Earthquake Prediction and Hazard Mitigation--
Options for USGS and NSF Programs

September 15, 1976

N O T I C E

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This document constitutes a plan based upon staff working papers, two Advisory Gp meetings (June and August 1976), input fr Advis Gp members and subpanels, and comments, suggestions and criticism received from others. Contents include 4 chapters: (I) Introduction, including list of Advis Gp members; (II) Brief assessment of available social, political, economic measures for mitigating impacts of earthquakes and the current state of the technological basis for these measures; (III) Discussion of current earthquake research efforts and options for future augmentation of earthquake research, including activities, funding levels, technical milestones, and public benefits; (IV) Discussion of the efforts and options for improving utilization of research results and coordination mechanisms. The document builds upon numerous studies of the earthquake problem and analyses of strategies for response to it that have already been made. Some of the most significant of these are listed in Appendix I.

17. Key Words and Document Analysis. 17a. Descriptors

Earthquakes
Earth movements
Geological faults
Seismic epicenter
Seismic waves
Seismology
Shock waves
Soil dynamics
Tsunamis
Earthquake warning systems
Seismic arrays
Seismic detection
Seismological stations
Seismic investigation
Seismic prospecting
Seismic reflection
Seismic refraction
Seismic surveys
Seismographs
Seismometers
Hazards
Safety devices
Safety engineering
Safety warning systems

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PREFACE

At the request of the Science Adviser to the President this plan presents options for augmenting the earthquake related research programs of the Department of Interior/U.S. Geological Survey (USGS) and the National Science Foundation (NSF). It was prepared by an external Advisory Group on Earthquake Prediction and Hazard Mitigation and a special staff planning group from USGS and NSF.

In focusing on the programs of these two agencies we would be remiss in not pointing out the importance of related activities of other agencies which we assume will continue and be strengthened. We have sought their comments on this plan and received valuable inputs from them. These other Departments and Agencies include the:

Department of Interior
- Bureau of Reclamation

Department of Housing and Urban Development
- Federal Disaster Assistance Administration
- Federal Insurance Administration

Department of Commerce
- National Oceanic and Atmospheric Administration
- National Bureau of Standards

Department of Defense
- Advanced Research Projects Agency
- Defense Civil Preparedness Administration
- Corps of Engineers

Department of Transportation
- Federal Highway Administration

General Services Administration
- Federal Preparedness Agency

National Aeronautics and Space Administration

Energy Research and Development Administration

Veterans Administration

Nuclear Regulatory Commission

Table of Contents

I. Introduction

A. The Nature of the Earthquake Problem

The popular conception of earthquake hazard in the United States limits it to the Pacific Coast, especially California, and to such well-known earthquake disasters as the ones at San Francisco in 1906, Long Beach in 1933, southern Alaska in 1964, and San Fernando in 1971. But major earthquakes are by no means unknown to the rest of the country. Earthquakes occurred in the St. Lawrence River region on several occasions from 1650 to 1928, in the vicinity of Boston in 1755, in the Central Mississippi Valley at New Madrid, Missouri in 1811 and 1812, in Charleston, South Carolina in 1886, and at Hebgen Lake, Montana in 1959. Known damaging earthquakes in the United States through 1970 are shown in Figure 1.

Because of the extensive development in this century, recurrence of a great earthquake would result in much greater damage and loss. Another catastrophic San Francisco earthquake, for example, could cause losses in the tens of billions of dollars. Clearly, earthquakes now pose an increasingly costly threat to the local and national community.

What's more, earthquakes affect human beings and their activities over widely spread areas. The San Francisco quake was felt over a 400,000 square mile area; the quakes at Charleston, New Madrid, and along the St. Lawrence were felt over an area of 2 million square miles. And in 1973, earthquakes were felt in 34 states. This last figure may be a better index of the extent of earthquake hazard in the United States. A recent study suggests that all or portions of 39 states lie in regions of major and moderate risk -- with a combined population in 1970 of more than 70 million persons. Current construction investments are estimated at approximately $150 billion per year of which about $50 billion per year is for construction located in high and moderate seismic regions of the country, and this cumulative investment needs protection.

Fortunately, a damaging earthquake at a given site is a relatively rare event in this country. And perhaps that is why the average annual loss from earthquakes is relatively low. During the past century, it has amounted to about $30 million per year. However, historical data can be misleading. The development of dense populations in seismically hazardous regions, for example, is a relatively recent phenomenon in the United States. If such development continues estimates of the average loss for the rest of this century resulting from earthquakes could exceed $1 billion per year (Wiggins, et al., 1974 [see References, p. 108]).

Earthquakes resulting in substantial property damage since 1860 are listed in Table 1. The damage figures for these events are given in terms of then-current dollars and do not represent present inflated values. Deaths from U.S. earthquakes are shown in Table 2. It should be noted that property damage and loss of life are only two aspects of loss due to earthquakes. Other losses include injuries, economic loss due to casualties, loss of income due to business disruption, cost of emergency operations, and so on. There is little available data on the extent of these indirect costs of earthquakes. They most certainly exceed the direct costs.

Losses from earthquakes are not limited to the direct effects of faulting and shaking. The seismic seawaves, or tsunamis, often associated with large submarine or coastal zone earthquakes can cause great damage by inundation and wave impact on shorelines thousands of miles from their source, as well as on shorelines near the epicenter of the earthquake that produces them. For example, Hilo, Hawaii suffered extensive damage from a tsunami generated off the Chilean coast in 1960. Table 3 lists damage and loss of life from tsunamis affecting the United States.

Zones of earthquake vulnerability are shown in a general way by seismic risk maps (Figure 2, conterminous United States; Figures 3 and 4, Alaska and Hawaii). Risk zone levels, ranging from 0 (no damage) to 3 (major damage), are defined in the legend of Figure 2. The distribution of population and states by risk zone is summarized in Table 4.

Several events of the past year or so have brought renewed attention to the threat of earthquakes. On February 1975 a major earthquake of magnitude 7.3 destroyed the town of Haicheng in the Peoples Republic of China and damaged industrial plants. Chinese scientists actually predicted this earthquake. The population was removed from hazardous buildings and only a few were killed even though 1 million people live in the area. According to recent reports Chinese scientists successfully predicted earthquakes in May 1976 (Yunnan Province) and August 1976 (Szechwan Province) and endangered people were evacuated from hazardous structures.

The Chinese, however, did not predict accurately what may be one of the worst earthquakes in this century, that struck the Tangshan-Tientsin region of north China on July 27, 1976. Other disastrous earthquakes have struck Guatemala, Italy, Western New Guinea, Bali and Mindanao in the Philippine Islands in 1976. This year will be recorded as possibly the worst, and certainly one of the worst, years in this century for deaths due to earthquakes.

In the Los Angeles area, Geological Survey scientists reported an uplift of the earth's crust along a section of the San Andreas Fault that has been relatively quiet since a great earthquake in 1857. This uplift is not necessarily an earthquake precursor, since such uplifts are not always followed by a major earthquake, but it is cause for concern.

While there are understandable disagreements as to priorities within Federal earthquake research efforts, there is no disagreement regarding the probability of a very high payoff of a well-planned research program. There is now an overwhelming concensus among workers in earthquake-related research (e.g., seismologists, geologists, engineers, social scientists) that we are ready to make substantial progress toward relieving the threat from earthquakes. In addition, there is general agreement that we have adequate professional and technical personnel to undertake additional efforts should greater funding levels be made available.

While both public and private decisions and resource commitments are difficult in problem areas such as earthquakes because while they can be catastrophic they have a relatively low probability of occurring in a specific location over short periods of time, it is important to recognize that:

a. Decisions are being made continuously regarding the location and design of earthquake-sensitive facilities that require judgments about seismic hazards and knowledge that are not adequately available; and,

b. government and private groups spend a great deal of money on relief of earthquake disasters; therefore, it is in our national interest to seek effective ways to mitigate these disasters.

B. Some Recent Actions

Early last winter, these items and recent earthquakes in other parts of the world were brought to the attention of the President by several means. The Presidential science advisory committees known as the Baker-Ramo Committees, then examining new opportunities in science, determined that the area of earthquake hazard reduction might be an area where increased research could be especially beneficial. Discussion of this subject among officials of the Executive Branch was being undertaken at about the time that extensive land uplift in southern California centered on Palmdale was first reported. In response to this situation, it was decided to reprogram 2.6 million dollars in research funds of the USGS and NSF, of which 2.1 million dollars is to monitor the uplift and 0.5 million is to partially restore reductions in the USGS earthquake hazard reduction program. Whether this uplift is a premonitor of an earthquake is as yet unclear. The research to be undertaken by the Geological Survey and non-government research organizations is intended to help determine whether this is indeed the case, and to evaluate the potential hazard.

The growing prospects for earthquake prediction, based in part on the still tentative experience of the Chinese, Japanese, and the Soviets suggest that in coming decades we may have a capability to predict earthquakes in the United States. The achievement of prediction will depend largely on the capability and capacity of our scientists to observe and interpret premonitory effects. It should be noted, however, that local communities and State governments need to make changes in their land use and building codes to reduce earthquake vulnerability if the goal of a significant capability to predict the location, time and magnitude of earthquakes is to result in reduction in property damage and life loss.

Damaged or collapsing structures are the source of most life loss and injury during an earthquake; therefore, nearly all impacts of an earthquake ultimately revolve around damage to structures. Although the Federal Government has been funding most research on earthquake prediction and hazard mitigation, the principal responsibility for applying this knowledge to the reduction of damage to buildings rests with State and local government and private individuals. Thus, the actual limitation of the impact of earthquake prediction and mitigation research lies in non-Federal hands.

As noted above, the reprogramming of funds from the NSF and the USGS to undertake a $2.6 million research activity will help us understand the Palmdale uplift as a possible premonitory effect of a major southern California earthquake. In addition, NSF and USGS were asked by the Science Adviser to jointly prepare a plan to outline the research which would be necessary to provide the technological base for making predictions, changing building codes, and restructuring land use. An outside Advisory Group on Earthquake Prediction and Hazard Mitigation to assist in this effort was established.

A list of the members of the Science Adviser's Advisory Group on Earthquake Prediction and Hazard Mitigation follows:

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C. The Contents of This Plan

This document constitutes a plan based upon staff working papers, the Advisory Group meetings of June 14, 1976 and August 12-13, 1976, inputs from Advisory Group members and subpanels, and comments, suggestions, and criticism received from others.

The contents of the remaining chapters of this draft plan are as follows:

Chapter II - A brief assessment of the available social, political, and economic measures for mitigating the impacts of earthquakes and the current state of the technological basis for these measures.

Chapter III - A discussion of current earthquake research efforts and options for future augmentation of earthquake research -- including activities, funding levels, technical milestones, and public benefits.

Chapter IV - A discussion of the efforts and options for improving utilization of research results and coordination mechanisms.

This document builds upon the numerous studies of the earthquake problem and analyses of strategies for response to it that have already been made. Some of the most significant of these are listed in Appendix 1.

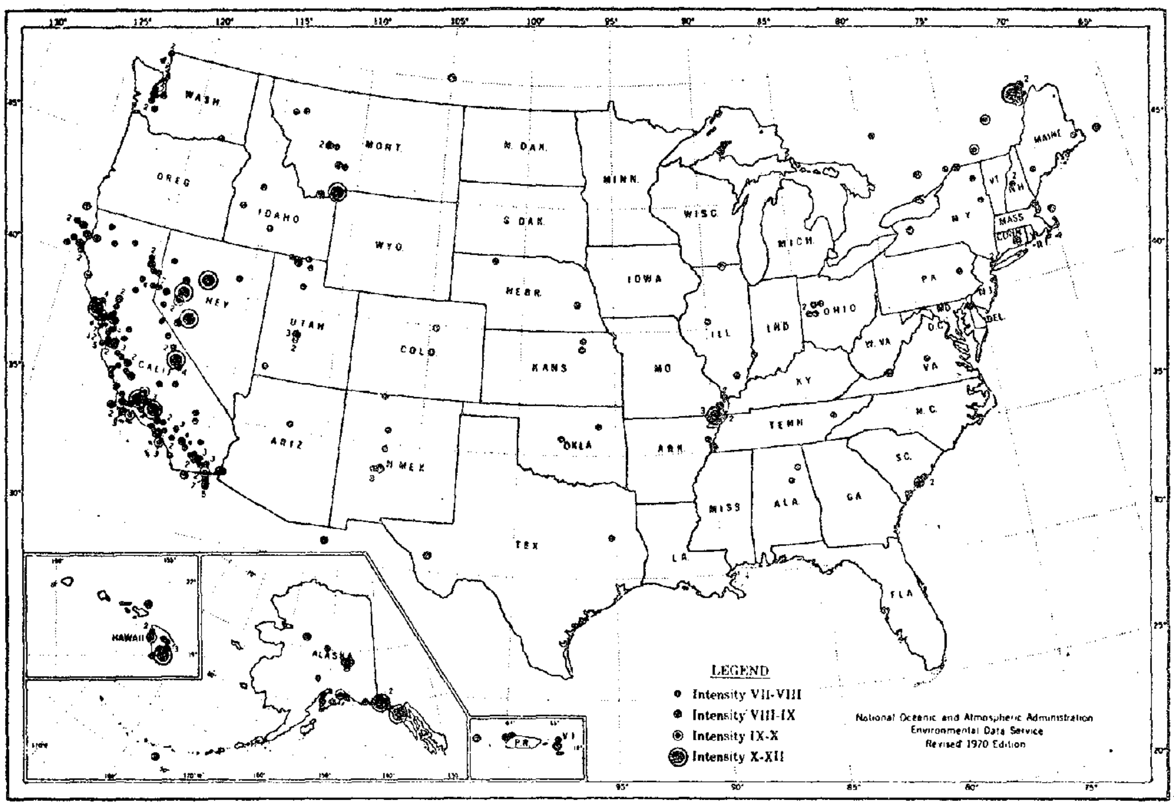

Figure 1. Intensity and location of known damaging earthquakes in the United States through 1970.

