help develop techniques for better understanding of earthquakes and perhaps eventually the ability to predict them.

The committee's interest in and support of the Nation's space program is well known and deeply appreciated. The chairman's, and the committee's, interest in the earthquake phenomenon is understandable and most appropriate. Mr. Charles Mathews, NASA's Associate Administrator for Applications, has testified in a general way before your committee on this matter; and I am pleased to be able today to go into it in more detail, as you have requested.

NASA's Office of Applications has an Earth and ocean physics applications program—EOPAP—that has as one of its objectives support to the solution of important problems in each and ocean dynamics that can be best addressed by the application of space techniques. Within the area of earth dynamics the principal objectives are the monitoring of motions of the whole Earth and its crust. This information should lead to a better understanding of the processes that produce earthquakes with the expectation that this will lead to the development of techniques for predicting the occurrences, magnitude, and location of earthquakes.

During the past several years, NASA has been working with the U.S. Geological Survey, National Oceanic and Atmospheric Administration, and a broad cross section of the scientific community to develop plans and programmatic milestones; and conducting experiments which will help accomplish these objectives. It is our belief that technology, systems, and techniques that have been developed as part of the U.S. space program can make an important contribution to our understanding the causes of earthquakes.

During the sixties, our understanding of the origin of earthquakes, volcanism, faulting, and mountain building made a major advance with the development of the theory of plate tectonics. In this theory, the Earth's outer layer, the lithosphere, is broken into six large plates and about a dozen smaller ones, all of which are moving with respect to each other at speeds of 1 to 15 cm per year. Along the plate boundaries where adjacent plates are moving toward each other, one is forced below the other to form a subduction zone and to create new mountains. Where adjacent plates are separating—spreading zone—new lava wells up from within the Earth to form new crust; this process is called sea-floor spreading. Where plates slide past one another, strike-slip fault systems are formed, and the San Andreas Fault system of the Western United States is just such a system. Furthermore, most earthquakes, and volcanic activity usually take place near the boundaries of these plates, and it is from the motion of these plates that the energy released in seismicity is derived. In fact, nearly all large-scale geophysical phenomena occurring on the Earth's surface appear to be intimately related to this global pattern of plate motions. Figure 1 shows the division of the Earth into the major tectonic plates and the distribution of earthquakes between 1961 and 1967. The correlation between seismicity and plate boundaries is clearly evident.




MAJOR TECTONIC PLATES

Figure 1

The motions of the tectonic plates create stresses within the plates that manifest themselves as physical distortions. Thus, the measurement of plate motion and motion along faults can provide fundamental information important in the development of models of regional strain accumulation. Taken over a period of time, therefore, accurate measurements of the change in position of points on the Earth's surface will lead to the development of quantitative models of present-day plate and fault motion from which strain models can be derived, hopefully, for eventual use in earthquake prediction. Furthermore, extensive shifts of mass within the Earth's crust are thought to accompany most large earthquakes and are probably of sufficient size that they alter the rotation rate of the Earth and the position of the pole of rotation. Further, it is highly probable that much of the mass movement occurs prior to the earthquake itself; and, therefore, careful monitoring of the rotational behavior of the Earth might lead to additional information about changes taking place in the crust that could eventually, perhaps, be useful in predicting the time, place, or magnitude of earthquakes. At present, however, there is only limited statistical evidence for a causal relationship between changes in Earth rotation and the occurrance of earthquakes; and the quantifying of this relationship awaits a major improvement in our ability to measure the rotation of the Earth. It is in both of these areas, precise positioning and the accurate measurement of Earth rotation, that NASA has unique capability.

As part of its tracking, geodetic, and lunar programs, NASA has developed systems and techniques capable of measuring the relative positions of points on the Earth's surface, hundreds and even thousands of kilometers apart and it is one of the EOPAP program's major goals to apply this capability to assisting the USGS and other agencies in the understanding of the causes of earthquakes. The systems and techniques that can presently be used are laser distance measuring—ranging—to artificial satellites and the Moon, and very long baseline interferometry—VLBI. Both techniques, laser ranging and VLBI, are projected to have the required accuracy of about 5 centimeters to make these measurements in the near future; but it will not be until toward the end of this decade that these systems will be able to provide the plate and fault motions, already described, to the user community because of the very small motions—centimeters per year—that must be measured and the relatively long period over which the measurements need to be made. In addition, both of these techniques are expected to provide measurements of Earth rotation with an accuracy of about 5 cm, which is expected to be sufficient to resolve the relationship between Earth motions and earthquakes.

The technique of laser ranging utilizes artificial satellites equipped with retroreflectors, or the retroreflectors placed on the Moon in the Apollo program, and laser tracking stations that beam light—pulses—to the targets which reflect the beam back to the station and is recorded. From a knowledge of the speed of light, the distance of the target can be derived from the time taken for the laser pulse to travel from the tracking station to the target and back. By tracking satellites or the Moon in this manner from different stations, precise positions of the stations relative to each other can be derived. Figure

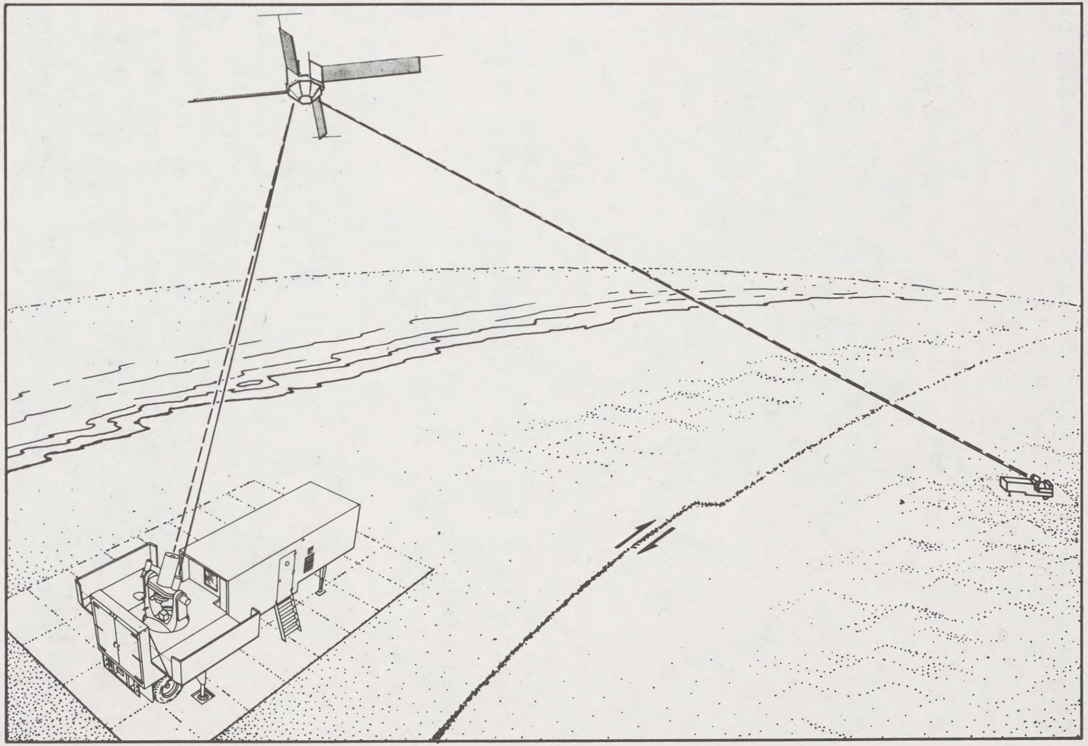


Figure 2

From laser distance measurements to an artificial earth satellite, or the moon, from two or more sites the relative distance between the laser tracking systems can be derived.

2 shows a sketch of two laser tracking systems on opposite sides of a fault tracking a satellite from which the distance between the tracking systems can be derived. Repeating these measurements on a regular basis will enable the crustal motions to be derived from changes in the positions of the stations. In order to make measurements from a number of locations, mobile laser tracking stations have been developed providing a flexibility to determine the position or motion of almost any point on the Earth's surface. Figure 3 shows a mobile laser system for tracking artificial satellites while operating from the Otay Mountain site near San Diego.

The other technique, very long baseline interferometry—VLBI—utilizes existing radio antenna stations to track quasars, very distant radio stars. By recording the signals emitted from the stars at different stations and carefully comparing the arrival time of the signals, the delay of arrival at one station compared to another, coupled with our knowledge of the speed of light, again enables us to compute the relative positions of the stations. Figure 4 shows a sketch of the VLBI technique. The main advantage of these space techniques compared to conventional ones is that the accuracy is not nearly as dependent upon the length of the baseline to be measured. Hence, we can measure regional and global scale distances of hundreds to thousands of kilometers with the acuracy required to monitor the plate motions.

At the present time, the NASA tectonic plate motion project involves three experiments designed to demonstrate the capability of these space techniques. One, the San Andreas Fault Experiment—SAFE—is employing laser tracking of satellites for the measurement of regional motions in the Western United States over distances of the order of 1000 km. The second and third experiments utilize very long baseline interferometry. The astronomical radio interferometric earth surveying—ARIES—experiment is studying local motions in the Los Angeles basin while the Pacific plate motion experiment—PPME—will apply the VLBI technique to the measurement of global distances, connecting Hawaii and Alaska with points on the eastern and western coasts of the United States. Thus, these three experiments address the global, regional, and local accumulation of strain and directly complement the work of the USGS by providing an accurate framework for their measurements of the detailed motions actually on the fault. It should also be noted that these precision measuring systems are playing a major role in other activities within NASA, including the routine tracking of spacecraft, improving upon our knowledge of the Earth's gravitational field and tides, and the calibration of the radar altimeter on the Geodynamic Experimental Ocean Satellite, GEOS–3, launched earlier this month.

Early in 1976 the Lageos satellite is scheduled for launch. Lageos will be a spherical satellite weighing 411 kg covered with 426 laser retroreflectors, and has been specially designed for very precise laser ranging. It will be launched into a 6,000 km high orbit and will enable intercontinental distance measurements and precise Earth rotation measurement to be accomplished with the satellite laser ranging technique. Figure 5 shows a picture of this satellite during construction.

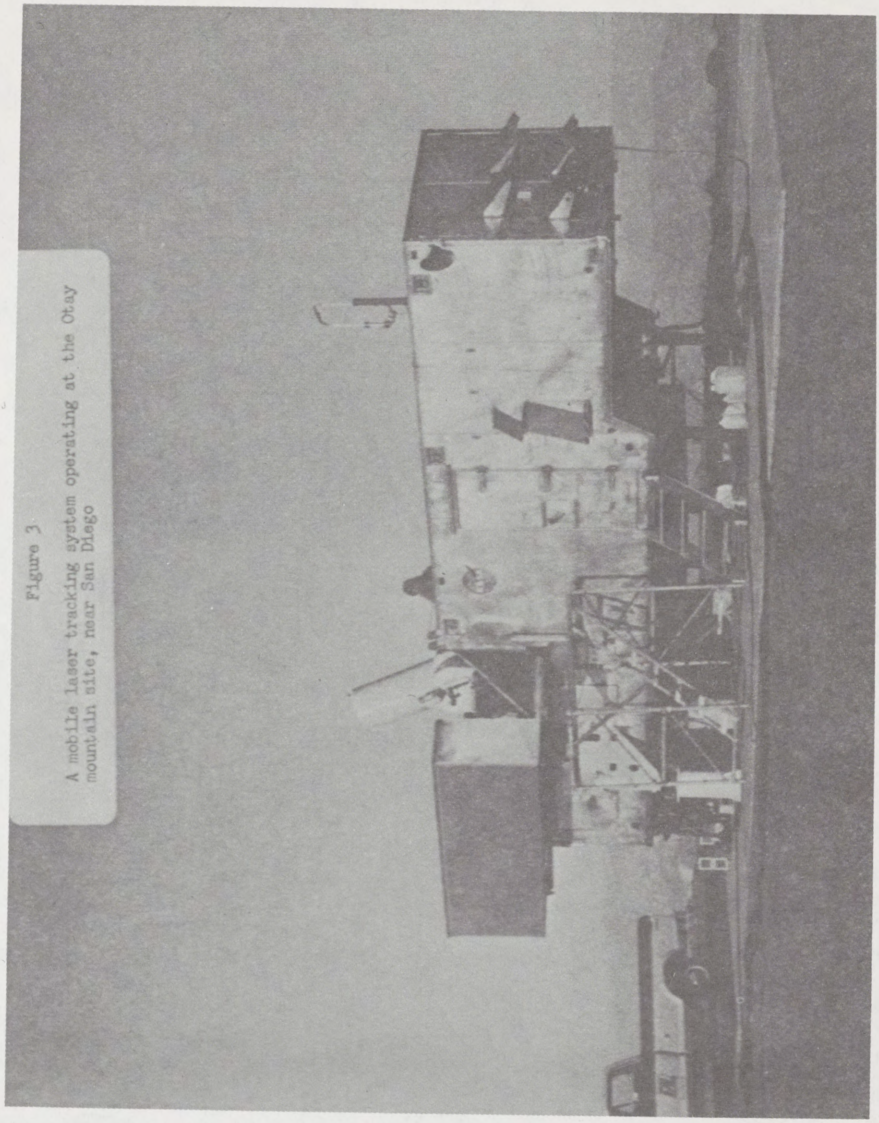
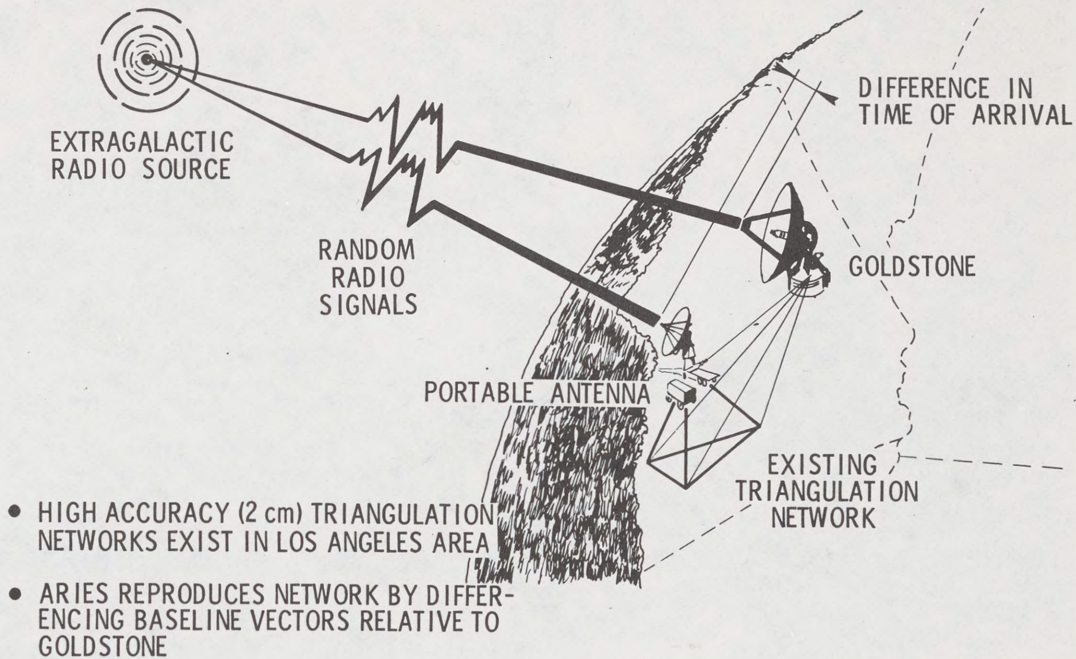


