Summary and Policy Options 1

Earthquakes have caused massive death and destruction, and potentially damaging earthquakes are certain to occur in the future. Although earthquakes are uncontrollable, the losses they cause can be reduced by building structures that resist earthquake damage, matching land use to risk, developing emergency response plans, and other means. Since 1977, the federal government has had a research oriented program to reduce earthquake losses—the National Earthquake Hazards Reduction Program (NEHRP). This program has made significant contributions toward improving our understanding of earthquakes and strategies to reduce their impact. Implementing action based on this understanding, however, has been quite difficult.

This chapter provides an introduction to earthquakes: a summary of the earthquake hazard across the United States, a review of the types of losses earthquakes cause, a discussion of why earthquakes are a congressional concern, and an introduction to *mitigation*—actions taken prior to earthquakes that can reduce losses when they occur. The federal policy response to date, NEHRP, is then described and reviewed. Finally, specific policy options for improving federal efforts to reduce future earthquake losses are presented.

INTRODUCTION TO EARTHQUAKES

When and Where Earthquakes Occur

Many parts of the United States are subject to earthquakes, which occur when stress accumulates in underground rocks. This buildup of stress typically reflects the slow but continuous motion of the earth's outermost rocky layers, large sections of which drift about the globe as moving *tectonic plates*. Where adjacent plates collide or grind against one another, rocks are highly stressed, and this stress is released in sudden shifts in the earth's surface. As a result, plate boundaries are the primary breeding ground for earthquakes.

One such boundary lies in California, where two major plates slide against one another along the San Andreas fault. Stresses along this and associated faults make California subject to frequent and sometimes powerful earthquakes. In the north of the state, detailed earth science research suggests **a 67 percent probability of one or more earthquakes of magnitude 7[1] or greater in the San Francisco Bay area by 2020.[2]** To the south, where hazard assessments are less certain due to the geologic complexity of the Los Angeles region, a recent report estimates **an 80 to 90 percent probability of a magnitude 7 or greater earthquake in southern California before 2024**.[3]

The colliding of adjacent plates produces extremely powerful earthquakes along the Alaskan coast, one of which severely damaged the city of Anchorage in 1964. A similar earthquake threat has recently been recognized in the Pacific Northwest states of Oregon and Washington: according to a 1991 study, **a great earthquake (magnitude 8 to 9) is possible in the Pacific Northwest; magnitude 6 to 7 earthquakes have occurred in this area in the past and are likely to occur in the future**.[4]

Other parts of the United States are also seismically active—due not to plate collisions, but to other processes not well understood. **Regions experiencing damaging earthquakes in the recent past include parts of the Intermountain West (i.e., sections of Utah, Idaho, Wyoming, Montana, and Nevada); the Mississippi Valley region of the central United States (centered on an area north of Memphis, Tennessee); and cities on the Atlantic seaboard (notably Charleston, South Carolina, and Boston, Massachusetts).** (See figure 1-1.) Earthquakes in these regions (called *intraplate* earthquakes because they occur far from current plate boundaries) are infrequent but potentially powerful.

Earthquake Effects

Earthquakes can cause deaths, injuries, and damage to buildings and other structures, and may inflict a wide range of longer term economic and social losses as well.[5] Although estimating future losses is very uncertain (see box 1-1), there is general agreement that in the next 50 years or so **one or more damaging earthquakes will occur in the United States, resulting in at least hundreds of deaths and tens of billions of dollars in losses**. Larger events, involving thousands of deaths and hundreds of billions of dollars in losses (such as that seen in the 1995 earthquake in Kobe, Japan), are also possible, although scientific uncertainty makes it difficult to estimate their likelihood.

The primary hazard associated with earthquakes is ground shaking, which can damage or destroy buildings, bridges, and other structures. Figure 1-2 shows expected ground motions from

[1] A magnitude 7 earthquake is one large enough to cause serious damage. For comparison, a magnitude 5 will cause slight damage, and a magnitude 8 or greater can cause total damage. See chapter 2 for a discussion of earthquake magnitude scales.