Table 1 - Property Damage in Major U.S. Earthquakes in Millions of Dollars (Actual), 1865-1975*

Year	Locality	Damage ($M)
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.	524.0
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 coast)	25.5
1961	Terminal Island, Calif. (oil wells only)	4.5
1964	Alaska and U.S. West Coast (includes tsunami damage from earthquake near Anchorage)	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
1973	Hawaii	5.6
1975	Aleutian Is.	3.5
1975	Idaho/Utah (Pocatello Valley	1.0
1975	Hawaii	3.0
1975	Humboldt, Calif.	.3
1975	Oroville, Calif.	2.5
	TOTAL	1878.0

* These damage estimates are at the time of the earthquake. They do not include the effects of inflation. They are not estimates of the likely damage if a similar earthquake occurred today.

Table 2 - Lives Lost in Major U.S. Earthquakes, 1811-1975*

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
1975	Hawaii	2

* These figures are the lives lost at the time of the earthquake and do not reflect the likely loss of life if a similar earthquake were to occur today.

Table 3 - Casualties and Damage in the United States from Tsunamis**

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
1958	2	-	50	Alaska
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
1975	1	-	2,000	Hawaii

*Damage reported, but no estimates available.

** These figures are the lives lost at the time of the tsunami and do not reflect the likely loss of life if a similar earthquake and tsunami were to occur today.

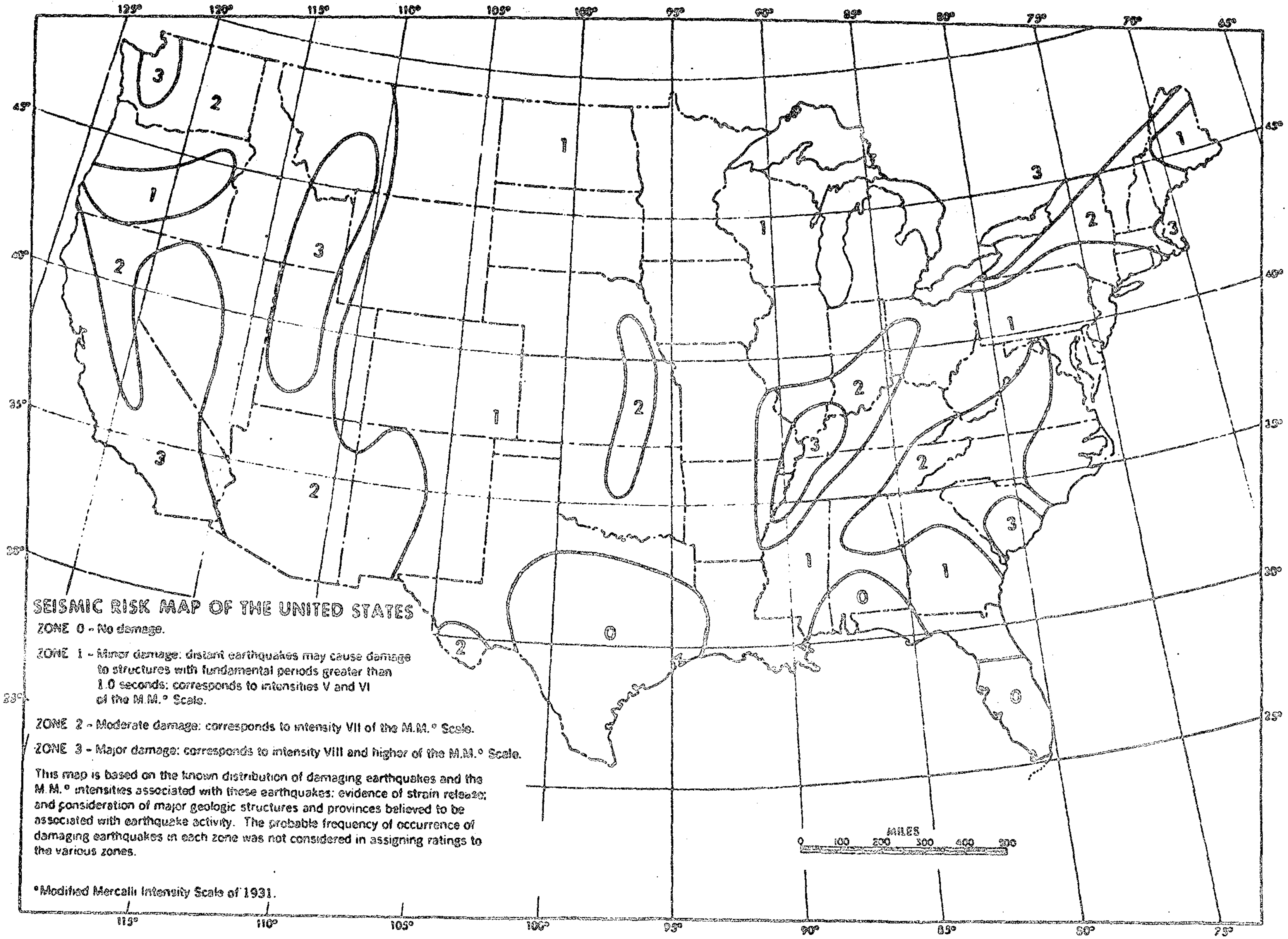

Figure 2
(Algermissen, 1969)

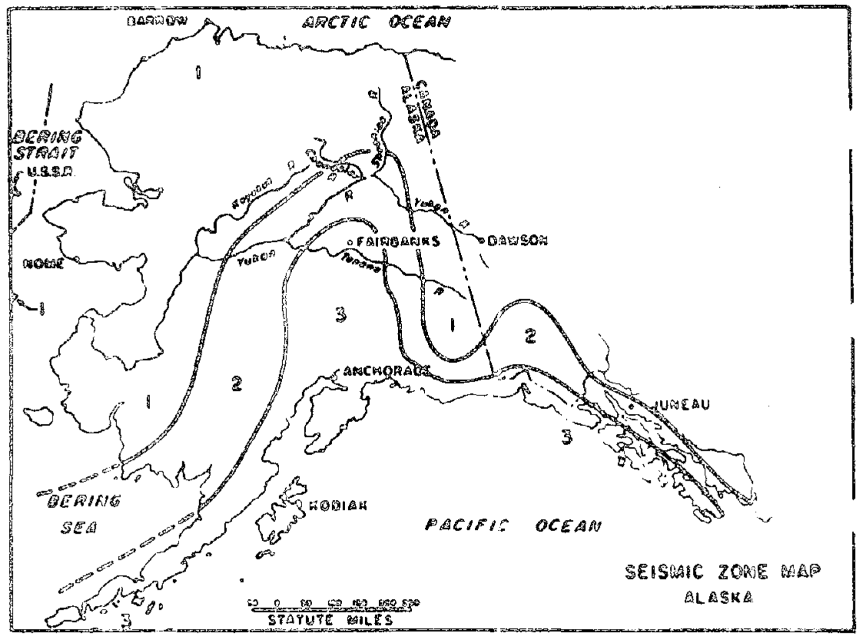

Figure 3 - Seismic Risk Map of Alaska
(Uniform Building Code, 1973)

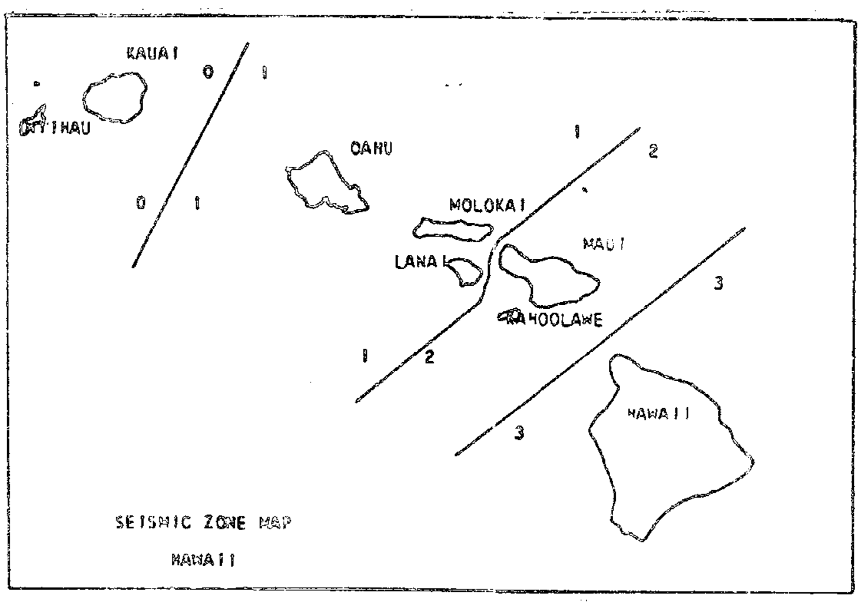

Figure 4 - Seismic Risk Map of Hawaii
(Uniform Building Code, 1973)

Table 4 - U.S. Population vs. Earthquake Risk Zones

Risk Zone	Population		Number of States Affected
	Millions	% of Total	
0 (low)	17	8	5
1	115	57	42*
2	40	20	39
3 (high)	31	15	21
TOTAL	203		51*

*Including the District of Columbia

II. Measures for Mitigating Earthquake Effects

A. Possible Mitigation Measures--What can we do?

Mitigating the impact of an earthquake disaster requires social, economic, and political actions, especially at State and local levels. But the extent to which these mitigation actions are effective and the cost of these actions depends in large measure on the extent to which they are based on factual information about the physical processes involved. Potential and actual earthquake disasters in other parts of the world and in the U.S. have demonstrated that reliable earthquake prediction can reduce casualties, that improved design and construction practices can reduce casualties and decrease losses, and that soundly based relief policies can reduce post-event suffering and accelerate the return of the community to its normal functioning. There are five basic strategies that can be undertaken by individuals, groups and government entities, as appropriate, to moderate impacts:

- <u>Preparation</u> - Preparation for an earthquake includes having plans for warning, response and recovery. These steps reduce the economic and social dislocations by community preparedness prior to the event, providing relief during the emergency period, and assisting in redevelopment and recovery.
- <u>Land Use</u> - By considering the regional and local variation of seismic risk in local and State land use plans, the vulnerability of new development can be reduced. Each of the principal sources of earthquake damage (e.g. ground shaking, fault movement, ground failure) is affected by the type of soil and geologic properties

of the site, and the position of the site with regard to the location of the earthquake. Effective local and State land use controls can either prevent occupation of a hazardous site, or characterize the hazards at the site so that facilities can be appropriately designed and built.

- Building Codes, Standards and Design Practices - The principle that the public has a right to control private and public property for the minimum safety of occupants lies behind public regulation of building. Such regulations are generally adopted as laws of local communities, e.g. building codes. Building codes and standards may be applied to new construction, and, potentially, to the correction or elimination of hazardous old buildings. In addition, conditions have been adopted for the receipt of financing, e.g. the Minimum Property Standards of FHA, or for the receipt of relief, e.g. flood plain zoning. Such regulations and conditions thus enable the community to express values and establish priorities.
- Insurance and Relief - The economic impact can be moderated by insurance, loan programs, and public and private relief efforts. Historically, the public and government have responded to the suffering of disaster victims both through the provision of immediate economic aid and long-term economic assistance. Insurance provides one means to spread the economic risk of the disaster.
- Information and Education - Through information and education, individuals acquire the background for making decisions at Federal,

State, local, corporate and family levels. The acceptance and effectiveness of any mitigation measures--many of which require an economic commitment--will depend critically on the public's perception of the necessity and utility of the measures, as well as on the reliability of the technological information upon which they are based.

B. Current Mitigation Practices--What are we doing?

Each of these mitigation means is now being utilized to some extent. Many more preventive and protective actions 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 afterward. Communications systems, such as between hospitals and police units, can be developed, serums and medicines can be stockpiled, and alternate transportation routes can be planned. Exercises and tests designed around earthquake scenarios can be undertaken. So can a plan of administrative action continuously updated by an ever-changing group of public officials.

A great many potentially affected communities have no disaster plans, and present levels of preparedness commonly fail to address earthquake hazards. Long-term recovery in the public sphere is often limited to grants and loans which end up encouraging redevelopment as vulnerable as ever to earthquakes.

The State of California has begun to take advantage of the existing information on earthquake hazards in the development of land use regulation and building codes. Land use planning and control has been little used as a mitigation measure outside that State. In 1971, the California legislature adopted an amendment to the State Planning Law that requires a "Seismic Safety Element" as a mandatory part of the General Plan of each city and county. Information about the locations of fault traces likely to rupture during future earthquakes has been taken advantage of in California by the passage and implementation of the Alquist-Priola Geologic Hazard Zones Act of 1972. This act requires the State Geologist to delineate zones along active faults in which special geologic studies must be carried out prior to development. Implementation of similar acts has not begun in other states with active faults capable of surface rupture. Some cities and counties, in California particularly, have taken advantage of information about landslides and landslide hazards in local land use planning, but this practice is not widespread. Substantial progress has been achieved on techniques for delineating liquefaction hazard. But the data base on subsurface conditions is vastly inadequate for land use planning, and little effort has been made to use the existing data for planning and control. In Japan and the Soviet Union, many cities in earthquake-prone regions are "zoned" to reflect anticipated variations in earthquake shaking--the most pervasive earthquake hazard--based on the distribution of geologic deposits. Such work has only begun in a very experimental way in the United States. The assessment of earthquake hazards at specific sites is for the most part restricted to special facilities, particularly those that pose substantial life hazards (e.g., reactors and dams) or those that are very expensive (e.g., tall buildings). These assessments commonly raise issues which cannot be satisfactorily resolved because of an insufficient data base or an inadequate understanding of the threatening phenomena.