Figure 3

A mobile laser tracking system operating at the Otay mountain site, near San Diego

Figure 4

Very Long Baseline Interferometry (VLBI)



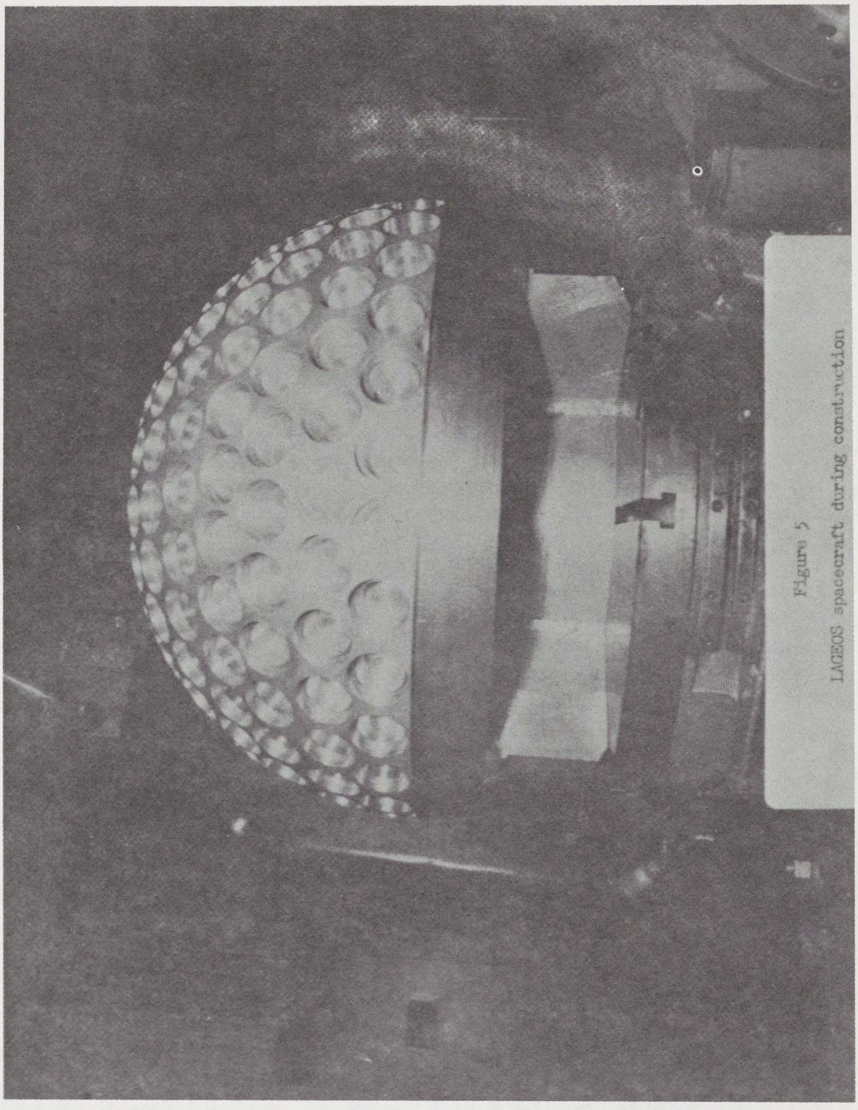


Figure 5

LAGEOS spacecraft during construction

As well as in the area of precision measurements, NASA is also providing additional information of value in the understanding of earthquakes through its imagery with the LANDSAT spacecraft. Of particular interest has been the identification of geologic faults that are sometimes not shown on geologic maps. Figure 6 is a LANDSAT image of the Monterey region of California together with geological interpretation. By careful scrutiny of the LANDSAT images, faults, lineaments, and other geological features are being identified for the first time.

### THE SAFE EXPERIMENT

The basic objective of the San Andreas Fault experiment—SAFE—is to determine the gross tectonic and fault motion of the Western United States with particular emphasis on California, by repeatedly measuring the relative location of five widely spaced points along the west coast of the United States and northern Mexico. Over a period of about 6 years, it is planned to measure the average motion to an accuracy of about 0.5 cm/year. The San Andreas Fault is the boundary between the tectonic plates of the Pacific and North America. Points to the west on the fault, such as Los Angeles and San Diego, are moving northward with respect to points on the eastern side, such as Sacramento and Fresno. This motion causes deformation of the crust on either side of the boundary and a buildup of stress which may subsequently be released as an earthquake. Figure 7 shows the locations of earthquakes in western North America between 1960 and 1972. The concentration of earthquakes along the broadband of the San Andreas Fault system and a branching to the north and northeast into Nevada and Utah are clearly evident. There is probably no more readily accessible place on Earth than this system of the Western United States for the studying and understanding of the past and present dynamic processes along a major fault zone of continuing intense seismic activity.

SAFE plans to determine the accumulation of strain along the fault by measuring the changes in distance between points on opposite sides of the fault system. Two sites for the experiment have already been established, Otay Mountain near San Diego, and Quincy in northern California, on opposite sides of the fault. During the first part of the experiment the lines connecting these sites were measured with a precision of about 15 cm and will be followed by measurements from a site near Bear Lake, Utah. Subsequently, we hope to be able to establish two sites in Mexico on opposite sides of the Gulf of California. Figure 8 shows the SAFE tracking sites and figure 9 is an image of northern Utah and southern Idaho from the LANDSAT 1 satellite in 1972. The dark area in the lower left-hand corner is the Great Salt Lake and the dark area in the upper center is Bear Lake. The laser tracking site is planned to be located approximately 1 mile west of Garden City near Route U.S. 89.

Our present knowledge of the motion along the San Andreas Fault system indicates much greater motions along the fault systems in northern Mexico than in northern California. If this is truly the case, then some of the strain that is accumulating in the more southerly regions must be taken up in regions east of the major fracture of the

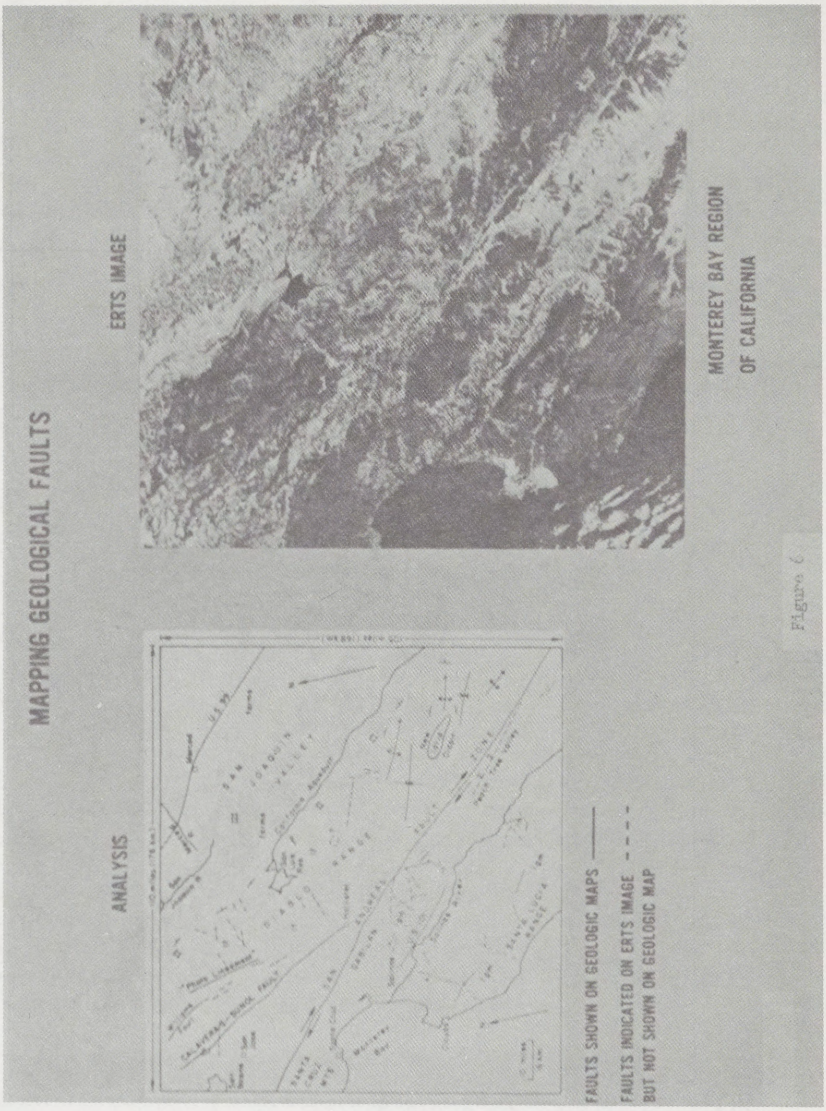

MAPPING GEOLOGICAL FAULTS
ANALYSIS
ERTS IMAGE
SAN JOAQUIN VALLEY
DIABLO RANGE
SAN ANDREAS FAULT ZONE
SANTA CRUZ MTS
SANTA LUCIA RANGE
FAULTS SHOWN ON GEOLOGIC MAPS
FAULTS INDICATED ON ERTS IMAGE BUT NOT SHOWN ON GEOLOGIC MAP
MONTEREY BAY REGION
OF CALIFORNIA

Figure 6

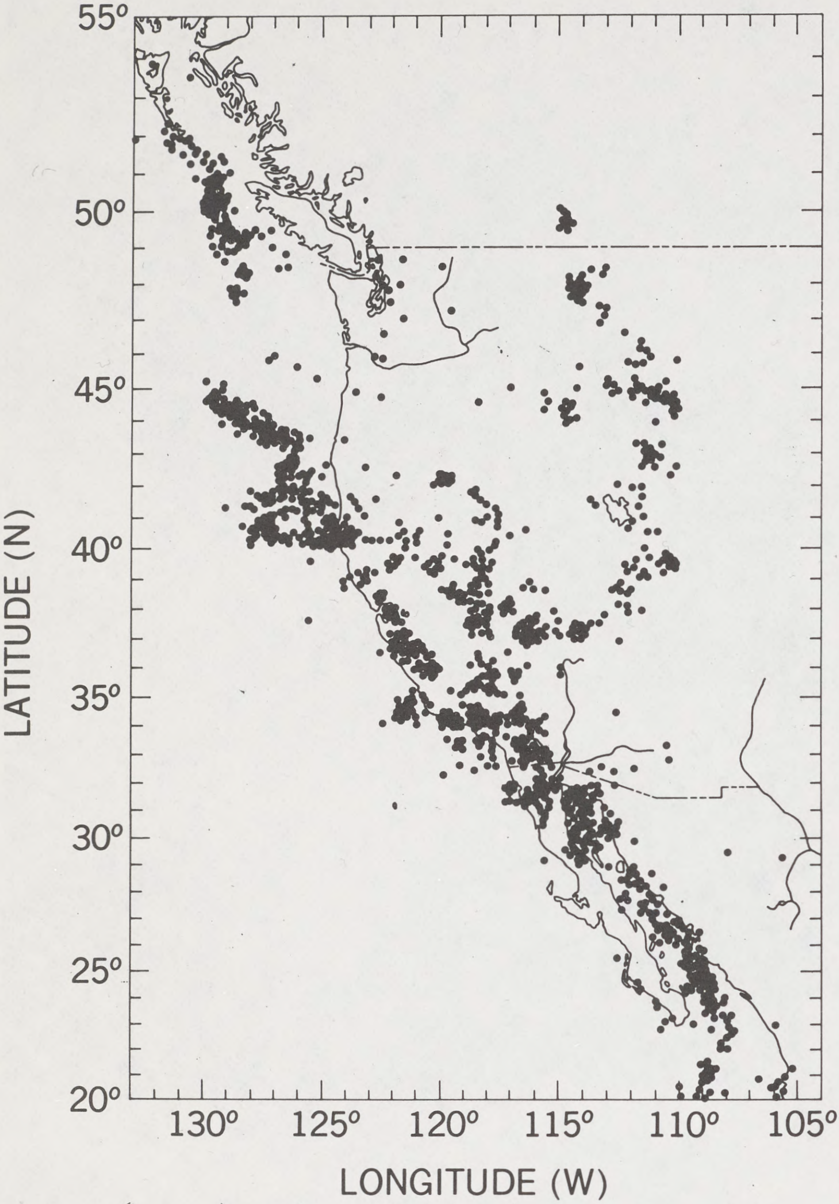



Figure 7

Earthquakes in the western United States
1960 - 1972

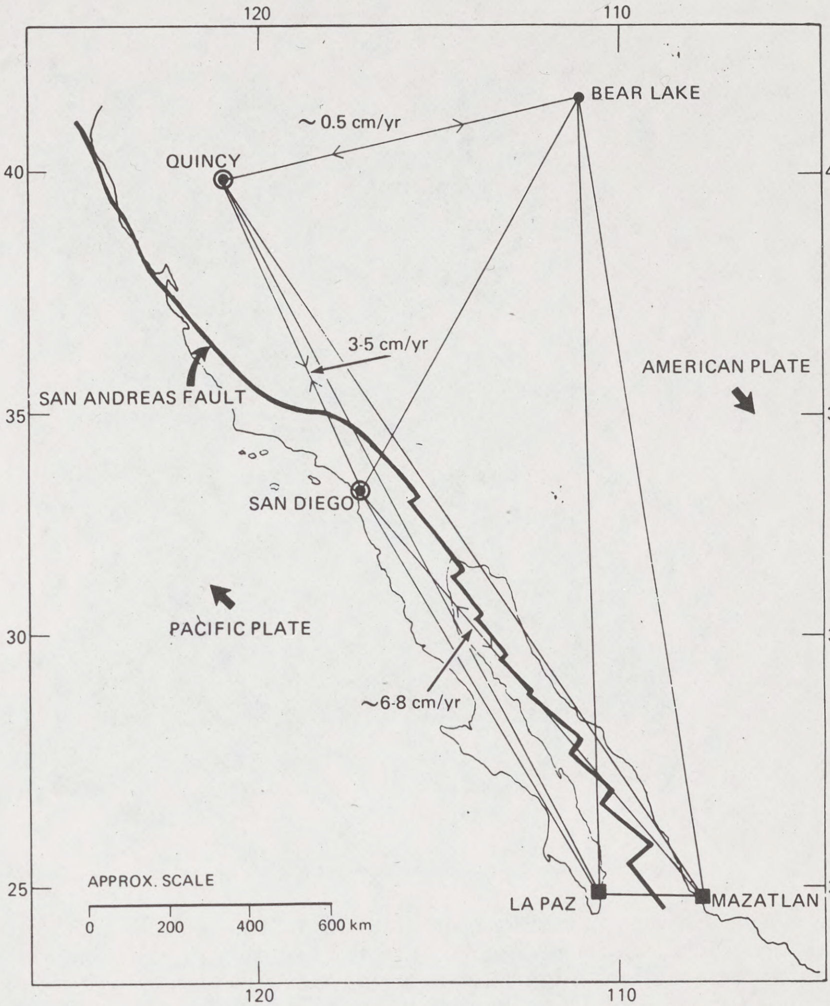



Figure 8

San Andreas Fault Experiment (SAFE) laser tracking sites

San Andreas Fault and is probably the basic cause of the earthquakes occurring in Nevada and Utah. Thus, in discussions with the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the University of California, and Columbia University, it was decided to try and establish the additional sites in Utah and Mexico. At the completion of the SAFE experiment in the early eighties, a broad picture of the motions in western North America will be available. Based on our present understanding we expect to