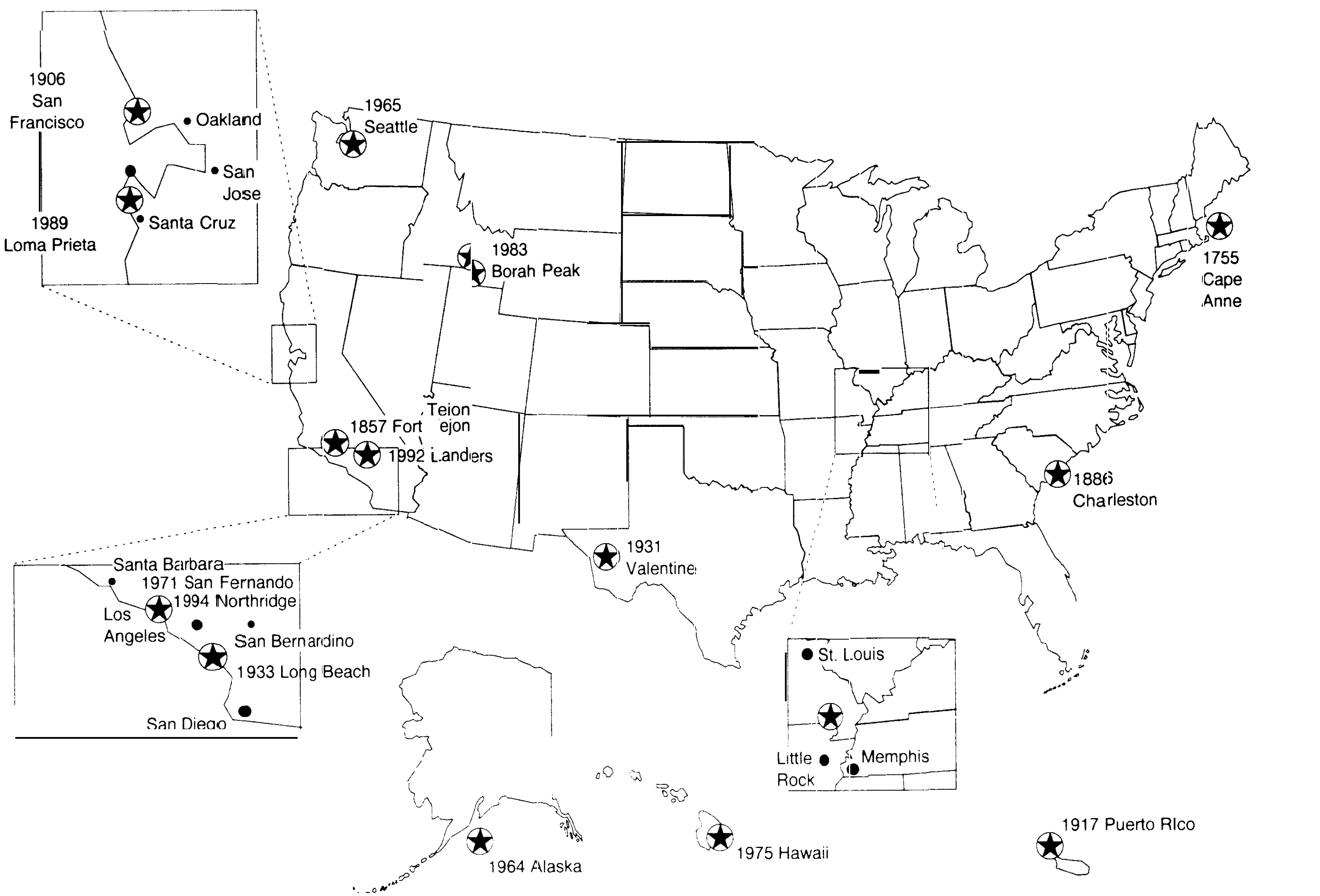
[2] Working Group on California Earthquake Probabilities, *Probabilities of Large Earthquakes in the San Francisco Bay Region, California*, U.S. Geological Survey Circular 1053 (Washington, DC: U.S. Government Printing Office, 1990).

[3] Working Group on California Earthquake Probabilities, "Seismic Hazards in Southern California: Probable Earthquakes, 1994-2024," *Bulletin of the Seismological Society of America*, vol. 85, No. 2, April 1995, p. 379.

[4] Kaye M. Shedlock and Craig S. Weaver, *Program for Earthquake Hazards Assessment in the Pacific Northwest*, U.S. Geological Survey Circular 1067 (Washington DC: U.S. Government Printing Office, 1991), p. 1.

[5] *Damage* generally refers to the direct physical effects of earthquakes, while *losses* include all the societal effects including deaths, injuries, direct financial costs, indirect costs (such as those resulting from business interruptions), and social impacts such as increased homelessness.