Building codes--which provide the most effective check against building collapse in an earthquake--vary greatly in their incorporation of seismic safety provisions and in practice. Further, many aspects of earthquake-resistant design cannot be covered effectively in building codes. These aspects must include the responsibility of the architect and engineer. A code is of value only as long as it is followed, enforced, and maintained. Construction practices also play a critical role. The success of the Field Act in California in reducing damage to schools during earthquakes demonstrates the efficacy of a comprehensive program of building regulation, design review, construction inspection, and maintenance.

Although earthquake insurance is generally available, the vast majority of residential property owners do not take advantage of it. In California, following the San Fernando earthquake of 1971, there was no substantial increase in the total premiums written for earthquake insurance. Insurance companies have not successfully promoted earthquake insurance. Insurance without hazard mitigation requirements would reduce incentives to employ earthquake-resistant design and other hazard reduction procedures. The current state of earthquake hazard mitigation information, procedures, and practices has to date impeded development of insurance plans.

The availability of information about earthquake hazards does not, of itself, insure the use of that information. However, where it exists and the citizenry is aware and concerned, steps can and have been taken--for example, amending land use policies and building codes to reflect seismic and geologic conditions. But more important, no mitigation measure can succeed in a pluralistic society like our own without a solid base of public understanding. To date, the dissemination of information to the public has been primarily in response to inquiries by individuals or the press. Little or no effort has been made to educate the public systematically about the causes and effects of earthquakes and what they can do to moderate the impacts. As an instructive example--albeit in a political environment drastically different from our own--the earthquake hazard mitigation program in the People's Republic of China has a strong public education component. The value of this effort can be seen vividly in the response of the Chinese people to the Haiching earthquake of February 4, 1975. First, an unsuccessful and then, finally, a successful prediction of an earthquake were preceded by an intensive public education campaign. As a result of this campaign, the people understood not only the causes and effects of possible earthquakes, but also the uncertainties of the predictions. They were able to put the inconveniences associated with an uncertain prediction into perspective with the severe risks associated with the earthquake. Consequently, they were socially and psychologically prepared for the earthquake, and the trauma and suffering were lessened by the actions taken.

C. Dependence of Mitigation Measures on Technological Information--
What might we do better?

How will better understanding of the physical bases of earthquakes lead to an increased ability to mitigate the hazard through social means? All of the mitigation means depend on technological information, which can be classified into four categories:

- Prediction - forecasting the time, place, magnitude and ground motion of an earthquake.
- Induced Seismicity - prevention or modification of an inadvertantly induced or natural earthquake.
- Hazard Assessment - identification and analysis of the potential for earthquakes within a region, their frequency and their effects.
- Engineering - design and construction of facilities for acceptable performance during and after an earthquake.

Examination reveals several areas where increased understanding provides substantial additional leverage for mitigation. The following are some examples.

1) Preparedness could be made more effective by a reliable earthquake Prediction capability. Emergency services could be put on the alert. Hazardous structures could be selectively reinforced or evacuated, depending on the time available. Management plans of critical utility services and potentially hazardous facilities--such as dams, nuclear reactors, pipelines, etc.--could be altered

for more satisfactory post-earthquake operation.

2) Land use decisions could be more effective if information from Hazard Assessment of the location of faults and unstable site conditions were available.

3) Building Codes and Standards --as the first line of defense against earthquake disaster--can be made more effective by better application and improvement of Engineering techniques.

4) Insurance could be a more viable mitigating factor if increased information about seismic risk from Hazard Assessment were available.

5) Information and Education, as the primary means involving the general population in mitigation, must flow from fundamental understanding. Information and education are critical, considering that most significant Preparedness, Land Use and Building Codes and Standards decisions are made and implemented at the local level.

6) Understanding of Induced Seismicity would permit the adoption of appropriate mitigation measures around new large reservoirs.

7) Incentives provided by Federal and State Governments could help local jurisdictions deal more effectively with reducing earthquake vulnerability, particularly in the upgrading of existing hazardous structures and conditions.

D. Status of Technological Information Required for Mitigation--What do we know?

The technological bases for mitigation of earthquake hazards are at a variety of stages of development. Some techniques, such as earthquake prediction and control are at an embryonic stage. At the same time, some techniques for earthquake hazard evaluation and engineering design have already been developed to a high degree but have not yet been applied to many hazard-prone regions. Other techniques, such as the delineation of active faults, are partially developed and have been applied successfully in some regions already; the results of these applications are currently being used as the basis for land use planning decisions. Because these techniques are in various stages of readiness, the results from research on earthquake prediction and hazards mitigation will have impacts on a variety of time scales. Some results can be implemented immediately; others will not be ready for years.

The hypothesis that earthquakes are generated by the release of elastic strain energy—formulated by Reid following the 1906 San Francisco earthquake--underlies thinking about earthquake prediction today. Coupled with the modern concepts of plate tectonics, this classical idea gives earth scientists fundamental confidence that earthquakes can be predicted. The as yet poorly understood link in this process is the failure—or actual earthquake itself--and phenomena leading up to this failure.

Research programs in the USSR, Japan, People's Republic of China and U.S. have detected several possible precursors to earthquakes and models and theories to explain them. The precursors include variations in the velocity of seismic waves, the magnetic field, electrical resistivity, tilt and strain at the Earth's surface, water level in wells and others. Many attempts--principally based on analogy with laboratory experiments--to explain the processes leading up to an earthquake and to interpret the precursors have led to some success. However, there is not yet a unifying theoretical framework.

Observations with sufficient density in time and space are required to detect, document and analyze earthquake precursors. The relative infrequence of moderate earthquakes in any particular small area and the vastness of the potential source areas make this a large and costly task. Supporting laboratory, theoretical and computational studies are needed to provide a basis for interpretation of the precursors.

While not all the desired instrument systems are developed to the point where massive deployment is reasonable, some systems are well developed, field tested, and ready. Included in the latter category are short-period seismometer and telemetry systems, tiltmeters, magnetometers, gravimeters, some types of strainmeters, water-level recorders, digital telemetry systems, laser distance-ranging systems and classical surveying techniques. While improvements and evolutionary changes can be expected in these systems, substantial development work is still required in systems to measure deep electrical resistivity, telluric currents, geochemical parameters and stress, for some kinds of strainmeters, for multicolor laser-ranging systems, and other proposed instrumental and observational systems.

Substantial progress has been made over the last several years in the development of techniques and programs for the automatic processing and manipulation of the data recorded by these systems. These techniques are ready for application to the massive volumes of data that could be collected.

There are over 20 cases around the world where the filling of large reservoirs appears to have triggered or induced earthquakes. The triggered earthquakes range from microearthquakes recorded only instrumentally to earthquakes as large as magnitude 6-1/2. The largest earthquake thought to be so induced, near the Koyna Dam in India, December 10, 1967, resulted in 177 killed, 2,300 injured and extensive damage. While few large reservoirs are known to have triggered earthquakes, there is currently no accepted procedure to determine in advance of construction whether filling a reservoir will trigger an earthquake. Nor is there a procedure defined to allow operation of a reservoir (raising and lowering the head of water behind the dam) without danger of triggering earthquakes.

Experience with inadvertantly triggered earthquakes associated with the deep waste disposal well near Denver, Colorado, and in a recently completed earthquake-control experiment in an oilfield near Rangely, Colorado, shows that man can influence the occurrence of earthquakes under certain conditions. The procedure is based on the Hubbert-Rubey hypothesis that an increase in the pore pressure of fluids at depth results in a decrease in shear strength in the rock or fault zone, which could in turn allow the release of tectonic strain in an earthquake. The experiences at Denver and

Rangely confirmed this hypothesis. It is reasonable to expect that techniques based on this hypothesis can be developed that can greatly reduce, if not eliminate, the problem of the inadvertant triggering of earthquakes. Further, it is possible that this hypothesis might lead in certain areas to a technique for modifying natural earthquakes.

The assessment of seismic risk--i.e., the expectable size and frequency of earthquakes--through the United States is fundamental to all evaluation of earthquake hazard. A variety of seismic risk maps have been prepared for all or part of the United States, but the relatively short (from a geologic point of view) period of observation and the lack of understanding of the physical and geologic origins of earthquakes, particularly in the eastern U.S., have made these maps deficient in important respects. Most maps, for example, have been based on historic data alone. The less than 300 years of written history for most of the U.S. is inadequate to estimate reliably a phenomenon that may reoccur only every several hundred years or more in some regions. Obviously a great need exists to utilize geologic data on the recency of fault movement and other tectonic activity in order to extend this time base and to apply sophisticated probability techniques to the estimation of seismic risk. Some regions are covered poorly, if at all, by existing maps.

Some techniques for mapping and evaluating earthquake geologic hazards are relatively well developed. Within certain constraints, faults capable of rupturing the ground surface can be recognized and mapped. Techniques also exist for identifying slopes susceptible to landsliding. The processes of soil liquefaction and differential settlement are understood in general terms, if not in detail. Rough techniques for predicting tectonic surface distortions and level changes, critical for the prediction of the post-earthquake operability of canals and pipelines also exist.

The most pervasive and important hazard--ground shaking--can now be estimated only within broad limits. The strength and character of ground shaking at a site depend on the geologic conditions there, as well as on the distance and characteristics of the earthquake's source. Not all of the mechanisms and details of this dependence are clear.

Most of these techniques for hazard assessment require additional development, but most may be applied region by region at present to varying degrees. They require substantial field investigation and the gathering of significant regional geologic data. To predict areas susceptible to liquefaction, for example, requires substantial information about subsurface soil and ground water conditions. Only in the San Francisco Bay region, where experimental projects have been underway for several years, are data bases nearly adequate. Elsewhere, efforts to obtain the required data and apply these techniques have begun only at a low level or are nonexistent.

Methodology for estimating earthquake damage and loss, including methods for estimating damage patterns, is developing. Obviously such methodology would be of great value in making social and economic decisions ranging from insurance to relief and recovery.

Earthquake engineering encompasses various disciplines, including architecture, structural, and mechanical engineering and others. It is concerned with the design and development of physical systems that withstand earthquakes.

An earthquake causes damage to a supported structure by heavy ground shaking, slow or rapid fault slip, subsidence and landslides. Fundamental to understanding these damaging phenomena is the accurate knowledge of how the ground moves. There are two essential approaches to gaining this information: first, placing instruments to measure how the ground responds to earthquakes; and second, developing analytic models that consider source mechanism, propagation path properties, and soil conditions. Such models may anticipate site spectra, maximum acceleration, duration, velocity, and displacement and time histories and help formulate and verify analytic procedures.

A structure can be damaged either by the failure of the soils or rock that support it (and/or its subsequent movement under gravitational loads), or by the shaking transmitted to it by the surrounding soil. When soils are strongly shaken they may amplify the displacement imparted to the supported structure or may fail through a variety of mechanisms, including settlement of cohesionless soils, bearing capacity failure, embankment failure and soil liquefaction.

Structural integrity depends upon the complementary activities of design and construction. The basic problem in design is to synthesize the structural configuration (size, shape, materials and interrelation of load bearing and nonload bearing elements) with methods of fabrication so that the structure will safely and economically withstand earthquake induced loads. Analysis forms the basis for design. The ability to analyze a hypothetical structure for the stresses and displacements produced by a specified loading is essential. The more accurately this can be done, the more efficient and economical is the design and the more reliable the design factor of safety. The design and analysis processes are complicated because: First, even simple structures are exceedingly complex dynamic systems; second, the nature of earthquake occurrences and input motions is probabilistic; and third, the construction process leads to a structure that cannot be precisely described. Design and analysis must be carried out for all aspects of the structure, load bearing and nonload bearing, and by each member of the design team: the architect, foundation engineer, structural engineer, and mechanical engineer. Of special importance are assessing and possibly improving the earthquake resistance of structures built with inadequate resistance.

The operation of a community during and after an earthquake depends upon how well the utility and public service facilities function as a system with elements located at many sites. 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 performance characteristics required of the total system, not just the individual elements. Both physically connected (e.g. water distribution), and nonconnected (e.g. hospitals, clinics and laboratories) systems must be considered. The design of systems with appropriate seismic resistive characteristics is intimately related to local and regional planning. Such planning must consider both the direct impact of ground displacement and ground shaking as well as the indirect impacts indicated above.

III. Program Options

A. Program Objectives

The goal of earthquake prediction and hazard mitigation activities is to reduce casualties, damage, and social and economic disruption from earthquakes. The social, economic, and political actions that can be taken to attain this goal are based on technological capabilities that require development through research. The primary objectives of this research are:

- Earthquake Prediction - Develop the capability to predict the time, place, magnitude and effects of earthquakes so that more effective preparedness actions can be undertaken.
- Earthquake Modification and Control - Develop techniques that allow the control or alteration of seismic phenomena.
- Land Use - Develop procedures for assessing seismic risk and evaluating earthquake hazards so that appropriate construction and land use plans can be implemented.
- Design Improvement - Develop improved, economically feasible design and construction methods for building earthquake resistant structures of all types and for upgrading existing structures.
- Social and Behavioral Response - Develop an understanding of the factors that influence public utilization of earthquake mitigation methods.