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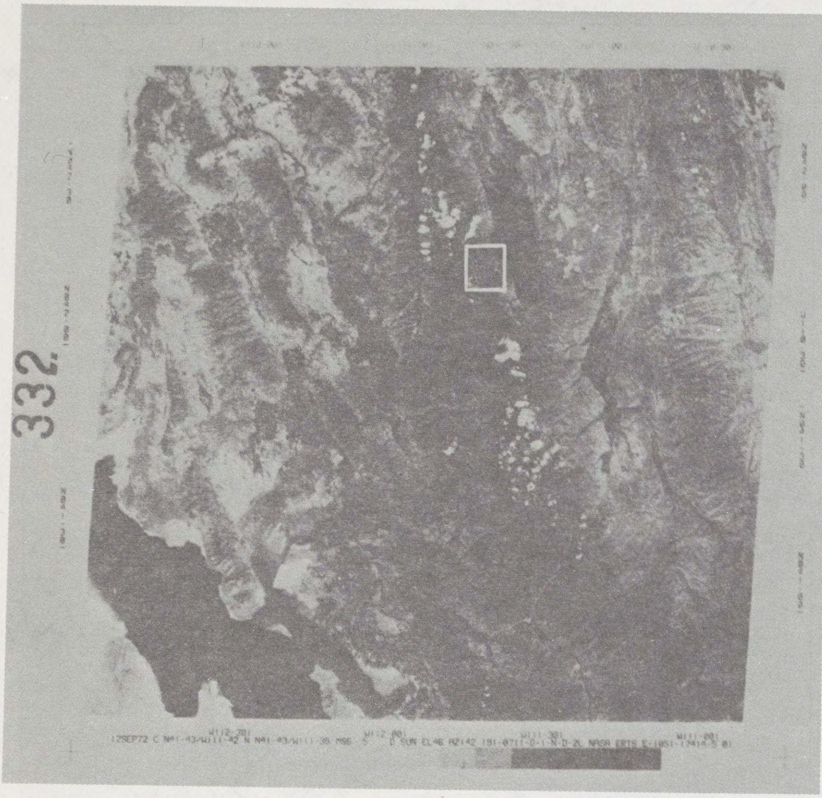


Figure 9

LANDSAT image of northern Utah and southern Idaho showing location of Bear Lake laser tracking site

see motion between points on opposite sides of the fault in northern California of the order of 3 to 5 cm/year. In southern California and Mexico these motions might be 6 to 8 cm/year. Across northern California, Nevada, and Utah, we anticipate a spreading at less than 1 centimeter per year confirming the idea that forces are present deep inside the Earth that are trying to force northern California and Utah apart.

At the present time the magnitudes of these motions are rather speculative but we anticipate SAFE will provide quantitative answers on the scale of a 1,000 km that can be used as an accurate framework within which the highly precise measurements of the USGS on a much smaller but more detailed scale can be placed.

THE PPME EXPERIMENT

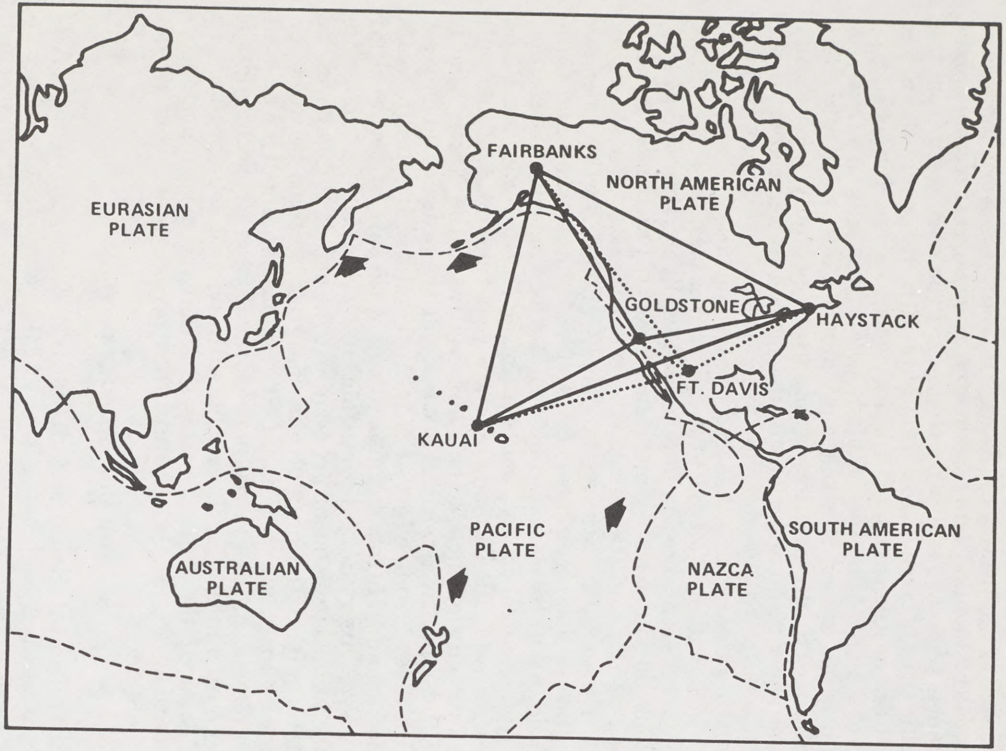
The primary objective of Pacific Plate Motion Experiment [PPME] is to measure directly the movement of the central part of the Pacific Plate relative to the North American Plate as indicated by the motion of the island of Kauai, Hawaii. The very long-term movement of the Pacific Plate is estimated from current tectonic plate motion models to be about 8 cm/year toward the northwest from the East Pacific Rise [large arrow in figure 10]. However, there has been no direct measurement of this movement except for local geodetic surveys along bounding faults, such as the San Andreas; in addition, it is not known how this motion varies over relatively short periods of time. Such variation is important not only scientifically but because short-term variations in the motion of the center of the plate with respect to its edge are an indication of strain buildup along bounding shear faults that lead to earthquakes.

The PPME will use VLBI systems to measure very accurately the distances between a station in Kauai, Hawaii, on the Pacific Plate, and stations on the North American Plate at Fairbanks, Alaska; Goldstone, Calif.; and Haystack Observatory, Mass., as shown in figure 10. Because the western boundary of the North American Plate is a broad one, intraplate movements of the Alaskan and California stations will be measured by VLBI measurements of baselines to the Haystack Observatory, well within the North American Plate. The measurements will be made over a 3-year time interval and will enable the velocity of the Pacific Plate relative to the North American Plate to be measured with an accuracy of the order of 2 cm/year.

The PPME is a group effort of NASA, the Massachusetts Institute of Technology and Haystack Observatory with part of the work of the Haystack Observatory being funded by the USGS under its earthquake hazard assessment program. At the end of this experiment in the early part of the next decade the gross motions between the east and west coasts of the United States, Alaska, and Hawaii will have been measured, thus providing information on the accumulation of strain on an almost global scale but with particular importance to the west coast of the United States. Preliminary measurements between Massachusetts and California to a precision of about 20 cm have been obtained.

### THE ARIES EXPERIMENT

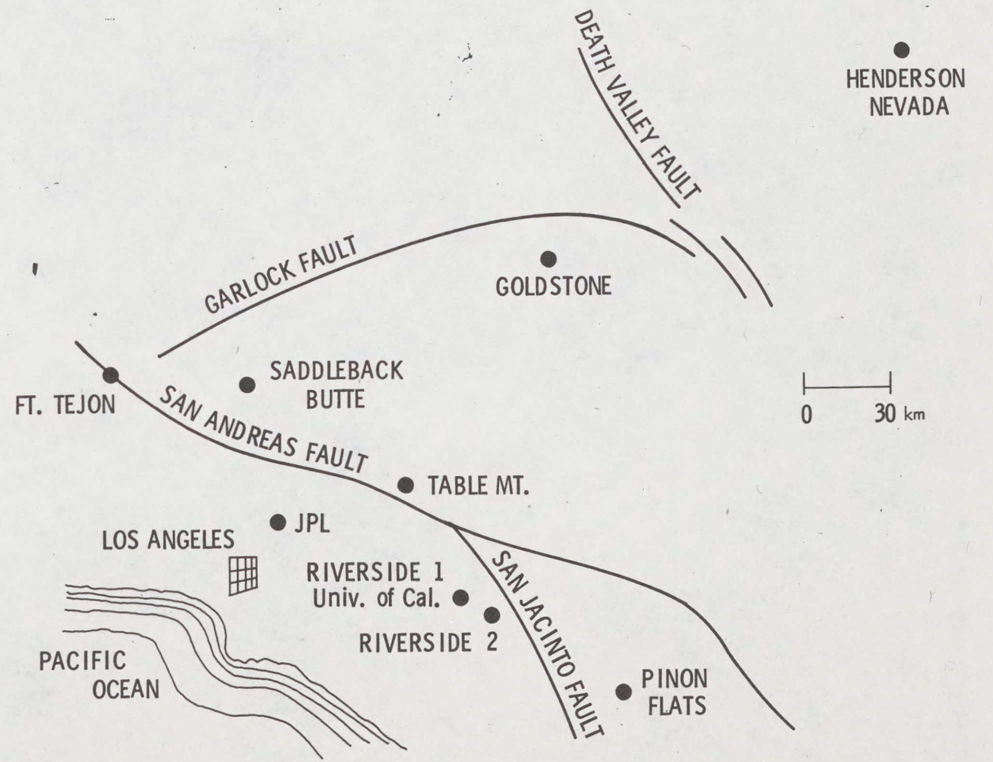
The Astronomical Radio Interferometric Earth Surveying [ARIES] experiment is employing the VLBI technique to make subregional scale measurements of crustal motion over distances which will be in the 50 to 200 km range. In the initial phase these measurements are being made between points in the Los Angeles Basin, depicted in figure 11. A portable ARIES antenna will observe at these sites at the same time as data are being taken at the large antenna at Goldstone, Calif. The analyses of the ARIES data will then be used to determine precise positions and later changes in position between the points in figure 11. During this past year the portable station was positioned at various locations near Goldstone for technical verification and calibration. Figure 12 shows the ARIES portable antenna used in the ARIES demonstration of accuracy conducted in cooperation with the National Oceanic and Atmospheric Administration. The portable antenna was moved around an existing triangulation network and relatively short baselines were determined to an accuracy of about 10 cm.




PACIFIC PLATE MOTION EXPERIMENT

Figure 11

Astronomical Radio Interferometric Earth Surveying (ARIES) experiment



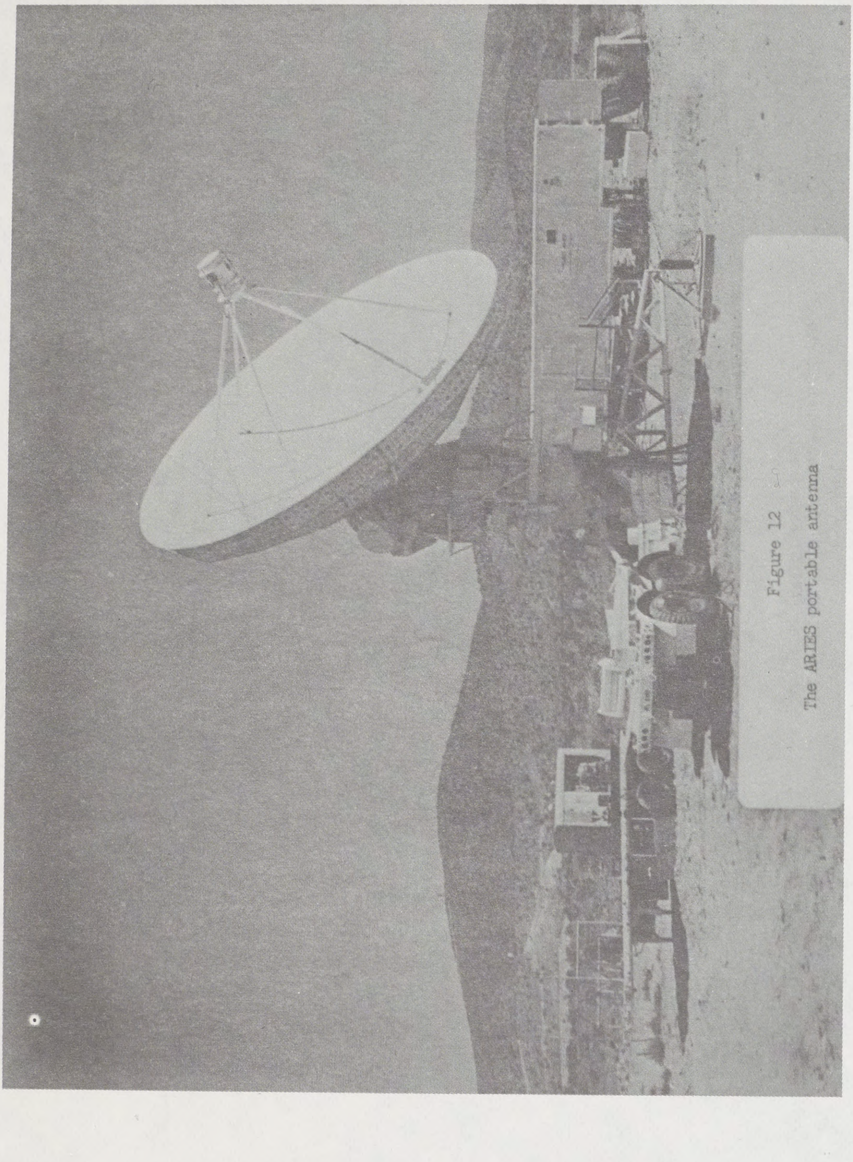


Figure 12

The ARIES portable antenna

Of particular interest in the ARIES experiment is the possibility of observing evidence of a phenomenon called, dilatancy, that has recently been observed to accompany a limited number of certain types of earthquakes. Preceeding these particular earthquakes many geophysical parameters in the region surrounding the impending quake have been observed to change. One of these parameters is vertical motion and it is believed to result from the breaking of rock material below the surface and may occur weeks, months, even years, before the earthquake actually occurs. The breaking of the material is thought to increase the volume and cause the ground to rise. It is believed that the earthquake finally occurs when the cracks are eventually lubricated with water. Generally, the vertical motion is believed to be of the order of centimeters but its measurement could be of great value since it represents a precursor of a seismic event.