FIGURE 1-1: Recent Selected Significant Earthquakes in the United States



NOTE: Not to scale

SOURCE: Office of Technology Assessment, 1995, based on U.S. Geological Survey

BOX 1-1: Loss Estimation

Dependable estimates of likely losses from earthquakes would be useful in developing appropriate policies for earthquake mitigation—for example, by allowing comparisons with other threats to life and property. Unfortunately, the huge uncertainties in the location, timing, and magnitude of earthquakes themselves; in the response of the built environment to earthquakes; and in the inventory of structures that might be damaged make estimating future losses very difficult. '

Despite these difficulties, some estimates of future losses have been made. The results of several such studies are summarized here to provide a sense of the probable range of such losses. These studies cannot be compared, since they examine different geographical areas and different types of losses. As a group, however, they give some indication of the expected scale of future losses A 1992 study for the property Insurance industry estimated losses for several geographic areas, including sections of California, the Pacific Northwest, and the central United States. Total losses due to building damage for a magnitude 7.8 earthquake on the northern section of the San Andreas fault near San Francisco, for example, were estimated at $35.2 billlon.[2] This does not include public sector losses, such as those due to damaged schools or bridges. Another study estimated both dollar losses and fatalities for scenario earthquakes in California and in the central United States. For the larger earthquakes (magnitude 7.5 or greater), losses were on the order of tens of billions of dollars and fatalities in the thousands.[3]

Much more dramatic results can be seen from attempts to predict damages from worst-case earthquakes-great earthquakes that strike close to population centers. A repeat of the 1906 magnitude 8.3 earthquake in San Francisco could cause 2,000 to 6,000 deaths.[4] A repeat of the 1811 central U S earthquake could cause more than $100 billion in damage due to ground motion [5]

An alternate method for arriving at an overall sense of future earthquake damage IS to examine the damage caused by past earthquakes. As shown in the table below, U.S. earthquakes since 1900 have, in total, resulted in about 1,200 deaths and $40 billion in damage. However, extrapolating from historical earthquake damages IS problematic for several reasons"

- All else equal, damage will Increase over time as both population and urbanization Increase—especially in the western United States, which has experienced rapid population growth in recent years
- The recent historical record shows no major earthquakes in the eastern United States, although such earthquakes have occurred and may occur again.

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[1] According to a National Academy of Sciences report, "even using the best of today's methods and the most experienced expert opinion, losses caused by scenario earthquakes can only be estimated approximately Overall property loss estimates are often uncertain by a factor of 2 to 3, and estimates of casualties and homeless can be uncertain by a factor of 10 " National Research Council, *Estimating Losses from Future Earthquakes* (Washington, DC National Academy Press, 1989), p 3

Although loss estimation methods are still relatively crude and hampered by lack of data, recent technological advances suggest that loss estimation may soon be a more useful and accurate policy analysis tool The rapid development of computer hardware and software-specifically the ability to store large amounts of data on CD-ROMs or tapes, and the availability of software that can make sense of these data—has made it possible to manage detailed databases of all structures in specific geographic areas Geographical information systems are now being used in combination with probabilistic ground motion data to yield useful forecasts of likely and worst-case earthquake damages The Federal Emergency Management Agency, for example, IS supporting the development of a computer-based loss estimation tool that would be available to city planners and emergency managers on their desktop computers

[2] Risk Engineering, Inc. , "Residential and Commercial Earthquake Losses in the U S ," prepared for the National Committee on Property Insurance, Boston MA, May 3, 1993 Zero-deductible assumption "Loss" does not reflect deaths or injuries

[3] R Litan et al , "Physical Damage and Human Loss The Economic Impact of Earthquake Mitigation Measures, " prepared for The Earthquake Project, National Committee on Property Insurance, February 1992 Base-case scenarios, without mitigation Expected losses do not include deaths or injuries.