Because present knowledge is inadequate to develop acceptable procedures for many aspects of earthquake mitigation, decision makers are severely constrained in actions they can take to reduce earthquake losses. For example, many factors influence the intensity of ground shaking by an earthquake, but an accepted procedure has not been developed for evaluating the relevant parameters. As a consequence, local and State land use zoning based on seismic risk cannot be implemented except in a very limited way. Similarly, earthquake precursors have been widely observed, but their characteristics are not sufficiently well known and instruments are not deployed in sufficient numbers to permit reliable earthquake prediction. The basic approach to earthquake prediction and hazards mitigation is to undertake research on the scientific and engineering problems that currently slow application. At the same time, improved implementation procedures must be developed. Regardless of our limited understanding of earthquake mitigation methods, investments are being made, structures are being built, land is being developed, earthquake precursors are being observed, and interpretations based on current understanding are being made.

B. Program Elements

The activities of earthquake prediction and hazard mitigation are grouped for programmatic purposes into six main elements, four of which parallel the physical adjustments and goals described earlier. The other two, numbers 1 and 6 below, are identified separately to emphasize that the program should span the whole spectrum of studies from fundamental research to applications. The Elements are:

1. Fundamental Earthquake Studies

2. Prediction

3. Induced Seismicity

4. Hazards Assessment

5. Engineering

6. Research for Utilization

The nature of these Elements is discussed in the following sections. Each Program Element is divided into Subelements and Activities. FY 76 (ending June 30, 1976) appropriations and FY 77 budget requests are shown. Funds provided for studying the land uplift in southern California are also shown. In addition, the tables give funding options as recommended by the Advisory Group and the NSF and USGS staff.

In the tables in the following sections on each Element, funding levels are indicated as follows:

FY 76 Act - Actual funding in FY 1976. The amounts in parentheses in this column are the funds provided for new studies of the land uplift in southern California.

FY 1977 Req. - Requested funding in the President's FY 1977 budget.

FY 1978, 1979, and 1980: A, B, and C - Three funding options for augmenting the USGS and NSF earthquake prediction and hazard mitigation research programs are presented. Option C is clearly the preferred and most effective option for accomplishing the objectives spelled out in this plan. Option A is considered to be barely adequate to accomplish the objectives of this plan and will require postponement of implementation of many important aspects of this plan. The FY 1978 Option A would provide significant improvement in the national capability to accomplish the objectives, but will necessitate a longer time period and the elimination of certain activities as the discussions of public benefits and technical milestones spell out. Option B is an intermediate option between the highest funding levels of Option C and the lowest funding levels of Option A.

On the next page there is a Summary table that shows the amounts recommended for each Element and the totals.

SUMMARY

Sub-Element		FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
		Act.	Req.	A	B	C	A	B	C	A	B	C
1. Fundamental Earthquake Studies *NSF and USGS. See page 43.	*	4.5	5.2	7.0	7.9	10.7	7.8	9.1	11.2	9.4	10.2	11.7
Uplift Funds		(0.1)										
2. Prediction	USGS	4.9	4.6	9.7	14.3	23.2	13.6	17.9	25.4	19.4	21.5	27.5
Uplift Funds		(1.6)										
3. Induced Seismicity	USGS	0.0	0.0	0.2	0.4	1.0	1.0	2.0	3.0	2.0	2.0	3.0
4. Hazards Assessment	USGS	4.4	4.2	6.3	10.6	17.4	10.7	14.8	21.2	15.0	19.0	25.0
Uplift Funds		(0.7)										
5. Engineering	NSF	7.1	6.7	10.5	15.6	26.0	11.6	20.3	28.0	22.5	25.0	30.0
6. Research for Utilization	NSF	0.0	0.0	4.0	4.9	6.5	5.3	6.1	7.3	6.6	7.3	8.0
USGS TOTAL		11.2	10.5	18.5	27.9	44.8	27.8	37.8	53.2	39.8	46.1	59.5
NSF TOTAL		9.7	10.2	19.2	25.8	40.0	22.2	32.4	42.9	35.1	38.9	45.7
TOTAL		20.9	20.7	37.7	53.7	84.8	50.0	70.2	96.1	74.9	85.0	105.2

(Amounts are in Millions of Dollars)

1. Fundamental Earthquake Studies

Two distinctly different approaches to the attainment of reliable earthquake prediction can be envisioned. The first involves continuing in-depth studies and measurements of a basic nature directed at the development of a thorough understanding of the natural phenomena involved. The second is a comprehensive empirical program to seek consistently reliable indicators from field measurements made on well-chosen secondary parameters (precursors). At our present state of knowledge, there seems no question that both approaches must be implemented in parallel.

In addition to providing the infrastructure on which an applied program is based, a solid independent program of fundamental studies will help assure that an empirical program is scientifically sound and flexible, will provide direction for the optimal use of its resources and, of course, will provide the basis for a new start if current empirical approaches prove inadequate.

An empirical program will necessarily give priority to those precursors and geographical regions considered to be most promising. At the same time fundamental studies should be conducted in a number of other tectonic settings which will give us the long-time baseline required to distinguish anomalies from ordinary values or behavior in all major active seismic zones in the country. Seismicity and microseismicity studies should be conducted in all these areas, particularly in the Eastern United States, to better delineate the active seismic zones and relate them to geology.

To establish a scientific rather than an empirical approach to the prediction of earthquakes and of destructive ground motion requires a greatly increased understanding of the physical processes leading to and constituting an earthquake. We must understand these processes under conditions that exist in the upper crust, lower crust and upper mantle. We must develop theoretical models of the earthquake process consistent with the above information. Both pre-earthquake phenomena and the ground motion caused by the earthquake are tightly linked with the faulting process itself. We do not yet know what physical properties are the most critical, or the nature of the instability that causes an earthquake. The failure criteria and the role of stick-slip and pre-seismic, or co-seismic creep must be understood in order to calculate the fault propagation in the stress field and to determine the energy budget. In addition, the material properties and the tectonic setting affect the amount of energy released and the characteristics of the generated motion. Such studies have been going on for many years - in theory, in the laboratory, and in the field. However, there is still a long way to go.

The new plate tectonic theory envisions the earth's surface as comprised of a discrete number of large plates moving in relationship to each other. This concept has allowed us to explain the distribution of the bulk of the world's earthquakes and their seismic radiation patterns. We need a more detailed knowledge of how stress is accumulated, distributed and released along the boundaries of these moving plates. To date, basic studies of worldwide earthquakes have been the primary tool in outlining the plates, in determining their relative motions, in outlining the downgoing slabs, and in defining seismic gaps. Such studies are broad, interdisciplinary and conducted on a worldwide basis - on land and at sea. They provide essential basic data for the design of a more local earthquake prediction program and for a comprehensive theory of prediction.

Current knowledge of plate motions does not adequately explain the occurrence of large and destructive intraplate earthquakes (i.e. New Madrid, Boston, and Charleston). These earthquakes may have quite different causes than those along the San Andreas fault system and may well prove to be the most difficult to forecast. Measurements of intraplate stresses and measurement of intraplate strains, on a plate-wide and world-wide basis are required, together with more local studies on the relationship of seismicity to buried structure in known seismic regions. Studies of plate motions, their causes and consequences, are at the heart of understanding earthquake origins.

Seismic and other geophysical observatories and networks provide the essential data for all studies in seismology, including earthquake hazard reduction. The systematic location and cataloguing of earthquakes on a global basis is central to these studies. In addition to worldwide networks and data centers, and those specifically established for earthquake prediction research, there are a number of independent stations and nets, portable and permanent, that can be expected to contribute vital information to the problem.

Objectives

- To obtain a comprehensive understanding of the natural phenomena involved in the earthquake process.
- Improve global networks of seismograph stations to provide a sound data base for studies in observational seismology and provide associated data services.

Activities

a. The Earthquake Process - Develop a fundamental understanding of the earthquake process

   1) Develop theoretical models based on laboratory data and field observations. Study physical properties of rocks at conditions similar to those in the earth's crust and upper mantle and determine seismic source parameters from field observations.

b. The Implications of Plate Tectonics for Earthquake Hazards Reduction - Determine how stress is accumulated, distributed, and released along boundaries of moving plates and in plate interiors.

   1) Determine relative motions of plates, refine definitions of plate boundaries, determine deep-crustal and upper-mantle structure, identify seismic gaps, measure stress and deformation of plate boundaries and in intraplate regions, study the relationship of seismicity to geologic structures in intraplate regions.

c. Global Seismology - Collect and disseminate seismological data from around the world.

   1) Operate the Worldwide Standardized Seismograph Network (WWSSN) and reestablish a maintenance program for the stations that lapsed several years ago.

   2) Operate the data acquisition and processing capability of the National Earthquake Information Service, including use of satellite telecommunications, issuance of new seismicity maps, and routine computation of the parameters of the earthquake mechanism.

3) Upgrade about half of the WWSSN and establish the capability to produce integrated tapes of digital seismic data.

4) Acquire and operate a ten-station array of transportable broad-band seismographs for global seismic studies.

5) Operate an integrated digital network consisting of High-Gain Long-Period stations, Seismological Research Observatories, and the upgraded WWSSN stations called for in activity 3), and produce integrated tapes of digital seismic data.

6) Acquire, install, and operate 10 ocean-bottom seismographs.

These activities are related to programs of the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the Defense Advanced Research Projects Agency.

Present and Proposed Funding Options

Element: 1. Fundamental Earthquake Studies

Sub-Element		FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
		Act.	Req.	A	B	C	A	B	C	A	B	C
a. The Earthquake Process	NSF	1.1	1.6	2.3	2.6	3.4	2.6	3.0	3.6	3.0	3.3	3.8
b. The Implications of Plate Tectonics for Earthquake Hazard Reduction	NSF	1.5	1.9	2.4	2.7	4.1	2.7	3.0	4.0	3.0	3.3	3.9
c. Global Seismology	USGS	1.9	1.7	2.3	2.6	3.2	2.5	3.1	3.6	3.4	3.6	4.0
TOTAL		4.5	5.2	7.0	7.9	10.7	7.8	9.1	11.2	9.4	10.2	11.7

(Amounts are in Millions of Dollars)

Public Benefits and Technical Milestones

It is not realistic to attempt to predict the outcome of a fundamental research program in terms of "technical milestones". Nevertheless, we can reasonably predict that a significantly increased research effort, focused on projects with a strong potential for application to the earthquake prediction and hazard reduction program, will result in a more comprehensive understanding of the earthquake process. Progress in such basic understanding can be expected to increase the efficiency as well as the reliability of earthquake prediction, in that the large costs of gathering data by dispensing large arrays of field instruments could be reduced if we had comprehensive theories requiring relatively few data points. Strong, continuous support for the basic research program is thus likely to be highly cost-effective in the long-range earthquake program. Present approaches to the problem, while promising, may conceivably fail. If that happens, we will need the reservoir of imaginative ideas, new experiments and basic theory that fundamental studies can generate.

Current Program

The NSF fundamental earthquake research effort is heavily leveraged for returns from two to ten or more years in the future. The size of the program is constrained by the availability of funding, rather than the lack of good proposals. Available statistics easily demonstrate that a substantial pool of unfunded or underfunded talent exists in the universities that can be used effectively to achieve more rapid progress toward the goals of the program. Because of the steadily increasing scientific interest in this area and the important economic and humanitarian need to forecast earthquakes reliably, the FY 77 budget in the Earth Sciences contains a proposed budget of $3.5M for fundamental earthquake studies. This figure, of course, was not proposed as an adequate response to an accelerated national program.

The FY 76-77 support of observational seismology by the USGS does not allow for necessary maintenance and calibration visits to stations of the Worldwide Standardized Seismic Network, nor for the desired upgrading of selected stations.

The Options

Fundamental Research (NSF)

The proposed expenditures for fundamental research on earthquakes averages 9% of the total program over all the available options. This percentage decreases steadily from 12.5% at the lowest option in FY 78 to 7.3% at the highest option in FY 80.

In light of the current state of the art in earthquake prediction and related aspects of hazard reduction, this is considered a conservative level of effort and fully compatible with the national need to achieve new fundamental data.

The following table indicates that Option A and B represent gradually increasing budgets, in which Option B allows the attainment of a given level of support one year sooner than Option A. In contrast, Option C, the preferred budget, represents nearly level funding (FY 78-80) at a [illegible] of $4.4M.

[illegible] earth-

[illegible] (\$2.5M).

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community for many years. Support for this operation is included herein because data from this network is indispensable for modern earthquake research. The existence of data from this network is responsible, in a major way, for the rapid advances in seismology, earthquake prediction, and plate tectonics in recent years.

Option A will allow a stable, just sufficient, operation of the WWSSN, and the operation of the data acquisition and processing capability of the National Earthquake Information Service (NEIS) in FY 78-80, a very limited start in upgrading a few of the WWSSN stations in FY 79, and the incorporation of the existing High Gain-Long Period stations and Seismic Research Observatories into an expanded WWSSN in FY 80.

Option B will allow a partial reestablishment of the maintenance program that lapsed several years ago, the upgrading of about half of the WWSSN stations to produce integrated types of digital seismic data by the end of FY 80.

Option C allows the acquisition and operation of a ten-station array of broad-band seismographs for global seismic studies.

resources than in the U.S. Consequently, in some regions, prediction represents the logical focus for reducing earthquake casualties. Development of reliable earthquake prediction techniques would be of major benefit to the safety of Americans and people throughout the world living in earthquake-prone regions.