Earthquakes of this type are believed to take place in the Los Angeles Basin where the ARIES experiment will be making measurements. As the portable antenna is moved from site to site over a period of time any changes in vertical position will be of particular interest because of the dilatancy effect. There is also evidence to show that the disastrous San Fernando, Calif. earthquake of February 1971, exhibited some effects of dilatancy over 3 years earlier. Thus, the potential of this phenomena and the value of the ARIES measurements should not be underestimated.

In summary, Mr. Chairman, we are proceeding very satisfactorily with the development and validation of these unique earth dynamics measurement systems. We believe that these systems will provide some of the critical information needed to understand tectonic plate motion and earthquakes and will ultimately contribute to the capability to predict earthquakes. Finally, we believe we have a good working relationship with USGS, on whose shoulders earthquake prediction rests, and are attempting to support their effort with the latest technology and systems that NASA has to offer.

Chairman Moss. Thank you for your statement. Have you been able to measure movement of those tectonic plates as yet in any specific measurement?

Dr. Smith. We have made distance measurements but we don't have velocity yet between those points, the first time between San Diego and Quincy was in 1972, we went again in 1974, the results are being analyzed now which could conceivably show something specific. We will be going again in 1976 and visit Utah in 1977 or thereabouts. We have laid them out, but it'll be until the end of the decade before we can give any useful numbers to the gentlemen you heard earlier today for input to prdiction models from the satellite.

Chairman Moss. By being able to make measurement of movement, you can make observations from that as to where earthquake activity might occur, is that your objective?

Dr. Smith. That's right. On the very broad scale that we are talking about in these experiments, in addition, we need to know how stable these plate motions are. For example, over something like 200 million years the opening of the Atlantic has been an average of one or two centimeters per year, but it doesn't tell us whether it was 10 centimeters in 1 year and only one for the next several years, and this possibility still exists. We need to make these measurements over several years to get some idea how constant these motions are.

Chairman Moss. On this first figure where you had all the data, I suppose each one is representing a recording.

Dr. Smith. Earthquake, yes.

Chairman Moss. How far back does that stretch?

Dr. Smith. That's only 6 years.

Chairman Moss. Only 6 years?

Dr. Smith. It's a worldwide pattern of earthquakes. It's a very distinctive pattern that helped considerably in the development of the theory of plate tectonics over the past years.

Chairman Moss. If I understand those, we're likely to have a rough ride. I'm really struck by the number on there; it seems unbelievable that there would have that many. Well, as you indicated, LANDSAT is of less value to us in the United States because so much actual geological work has been done on the ground. But in some more remote country, China or Iran or some place like that, will LANDSAT be able to repeat that picture again and again and again to give you a chance to do some measurement there simply on successive images?

Dr. Smith. I think to measure motion, that is unlikely. It might be useful before or after a large earthquake but we are talking about motions that are comparable to the growing of a fingernail, just a few centimeters per year, and unfortunately the LANDSAT imagery is just not up to that.

Chairman Moss. In other words, if the imagery is refined further, it may be more useful to be able to delineate fault motion.

Dr. Smith. In that respect Mr. Chairman yes, but it still has a value in showing features on the face of North America that we didn't know about previously. For example there are lineaments that appear on the imagery to go all the way across the United States that we still do not fully understand and are contrary to what we would expect

# The Federal Program in Earthquake Mitigation – Draft 6/5/74

I: The Problem

IA: Seismic History of the United States

The popular conception of the earthquake hazard in the United States often limits it to the Pacific coast, especially California, and to such well known disasters as San Francisco in 1906, Long Beach in 1933, the Alaskan Coast in 1964, and San Fernando in 1971. Major earthquakes are by no means unknown to the rest of the country with occurrences in the St. Lawrence River region on several occasions, the vicinity of Boston in 1755, the central Mississippi valley (New Madrid, Missouri) in 1811 and 1812, Charleston, South Carolina in 1886 and Hebgen Lake, Montana in 1959.

The dense population of the United States, particularly in those areas of substantial earthquake vulnerability, is a relatively recent phenomena. While there have been many reported earthquakes prior to 1860, the quality of the reported characteristics and resultant damage associated with these events is uneven. Table 1 lists the series of major events leading to substantial property damage and life loss since 1860. The damage figures quoted for these events are in terms of the then current dollars and do not represent current values. In estimating earthquake losses, it should be noted that property damage is only one aspect of loss due to an earthquake. Other losses include loss of life, (see table 2), injuries, economic loss due to injuries, loss of income due to business disruption, cost of emergency operations, etc. There is little available data on the extent of these costs although they most certainly exceed the direct costs involved.

Losses from earthquakes are not limited to the direct effects of ground faulting and shaking. Tsunamis are sea waves generated by submarine disturbances, often associated with earthquakes and volcanic eruptions. They are scarcely perceptible at sea, but as they enter the coastal margin their crests may build to great heights depending on the energy stored in the waves and on the coastal configuration. Tsunamis are limited in destructive effects to areas immediately adjacent to the coastline where they destroy by the impact of water and by inundation. Affected areas are not necessarily proximate to the earthquake site. For example, Hilo, Hawaii suffered extensive damage from a tsunami generated off the Chilean coast in 1960. Table 3 presents twentieth century data on tsunamis that have affected the United States and the associated life loss and damage.

**Table 1 - Property Damage in Major U.S. Earthquakes in Millions of Dollars (Actual), 1865-1971**

| Year | Locality | Damage |
|---|---|---|
| 1865 | San Francisco, Calif. | .5 |
| 1868 | San Francisco, Calif. | .4 |
| 1872 | Owens Valley, Calif. | .3 |
| 1886 | Charleston, S.C. | 23.0 |
| 1892 | Vacaville, Calif. | .2 |
| 1898 | Mare Island, Calif. | 1.4 |
| 1906 | San Francisco, Calif. | 24.0 |
| | Fire loss | 500.0 |
| 1915 | Imperial Valley, Calif. | .9 |
| 1918 | Puerto Rico (tsunami damage from earthquake in Mona Passage) | 4.0 |
| 1918 | San Jacinto and Hemet, Calif. | .2 |
| 1925 | Santa Barbara, Calif. | 8.0 |
| 1933 | Long Beach, Calif. | 40.0 |
| 1935 | Helena, Mont. | 4.0 |
| 1940 | Imperial Valley, Calif. | 6.0 |
| 1941 | Santa Barbara, Calif. | .1 |
| 1941 | Torrance-Gardena, Calif. | 1.0 |
| 1944 | Cornwall, Canada-Massena, N.Y. | 2.0 |
| 1946 | Hawaii (tsunami damage from earthquake in Aleutians) | 25.0 |
| 1949 | Puget Sound, Wash. | 25.0 |
| 1949 | Terminal Island, Calif. (oil wells only) | 9.0 |
| 1951 | Terminal Island, Calif. (oil wells only) | 3.0 |
| 1952 | Kern County, Calif. | 60.0 |
| 1954 | Eureka-Arcata, Calif. | 2.1 |
| 1954 | Wilkes-Barre, Pa. | 1.0 |
| 1955 | Terminal Island, Calif. (oil wells only) | 3.0 |
| 1955 | Oakland-Walnut Creek, Calif. | 1.0 |
| 1957 | Hawaii (tsunami damage from earthquake in Aleutians) | 3.0 |
| 1957 | San Francisco, Calif. | 1.0 |
| 1959 | Hebgen Lake, Mont. (damage to timber and roads) | 11.0 |
| 1960 | Hawaii and U.S. West Coast (tsunami damage from earthquake off Chile) | 25.5 |
| 1961 | Terminal Island, Calif. (oil wells only) | 4.5 |
| 1964 | Alaska and U.S. West Coast (tsunami damage from earthquake near Anchorage—includes earthquake damage in Alaska) | 500.0 |
| 1965 | Puget Sound, Wash. | 12.5 |
| 1966 | Dulce, N. Mex. | .2 |
| 1969 | Santa Rosa, Calif. | 6.3 |
| 1971 | San Fernando, Calif. | 553.0 |
| Total | | 1,862.1 |

Table 2 - Lives Lost in Major U.S. Earthquakes, 1811-1971

| Year | Locality | Lives Lost |
|---|---|---|
| 1811 | New Madrid, Mo. | Several |
| 1812 | New Madrid, Mo. | Several |
| 1812 | San Juan Capistrano, Calif. | 40 |
| 1868 | Hayward, Calif. | 30 |
| 1872 | Owens Valley, Calif. | 27 |
| 1886 | Charleston, S.C. | 60 |
| 1899 | San Jacinto, Calif. | 6 |
| 1906 | San Francisco, Calif. | 700 |
| 1915 | Imperial Valley, Calif. | 6 |
| 1918 | Puerto Rico (tsunami from earthquake in Mona Passage | 116 |
| 1925 | Santa Barbara, Calif. | 13 |
| 1926 | Santa Barbara, Calif. | 1 |
| 1932 | Humboldt County, Calif. | 1 |
| 1933 | Long Beach, Calif. | 115 |
| 1934 | Kosmo, Utah | 2 |
| 1935 | Helena, Mont. | 4 |
| 1940 | Imperial Valley, Calif. | 9 |
| 1946 | Hawaii (tsunami from earthquake in Aleutians) | 173 |
| 1949 | Puget Sound, Wash. | 8 |
| 1952 | Kern County, Calif. | 14 |
| 1954 | Eureka-Arcata, Calif. | 1 |
| 1955 | Oakland, Calif. | 1 |
| 1958 | Khantaak Island and Lituya Bay, Alaska | 5 |
| 1959 | Hebgen Lake, Mont. | 28 |
| 1960 | Hilo, Hawaii (tsunami from earthquake off Chile coast) | 61 |
| 1964 | Prince William Sound, Alaska (tsunami) | 131 |
| 1965 | Puget Sound, Wash. | 7 |
| 1971 | San Fernando, Calif. | 65 |

Table 3 - Casualties and Damage in the United States from Tsunamis, 1900-1971

| Year | Dead | Injured | Estimated Damage ($000) | Area |
|---|---|---|---|---|
| 1906 | – | – | 5 | Hawaii |
| 1917 | – | – | * | American Samoa |
| 1918 | – | – | 100 | Hawaii |
| 1918 | 40 | – | 250 | Puerto Rico |
| 1922 | – | – | 50 | Hawaii, California, American Samoa |
| 1923 | 1 | – | 4,000 | Hawaii |
| 1933 | – | – | 200 | Hawaii |
| 1946 | 173 | 163 | 25,000 | Hawaii, Alaska, West Coast |
| 1952 | – | – | 1,200 | Midway Island, Hawaii |
| 1957 | – | – | 4,000 | Hawaii, West Coast |
| 1960 | 61 | 282 | 25,500 | Hawaii, West Coast, American Samoa |
| 1964 | 122 | 200 | 104,000 | Alaska, West Coast, Hawaii |
| 1965 | – | – | 10 | Alaska |

*Damage reported, but no estimates available.

Table 4 - U.S. Population Resident in Various Earthquake Risk Zones

| Seismic Risk Zone | Estimated Population at Risk | Percent of total U. S. Population | Number of Effected States[1] |
|---|---|---|---|
| Zone 0 (Low) | 16,717,000 | 8% | 5 |
| Zone 1 | 115,091,000 | 57% | 42 |
| Zone 2 | 40,472,000 | 20% | 39 |
| Zone 3 (High) | 30,943,000 | 15% | 21 |
| TOTAL | 203,223,000 | | 51[1] |

[1]including the District of Columbia

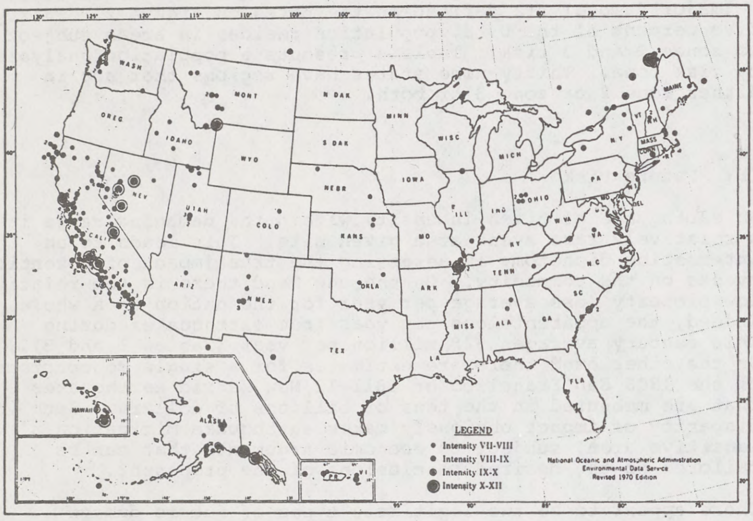
The most earthquake prone areas of the United States are along the Circum-Pacific belt. Parts of the coastal portion of California are among the most densely populated and rapidly urbanizing sections of the country. As noted above, much of the rest of the United States has notable seismic hazard. One way to illustrate this risk is to examine figure 1 which shows the epicentral location for damaging earthquakes from the earliest European occupation through 1970. Earthquakes have been felt in every state. Another way to represent the extent of risk posed by earthquakes is through the use of Seismic Risk Maps. They have been developed by seismologists and engineers to delineate in an approximate way zones of earthquake vulnerability. Figures 2, 3, and 4 are such maps for the contigious states, Alaska and Hawaii respectively. The zone levels of risk, ranging from zone 0 (no damage) to zone 3 (major damage) are defined in the notes on figure 2. Thirty-five percent of the U. S. population resides in areas subject to zones 2 and 3 risk. Table 4 presents a population analysis by risk zone. Thirty-nine states have regions that are in either zone 2 or zone 3 or both.

## IB: Future Risk

An earthquake of given intensity within the damaging range is a relatively rare event at a given site. This leads to an interesting dichotomy in assessing the true impact of potential events on the community. On the one hand there is the relatively low property loss average per year for the nation as a whole. Indeed, the apparent loss per year from earthquakes during this century averages $28 million per year (Tables 1 and 3). On the other hand there are estimates for a single reoccurrence of the 1906 San Francisco or 1811-12 New Madrid earthquakes that are measured in the tens of billions of dollars. Such disparity of impact obviously makes earthquake mitigation a sensitive area, subject to economic arguments that can be tailored to the desired conclusions of the proponent.

There appear to be two legitimate types of future damage estimation methods. The first is an annualized estimate, while the second is a sudden loss estimate. Noting that each area of the country is subject to different growth rates, population densities, construction standards, physical wealth, structural ages, building types, seismicity, and ground conditions requires that both damage estimation methods be applied at several different times to assure that the full implications are fully understood. A series of calculations which take into account each of these variables and their changes with time have been performed to estimate these losses.