Earthquake prediction depends on detecting precursors prior to earthquakes. Reliable prediction depends on observing a variety of precursors, understanding their causes, and understanding the basic physics of the earthquake source. Thus a prediction research program must be broad-based but will depend heavily on observations of precursors and earthquakes within networks of a variety of densely spaced instruments. The rate of progress toward a prediction capability is directly linked to the rate with which precursors can be observed. Multiple observations on a variety of instruments are needed to develop an accurate physical model for earthquake precursors. Dense instrumentation of an active fault zone with a wide variety of sensors costs about $12K per kilometer of fault to install and about $7K per kilometer to operate each year.

The existing U.S. program has progressed significantly. Reliable instruments for detecting most suspected precursors have been developed, tested, and deployed in small prototype arrays. Real-time and automated data processing techniques have been developed. Hypotheses as to the nature of the earthquake source and the cause of precursors have been developed and partially tested in the laboratory. Now that this groundwork has been laid, expansion of the national effort can be undertaken efficiently.

[illegible] carried out by seismic [illegible] seismologists [illegible] that the level [illegible] of nuclear [illegible]

[illegible] and [illegible]

[illegible] on the basis [illegible]

[illegible] through development [illegible]

[illegible] through development [illegible] phenomena observed.

Activities

a. Deformation Monitoring Instrumentation (Purchase and Installation) - Measure ground deformation in active seismic regions to monitor the long-term accumulation of strain, determine the physics of the seismic source, and observe precursors.

   1) Deploy continuously recording strain meters, tiltmeters, tide gauges, gravimeters, water-well level monitors, etc., in selected areas of high or unique seismicity.

b. Seismic-Monitoring Instrumentation (Purchase and Installation) - Determine the patterns of seismicity in time and space, the physics of the seismic source, and the variation in time of seismic source and seismic wave parameters.

   1) Deploy narrow and broad-band seismic instruments in selected areas of high or unique seismicity.

c. Geochemical, Magnetic, Electrical and Other Instrumentation (Purchase and Installation) - Study other types of phenomena that have been reported as earthquake precursors.

   1) Deploy geochemical sensors, magnetometers, resistivity arrays, telluric sensors, self-potential sensors, etc., and carry out studies with animals in selected areas of high or unique seismicity.

d. Operations - Operate networks of instruments installed and provide bulletins and computer files of uniformly processed data to provide bases for development of a theoretical and empirical framework for earthquake prediction.

   1) Operate networks of instruments including maintenance and routine data processing in selected areas of high or unique seismicity.

[illegible] implement automated [illegible] identification [illegible] techniques.

[illegible] present [illegible] and southern [illegible] major [illegible]

[illegible] hypothesized [illegible] of future [illegible]

[illegible] distribution of [illegible] predictive regions [illegible] precursors.

[illegible]

[illegible] field experiments [illegible] hypotheses [illegible] the origin and nature [illegible]

[illegible] such as aftershock [illegible] velocity [illegible] and short-term [illegible] combination of [illegible]

h. Detailed Analyses of Data and Theoretical Modeling - Analyze field and laboratory data, and develop and test hypotheses concerning the physics of the failure process and precursory phenomena.

1) Detailed analysis, theoretical modeling and synthesis of results from:

   o Strain Data

   o Seismic Data

   o Other Data and Syntheses

i. Instrument Development - Develop and improve instruments for field use that show significant promise of detecting earthquake precursors.

1) Develop or complete development of instruments, such as a portable multi-wavelength laser-ranging device, portable long-base tiltmeters, broad-band seismometers, data telemetry systems, absolute gravimeters, stress detectors, etc., and improve the reliability and sensitivity of instruments already utilized.

j. Laboratory Studies - Determine the physical behavior of rocks near rupture and model earthquake processes in the laboratory with specific application to earthquake prediction.

1) Examine the properties of rocks, the physics of fracture, and the occurrence of precursors prior to fracture on rock samples in the laboratory. Model earthquake processes in the laboratory.

2) Conduct laboratory experiments using large-size samples and small-scale field experiments.

[illegible] feasibility of
[illegible] natural fault zones by
[illegible]
[illegible] elements, and
[illegible]
[illegible] studies on fluid
[illegible] earthquakes.

[illegible] Aeronautics
[illegible] Administration,
[illegible]

Present and Proposed Funding Options

Element: 2. Prediction

Sub-Element	FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
	Act.	Req.	A	B	C	A	B	C	A	B	C
a. Deformation Monitoring Instrumentation	0.2	0.1	1.5	2.0	4.8	0.9	1.4	1.4	1.5	0.5	0.6
b. Seismic Monitoring Instrumentation	0.2	0.0	0.3	0.7	0.9	0.7	0.8	1.0	0.9	0.2	0.2
c. Geochemical, Magnetic, Electrical and Other Instrumentation	0.1	0.0	0.6	1.0	3.1	0.9	1.3	1.5	1.4	0.5	0.6
d. Operations	1.9	2.1	2.6	3.2	3.7	4.8	5.2	7.9	6.0	8.9	11.6
e. On-Line Computer Processing Capability	0.1	0.1	0.4	0.8	1.2	0.5	1.0	1.5	1.5	1.0	1.7
f. Land Deformation Surveys	0.3	0.3	1.0	1.5	2.0	1.6	1.9	3.0	2.0	2.0	3.0
g. Intensive Field Studies in Strategic Areas	0.2	0.2	0.3	0.5	0.8	0.6	0.8	1.5	1.0	1.5	2.0
h. Detailed Analyses of Data and Theoretical Modeling	1.1	1.1	1.5	2.5	3.4	2.0	3.1	4.0	2.6	4.0	4.5
i. Instrument Development	0.3	0.2	0.9	1.4	2.1	1.0	1.5	2.1	1.0	1.0	1.0
j. Laboratory Studies	0.5	0.5	0.6	0.7	1.2	0.6	0.9	1.5	0.7	1.1	1.5
k. Controlled earthquake experiments	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8
TOTAL	4.9	4.6	9.7	14.3	23.2	13.6	17.9	25.4	19.4	21.5	27.5

(Amounts are in Millions of Dollars)

[illegible]

[illegible] and the reduction of [illegible] means that [illegible] accomplished [illegible] governmental [illegible] not only scientific [illegible] effects of such [illegible] response of [illegible]

[illegible] the cost of [illegible] to the negative [illegible] community. Whether [illegible] including its [illegible] experience [illegible] as expected [illegible] regarding [illegible]

[illegible] depends on [illegible] development of a basis, [illegible] interpretation. [illegible] probably be achieved gradually, with prediction [illegible] some regions than others [illegible]. The ultimate technical milestone – "[illegible] earthquake prediction" – therefore, is a target [illegible] defined. Many scientists judge that observations are needed with a dense network of comprehensive instrumentation for on the order of 10 magnitude 5 or larger earthquakes as an adequate data base for either establishing a sound basis for prediction or deciding that the problem is much more difficult than presently believed. Acquisition of these observations is a specific goal for earthquake prediction efforts.

The rate of precursor observation is directly related to the number of instruments deployed and the level of earthquake activity in the area monitored. Several factors influence program planning to make the observations:

- Observations can be made at considerably lower cost in California and Nevada than elsewhere in the U.S. This is shown by detailed analysis of the seismicity per unit area, accessibility of the seismic zones, and logistical support required. Such observations, however, will not necessarily lead to development of a nationwide prediction capability.
- Instrumentation in areas of relatively low seismicity yields declining returns in precursor observation for invested funds, except in areas where a large earthquake appears imminent based, for example, on seismic gap theory and observations of possible precursors, or in areas of unique seismicity.
- Economies of scale permit observational functions to be expanded proportionally more rapidly than analytical, laboratory, theoretical and computational functions.

Taking these factors into account the costs and times to "achieve prediction," i.e., observe the 10 magnitude 5 or larger earthquakes, can be estimated as follows:

Level		[illegible]	[illegible]	4	5	6	7
Annual Program Cost ($M)	[illegible]	[illegible]	12	[illegible]	[illegible]	28	34
Total Program Cost ($M)	[illegible]	[illegible]	[illegible]	[illegible]	100	104	109
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	5	4.5
[illegible]	[illegible]	[illegible]	[illegible]	13	7	5.5	5

[illegible] lower annual invest-ment [illegible] functions, whereas higher annual investment [illegible] in areas of lower seis-micity [illegible] suggests that an investment of [illegible] minimum total cost [illegible].

[illegible] is installed within the first [illegible] activity is in general a [illegible] a short-term experi-ment can differ greatly [illegible]. As a result the [illegible] of years [illegible] earthquakes are useful for program formulation, but [illegible] for measuring program development.

The year of [illegible] milestones for each funding option is shown in the following table.

Fiscal Year

Technical Milestones	77	78	79	80	81	82	83	84
1. Establish dense seismic and strain instrumentation and undertake surveys of land deformation in areas of high or unique seismicity.				C		B		A
2. Undertake comprehensive studies of earthquake precursors other than seismic and strain:								
Water well level		BC	A					
Electrical resistivity		C		B				
Magnetic field		C		B				
Geochemical content of ground water		C			B		A	
Animal behavior		C			B			
3. Establish a computer-based data processing capability for both real-time monitoring and analysis of earthquake precursors.				C		B		A
4. Develop new instrumentation and techniques, and utilize for earthquake precursor detection:								
Three-color laser ranging instrument				C	B		A	
Gravimeters for vertical deformation				C	B		A	

Technical Milestones	Fiscal Year 77	78	79	80	81	82	83	84
C. Conduct laboratory, modeling and theoretical studies to establish a basis for interpretation of earthquake precursors								
Large-scale laboratory and quarry experiments [illegible] mechanics			C	B		A		
Computer modeling of [illegible] of a fault system				C		B		A
Comprehensive theory [illegible] of the earthquake [illegible]			C			B		A

3. Induced Seismicity

Recent research at Rangely, Colorado has demonstrated that fluid pressure has a profound effect on earthquake activity. This phenomenon was originally observed as an inadvertent effect of injecting water underground at high pressure. In experiments at Rangely, Colorado, earthquakes were successfully controlled by altering the fluid pressure within a fault: lowering the pressure halted the earthquakes; raising the fluid pressure above a critical value started the earthquakes up again. Injection is becoming more common with the advent of deep well disposal of noxious wastes and secondary recovery of oil. Thus, deep-well injection poses both a risk of increased local seismicity and offers the potential for releasing seismic energy in earthquakes that are below the damaging level.

Filling reservoirs behind dams has apparently triggered earthquakes, as large as magnitude 6 to 6 1/2 in a few cases causing damage and loss of life. Although triggering of these events by increase of fluid pressure is likely to be the cause, at present there is no sound basis for evaluating which reservoirs might trigger earthquakes, or what to do about earthquake activity once it is stimulated. The Rangely experience suggests that certain engineering actions may be available to limit reservoir-induced seismicity.

The Rangely experiment also suggests that potentially destructive natural earthquakes are, at least theoretically, controllable. The ability to control them successfully would depend on, among other things, the permeability of fault zones.

Objectives

- Develop techniques for forecasting in advance of reservoir impoundment or fluid injection in wells whether a particular site holds the potential for triggered earthquakes.
- Develop techniques to permit development and operation of large reservoirs and deep injection wells including a basis for remedial action should earthquakes be triggered.
- Determine to what extent theories and models are successful in explaining induced or triggered earthquakes apply to natural earthquake processes.
- Determine the feasibility of artificially modifying natural seismicity by changing the physical properties of fault zone materials [illegible]. Select a site for a field experiment in an uninhabited area.

Activities

a. Reservoir-Induced Earthquakes - Determine the effects of reservoirs on seismic activity and the reasons for these effects.

   1) Monitor in detail the seismicity, the strain field, and the fluid pressure at depth around major reservoirs before, during, and after they are constructed.

b. Drilling into Fault Zones - Determine the physical properties of fault zones and fault gouge.

   1) Drill several holes into major faults and measure such properties as permeability, porosity, elastic parameters, temperature, fluid pressure and stress.

These activities are focused on the process of reservoir-induced earthquakes and are considered to be supplementary to monitoring and baseline studies by agencies responsible for reservoirs, e.g., the Bureau of Reclamation and the Corps of Engineers.

Present and Proposed Funding Options

Element: 3. Induced Seismicity*

Sub-Element	FY 78	FY 79	Fiscal Year [illegible]			Fiscal Year 1979			Fiscal Year 1980		
	Est.	Req.	A	B	C	A	B	C	A	B	C
a. Reservoir-Induced Earthquakes	0.0	0.0	0.2	0.4	1.0	0.6	1.7	1.5	1.1	1.1	1.5
b. Drilling into Fault Zone	0.0	0.0	0.0	0.0	0.0	0.4	0.3	1.5	0.9	0.9	1.5
TOTAL	0.0	0.0	0.2	0.4	1.0	1.0	2.0	3.0	2.0	2.0	3.0

*These studies should be supplementary to studies by agencies responsible for reservoir construction, as outlined in the text.

(Amounts are in Millions of Dollars)

Public Benefits and Technical Milestones

Studies of induced seismicity will lead to improved knowledge about how reservoir impoundment and fluid injection in deep wells cause earthquakes. This information in turn will aid in developing better criteria for siting and operating reservoirs and injection wells. The public will benefit from increased safety from both dam failure and triggered earthquakes, and from savings in economic loss that could result if a dam could not be utilized or if construction were delayed owing to unresolved issues related to induced seismicity.