**Figure 1 - Intensity and Location of Damaging Earthquakes in the United States from Earliest History Through 1970**



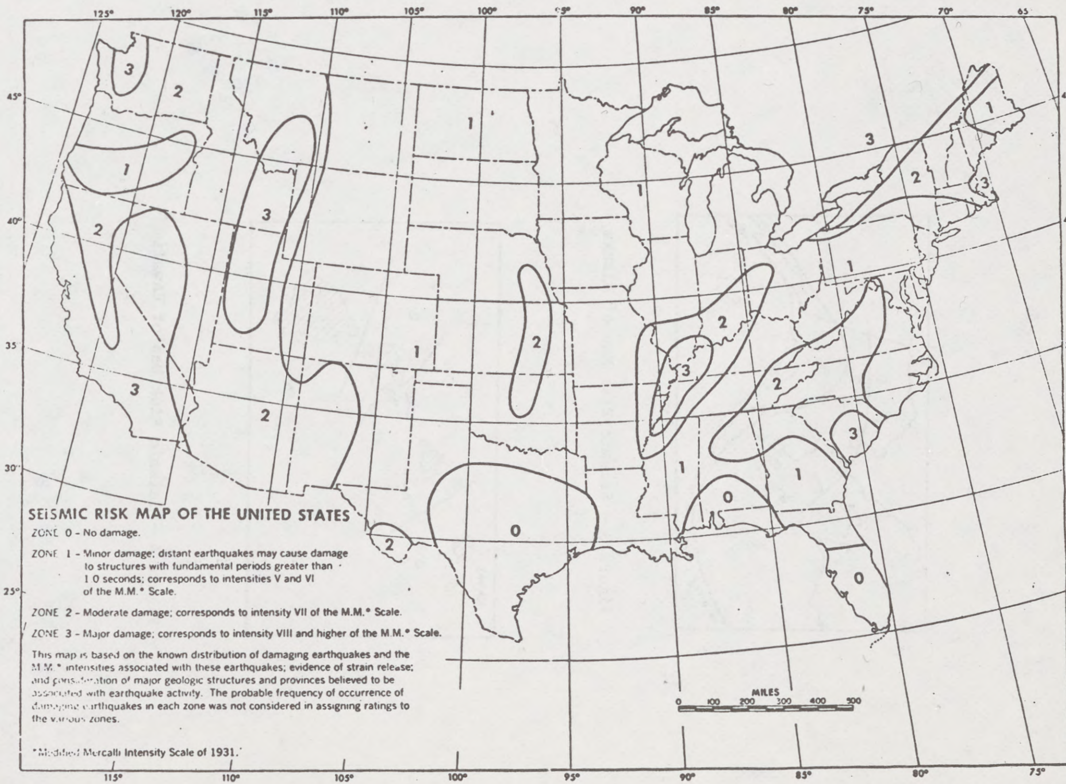



Figure 2 - Seismic Risk Map of the Conterminous United States

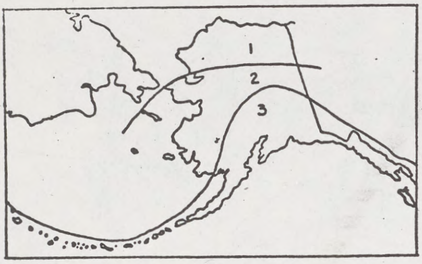



Figure 3 - Seismic Risk Map of Alaska

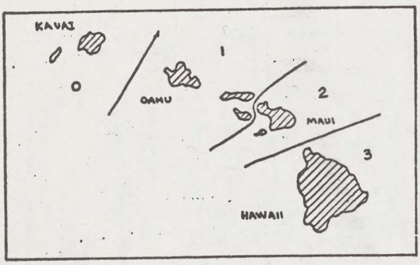



Figure 4 - Seismic Risk Map of Hawaii

The annualized loss figure estimates are based on the expected probability of an event of a specific intensity per year. The expected damage for a given area is then obtained by summing over intensities the product of the probability of the intensities, occurrence, the percent damage expected at that intensity and the current valuation of capital structures. These figures may then be integrated for the entire risk area. The smallest unit considered has been the Standard Metropolitan Statistical Area (SMSA). The results of these calculations are presented in Table 5 and 6 for the U.S. as a whole and for four regions of the country. The tables indicate the total value of structures in the area and the expected annual loss from earthquakes both as a percentage of total value and as a dollar figure for each tenth year through the year 2000. It is interesting to note that while the expected value of annual loss increases from $631 million in 1970 to $1,318 million in year 2000, the annual percent risk loss decreases from 0.04% to 0.032% per year. This latter reduction occurs as new and better construction comes on line; and older, deteriorated construction phases out. A simple integration shows that the estimates of table 5 suggest an expected total loss of $30 billion for the entire United States as a result of earthquakes occurring from 1970 through 2000, inclusive. The western region of the U. S. can expect $22.5 billion of this total damage, or about 75% of the cumulative estimated annualized loss. This geographical area contains approximately 20% of construction in the U. S.

The sudden loss potential has been estimated for two specific events: The 1906 San Francisco and 1811-12 New Madrid earthquakes. These events are generally characterized as the representative major destructive earthquakes that may reoccur and for which there is reasonable intensity data. Table 7 presents the damage that can be expected to occur if the hypothetical event would occur in 1970, 1980, 1990, or 2000. The damage from the San Fernando scenario is measured in tens of billions of dollars lost, while New Madrid, although very serious, is less than thirty percent as damaging because more property is exposed in the epicentral region of the San Francisco event than for the New Madrid event. The new Madrid scenario has been calculated on the basis of a currently accepted epicenter. If this region were shifted to the north by 100 miles, the damage could easily be trebled. St. Louis and Chicago would then be in higher intensity zones, thus significantly increasing the total property at risk.

Thus far, we have only considered property losses from earthquakes. We have been very fortunate in previous U. S. earthquakes that relatively few lives have been lost compared with similar events in many other countries. Although the data base is constrained,

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**Table 5 - Annualized Losses to Structures, U.S. Totals**

| NATIONAL YEAR | MILLION 1970 $ AT RISK | MILLION 1970 $ LOSS | AT RISK LOST (%) |
|---|---|---|---|
| 1970 | 1,616,114.80 | 631.22 | .03905 |
| 1980 | 2,322,156.60 | 832.07 | .03583 |
| 1990 | 3,149,514.00 | 1,044.41 | .03316 |
| 2000 | 4,098,186.90 | 1,318.50 | .03217 |

**Table 7 - Losses Due to the Reoccurrence of the New Madrid and San Francisco Earthquakes**

| NATIONAL YEAR | Value at Risk in Area MMI>6 Million 1970 $ | Population at Risk in Area MMI≥6 | Loss in Value Million 1970 $ | Total Value at Risk Lost (%) |
|---|---|---|---|---|
| | | San Francisco Scenario | | |
| 1970 | 76,488.44 | 7,795,137 | 10,242.63 | 13.39108 |
| 1980 | 113,348.00 | 9,252,058 | 13,720.72 | 12.10495 |
| 1990 | 157,317.87 | 10,708,978 | 17,553.36 | 11.15789 |
| 2000 | 208,398.04 | 12,165,899 | 20,839.80 | 10.69175 |
| | | New Madrid Scenario | | |
| 1970 | 118,131.08 | 19,525,116 | 3,063.47 | 2.59328 |
| 1980 | 165,543.01 | 21,683,916 | 3,876.41 | 2.34163 |
| 1990 | 220,154.64 | 23,842,716 | 4,683.37 | 2.12731 |
| 2000 | 281,965.99 | 26,001,515 | 5,760.40 | 2.04294 |

**Table 6 - Annalized Losses to Structures by National Region**

| REGION | VALUE OF STRUCTURES (MILLION 1970 $) | LOSS (%) | LOSS (MILLION 1970 $) |
|---|---|---|---|
| NORTHEAST | | | |
| 1970 | 475,785 | .02306 | 109.7 |
| 1980 | 680,559 | .02059 | 140.1 |
| 1990 | 919,823 | .01828 | 168.1 |
| 2000 | 1,193,577 | .01765 | 210.7 |
| NORTH CENTRAL | | | |
| 1970 | 430,924 | .00668 | 28.8 |
| 1980 | 612,682 | .00563 | 34.5 |
| 1990 | 824,243 | .00479 | 39.5 |
| 2000 | 1,065,556 | .00441 | 47.0 |
| SOUTH | | | |
| 1970 | 370,623 | .00827 | 30.7 |
| 1980 | 531,462 | .00772 | 41.0 |
| 1990 | 719,693 | .00724 | 52.1 |
| 2000 | 935,317 | .00709 | 66.3 |
| WEST (including Calif.) | | | |
| 1970 | 338,782 | .13639 | 462.1 |
| 1980 | 497,437 | .12390 | 616.3 |
| 1990 | 685,755 | .11441 | 784.6 |
| 2000 | 903,736 | .11004 | 994.5 |

recent U. S. earthquakes exhibit a relative proportionality between the number of lives lost and the property damage from individual events. These proportionalities form two sets, one for daytime and the other for night time events. The latter being approxiamtely one-third the former. On the average, we can expect the loss of one life for each $2 million in property damage. This figure is based on 10 events. The data available on the number and type of injuries is very sparce and must be considered carefully. For each death we can expect 43 (± 24 with 95% confidence) injuries of which 2.7 (± 0.24) are serious.

Numerous studies have attempted to determine the value of a human life. While this is primarily an apples and oranges proposition, there is some concurrence that a mean value of $150,000 (1970 dollars, with an appropriately large standard deviation) is representative. The cost of an average injury including wages and time losses, medical expenses and insurance administration is about $1,850.

The indirect costs of an earthquake due to the disruption of the communities' normal development have not been estimated. Indirect costs of automobile accidents have been estimated to equal all directly accountable costs. A hazardous guess would be that total earthquake loss costs to society are twice the direct property damage, life loss and injury costs.

Noting the hazard in performing this calculation before hand, we can now estimate that for each million dollars in damage from an earthquake, life loss and injury will add $103 thousand. Thus to a first approximation life loss and injury increase the "cost" of an earthquake either in the annualized or scenario estimates by 10%.

To summarize the potential impact of earthquakes, we repeat the following statistics for the year 2000.

| | |
|---|---|
| Annualized National Loss estimates for the year 2000 | $1.3 billion property loss<br>593 lives lost<br>25,500 injuries |
| Sudden Loss estimate for San Francisco event in the year 2000 | $20.8 billion property loss<br>9,400 lives lost<br>402,000 injuries |
| Sudden loss estimate for New Madrid event in the year 2000 | $5.8 billion property loss<br>2,600 lives lost<br>112,000 injuries |

Clearly earthquakes pose a most serious destructive threat to the local and national community that can not be ignored. These figures assume that we continue doing things in exactly the same way we do them today and that we make no conscientious effort to decrease our individual and national vulnerability to earthquakes.

## Section II Adjustments

The occurrence of an earthquake, or any other natural disaster event, is important only insofar as it affects man and his works. It is the disaster potential of earthquakes that has caused man individually and collectively to seek adjustments to his physical and social environment that decrease his vulnerability. The measurement of vulnerability is related to the potential or realized loss of life (and injury), property damage, and/or disruption of function. While each individual or group will apply a different normative combination of these measures in its decisions, the general objective remains the same and that is, to control the sequences of the event.

As adjustments, one may seek either to change the phenomenon or to alter the response of man and his works to the phenomenon. Possible physical adjustments the decision maker may seek to accomplish are:

- o Control the event by prevention or modification of the event.
- o Anticipate the event so that remedial actions may be taken.
- o Identify the seismic potential of areas.
- o Construct facilities so as to perform acceptably during and after the event.

Among the possible social adjustments, the decision maker may seek to:

- o Plan for the warning, response and recovery to the event.
- o Distribute economic risk.
- o Generate and select alternative physical development plans.
- o Adopt and enforce zoning, construction and management standards.

Clearly the physical and social adjustments depend critically on each other. It must be remembered that adjustments to earthquakes are not made in vacuo; there are other considerations in making decisions regarding vulnerability reduction that may be dominant by comparison.

In the remainder of this section we shall investigate the potential impact of several adjustments as the first step in assessing the viability of different earthquake mitigation procedures. The impacts of these representative adjustments are based on the same data base and calculation methodologies as presented in the previous Section. Only direct effects such as faulting and ground shaking are considered, while Tsunami damage is not included in this evaluation.

ADJUSTMENT 1: A land use mechanism

The State of California, or the counties and communities affected could decide to halt population growth in those areas that have a Modified Mercali intensity 9 for a reoccurrence of the San Francisco Earthquake. Assuming that these areas have zero population growth, the following reductions in property losses are derived for the San Francisco Scenario:

| Year | Before Adjustment (Billion 1970 $) | After Adjustment (Billion 1970 $) | Difference (%) |
|---|---|---|---|
| 1970 | 10.2 | 10.2 | 0 |
| 1980 | 13.7 | 12.0 | -13 |
| 1990 | 17.6 | 13.7 | -22 |
| 2000 | 20.8 | 15.8 | -24 |

By the year 2000, this policy would cause a reduction in the normally expected population of this region of 7.1%. The adjustment must be considered carefully because no effort has been exerted to redistribute these pople to other areas in the loss calculation.

Zero population growth in highly hazardous areas and by implication a form of land use control is clearly a very effective way to decrease the scenario cost of a San Francisco type earthquake.

ADJUSTMENT 2: Strengthening of Structures

The expected damage to a structure increases logarithmically with the Modified Mercalli Instensity of its site. An effective method of decreasing the damage to a building is to strengthen it so that it performs better during the event. It would be unrealistic to propose to reinforce all the structures in the U.S. such that they are more earthquake resistant. It is realistic, however, to reinforce structures in highly vulnerable areas. Suppose that all structures in the 42 highest hazard counties in the country are reinforced so that they will perform as if the apparent MMI intensity at the site were decreased by one unit, the following national savings would result.

| Year | No Adjustment % Value Lost Per Year | With Adjustment % Value Lost Per Year | Difference (%) |
|---|---|---|---|
| 1970 | .039 | .030 | -24 |
| 1980 | .036 | .027 | -24 |
| 1990 | .033 | .025 | -24 |
| 2000 | .032 | .025 | -24 |

These figures assume that the adjustment becomes instantaneously effective in 1975. These counties contain 9.7% of the national construction value (1970) and 8.0% of the national population (1970). About $430 billion in construction costs would be affected by this adjustment through the year 2000. The estimated cumulative savings in damage would be $5.0 billion during the same period. Thus if strengthening costs average over 1.4% of structural value, the savings purely on the basis of property costs would be less than expected losses. This percentage will increase for longer periods of consideration.

<u>ADJUSTMENT 3</u>: Improved Building Code

The Uniform Building Code approaches the problem of assigning seismic loads for different regions of the country by assigning a multiplicative factor according to the zones of figure 2. The factor doubles for each single zone increment. Increasing the coefficient improves the performance of buildings during an earthquake. Generally, earthquake forces are the dominant hazard design consideration in Zones 2 and 3. Thus for this adjustment we suppose that the code coefficient be doubled from its current values for Zones 2 and 3 and that these new requirements be applicable to all new construction starting in 1976. This adjustment yields the following annualized loss reductions on a national basis.

| Year | No Adjustment % Value Lost Per Year | With Adjustment % Value Lost Per Year | Difference (%) |
|---|---|---|---|
| 1970 | .039 | .039 | 0 |
| 1980 | .036 | .035 | -3. |
| 1990 | .033 | .031 | -7. |
| 2000 | .032 | .029 | -11. |

By the year 2000, this adjustment would have affected approximately $500 billion in new construction, representing 12.1% of the national value. The cumulative savings to that time of the adjustment based on the annualized loss model would be about $1.7 billion in property loss.

ADJUSTMENT 4: Accelerated Replacement

Older buildings are generally regarded as presenting a greater seismic risk. The application of earthquake resistant design procedures is relatively recent. Many older structures, particularly those built prior to 1933 in California and most structures outside of California, were designed without earthquake considerations. These structures generally pose the most serious life and property risk of all the structures in our national inventory. Elimination of older buildings is a means of decreasing vulnerability. This may be economically and socially impractical. However, it is practical to adopt a replacement strategy that decreases the useful life of older buildings for hazardous areas. The possible adjustment is to replace buildings ten years earlier than normal in risk zones 2 and 3. This adjustment starting in 1976 yields annualized damage reductions as follows:

| Year | No Adjustment % Value Lost Per Year | With Adjustment % Value Lost Per Year | Difference |
|---|---|---|---|
| 1970 | .039 | .039 | -0. |
| 1980 | .036 | .035 | -3. |
| 1990 | .033 | .031 | -5. |
| 2000 | .032 | .030 | -7. |

By the year 2000, $16.9 billion in building values would have been affected. This does not represent value lost, it is only the value of the buildings that are replaced ten years before their natural lifetime and replacements built ten years earlier. Using this adjustment, $1.15 billion is the expected cumulative savings in earthquake property damage through the year 2000.

ADJUSTMENT 5: An Earthquake Warning Mechanism

Assessing the impact of earthquake warning is very difficult because it depends on a group of actions and strategies that have yet to be addressed. One of the specific actions that can be taken upon the issuance of a warning is to begin the strengthening of the existing structures and a revision of the building code for new structures. Obviously the degrees to which these actions can be taken depend upon the time and financial resources available. If the prediction is a few days in advance, all that can be done is to vacate previously identified hazardous buildings and selectively remove or harden the contents. Special structures such as nuclear reactors and dams can be closed down. With a 30 day warning period building inspections can be performed to identify hazardous buildings and conditions. In most circumstances there will be neither the professional expertise, skilled labor, or materials available to reinforce hazardous buildings in this extremely short time frame. These preventive actions become widely realistic in the nine to eighteen month warning period. Beyond this time frame, revised building codes and land use regulations can be adopted and enforced, condemnation procedures implemented, etc. These are long term earthquake mitigation procedures that now have the force of a definite event to hasten their adoption and enforcement.

The general rational which prompted the evaluation of this adjustment is the fact that the longer the time period from warning to occurrence, the greater the reduction in the apparent Modified Mercalli Intensity (MMI) of the event. For explicitness, the San Francisco Scenario has been recalculated assuming that building structures perform better after the adjustment than before by a specific MMI increment. The maximum intensity of the San Francisco Scenario was reduced by increments of 1/4 MMI of the 1970 base data. Varying reductions yield these reduced damages.

| Intensity Reduction (MMI) | California Damage (% at Risk) | Difference (%) | Amount Saved (Billion $) |
|---|---|---|---|
| 0 | 5.2 | 0 | .0 |
| .25 | 4.2 | -20 | 2.0 |
| .50 | 3.4 | -37 | 3.7 |
| .75 | 2.7 | -49 | 5.0 |
| 1.00 | 2.1 | -59 | 6.1 |

For reference, the non-adjusted damage of 1970 is expected to be $10.2 billion. The total State property valuation is $196 billion.

These are definitely very large savings which can be reaped by instituting policies that reduce the vulnerability of the community to earthquake damages. By way of a hazardous guess, we may be capable of a 1/4 MMI reduction in 30 days, a 1/2 MMI reduction in 300 days, and a 3/4 MMI reduction in 3000 days (8 years). A full unit intensity is probably achievable only in a decade or more of total concentrated effort.

Each of these adjustments involves only the potential savings in property damage. Accounting for life loss, injuries and associated social costs would easily more than double the net possible savings for each adjustment.

Section 3

The previous section has illustrated the potentials for major national earthquake damage reduction by the implementation of policies that change the nature of the constructed environment and the response of its institutions to earthquake hazards. The impacts of these adjustments are preliminary, but indicative. Their scope is limited and representative of only a few of many possible adjustments. One of the sample adjustments is purely policy oriented in that we can now limit population growth although its economic, legal and social consequences are not yet known. The other adjustments, however, require the development of procedures and analytical methods that are also not now known. Their development requires a joint program of the application of research, experience, and intuition. The program developed in the remainder of this report is concerned with filling the knowledge base necessary to postulate, evaluate, and possibly implement adjustments that decrease the nation's vulnerability to earthquake events. The program is:

FEDERAL EARTHQUAKE MITIGATION PROGRAM OBJECTIVE:

To Develop methods that allow decision makers to mitigate the effects of earthquakes.

In furtherance of the principal over all objective, a program of research and implementation has been developed for five specific categories:

- Design — Develop economically feasible design and construction methods for building earthquake resistant structures of all types.
- Land Use — Develop procedures for integrating information on seismic risk with on-going land use planning and regulation processes.
- Warning — Develop the capability to identify the seismic hazard of an area and to forecast future individual events.
- Social Policy — Develop an improved understanding of the social and economic consequences of individual and community decisions on earthquake related issues with emphasis on risk control, pre-event planning, provision of emergency services, rescue, recovery, and redevelopment.
- Hazard Alteration — Develop methods and procedures that allow the control or alteration of seismic phenomena and their effects on existing structures.

Section 4 Program Areas
SPECIFIC OBJECTIVES AND PROGRAM ELEMENTS

In order systematically to structure a program over a period of years aimed at achieving the six general objectives, seventeen program elements have been identified. With each of these elements are associated several specific objectives, which serve as guidelines for developing that element. In the context of the present paper, however, particular porject descriptions are inappropriate; rather, the program elements serve as categories into which specific research activities can be divided. They are listed below and expanded in the following text.

| | | | |
|---|---|---|---|
| I. | Tectonics | IX. | Coastal and inland waterways |
| II. | Earthquake Modification | X. | Risk Analysis |
| III. | Event Prediction | XI. | Warning and Preparedness |
| IV. | Hazard Identification | XII. | Economic Analysis |
| V. | Ground Motion | XIII. | Response and Redevelopment |
| VI. | Soils response and analysis | XIV. | Regulation |
| VII. | Structural response and analysis | XV. | Technology Transfer |
| VIII. | Systems response | XVI. | Public Information |

It should be noted that this method of structuring earthquake activities owes a large debt to several previous reports.

The seventeen elements have been framed so as to deal with specific problems in the design, analysis and synthesis of social engineering and scientific knowledge to control the consequences of earthquakes, measured by life loss, property loss, and/or function loss.

I. Tectonics

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 earthquake mitigation, that outline must be strengthend and fleshed out with many important details on the constitution and behavior of the boundary zones between plates that generate earthquakes and an understanding of interior plate mechanics that lead to non boundary focused events. Some of these studies should be made under the earthquake mitigation program, but the overall pursuit of tectonic concepts should be as broad as all the Earth sciences combined. This is a basic research area whose support is not amenable to specific objective catagorization.

## II. Earthquake Modification

The concept of earthquake control or modification implies the relieving of tectonic stresses on faults and thereby reducing the catastrophic effect of earthquakes. The size of earthquakes theoretically could be limited, or the potential for an earthquake might be eliminated or postponed by suitable actions.

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 exiting 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 and thus its damaging potential.

A concomitant problem is the inadvertent triggering of earthquakes in the development of waste disposal wells, geothermal energy extraction, reservoirs, and other activities. Field investigations of deep well disposal and their associated incremental seismic activity point not only to the possibility of earthquake modification, but to the possibility of causing events that may not otherwise be expected.

The objectives of this element are to:

A. Determine the feasibility of limiting the magnitude of earthquakes on active faults

B. Design subsurface waste disposal operations and reservoir siting so as to prevent inadvertent triggering of earthquakes.

## III. Event Prediction

Numerous lines of research give promise that forecasting of at least some earthquakes their expected time, magnitude, and place may become feasible. 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 seismic wave velocities, variation in the composition of water from wells or springs, and other physical changes. To a large extent, these leads represent an empirical approach. These data indicate that lead times for large events may be measured in many years. Such predictions could be major forces behind the implementation of improved building codes and land use controls. Shorter term predictions will allow the preparation and implementation of emergency rescue and recovery plans to decrease the social costs. It should be noted that both affirmative and negative event predictions may have value. The objective of this element is to

A. Develop the physical understanding and instrumental means required for forecasting the time, place and magnitude of earthquakes.

IV. Hazard Identification

All the hazards of earthquakes stem from the behavior of the ground-ground breaking along faults, ground motion, ground failure including landsliding, differential settlement and ground-level changes. Fundamental to being able to make any possible adjustment to mitigate the effects of an earthquake is a delineation of the earthquake hazard. This involves the identification of areas of historic activities, active and inactive faults, landslide areas, and the attenuation properties of geological systems.

The objectives of this element are to:

A. Conduct historical seismicity studies to determine hazardous areas.

B. Develop methods to identify earthquake faults and distinguish between active and inactive ones.

C. Develop methods to characterize the dynamic properties of local soils and geological formations.

D. Investigate the nature of attenuation of seismic waves in various parts of the country.

V. Ground Motion

Destructive ground motions resulting from earthquake action are of several different types, including heavy ground shaking, slow or rapid fault slip, subsidence and land slides. Fundamental to an understanding of any of these damaging phenomena, however, is an accurate knowledge of the actual earthquake ground motion. There are two essential methods of approaching ground motion characterization. The first is a constructive method where analytic models are constructed that may include source mechanics, path properties, soil conditions, etc., and may yield anticipated site spectra, maximum acceleration, duration, displacement, and time histories. The second method is the collection of catalogues of response measurements made during actual earthquakes. These measurements also are fundamental to the validation of structural design and analysis procedures to the actual structural response generated by the ground motion.

The measurement of destructive ground motions in the epicentral region of large earthquakes and the associated response of structures is achieved by placing a network of instruments at a variety of sites where earthquakes are likely to occur. Among the active recording systems used are accelerometers, pore pressure gauges to measure the liquid pressure in saturated soils, earth pressure gauges to measure the inertial effects of soils usually on a foundation wall, strain gauges and displacement meters. Among the passive instruments are the seismoscope, a conic pendulum that records motion on a smoked glass, scratch strain gauges and extensometers.

The objectives of this program element are both research and data collection related:.

A. Develop constructive methods that characterize the nature of ground motion suitable for application in design, analysis and regulation.

B. To support the research program by measuring pertinent quantities to validate, calibrate and/or formulate theories of earthquake response.

C. To support the designer's need for earthquake motion information at varying geological and seismological sites.

D. To obtain a comprehensive data base to perform microregionalization of earthquake risk areas based on events in the areas.

VI. Soils Response and Analysis

One of the greatest potential sources of property loss is damage to structures that rest on soils or on foundations which, although adequate to support the structures under ordinary circumstances, might fail during an earthquake. A great potential for life loss resides in the possibility of a dam failure. The following areas represent forms of soil failure under consideration by the program: settlement of cohesionless soils; bearing capacity failure; embankment failure; soil liquefaction; waterfront bulkhead failures, etc.

The dynamic behavior of a structure during an earthquake depends on the shaking transmitted to it by the surrounding soil. These motions are imparted to the structure through the interaction between its foundation and the supporting soil and/or bedrock and include amplification effects.

The objectives of this element are to:

A. Develop methods to evaluate and control soil failure potentials.

B. Develop analysis and design methods to evaluate and control soil amplification.

C. Develop design and analysis methods to characterize the loadings transmitted to structures through soil-foundation interaction.

VII. Structural Response and Analysis

The realization of a structure rests on two complementary activities: analysis, and synthesis and design. Analysis forms the basis for design. The ability to analyze a hypothetical structure and determine the stresses and displacements that would be produced by a specified loading is an essential part of the design process. The more accurately this can done, the more efficient and economical can be the design and the more reliable the design factor of safety. The analysis of a structure can be exceedingly difficult, first, since ordinary structures are exceedingly complex dynamic systems; second, because the ground motions which the structure will be subjected to during its lifetime are probabilistic; and third, because the construction process leads to a structure which is not precisely known. The analysis of structural response requires knowledge of the full system, including foundations, adjacent soils and in some cases the properties of adjacent structures.

The objectives for this program element are to:

A. Determine appropriate models for element (e.g., beam, column, plate, etc.,) response to strong motion excitation from analytic and experimental studies.

B. Develop digital computer methods of analysis that predict earthquake response of structural systems comparable in complexity to real structures.

C. Validate and calibrate these models by comparison with earthquake measured motions and damage to structural system and elements.

The basic problem of earthquake design is to synthesize the structural configuration; the size, shape, and materials of the structural elements; and the methods of fabrication, so that the structure will safely and economically withstand the action of earthquake ground motions. The object of design is to control the effects of an earthquake on a structure and keep damage within acceptable bounds. A further series of objectives has been determined for this element:

D. Determine the dynamic properties of structures, elements and materials under conditions of large strains, beyond the yield point and up to failure.

E. Develop reliable, practical and simplified methods of earthquake design for widely used and special important structures: e.g., low rise residential, low rise commercial, school houses, high rise buildings, dams, bridges and industrial structures.

F. Thoroughly study structures that failed during an earthquake, as well as those that did not fail, to refine design principles.

G. Develop design and analysis methods for nonstructural elements and mechanical components of structures.

H. Develop procedures to improve the performance of existing structures by reinforcement, repair or other alterations.

VIII. Systems Response

Previous elements of the research program have dealt almost exclusively with localized structures, that is, a single building, dam, etc. The operation of the community during the emergency and recovery periods is dependent on the functioning of utility and public service facilities that function as a system with elements located at many sites in the affected area. The failure of an element can cause the total system to malfunction or be inoperative. Thus the design of system elements must consider the seismic characteristic requirements of the extended system. Both physically connected and non-connected systems are to be investigated. An example of a connected system is fire water distribution (storage, pumping stations, water mains, etc.) while a non-connected system is represented by emergency health care facilities (hospitals, clinics, laboratories, etc.).

The objectives of the element are to:

A. Develop principles of planning and laying out facilities for minimum disruption of operations due to earthquake ground displacements.