Progress in understanding induced seismicity requires instrumental observations of a variety of phenomena that could be affected by reservoirs and injection wells: seismicity, land deformation, and fluid pressure in wells. Past studies, both in the U.S. and foreign countries, have focused only on seismicity, and often a bare minimum of seismograph stations have been deployed with resulting deficiencies in data. Consequently, existing information on induced seismicity is fragmentary and does not provide a sound basis for establishing criteria. Comprehensive studies of large reservoirs are needed.

Technical milestones for induced seismicity, therefore, mark the installation of instrumentation and the undertaking of surveys to monitor reservoir impoundment or well injection. Such studies must precede construction by a year or more to establish baseline data, and should continue for several years or more depending on the nature of the project.

Interpretation of data on induced seismicity can be greatly enhanced if information on the physical properties of material at depth in the vicinity of the earthquakes is available. For example, properties influencing fluid flow and the physical properties of rocks that affect the strength of faults are relevant. This information can be obtained only in wells. Drilling of a hole, therefore, constitutes a milestone that indicates progress in improving information.

The following table shows year of attainment of technical milestones for each funding option.

Technical Milestones	Fiscal Year							
	77	78	79	80	81	82	83	84
1. Establish instrumentation and undertake surveys to monitor three large reservoirs for a variety of phenomenological variations.				C		B		A
2. Drill 10 holes to about 2000 foot depths to sample fault zones and measure physical properties					C		B	

4. <u>Hazards Assessment</u>

Earthquake hazards assessment involves the delineation and characterization of potential effects from seismically induced processes at or near the ground surface. Estimates of how strongly and how often the ground will shake are basic to building codes and engineering design. Knowledge of areas susceptible to strong shaking, ground failure, surface faulting, or inundation by tsunamis or dam failure is necessary for land-use planning in earthquake-prone regions. Appraisals of probable damage patterns can guide both pre- and post-disaster planning. The accurate assessment of earthquake hazards also is a key element in effective action to take advantage of an earthquake prediction capability.

At present, our ability to evaluate earthquake hazards varies considerably, with the state of the art at different stages for different hazards. For example, many faults capable of displacing the ground surface can be recognized and mapped, and expectable future movement can be estimated within reasonable limits. In contrast, the current capability for assessing of other types of earthquake hazards has some severe limitations. The potential effects of strong ground motion presently can be characterized only in the most general way, and the prediction of possible earthquake-induced landsliding or liquefaction is even more difficult. There are few geologic or geophysical bases at present for deciding where and how often earthquakes in the eastern and central United States are likely to occur.

This program element has two aspects (1) the geographic delineation of potential earthquake hazards, initially using existing methods and (2) the development of improved techniques.

Objectives

- Determine the expected location, size, frequency, and characteristics of earthquakes and of associated surface faulting for various regions of the United States.
- Develop a physical basis for predicting the character of damaging ground motion as a function of distance from a postulated earthquake and varying geologic site conditions.
- Develop a physical basis for predicting the incidence, nature and extent of earthquake-induced ground failure and flooding.
- Delineate geographical variations in the nature and likelihood of occurrence of earthquake hazards.
- Evaluate earthquake risk (e.g., hazard assessment and vulnerability analysis) on a nationwide and regional basis.

Activities

a. Earthquake Potential - Determine the expected location, size, frequency, and characteristics of earthquakes and of associated surface faulting for various regions of the United States.

   1) Improve the location, accuracy and completeness of historic earthquake data including a relocation of poorly located historic (both instrumental and felt) events.

   2) Delineate seismically active faults by monitoring regional earthquake activity in selected zones of the U.S. by determining accurate epicenters, focal depths, and focal mechanisms.

   3) Investigate earthquake recurrence from analysis of Quaternary history of individual faults.

   4) Delineate seismic source areas on the basis of seismic, geologic, and geophysical characteristics. Estimate rates of activity and evaluate upper bound earthquakes.

   5) Delineate active faults and seismic source areas and monitor earthquake activity in selected areas of the outer continental shelf.

b. Geologic Factors Influencing Ground Motion - Develop a physical basis for predicting the character of damaging ground motion as a function of distance from a postulated earthquake and varying geologic site conditions.

c. Geologic and Hydrologic Effects - Develop a physical basis for predicting the incidence, nature and extent of earthquake-induced ground failure and flooding.

   1) Investigate mechanisms of earthquake-induced liquefaction and mass movements; refine criteria for predicting the occurrence of ground failure.

2) Develop improved methods to predict inundation and the consequences of flooding caused by subsidence, tectonic downwarping, massive landslides into water, tsunamis, and other secondary earthquake effects.

3) Conduct geologic hazards evaluations of the effects of damaging earthquakes.

d. Earthquake Hazards - Delineate geographical variations in the nature and likelihood of occurrence of earthquake hazards.

1) Prepare refined probabilistic ground motion maps for entire United States.

2) Expand state-of-the-art evaluation and mapping of earthquake hazards (ground shaking and failure, surface faulting, elevation changes, and inundation) in areas of high seismic risk; develop new methods for probabilistic hazard evaluation, including faulting, ground failure, and tsunami effects.

e. Earthquake Risk - Evaluate earthquake risk on a nationwide and regional basis.

1) Develop and improve methods for estimating damage and loss based on probabilistic maps of earthquake hazards. Apply methods to estimate risk on a regional and nationwide basis.

These activities are related to programs of the Department of Housing and Urban Development, the Nuclear Regulatory Commission, the Department of Transportation, and the Veterans Administration.

Present and Proposed Funding Options

Element: 4. Hazards Assessment

Sub-Element	FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
	Act.	Req.	A	B	C	A	B	C	A	B	C
a. Earthquake Potential	2.5	2.4	3.1	5.5	9.8	6.2	8.7	12.5	9.3	12.0	15.6
b. Geologic Factors Influencing Ground Motion	0.4	0.4	0.8	1.3	2.2	1.3	1.7	2.7	1.6	2.0	3.1
c. Geologic and Hydrologic Effects	0.1	0.1	0.2	0.8	2.0	0.9	1.3	2.4	1.6	1.8	2.6
d. Earthquake Hazards	1.4	1.1	2.2	3.0	3.1	2.3	3.0	3.3	2.4	3.0	3.4
e. Earthquake Risk	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.3	0.1	0.2	0.3
TOTAL	4.4	4.2	6.3	10.6	17.4	10.7	14.8	21.2	15.0	19.0	25.0

(Amounts are in Millions of Dollars)

Public Benefits and Technical Milestones

The public benefits from hazards assessment are the reduction of casualties and damage in an earthquake as a result of land use, construction and emergency preparedness policies that wisely take into account the existence of potential earthquake hazards. Such policies are developed from technical information on the distribution and character of the hazards. Utilization of the information is based on societal attitudes and values with regard to earthquake risk and the implementation of policies by local and State governments. The public benefits from hazard information depend on the degree of utilization with respect to the severity of the hazard.

Information about earthquake hazards is generally portrayed on maps that delineate the geographical extent of the potential hazard, indicate the likelihood of occurrence, and indicate the nature of the expected effects. Utilization of this information in implementing earthquake hazard mitigation measures is accomplished by individuals, groups, or public officials either directly using the information or obtaining advice from professional scientists based on the information.

The publication of maps showing potential hazards, therefore, is a tangible technical milestone that marks progress in the hazard assessment field. Map publication follows months, or more typically years, of research and data gathering. A comprehensive base of geologic, geophysical, and seismologic data is needed for evaluation of any region. Maps are often revised as new information is developed and special-purpose maps are sometimes issued to portray the distribution of selected parameters or features of special relevance for hazard mitigation.

Development of new techniques for evaluation is also an important product of hazards assessment research. An example is the specification of seismic design criteria for a critical facility such as a nuclear reactor or dam at a particular site. New methods in hazards evaluation require synthesis of data and theory from many fields of earthquake research and commonly entail laboratory and field investigations.

Consequently, technical milestones in hazards assessment studies mark the completion of the data gathering or research phase of particular studies and publication of significant contributions to the information base for decision making. Milestones can be developed for both geographical areas and scientific topics. Level of effort, i.e., professional manpower, and dates of important publications are both useful measures in the case of hazards assessment.

The year of attainment of major technical milestones for each funding option is shown in the following table.

Technical Milestones	Fiscal Year 77	78	79	80	81	82	83	84
1. Publish maps and evaluations of earthquake hazards suitable for land use planning and emergency preparedness in major urban areas at high seismic risk:								
San Francisco Bay Region	Req							
Los Angeles-San Diego Region				C		B		A
Seattle Region					C		B	
Salt Lake City Region					C		B	
St. Louis-Memphis Region						C		B
Anchorage Region						C		B
Boston Region							C	
Buffalo Region							C	
Charleston Region							C	
2. Undertake comprehensive topical studies to develop new methods for hazards evaluation:								
Earthquake Recurrence			C		B		A	
Strong Ground Shaking			C		B		A	
Ground Failure				C		B		
Surface Faulting				C			B	

5. Engineering

Earthquake engineering involves the design and development of the physical environment to withstand earthquakes. It encompasses many fields including architecture, structural engineering, mechanican engineering and systems design. It serves as a bridge between the earth sciences, oceanography, and theoretical mechanics, on the one hand, and engineering design and construction practice, systems planning, and social and economic assessments of hazard and risk on the other. Engineering studies interface with geological studies of hazards and their mitigation, and with seismological studies of ground motion and its recurrence. Research in earthquake engineering aims at improving the procedures used in engineering design, in land-use and systems planning, and in codes and regulations. The protection of human life and property are basic to engineering design.

The characterization of earthquake ground motions as input motions for engineering studies depends upon the procedures used in the design and planning process. In the design of simple, non-critical structures, the general level of ground motion in frequently occurring events and the maximum probable motion from infrequently occurring events are both important. On the other hand, a characterization of the time-history of anticipated motion at both levels of severity is required in the analysis of critical facilities.

Research can define the relative motion of nearby points on the ground surface and at different depths. These relative motions may influence the design of extended structures such as dams, multi-span bridges, long buildings, and underground facilities, as well as interconnected systems such as pipelines, aqueducts, and transmission lines.

Research can determine the potential merit or hazard in selecting foundation designs, elevations, and embedments for various site conditions. Closely related to the study of foundation design is the study of how the supporting soils will interact with the structure to be located at the site.

Basic principles of planning dictate that systems should not be located where soil failure (liquefaction or landsliding) is likely to occur. Many times, however, systems such as wharfs, bridge approaches, and highways must be located at sites where soil filure is likely. In such cases, methods for controlling soil failure or alleviating its consequences must be developed.

The analysis and design of structures and systems depends on the formulation of appropriate conceptual and mathematical representations of their characteristics. These models must represent the capacity of the structures and systems at various levels of motion which occur in potentially damaging earthquakes. They must include multidimensional, nonlinear, and inelastic characteristics. At present, design procedures are largely based on linear, elastic, one dimensional models. To obtain the data required to evaluate modeling procedures will require using instrumentation of real structures in seismica-ly active areas as well as laboratory studies of the ultimate capacity of elements and substructures. Since the analysis of structures and systems at damaging motion levels involves nonlinear and inelastic properties, such analyses are necessarily complex. In the design of large or critical structures and systems it is necessary to develop reliable methods that sequentially increase in complexity as the design process proceeds. The economics of the design and construction of smaller, noncritical structures does not permit extensive or complex design or analysis of individual structures, in spite of the fact that they comprise the largest aggregate value of structures likely to be damaged.

Many systems (e.g. pipeline, water mains, power grids) must cross areas where they are likely to be damaged. Consequently, design of such systems must minimize the damage, provide for temporary rerouting of service, and permit rapid repair and reconstruction. Similar principles should be applied to the planning of fire, police and regional hospital facilities that become critical in the immediate aftermath of a damaging earthquake.

Dams, reservoirs, tanks, and other structures that contain water and other liquids pose a special set of earthquake hazards. The action of the liquid within the structure creates complex loading under the dynamic conditions during an earthquake and the failure of such structures can cause serious flooding. As noted earlier in the section on induced seismicity, large reservoirs may stimulate local seismic activity. The extent to which this activity should influence the dam's design and operation is not yet clear.

A tsunami can cause great damage to coastal regions by both inundation and the force of moving water. Selective land use is usually the most appropriate way to mitigate this impact. But the design of facilities that must be located along the shore, must also allow for the impact of the tsunami.

In addition to the basic structural design, elements that influence a building's earthquake damage potential include site planning, selection of the architectural configuration, exterior and interior cladding, accessibility and circulation, mechanical equipment and facilities, and electrical power systems, to name a few. Geologic hazards should influence site selection and land-use planning. An inappropriate choice of building configuration may also make earthquake resistance in the structural system excessively expensive. The selection of proper exterior and interior cladding can greatly reduce the potential earthquake hazard. The design of circulation within and accessibility to a building or industrial facility can control emergency actions in the aftermath of a damaging earthquake. Failure of mechanical and electrical systems will greatly impair the post-earthquake functioning of a building and is critical for the emergency services provided by hospitals, communication centers, and fire and police stations. Studies many earthquakes indicate that even when the structural system of a building avoids severe damage, 60 percent of the building's replacement cost may be lost by damage to the architectural, mechanical, and electrical systems.

Objectives and Activities

This section outlines the objectives of earthquake engineering research and the activities required to accomplish those objectives. An activity common to all subelements of this research is the dissemination of the results to practicing engineers and architects, and to code and regulatory organizations.

Subelement a. Characterization of ground motion for structural analysis and design.

Objective: Develop methods to characterize the nature of the input motions and corresponding response of simple systems for use in engineering analysis, planning, and design.

Activities

1. Develop analytic models to estimate the special characteristics of ground motion and the acceleration, velocity, and displacement time-histories of this motion for use as input motion in structural analysis and design. Such models will include the effects of the earthquake source, the transmission path, the amplification caused by local site conditions, and the influence of the presence of a structure on this motion (soil-structure interaction).

2. Develop techniques for measuring the severity of earthquake effects based on parameters significant in engineering analysis and design. Apply these techniques in post-earthquake investigations and pilot studies of zoning.

Subelement b: Acquisition of Strong-Motion Data

Objective: Obtain a comprehensive data base on the nature of the earthquake motions at typical sites and in representative structures.

Activities:

1. Improve the national strong-motion instrumentation network by:
   (a) Replacing obsolete instruments,
   (b) Installing adequate instrumentation arrays in all seismic regions,

(c) Developing arrays to measure the two and three dimensional distributions of ground motion.

(d) Instrumenting representative types of structures particularly in the more active parts of the country. A high priority must be placed on obtaining an adequate number of records from the next major earthquake. A predicted earthquake provides an opportunity to gather valuable, comprehensive ground motion and structural response data.

2. Develop new instruments with a view to minimizing total costs of instrumentation, data acquisition, and data processing.

3. Expand data gathering activity, including studies in those active areas in other parts of the world where data of importance to the U.S. can be obtained, possibly at a greater frequency.

Subelement c: Investigation of Dynamic Soil Properties and Failures.

Objective: Develop in-situ and laboratory methods to determine the dynamic properties of soils and analytical procedures including the potential for failure of slopes, embankments and foundations.

Activities:

1. Develop techniques for determining the dynamic properties of soils, both in-situ and in laboratories.

2. Develop analytical methods to evaluate soil failures (liquefaction and landslides) and to assess the possibility of controlling such failures.

3. Investigate the dynamics and design of various types of foundations (include spread footings, mats or rafts, piles or caissons, and

deep foundations), and develop criteria for selecting a type of foundation appropriate to various settings and soil conditions.

Subelement d: Investigations of Structural Response

Objective: Develop analytical procedures for characterizing the earthquake response of structures and structural elements based on both analytical and experimental studies.

Activities:

1. Investigate the dynamic behavior of structures and components experimentally to determine performance characteristics up to ultimate capacity and to provide a basis for the formulation, development, and validation of analytical methods of analysis and design. This may require the development of substantial new experimental facilities.
2. Develop analytical methods to characterize the earthquake response of structures and structural components with an emphasis on three dimensional, nonlinear, and inelastic behavior to ultimate capacity. Simplify these analytical procedures for computer aided structural design.
3. Develop methods to assess the hazard vulnerability of existing structures and to upgrade their performance when subjected to earthquake motions.

Subelement e: Studies of Special Structures and Systems

Objective: Develop analytical methods to evaluate the earthquake response of special types of structures (dams, critical facilities, bridges and other extended structures) and of interconnected structures and systems (pipelines, transmission lines, etc.).

Activities:

1. Develop design, construction and analysis methods to minimize the impact of earthquakes on critical facilities such as hospitals, power plants, other emergency facilities, and structures housing or storing hazardous materials.

2. Improve the procedures for analyzing the effects of contained liquids on dams, reservoirs, tanks, etc. This should include the effects of waves generated by seiches or landslides and the design of systems to perform adequately during tsunamis.

3. Develop methods of planning and construction of utility and public service structures, including facilities for storing emergency supplies to minimize disruptions caused by earthquakes. Develop criteria for systems design that are compatible with other comprehensive urban and regional planning considerations.

Subelement f: Post-earthquake Investigations

Objective: Obtain information for engineering analysis and design from observations of damage (or lack of damage) following earthquakes that support the development of improved U.S. engineering practices and construction techniques.

Activities:

1. Investigate all potentially damaging earthquakes in the U.S. with an emphasis on correlations of damage or lack of damage with design and construction practices.
2. Investigate earthquakes in foreign countries that are likely to provide information that can improve engineering design and construction practices in the U.S.

These activities are related to programs of the National Bureau of Standards, the Department of Transportation, the Department of Housing and Urban Development and other agencies concerned with earthquake-resistant design of structures.

Present and Proposed Funding Options

Element: 5. Engineering

Sub-Element	FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
	Act.	Req.	A	B	C	A	B	C	A	B	C
a. Ground Motion Characterization	0.7	0.7	1.0	1.4	2.1	1.2	2.3	2.5	2.0	2.4	2.6
b. Strong-Motion Data Acquisition	0.9	0.9	2.0	2.6	3.6	2.2	3.0	3.8	3.1	3.3	4.0
c. Soil Properties and Failure	1.6	1.5	1.5	2.3	4.8	1.7	3.8	5.5	4.9	5.2	6.1
d. Response and Structures	2.6	2.6	3.7	5.7	9.0	3.9	6.6	9.4	7.2	8.1	9.8
e. Special Structures and Systems	1.2	0.9	2.1	3.3	6.1	2.3	4.2	6.3	5.0	5.6	7.0
f. Post Earthquake Investigations	0.1	0.1	0.2	0.3	0.4	0.3	0.4	0.5	0.3	0.4	0.5
TOTAL	7.1	6.7	10.5	15.6	26.0	11.6	20.3	28.0	22.5	25.0	30.0

(Amounts are in Millions of Dollars)

Public Benefits and Technical Milestones

The predominant public benefits from a sound earthquake engineering research program are improvements in planning and design that lead directly to reduced casualties and property damage during an earthquake, and indirectly reduced investment required to achieve this adequate earthquake performance.

The reduction in total losses is accomplished by the cooperation of all groups and professionals involved in the construction process. These include professional engineers and architects, builders, model code and local building regulatory groups, local government officials, and those in private industry. With the concerted assistance of all parties the mitigation of life and property losses as a result of an earthquake can be achieved. Successful mitigation can only be realized through assimilation and dissemination of information and knowledge to all parties concerned in its application.

The benefits of a well planned engineering research program become apparent when one considers that construction investments alone are at a rate of approximately $150 billion per year. Of this total amount, $50 billion per year is located in high and moderate seismic regions of the country. Tangible benefits from a sound program of earthquake mitigation include: the reduction in down time and subsequent loss of production, much of which is required for the basic needs of the community; reduced loss of services such as water supplies, communications, utility lines, and transportation; and reduced loss of the total operation and functioning of a community. Intangible benefits include the greatly lessened social and economic disruptions that accompany any disaster. Although an earthquake shock is an action that is only momentary in duration, its devastating results may disrupt a community and the surrounding region for years or even decades.

The realization of benefits from an increased program in earthquake engineering research will be reflected primarily in the rate at which the research results are incorporated into architectural, engineering and construction practices. The selection of any one of the three levels of funding proposed will determine the priorities and rate of accomplishment of the objectives outlined above. Some results can be achieved only by interpretation of the results of future earthquakes that are not yet predictable in time. Other results can be achieved at a rate more directly associated with the rate of expenditure of funding. The degree to which the research results will reduce losses in lives and property damage will depend on the rate of incorporation of the research results into practice.

The following table indicates the anticipated year of attainment of technical milestones for each funding option.

Fiscal Year

Technical Milestones	77	78	79	80	81	82	83	84	Bey. 84
1. Characterization of Input Motions.									
a. Improve methods based on peak parameters.			C	B		A			
b. Develop methods to include the effects of the source, transmission path, local site conditions, and soil-structure interaction.				C		B		A	
c. Develop methods for estimating time-history motions, including effects indicated in b.					C		B		A
d. Improve response spectrum techniques for use in design to include inelastic effects.					C		B	A	
e. Develop methods applicable to underground structures.						C			AB
f. Develop methods for characterizing the earthquake severity in terms of engineering design parameters.					C		B		A
g. Develop techniques for including engineering parameters in microzonation processes.							C		AB
2. Improve the National Network of Strong-Motion Instrumentation.									
a. Replace obsolete instruments			ABC						
b. Develop adequate regional arrays.			C		B		A		
c. Develop special two- and three-dimensional arrays.				C		B			A
d. Instrument representative types of structures.				C	B		A		
e. Develop new strong-motion instrumentation.				C		B		A	

Fiscal Year

Technical Milestones	77	78	79	80	81	82	83	84	Bey. 84
2. Improve the National Network of Strong-Motion Instrumentation (cont)									
f. Expand the strong-motion network to include selected sites in other parts of the world.						C		B	A
g. Improve the data dissemination operations.			C		B		A		
3. Investigate Dynamic Soil Properties, Soil Failures, and Foundation Design									
a. Develop improved techniques for determining the dynamic properties of soils both in-situ and in the laboratory.					C		B		A
b. Develop analytical methods to evaluate liquefaction and landslides.					C		B		A
c. Assess the probability of controlling soil failure during earthquakes.								C	AB
d. Investigate the dynamic response and design of various types of foundations.						C		B	A
e. Develop Criteria for the selection of types of foundations appropriate to various seismic settings and soil conditions.							C		AB
4. Investigations of Structural Response.									
a. Determine the dynamic capacity of components and subassemblies experimentally.				C	B		A		
b. Determine the dynamic capacity of small-scale structures and substructures experimentally.						C		B	A
c. Develop analytical methods to characterize the ultimate capacity of structural systems.					C		B		A

Fiscal Year

Technical Milestones	77	78	79	80	81	82	83	84	Bey. 84
4. Investigations of Structural Response (continued).									
d. Develop simplified methods for computer-aided design.						C		B	A
e. Develop methods for assessing the hazard vulnerability of structures and structural systems.					C		B	A	
f. Develop methods for assessing the hazard vulnerability of mechanical and electrical systems.						C		AB	
5. Investigations of Special Structures and Systems.									
a. Develop analysis, design, and construction methods to minimize the earthquake impact on hospitals and emergency facilities.					C	B		A	
b. Develop analysis, design, and construction methods to minimize the earthquake impact on power plants, utility systems, and other community lifelines.					C		B	A	
c. Improve the techniques for analyzing the response of dams, reservoirs, tanks, etc. including the effect of the contained liquids.				C		B		A	
d. Improve the procedures for analyzing the effects of waves generated by tsunamis, seiches, or landslides on the design of structures.							C		AB
e. Develop methods for planning, design, and construction of utility and public service facilities to minimize their disruption during earthquakes.						C	B		A

Technical Milestones	Fiscal Year 77	78	79	80	81	82	83	84	Bey. 84
5. Investigations of Special Structures and Systems (continued).									
f. Develop criteria for system planning that are compatible with other comprehensive urban- and regional-planning considerations.						C		B	A
6. Post-Earthquake Investigations.									
a. Develop procedures for the investigation of potentially damaging earthquakes with an emphasis on coorelation of damage (or lack of damage) with design and construction practice.					C		B		A
b. Investigate all potentially damaging earthquakes that are likely to provide information that can be used to improve engineering and construction practice in the U.S.					C		B	A	

6. Research for Utilization

The previous sections of this plan have concentrated on the development of physical science and technology capabilities to reduce earthquake impacts. Research has focused primarily on technologically oriented solutions to problems of natural hazards, rather than on the social, economic, legal, and political factors which lead to the adoption or nonadoption of technological findings. The present section describes activities to develop social adjustments that can be undertaken by individuals, private groups and government, especially at the local and State level, to mitigate earthquake impacts.

In Chapter II, possible mitigation measures were discussed which, if adopted, could reduce earthquake impacts. Among these measures are Preparation, Land Use, Building Codes and Standards, Insurance and Relief Incentives, and Information and Education. While each of these is being pursued in varying degrees and with widely divergent effectiveness, there is scant research that has been performed or is currently underway to develop more effective and efficient adoption and implementation of mitigation measures.

Changes in building codes and land-use regulations, and the issuance of earthquake predictions and warnings can have serious ramifications for the social, economic, legal and political aspects of American life. Whether a research product has a positive or negative effect in mitigating earthquake hazards, or is ignored altogether, could depend very much on the method of communication and utilization of the product. The use of any research product is highly unlikely unless it is made adaptable to a recognizable need in a form appropriate for fulfilling that need.

It is essential that a thorough analysis be made of the options for loss reduction through social mitigation measures--land use, preparedness, relief, recovery, standards setting (codes), insurance, public information, and education. Adoption of an appropriate balance among these measures depends on a fundamental understanding of, and the ability to establish a meaningful social and economic benefit-cost relationship.

The object of community preparedness is to enhance the stability of the community in time of disaster and to reduce losses. Community preparedness for earthquakes has proceeded on the assumption that an earthquake occurs without warning. In some areas of the country, there may be specific event warnings based on the developing capability for earthquake predictions. Community preparedness as developed by local, State or private entities can be achieved both by the preparation of plans for actions to be taken when the event occurs or is forecast, and by adopting strategies in building, land and facilities use that decrease vulnerability.

Public reaction to the issuance of an earthquake prediction will be very difficult to anticipate. It is clear that public information programs, preparedness planning, and governmental coordination must go hand in hand with prediction. The potential positive benefits of predictions are clear in the saving of lives and reduction of damage. But potential negative effects of predictions are also present.

In public and private actions society regulates physical development through local and State building codes, land use controls, building occupancy codes, insurance requirements, mortgage and finance requirements, taxation policies, police powers, etc. Earthquake safety involves decisions and actions on the part of the individual, property owner, financing agency, architect, engineer, builder, foreman, inspector, manufacturer of components, insurer, and appropriate officials of the municipality or other governmental subdivision. Participants in the decision process are often so remote in time and place from the individual victim in the event of disaster that in some cases they may feel little sense of responsibility. Experience has shown that because of the apparent low probability of immediate catastrophe, decision makers tend to ignore their responsibility.