B. Develop design procedures for special structures and equipment of each type of utility and public service facility. Among these, ranked in approximate priority order, are:

1. Nuclear power plants and related facilities
2. Emergency power and communications.
3. Hospitals and emergency agencies
4. General communications
5. Water services and sewage disposal
6. Electrical power and natural gas or fuel supplies
7. General transportation facilities

C. Develop and evaluate methods of land-use control, such as microzonation, that will allow a community to control its earthquake vulnerability.

IX. Coastal and Inland Waterways

An earthquake at sea may generate a tsunami, or tidal wave, that presents a real danger to coastal and island regions of the U.S. The risk posed by tsuanmis may best be controlled by land use regulation in vulnerable areas. Verification of the occurrence of a tsunami permits the evacuation of potential affected areas.

If a dam fails, an inundation wave may be generated when the reservoir empties. This wave can cause serious downstream damage. Structuring downstream land use, with this potentiality in mind, can reduce life and property loss. When a reservoir behind a dam is filled, a series of earthquakes often occurs in the vicinity of the impoundment. The incremental risk these quakes cause above the natural risk is at present uncertain.

The objectives of this element are to:

A. Develop methods to verify that an ocean-based earthquake has generated a tsunami.

B. Develop methods to anticipate tsunami run-up in coastal regions.

C. Develop methods to anticipate downstream inundation levels from earthquake ruptured dams.

D. Determine the incremental seismic risk associated with filling a reservoir and the degree that this risk should be part of the design criteria for the dam.

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## X. Risk Analysis

Up to this point, the research elements of the Federal Program have been directed at obtaining specific information on portions of the earthquake problem. The situation is seldom one in which there is full knowledge of the phenomena, structural behavior, or implications of unsatisfactory performance. Information is usually expressed in terms of probabilistic statements with varying degrees of certainty. The problem of design requires the balancing of individual decisions with uncertainty to achieve a whole that performs in an acceptable way. Such analyses may be performed to select among initial design alternatives, examine the way a component's vulnerability affects a system's performance, or aid in making decisions on repair, rehabilitation, or strengthening of system elements, among others.

## XI. Warning and Preparedness

The object of community preparedness is to enhance the stability of the community in time of disaster. Community preparedness for earthquakes must proceed on the assumptions that an earthquake occurs without warning, an earthquake strikes indiscriminately within a seismically active region, and because of the unpredictability of areas and items affected, the demand for decision making immediately after the impact will be greater than for most other natural hazards. In some areas of the country, there may be specific event warnings based on the developing capability for earthquake predictions.

Community preparedness can be achieved both by the preparation of plans of action that are exercised when the event occurs or is forecast, and by adopting strategies in building and land use regulation that decrease vulnerability.

## XII. Economic Analysis

The consideration of earthquake safety often becomes an economic contest between first costs, continuing costs, sudden losses and the concomitant recovery. Costs of natural hazards are borne by both the private and public sectors and are not restricted to those directly affected. First costs include the design and construction incremental costs of building safer structures, the cost of formulation of preparedness plans, the negative costs of not adding industrial capacity, the non-availability of structures due to their condemnation, etc. Continuing costs include maintenance of preparedness plans, operation of building inspection departments, earthquake insurance, warning system operation, and research programs. These two costs may be incurred to ease the financial impact of the event when it occurs.

Sudden losses not so covered or prepared for must be accepted or may be relieved by private agency actions or public agency generosity through grants, loans, commodities or services.

XIII. Relief and Recovery

Relief and recovery are the final stages in a disaster and constitute the restoration effort. Relief is the immediate response after impact to provide required services and commodities to disaster victims. Rehabilitation efforts are directed at three separate, but closely related, ends: (1) the restoration of individual emotional and physical health, employment, and standard of living; (2) the maintenance and restoration of material culture such as furniture, dwelling units, utilities buildings, roads, industrial and commercial structures, etc.; and (3) the development and application of procedures and methods that decrease the communities' vulnerability to the next event. There is a dilemma intrinsic in the relief and rehabilitation process: decisions to act quickly to relieve suffering and to get the economy functioning again often tend to undermine those actions that should be taken for long term recovery.

XIV. Regulation

Society through its public and private actions establishes, adopts and enforces restrictions on physical development through building codes, land use regulations, building occupancy codes, OSHA standards, insurance requirements, mortgage and finance requirements, etc. Structural resistance to earthquakes is a matter that should involve responsible decision and action on the part of the owner, financing agency or mortgagor, architect, engineer, builder, forman, inspector, manufacturer of components, insuror, and appropriate officials of the municipality or other governmental subdivision. Each of the participants in the decision process is often so remote from the ultimate user, renter or owner - the loser in the event of disaster - that there may in some cases be little sense of responsibility. Regulations have been a traditional way of establishing minimum requirements to insure a degree of responsibility.

XV. Technology Transfer

Within the Federal Program, utilization activities should be centralized and formulated as a specific program thrust, to be conducted by a core series of activities rather than solely distributed as a component in each individual activity.

The objectives in this element are to:

A. Maintain a technical reference collection of published reports and papers and unpublished data available to researchers and professionals; to provide for information dissemination.

B. Maintain a software center to archive, document, validate and distribute computer programs developed for earthquake mitigation applications.

C. Conduct regular conferences and workshops to act as foci for dialogues between the research and professional communities.

D. Conduct post earthquake inspections to obtain performance data, to identify unfulfilled research needs, and to observe operational program performance.

XVI. Public Information

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT,
FEDERAL DISASTER ASSISTANCE ADMINISTRATION,
*Washington, D.C., June 6, 1975.*

Hon. FRANK E. MOSS,
*Chairman, Committee on Aeronautical and Space Sciences,*
*U.S. Senate,*
*Washington, D.C.*

DEAR MR. CHAIRMAN: This is in reply to your letter of May 14, 1975, requesting information on the programs and activities of the Federal Disaster Assistance Administration with respect to coping with the effects of earthquake disasters.

Since enactment in 1950 of the first comprehensive Federal Disaster Act, Public Law 81-875, there have been six Presidential major disaster declarations for earthquakes under that law and succeeding legislation. All occurred prior to the transfer, on July 1, 1973, of Federal disaster relief authorities and functions from the Office of Emergency Preparedness (OEP) to the Department of Housing and Urban Development (HUD). The Federal Disaster Assistance Administration (FDAA) was established within HUD to administer the Disaster Relief Act of 1970, Public Law 91-606, as amended, the current disaster assistance legislation at that time.

This statement describes the types of assistance made available in major catastrophic earthquakes that have occurred since 1950, and outlines our present and projected plans for future earthquakes that may occur under the more liberal provisions provided by the current disaster relief legislation, the Disaster Relief Act of 1974, Public Law 93-288.

Of the six Presidential major disasters declared for earthquakes, two occurred in Hawaii and one each in Nevada, Alaska, Washington, and California. By far the most devastating of these disasters were the earthquakes which struck Alaska in March 1964 and California in February 1971. Information on the relief measures that were undertaken to restore the stricken areas and to alleviate suffering and hardship in these two disasters will be responsive to your specific inquiry.

### ALASKA EARTHQUAKE

At 5:36 p.m. on Friday, March 27, 1964, a severe earthquake (magnitude between 8.3 and 8.7 on the Richter scale) rocked south central Alaska, causing $500 million in property damage, 131 deaths, and hundreds of injuries. Seismic sea waves swept the Pacific Ocean from the Gulf of Alaska to Antarctica and caused coastal damage in British Columbia and California. Coastal area damage generally resulted from submarine landslides, slide-induced waves, and tsunami effects. Inland damage was due to landslides, fissures, and ground subsidence.

The major damage occurred to homes, businesses, public facilities, harbors, transportation systems, public utilities, and the fishing industry. The State and Federal Government response was immediate and effective. Local and State agencies, bolstered by the Red Cross and other private relief organizations, provided emergency feeding and housing, and medical care of the injured. First priority of Federal relief was directed to the emergency repair of damaged water and sewage systems whose disruption constituted an immediate health hazard. Power and communications services were also given prompt attention. Demolition of hazardous structures and the clearance of debris and wreckage proceeded without delay. The various modes of transportation were restored in a relatively short time, and within six months after the earthquake, a considerable amount of the total restorative work had been accomplished. A total of $55,755,230 was expended from the President's Disaster Relief Fund for this disaster, and many millions more in grants and loans were provided by other Federal agencies under their independent statutory authorities.

### CALIFORNIA EARTHQUAKE

The earthquake that occurred in the Los Angeles/San Fernando Valley area at 6:01 a.m. on February 9, 1971, represented the first major disaster declared under the Disaster Relief Act of 1970, Public Law 91-606, enacted into law on December 31, 1970. While of lesser magnitude (6.6 on the Richter scale), releasing only about 1/1000 as much energy as the Alaska earthquake, it nevertheless caused about the same amount of property damage and half as many deaths. Homes, commercial buildings, hos pitals, and schools bore the brunt of the earthquake's destructiveness. Two structures located at Sylmar were the worst hit: the 45 year old Veterans Administration Hospital and the Olive View Sanitorium, accounting for most of the total loss of life. Damage to highways and public utilities was extensive, with collapsed overpasses and buckled pavements, broken mains, and downed lines.

Due to the severity of the damage, the President declared a major disaster for California on the same day the earthquake struck. With the cooperation of Los Angeles County, OEP set up six Disaster Assistance Centers, manned by local, State, and Federal agency personnel, to assist the victims to obtain the recovery help to which they were entitled. The Red Cross established seven emergency welfare centers to care for those families whose homes had been condemned. The Salvation Army operated mobile feeding units in the stricken area. The shortage of drinking water was alleviated by the use of large tank trucks provided by local government, private industry, and the National Guard.

After the massive rescue, evacuation, and mass care operations, first consideration was directed to housing the earthquake victims. The greater portion of temporary housing requirements was met by Federal leasing of privately owned rental properties. This was done in accordance with local and State governments' desire to maximize occupancy of local properties.

Public Law 91–606, unlike the disaster legislation applicable to the Alaska earthquake, permitted unemployment benefits to those who lost their jobs as a result of a major disaster. These payments were made from the President's Disaster Relief Fund to eligible applicants through the affiliated State Unemployment Insurance Offices.

Along with the Veterans Hospital rescue effort, the most dramatic aspect of the first few days after the quake was a threatened break in the damaged Van Norman Dam. Had the dam given way, several billion gallons of water would have rushed out and flooded the adjacent area. 80,000 persons living below the dam were evacuated from their homes until a safe water level had been reached.

Debris clearance and the demolition of unsafe structures were assigned by OEP to the Army Corps of Engineers. Restoration work for water and sewer facilities of the City of San Fernando was also assigned to the Corps, which completed temporary water service by February 21, 1971, and sewer service, on an emergency basis, by March 12. Permanent repairs were started shortly thereafter. The Federal Highway Administration made immediate damage surveys and arranged for temporary detours on some essential major highways pending construction of permanent repairs. The Department of Health, Education and Welfare gave priority to assessing the damage to schools and hospitals in order to determine the amount of Federal funding that would be needed for repair and maintenance of operations.

To date, $122,145,137 has been obligated from the President's Disaster Relief Fund for recovery and rehabilitation purposes. The estimated remaining requirement from the Fund is $61,060,764, for a total estimated requirement of $183,-205,901. This total is supplemented by the many millions in grants and loans being provided by other Federal agencies under their independent statutory authorities.

The large difference in Federal disaster expenditures between the 1964 Alaska and 1971 California earthquakes for similar amounts of property damage is due to the expansion and liberalization of benefits, particularly to individuals, which were made available to California under the Disaster Relief Act of 1970, Public Law 91–606.

## EARTHQUAKE PREPAREDNESS

The current disaster legislation administered by the Federal Disaster Assistance Administration, the Disaster Relief Act of 1974, Public Law 93–288, further improves and expands the extent of available Federal aid in both the public and private sectors. While a major earthquake has not occurred since FDAA was established, the agency is aware of the dire consequences that may follow one and has taken appropriate planning and preparedness steps to mitigate its effects. The following indicates the actions taken in this direction by FDAA and its predecessor agency:

In March 1971, following the San Fernando earthquake of the preceding month, OEP initiated a program of earthquake studies and plans for high seismic risk areas of the United States. The program envisioned a series of earthquake vulnerability analyses of selected, densely populated metropolitan areas and a set of coordinated Federal, State, and local emergency response plans, based on such studies.

The initial effort was focused on the nine-county San Francisco Bay area. At the request of and with financial assistance from OEP, the National Oceanic and Atmospheric Administration (NOAA) conducted a study of the potential effects of a maximum credible earthquake on the people, properties, and key life-sustaining facilities and systems of the Bay area. The purpose of the study was to provide a common base upon which to prepare appropriate emergency response plans at each level of government—Federal, State, and local. The report, entitled *A Study* *of Earthquake Losses in the San Francisco Bay Area*, was completed and published in June 1972.

In January 1973, again at the request of OEP, NOAA began a second and similar analysis of the potential effects of a major postulated earthquake occurring in the Los Angeles-Orange County area of California. A *Study of Earthquake Losses in the Los Angeles Area* was completed in December of that year. Like its predecessor, it provides a scientific and engineering analysis of the probable effects of such a disaster on the communities within the affected area.

Concurrently with the development of these studies and in anticipation of their findings, OEP entered into a contract with the State of California in September 1972 under the provisions of PL 91–606. In accordance with the terms of the contract, California received a $250,000 matching grant for the development of a set of complementary State and local emergency plans for response to major earthquakes in the San Francisco Bay and Los Angeles areas.

During the same period, OEP commenced development of a Federal earthquake response plan for the San Francisco Bay area. This plan, involving the coordinated efforts and participation of some 50 Federal agencies and private relief organizations, is designed to supplement the disaster relief efforts of State and local governments, and to intermesh with their respective planning efforts. All of these plans—Federal, State, and local—are in an advanced stage of development and are currently under revision to reflect the provisions of PL 93–288. Appropriate exercises to test the plans are anticipated in the fall of 1975.

In January 1974, FDAA entered into a second interagency agreement for the development of earthquake vulnerability analyses of two additional areas: Puget Sound, Washington, and Salt Lake City, Utah. This agreement was made with the U.S. Geological Survey (USGS) which had, at that time, inherited the personnel and responsibilities for earthquake studies formerly assigned to NOAA.

Both of these studies are scheduled for completion in September 1975. As in the case of the California studies, each will examine the probable effects of major postulated earthquakes on the people and key facilities and systems within the affected area and will, thereby, provide credible bases upon which the Federal Government, the States of Washington and Utah, and their respective local jurisdictions will develop emergency plans to respond to the needs of potential earthquake victims.

During 1974, the State of Washington applied for and will receive a total of $250,000 of Federal funds under the matching grant provisions of PL 91–606. One hundred fifty thousand dollars of this sum, matched by its equivalent from the State, will be applied to the development of an earthquake response plan, based on the USGS study.

The State of Utah has also applied for and will receive a Federal grant of $234,335 under the provisions of PL 93–288 for the development of its disaster plans, programs, and capabilities. A significant portion of this Federal grant will be used for the preparation of a State earthquake response plan, based on the corresponding USGS study. Complementary Federal earthquake response plans for the provision of supplementary Federal assistance in the event of a major earthquake disaster will be initiated during the current year for both Washington and Utah.

PL 93–288 authorizes a $250,000 development grant to each State, with another $25,000 per year available to each to improve, maintain, and update planning. The May 22, 1975 deadline—one year after enactment of this legislation—for applying for the new preparedness development funds has been met, either by formal application or by preliminary letters of intent from the Governors of all fifty States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, American Samoa, Guam, the Trust Territory of the Pacific Islands, and the Canal Zone.

FDAA has also undertaken the preparation of a *Directory of Disaster Related Technology* that contains summaries of ongoing and recently concluded studies and research on assistance and preparedness for all major disasters, including earthquakes. The directory will serve to improve the application of seismic science and technology by Federal, State, and local governments and the private sector through an exchange of earthquake-related information on the results of recently completed research and studies. Such applications might include new disaster legislation, land use planning and regulations, building codes and standards, design and construction practices, emergency response plans and operations, and other mitigation measures.

I hope the foregoing statement on FDAA programs and actions on the subject of earthquake disasters adequately responds to your inquiry.

Sincerely,

THOMAS P. DUNNE,
*Administrator.*

# STATEMENT OF LLOYD S. CLUFF
# FOR WOODWARD-CLYDE CONSULTANTS
# BEFORE U. S. SENATE COMMITTEE ON
# AERONAUTICS AND SPACE SCIENCES
# INVESTIGATION AND INQUIRY ON EARTHQUAKES

I am pleased to provide this statement in lieu of my personal testimony in Salt Lake City on April 26, 1975. I have been asked to address my comments to the following three basic questions:

1. In terms of earthquake research, what is private industry doing now?
2. How can the Federal Government benefit by cooperation in research projects with private industry?
3. What is the potential for private industry in earthquake research on a national basis?

In answering these questions, I have incorporated information from several of my professional colleagues at Woodward-Clyde Consultants. I would like to specifically mention two of these individuals because they are international leaders in their respective fields of earthquake research: Dr. I. M. Idriss, who has carried out extensive earthquake research in the fields of soil dynamics, ground response, liquefaction, and soil-structure interaction, and Dr. Don Tocher, who, before joining Woodward-Clyde Consultants, was Research Seismologist at the U. S. Geological Survey and former Director of the Earthquake Mechanism Laboratory in San Francisco. Dr. Tocher's activities have included basic research on earthquake mechanisms, surface faulting and fault creep, crustal movements, earthquake energy, microearthquake monitoring, earth strains and tilts, and engineering seismology. Both of these individuals have significantly advanced the state of knowledge and the art of understanding earthquake mechanisms and earthquake effects. I believe I can best answer the first question by giving a brief explanation of our firm and of the types of earthquake-related research and studies that have been and are currently being conducted by the staff of Woodward-Clyde Consultants.

Woodward-Clyde Consultants (WCC) is a group of practicing earth and environmental scientists. Our organization is divided into the following professional groups: Geology, Seismology, and Geophysics; Earthquake Engineering; Soils Engineering; and Environmental Studies. We have the capability to perform regional and local fault investigations; siting studies for important structures such as power plants, hospitals, fire stations, schools, and high-rise buildings; foundation studies; soil-structure interaction studies; and environmental impact studies. There are 646 professionals at WCC, and most of them are working on projects that involve some aspect of earthquake research.

Our basic philosophy at Woodward-Clyde Consultants is to utilize an interdisciplinary team approach involving seismology, geology, geophysics, earthquake engineering, planning, and the social sciences. Many of our completed projects and those on which we are currently working utilize this interdisciplinary team approach. The use of the interdisciplinary approach, which has proven to be very successful in dealing with earthquake-related problems, is sometimes difficult to apply most effectively because of the large volume of data from the different disciplines that must be incorporated. In order to utilize all of this technical input most efficiently, Woodward-Clyde Consultants has developed and fostered decision-analysis theory. The use of decision-analysis theory is proving very successful in some of our more difficult studies in managing the complexities of the interdisciplinary data and in considering potential social impact.

Funding for earthquake studies at WCC comes mostly from private industries; although, we do receive research funds from various governmental agencies that are particularly interested in practical solutions for mitigating and minimizing earthquake and geologic hazards. We have worked and are presently working with several governmental agencies in the United States on earthquake research, including the U. S. Geological Survey, the Tennessee Valley Authority, the U. S. Army Corps of Engineers, the Veterans Administration, the General Services Administration, the USDA Soil Conservation Service, the U. S. Agency for International Development, the Nuclear Regulatory Commission, and the Energy Resources Development Administration.

Woodward-Clyde Consultants is also working with the governments of Mexico, Nicaragua, Venezuela, Peru, Chile, Italy and Iran. Our studies there are aimed primarily at understanding how earthquake forces and effects may cause damage and loss of life so that critical structures may be sited in order to minimize the earthquake hazard in regions of potential seismic activity.

We cooperate with other organizations such as the University of Utah, Brigham Young University, the Utah Geological and Mineralogical Survey, Boise State College, the University of California at Berkeley, the University of California at Los Angeles, the University of Nevada, the Colorado School of Mines, California State University at Humboldt, St. Louis University, the University of Arizona, Massachusetts Institute of Technology, and California Institute of Technology. These cooperative research programs are particularly helpful in exchanging knowledge and ideas with other scientists involved in research on earthquake problems.

Woodward-Clyde Consultants also sponsors company research that includes earthquake and geologic hazard studies that have been completed in many parts of the United States, and in other countries including Mexico, Guatemala, Nicaragua, Venezuela, Columbia, Ecuador, Peru, Bolivia, Chile, Japan, Taiwan, New Zealand, Australia, Italy, Switzerland, Germany, Turkey, Iran, Iceland, Mozambique, Lebanon, and Saudi Arabia. Company-sponsored research has included investigating and studying the effects of the following damaging earthquakes:

1. The 1959 Hebgen Lake, Montana, earthquake.
2. The 1964 Alaska earthquake.
3. The 1964 Niigata, Japan, earthquake.

4. The 1966 Parkfield, California, earthquake.
5. The 1967 Caracas, Venezuela, earthquake.
6. The 1968 Dasht-E Bayāz, Turkey, earthquake.
7. The 1970 Peru earthquake.
8. The 1971 San Fernando, California, earthquake.
9. The 1972 Managua, Nicaragua, earthquake.

Following are brief descriptions of some projects that were undertaken by Woodward-Clyde Consultants. These descriptions should give the panel an idea of what private industry is doing in the field of earthquake research.

WCC performed a nuclear power plant siting study in California for Pacific Gas and Electric Company. The purpose of this study was to find areas in northern and central California that were geologically and seismologically favorable for nuclear power plant siting. The study included a Phase I program that utilized the existing literature and interpretation of remote-sensing information, including ERTS and high-altitude photography available through NASA's efforts, in order to locate areas free of known surface faulting, having low levels of seismic activity, and containing very few lineaments. Five such areas were delineated and studied in detail during Phase II in order to select candidate sites in each area. These detailed studies included analysis of low-sun-angle aerial photography, field mapping, age-dating and stratigraphy studies, drilling, and trenching. Similar, but less detailed, siting studies are being conducted for the entire State of Washington, and parts of Oregon and Idaho.

WCC is deeply involved in the mapping of the complex fault system in Managua, Nicaragua, in connection with the rebuilding of that city. The maps that we are developing through our studies there will be used to help to zone the city as to the types of structures that will be allowed and the location of green belts and parks in order to minimize the damage from future earthquakes.

Our firm did a seismicity and seismic geology evaluation of northwestern Venezuela for Compania Shell de Venezuela and other associated oil companies. The objective of this study was to evaluate the future earthquake activity in all of northwestern Venezuela and to provide earthquake design criteria for industrial development within this region. The investigation was conducted in three phases: 1) field evaluation of the geology and fault systems in an area of 250,000 square miles, 2) compilation of 400 years of recorded earthquake history in Venezuela and Colombia, and 3) detailed evaluation and analysis of the faults in relation to the degree of activity and potential for causing large earthquakes. A 400-year earthquake catalogue and map were prepared that showed the relationship between historical seismicity, and fault location and activity. A series of earthquake recurrence curves were prepared based on the records and used with the active fault data in order to assign "maximum credible," and "maximum probable" design earthquakes. The probable related effects of tsunamis, landslides, and subsidence were also evaluated.

WCC conducted a fault study along the proposed route of the Trans-Alaska Pipeline, investigating the activity of known faults and locating and classifying previously undetected faults. Detailed investigations were performed at all locations where the pipeline would cross faults. We estimated the amounts of displacement that could be expected on these faults so that the pipeline could be designed accordingly in these areas.

Our studies of the Wasatch fault in Utah and Idaho have been aimed toward identifying and locating the most recently active trace of the fault and other fault-related hazards. They also provide examples of legislation for reducing risk from earthquake-related hazards. These studies, which have been completed for the Utah Geological and Mineralogical Survey and the U. S. Geological Survey, have resulted in a series of maps for planning purposes that delineate the Wasatch fault between Gunnison, Utah, and Malad City, Idaho, and include Salt Lake City, Provo and

Ogden. We have studied, in a similar manner, the East Cache Fault in Logan, Utah. Current investigations of the Wasatch fault are intended to yield data regarding the frequency of moderate to large earthquakes by means of geologic study of young fault displacements recorded in the strata along the fault.

In Italy, we are providing guidance to Ente Nazionale per l'Energia Elettricia, the national electric authority, regarding safety-related topics in the siting of both conventional and nuclear power plants. This is a joint effort with Italian geoscientists, wherein our firm provides expertise in seismic geology, seismology, geophysics, and earthquake engineering. Specific, safety-related topics that have been evaluated to date include: surface faulting, design earthquakes, tsunami potential, earthquake ground motion characteristics, and liquefaction potential. Site studies to date extend from Sicily northward to the Swiss border, and include four nuclear and four conventional power plant sites, plus the proposed Messina Strait bridge crossing.

We have completed an extensive geologic hazard study of the entire State of California for HUD and the California Division of Mines and Geology. This was a major interdisciplinary study involving Woodward-Clyde Consultants; Livingston and Blayney, city and regional planners; McClure and Messinger, structural engineers; and a board of distinguished consultants. The main objective of this statewide study was to develop a method for assigning priorities for geologic investigations in the urban areas of California. The method was intended to identify areas in the state where the combination of geologic hazards and high population growth rates demonstrated a need for geologic investigation by the Division of Mines and Geology. The method utilized computers to process information on geologic hazards and population growth trends. The geologic hazards considered include: active faults, earthquakes, landslides, volcanic eruption, tsunami, flooding, erosion, expansive soil, subsidence, and loss of mineral resources. By applying the method statewide, a series of maps was produced showing the relative priority for geologic study in each of the 7-1/2 minute quadrangles in the state, and in each quarter quadrangle in urban areas.

In the field of earthquake engineering, Woodward-Clyde Consultants has conducted a wide variety of research and applied studies in order to provide quantitative estimates of the ground motions to which structures may be subjected during earthquakes, and to estimate the potential for ground failure, including liquefaction, during earthquakes. The results of our research provide criteria for structural design of many types of critical facilities, including nuclear power plants, hospitals, schools, and offshore oil platforms. Some typical studies are the following.

During the 1971 San Fernando, California earthquakes, major structural damage and ground failure occurred at a newly constructed water treatment plant. We conducted extensive studies in order to determine the causes of the damage. Research of this nature provides data that can be used to improve earthquake-resistant design.

Earthquake engineering studies being conducted in Managua, Nicaragua, which was destroyed by a local earthquake in 1972, are aimed at under standing the characteristics of ground motions in different parts of the city due to local and distant earthquakes. This results of our study will be used as a basis for seismic design criteria for new buildings.

WCC has conducted stability studies for several existing hydraulic-fill dams located in highly seismic regions. Many such dams were constructed prior to the present accumulation of knowledge regarding the effects of earthquake vibrations on soils, and some of these dams have failed during earthquakes in recent years. Many old dams are being strengthened or replaced based on the results of such studies. Proposed dams are also being analyzed in order to minimize the potential for failure during earthquakes.

In answer to the last two questions, I believe that it can be seen that there is considerable potential for private industry in earthquake research. Woodward-Clyde Consultants is already involved in earthquake research on a national and international basis which obviously benefits, directly or indirectly, the people of the United States. Earthquake research could be further enhanced by cooperation between private industry and the Federal Government in the following ways.

We at Woodward-Clyde Consultants, as a scientific and professional group, feel very strongly that studies of faulting and earthquakes must take into account the tectonics of an entire region, rather than just of the site or local area of specific interest. To do an adequate job of this requires an understanding of the plate tectonic regime in the region of interest or even, depending on the area, an understanding of global tectonics and how it affects an area.

I feel that the need for this approach was proven conclusively during the recent trips of American geologists and seismologists to mainland China. The Chinese have a 3,000-year historical record of earthquake occurrences that indicates a shifting pattern of seismic activity in China. As an example, there is a major regional fault system that, from a geologic point of view, looks as though it should be very active. There has, however, been no seismic activity on this fault system since the instrumental seismic monitoring program started in the 1930s. In the United States, many people would argue that a structure such as this, with no instrumental seismic record, is an inactive structure. In China, by examining the historical record, it can be determined that this fault system has had several periods of high seismic activity during which many destructive earthquakes were generated. These periods of seismic activity were each 200 to 300 years long and were as many as 400 years apart.

In the United States, where this historical record is lacking, we must depend on detailed geologic studies to unravel the seismic history of a region. Some of the tools that are very useful in such studies are the remote-sensing data available through NASA's efforts (high-altitude color, color infrared, black-and-white, multispectral, ERTS, Skylab, etc.). These various imageries allow us to do structural and tectonic interpretation of fairly large regions in a relatively short time. Of course, interpretation of remote sensing data does not answer all the questions; a great deal of ground work is also necessary. However, remote sensing provides an excellent reconnaissance tool upon which more definitive, detailed studies may be based and these imageries are very valuable to our profession.

In summary, the Federal Government could augment earthquake research by supplying more and better imagery and by making it more readily available to private industry than it is now. The Federal Government could also support age-dating research directed toward the dating of Pleistocene geologic materials. These data are very important when evaluating the seismic history of a region and with tools such as these available, it will be possible for private industry to continue to make significant contriutions toward understanding earthquake mechanisms and effects.

Private industry can be very effective in the effort to minimize the impact of earthquakes on man and his environment because it has specialists in almost every field of earth science engaged in applied research. It is required by its clients to provide pertinent information that can be used immediately. The main contribution that private industry makes to earthquake research is to use its background, expertise, and orientation to collect and analyze data regarding particular problems and to develop scientifically advanced, yet practical, programs for dealing with those problems within reasonable lengths of time.