One of the problems in the transfer of technology to an intended beneficiary is that often there is a mismatch between what is offered and the capability of the user to implement it. Some of this disparity is due to impediments caused by established functional responsibilities of the user and institutions. Current understanding of the relationship between the effective generation and implementation processes of new information is limited. A sound overall utilization strategy requires an understanding of these processes.

Objectives

- Define options for the mix of measures to mitigate earthquake hazards by considering research, social, economic, legal, and political barriers and incentives to policy implementation.
- Assess public and private regulation impacts and develop alternatives where necessary.
- Facilitate the beneficial utilization of earthquake hazard mitigation measures by developing effective techniques for communicating information to the public and decision makers.

- Increase the capability of public officials to implement earthquake hazard mitigation measures through land-use planning, preparedness planning, building regulation, and disaster response.
- Define alternatives the private sector could adopt for mitigating earthquake hazards.

Activities

a. Allocation of Earthquake Mitigation Resources: Develop comprehensive cost-benefit methods of analysis to provide a basis for choosing among possible earthquake mitigation actions.

1) Evaluate how people and organizations establish acceptable levels of risk for low-probability and potentially catastrophic events.
2) Develop a prototypical economic model for earthquake-prone regions for estimating the interactions among the public and private sectors for various earthquake mitigation measures (e.g. financial sector, building codes, land use, prediction).
3) Study the economic incentives and disincentives to correct or eliminate existing hazardous conditions, including buildings. This includes the availability of public and private financing.
4) Examine comprehensively the national implications of regional and local earthquake mitigation practices, and the local implication of regional and national practices and policies.
5) Develop cost-benefit analyses applicable to decisions at the individual, group, and community levels through case studies.

6) Study alternate strategies of mitigation based on comprehensive planning, statutory regulation, etc.

b. Preparedness: Develop a basis for preparedness planning in anticipation of an impending earthquake.

1) Investigate the division of functions and responsibilities among public and private sectors and develop plans for the coordination of preparedness and response activities.

2) Establish socioeconomic monitoring to develop baseline data to evaluate the impact of earthquake predictions and other mitigation procedures.

3) Examine the social, economic, legal, and political aspects of earthquake predictions and develop recommendations for maximizing the benefits of prediction.

4) Initiate comprehensive investigations of the legal issues likely to be encountered in the application of earthquake mitigation procedures.

5) Investigate the likely political consequences of alternative preparedness programs through case studies.

6) Develop model policies for implementing preparedness activities on local, state, and regional basis.

c. Relief and Rehabilitation: Assess and develop means to provide for the relief and rehabilitation of the disaster-struck community.

1) Develop and implement a comprehensive program to evaluate relief and rehabilitation programs; develop program guidelines to hasten community recovery and decrease future vulnerability to earthquake and other hazard agents.

2) Examine the trade-offs between the provision of post-disaster relief and rehabilitation and financial assistance for pre-disaster hazard reduction.

3) Conduct long-term, longitudinal studies of the return of the disaster-struck community, family, public agencies and utilities to normalcy. Such studies should include all aspects of the pre- and post-disaster periods as well as very long response.

4) Systematically conduct post-audits to collect information on the consequences of major disasters (including non-earthquake occurences).

5) Prepare model legislation to implement relief and rehabilitation.

d. Information Flow: Develop effective methods for communicating earthquake hazard mitigation information to decision makers and the public.

1) Investigate the flow of information within institutions and develop alternative ways to facilitate this flow.

2) Conduct training programs (e.g. seminars, continuing education to institutionalize earthquake mitigation measures in State and local government.

3) Establish workshops with representatives of the private sector (e.g. engineers, architects, bankers, model code agencies) on methods of reducing earthquake losses.

4) Initiate an information program to acquaint the public with earthquake hazard mitigation measures.

5) Examine alternative information strategies for informing the public of services and facilities available to reduce the disaster's impact.

e. Regulation and Assessment: Assess public and private regulation impacts on the achievement of disaster mitigation.

1) Assess the impact of earthquake mitigation measures on public and private attitudes and practices.

2) Evaluate the effectiveness of physical regulation (e.g. building code, land-use controls, occupancies) to achieve given levels of earthquake protection.

3) Evaluate the effectiveness of financial regulations and practices (e.g. insurance, mortgage and financial regulations, taxation policies) to achieve given levels of earthquake protection.

4) Evaluate the effectiveness of regulatory, operation and investment policies of public utilities (e.g. water, communications, transportation) in hazard prone areas to provide short and long term essential public services.

5) Prepare model legislation for different mitigation strategies based on matrix of seismic hazard and mitigation/benefit.

6) Analyze the feasibility and impact of extensive local micro-zonation.

7) Evaluate regulation and zoning changes to modify hazard of existing buildings.

These activities are related to programs of all governmental agencies concerned with reducing earthquake losses.

Present and Proposed Funding Options

Element: 6. Research for Utilization

Sub-Element	FY 76	FY 77	Fiscal Year 1978			Fiscal Year 1979			Fiscal Year 1980		
	Act.	Req.	A	B	C	A	B	C	A	B	C
a. Earthquake Mitigation Resources Allocation	0.0	0.0	0.8	0.8	1.1	1.0	1.0	1.5	1.4	1.5	1.9
b. Preparedness	0.0	0.0	0.8	0.8	1.2	1.2	1.2	1.2	0.8	1.2	1.3
c. Relief and Rehabilitation	0.0	0.0	0.0	0.0	0.8	0.0	0.8	0.8	0.8	1.0	1.2
d. Information Flow	0.0	0.0	2.4	2.4	2.4	2.2	2.2	2.2	2.0	2.0	2.0
e. Regulation and Assessment	0.0	0.0	0.0	0.9	1.0	0.9	0.9	1.6	1.6	1.6	1.6
TOTAL	0.0	0.0	4.0	4.9	6.5	5.3	6.1	7.3	6.6	7.3	8.0

(Amounts are in Millions of Dollars)

Public Benefits and Technical Milestones

If research is not put to practical application it becomes an academic exercise. Therefore, in order to realize the greatest benefit from research it is extremely important that the results be brought to the attention of potential user groups and/or decision making bodies.

The benefits to be derived by the general public are a greater awareness of the destruction which earthquakes can produce and the realization that the extent of destruction can be limited by their actions in preparing for the emergency to the extent that current knowledge allows.

The ultimate benefits are the reduced losses of life, injuries, and property damage, and the continued functional operation of the general community life and activities with a minimum of disruption.

The process of applying the results of research to a community is complex and varied and it involves all the elements and activities of the community.

The local governing and regulatory bodies can benefit from the research activities by having data and information available to assist them in their decisions involving building code changes and approvals, land use zoning and planning, emergency services preparation, utility preparedness for emergency measures, and a total plan for disaster response.

The public would benefit directly because they would be informed of the hazards and risks involved and could take appropriate action to suit their own particular situation. Private organizations would benefit because they would become aware of the dangers and risks and prepare for them in advance. Professionals from all fields would benefit from the application studies by incorporating the results into their activities at a very early stage in order to limit the total losses of the community when a disaster occurs. The entire community will thus benefit from the application of research results.

The dissemination of information to the decision makers depends directly upon the effort expended. To achieve an early utilization a maximum effort should be initiated at an early stage in order to develop the paths of communications and understanding. In this manner, future research results can be disseminated rapidly and efficiently with a maximum of utilization.

The following table indicates the anticipated year of attainment of technical milestones for each funding option.

	Fiscal Year								
Technical Milestones	77	78	79	80	81	82	83	84	Bey. 84
1. Determine acceptable levels of risk for low-probability and potentially catastrophic events.			BC	A					
2. Develop a prototypical economic model for earthquake-prone regions for estimating the interactions among the public and private sectors for various earthquake mitigation measures (e.g., insurance, building codes, land use, prediction).			ABC						
3. Determine alternative economic incentives and disincentives to correct or eliminate existing hazardous conditions, including buildings.				C	B			A	
4. Develop methods to quantify the national implications of regional and local earthquake mitigation practices, and the local implication of regional and national practices and policies.						C	B	A	
5. Develop cost-benefit analyses applicable to decision at the individual and group level.				C		B		A	
6. Ascertain strategies for mitigation based on a mix of alternatives: structural, nonstructural, social, public and private practices.				C			B	A	
7. Develop effective management techniques for coordination of preparedness activities.		C		B				A	
8. Develop and update model policies for implementing preparedness activities on local, State and regional basis.		ABC		ABC		ABC			
9. Establish socioeconomic monitoring to develop baseline data to evaluate the impact of earthquake predictions and other mitigation procedures (continuing).		ABC							

Technical Milestones	Fiscal Year 77	78	79	80	81	82	83	84	Bey. 84
10. Develop recommendations for maximizing the benefits of prediction.			C		B		A		
11. Develop guidelines for the evaluation of a comprehensive program for relief and rehabilitation.			BC	A					
12. Determine policies on the provision of post-disaster relief and rehabilitation versus financial assistance for predisaster hazard reduction.			C		B	A			A
13. Initiate long-term, longitudinal studies of the return of the utilities to normalcy.			BC		A				A
14. Conduct post-audits to collect information on the consequences of major disasters (continuing for all options).		ABC							A
15. Prepare and update model legislation to implement relief and rehabilitation.		ABC		ABC		ABC			
16. Develop alternative ways to facilitate information flow to and within institutions.			BC			A			
17. Conduct training programs to institutionalize earthquake mitigation measures in State and local governments (continuing).		C		C		C		C	
18. Conduct workshops with representatives of the private sector on methods of reducing earthquake losses (continuing).		C		C		C		C	
19. Initiate an information program to acquaint the public with earthquake hazard mitigation measures.	ABC								
20. Determine the effectiveness of physical regulation (e.g., building code, land-use controls, occupancies) to achieve given levels of earthquake protection.			C	BA					

Technical Milestones	77	78	79	80	81	82	83	84	Bey. 84
21. Determine the effectiveness of financial regulations and practices (e.g., insurance, mortgage and financial regulations, taxation policies) to achieve given levels of earthquake protection.					C	B	A		
22. Determine the effectiveness of regulatory, operational and investment policies of public utilities (e.g., water, communications, transportation) in hazard-prone areas to provide short- and long-term essential public services.						C		B	A
23. Prepare and update model legislation for different mitigation strategies.			ABC		ABC		ABC		

IV. Utilization of Results

Scientific and technological knowledge and its application should not be separated. One of the most significant benefits from the production of such information is in its ultimate application, or in its contribution to the process of technologically based change. Dissemination of the results of this program of research in the most appropriate forms is essential. Existing mechanisms and incentives do not appear to be adequate, however, to assure improvement in professional practice resulting from scientific and technological advancements. Practitioners and researchers could be more effective in communicating their knowledge, experience, and needs among themselves and between the two groups.

Communication of information is needed by the researcher, the practitioner, public agencies, private organizations and individuals. Research results and data must be readily available to other researchers to form the basis for further development, evaluation and validation. Similarly, research results must be available in an appropriate form to those who need it. This step must be pursued carefully so that it does not precipitate action based on inconclusive results or inadequate understanding of the implications.

The benefits of research are best brought to the professions and public policy-setting agencies in a synthesized form where care has been exercised to evaluate its technical merit and its validity.

The most significant primary influences of the practitioner's use of information are legal mandates, economic considerations, and the recognition of liability and professional responsibility. Effective understanding can only be developed by the training and experience of practical application. Consultants and advisors learn from education, training, experience, contact with other consultants, and technical translating publications that are synthesized from research results. It is important to note that research results per se do not have a particularly important direct impact on the practitioner. The traditional reliance upon conferences, workshops, libraries and educational materials, while important intermediaries in bringing the results of research to practice, are in themselves incomplete.

These information flow considerations form the basis for the overall utilization objectives:

Foster the training and experience of practicing professionals, especially through prototype on-the-job demonstration projects.

Prepare and distribute research syntheses and technology translating publications.

Facilitate the exchange of information and experience among practicing professionals.

These objectives will be augmented by activities that support technology transfer, e.g.:

Workshops and conferences,

Preparation of instructional materials,

Information and data services,

Publications.

The research process itself must be supported by readily accessible data and results from other researchers. This will be achieved through publications, information, and data services tailored to facilitate ready access and timely availability.

One of the most important aspects of facilitating improvements in the public's practice of earthquake mitigation is to make sure not only that products of research and experience are channeled to the user, but also that those who are performing the research and who have the experience are aware of the problems faced by the practitioner. These needs will be met by conducting

Regular workshops of users to surface and identify problems needing resolution,

Surveys of how practicing professionals use information,

Periodic priority assessments,

Regular evaluations of research programs and projects with emphasis on the program's relationship to user needs and capabilities.

The implementation of many of the methods developed in this program of research will depend upon actions taken by local, regional, and State governmental units. It is well established that in many jurisdictions there is not as much willingness to innovate as there is to imitate. Thus, it is likely that some form of incentives will be necessary to aid communities in undertaking selected applications. In some cases it may be in the interest of the Federal Government to provide continuing incentives for the achievement of selected objectives. Notable among these may be financial incentives to upgrade the seismic performance of existing buildings, particularly those of special importance to the community after an earthquake occurs.

Clearly implicit in this plan is the need for central coordination of the interests and activities of many organizations in Federal, State, and local governments, as well as in the private sector, all having important roles in earthquake hazards reduction. Central coordination of these diverse groups could best be done at a high level in Federal Government (e.g., the Executive Office of the President).

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APPENDIX 1

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to Mitigate Earthquake Effects

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