[4] See "'Repeat' Quakes May Cause Fewer Deaths, More Damage, " *Civil Engineering,* November 1994, pp. 19-21

[5] National Academy of Sciences, *The Economic Consequences of a Catastrophic Earthquake,* Proceedings of a Forum, Aug. 1 and 2, 1990 (Washington, DC National Academy Press, 1992), p 72

BOX 1-1 (cont'd.): Loss Estimation

Major U.S. Earthquakes, 1900-94

Year	LoCaliforniation	Deaths	Damages (million $1994)
1906	San Francisco, California	700	6,000
1925	Santa Barbara, California	13	60
1933	Long Beach, California	120	540
1935	Helena, Montana	4	40
1940	Imperial Valley, California	8	70
1946	Aleutian Islands, Alaska	n/a	200
1949	Puget Sound, Washington	8	220
1952	Kern County, California	12	350
1952	Bakersfield, California	2	60
1959	Hebgen Lake, Montana	28	n/a
1964	Anchorage, Alaska	131	2,280
1965	Puget Sound, Washington	8	70
1971	San Fernando, California	65	1,700
1979	Imperial County, California	n/a	60
1983	Coalinga, California	0	50
1987	Whittier Narrows, California	8	450
1989	Loma Prieta, California	63	6,870
1992	Petrolia, California	0	70
1992	Landers, California	1	100
1993	Scotts Mills, Oregon	n/a	30
1993	Klamath Falls, Oregon	2	10
1994	Northridge, California	57	20,000
TOTAL		1,225	39,160

KEY n/a = not available

SOURCE Office of Technology Assessment, 1995

- Some argue that in certain regions, more and larger earthquakes should be expected in the future.[6]
- A single event can influence the data significantly. More than half the deaths since 1900 occurred in just one incident—the 1906 San Francisco earthquake, while about half of the total dollar damages were from the 1994 Northridge event. This demonstrates the "lumpiness" of earthquakes: the deaths and losses occur not in regular intervals, but in large and catastrophic single events.
- On the other hand, new buildings meeting current seismic codes are much more resistant to structural failure than old buildings, which should help to reduce fatalities.

The uncertainties both in projecting losses and in extrapolating historical data make predicting future losses difficult. It is generally agreed, however, that in the next 50 years or so, damaging earthquakes WIII occur in the United States, resulting in at least hundreds of deaths and tens of billions of dollars in losses. Larger events, involving thousands of deaths and hundreds of billions of dollars in losses, are possible, although less likely.

6 J Dolan et al., "prospects for Larger or More Frequent Earthquakes in the Los Angeles Metropolitan Region," *Science*, vol 267, Jan 13, 1995, pp 199-205

STEINBRUGGE COLLECTION, EARTHQUAKE ENGINEERING RESEARCH CENTER

Failure of the ground itself can make an otherwise sound building unusable.

future earthquakes in the United States. Ground shaking can also cause liquefaction, landslides, subsidence, and other forms of ground failure that can endanger even the best-built structures, and moreover may generate coastal tsunamis (great surges of water popularly known as tidal waves).

The damage and destruction wrought by earthquakes has both short- and long-term implications. In the short term, people are killed and injured by collapsing buildings and falling debris. The fires that can result may be difficult to fight due to broken water pipes and roads blocked by debris. In the long term, the costs of repair or replacement coupled with the loss of customers and employees (e.g., due to impassable roads) can force businesses and industries to relocate or close. Local governments may be forced to cut services to cover the costs of infrastructure repair, and housing rents can increase (due to reductions in supply), leading to increased hopelessness.

Deaths

A single earthquake can cause thousands of deaths and tens of thousands of injuries. In just the last decade—1980 to 1990-earthquakes killed almost 100,000 people worldwide. About two-thirds of these deaths occurred in just two catastrophic earthquakes-over 25,000 deaths in Armenia[6] in 1988 and 40,000 in Iran in 1990.[7]

The historical record of U.S. earthquake fatalities is less unfortunate. Since 1900, about 1,200 people have died in U.S. earthquakes (see box 1-l). Most of these earthquakes occurred in regions that were, at the time, sparsely populated. Thus, the low fatality figures for earthquakes from 1900 to 1950 are not surprising. However. even those quakes occurring since 1950 in heavily populated areas of California have had relatively low fatalities, due largely to the fact that many buildings and other structures in California are built to resist seismic collapse.[8] Casualties from future earthquakes are uncertain. One estimate found that a repeat of the 1906 San Francisco earthquake would cause 2,000 to 6,000 deaths;[9] another study found that a large earthquake striking the New Madrid region of the central United States would result in 7,000 to 27,000 deaths. 10

Most deaths in earthquakes occur when structures collapse. In Armenia, for example,

6 L. Wyllie, Jr., President, Earthquake Engineering Research Institute, personal communication, May 11, 1995.

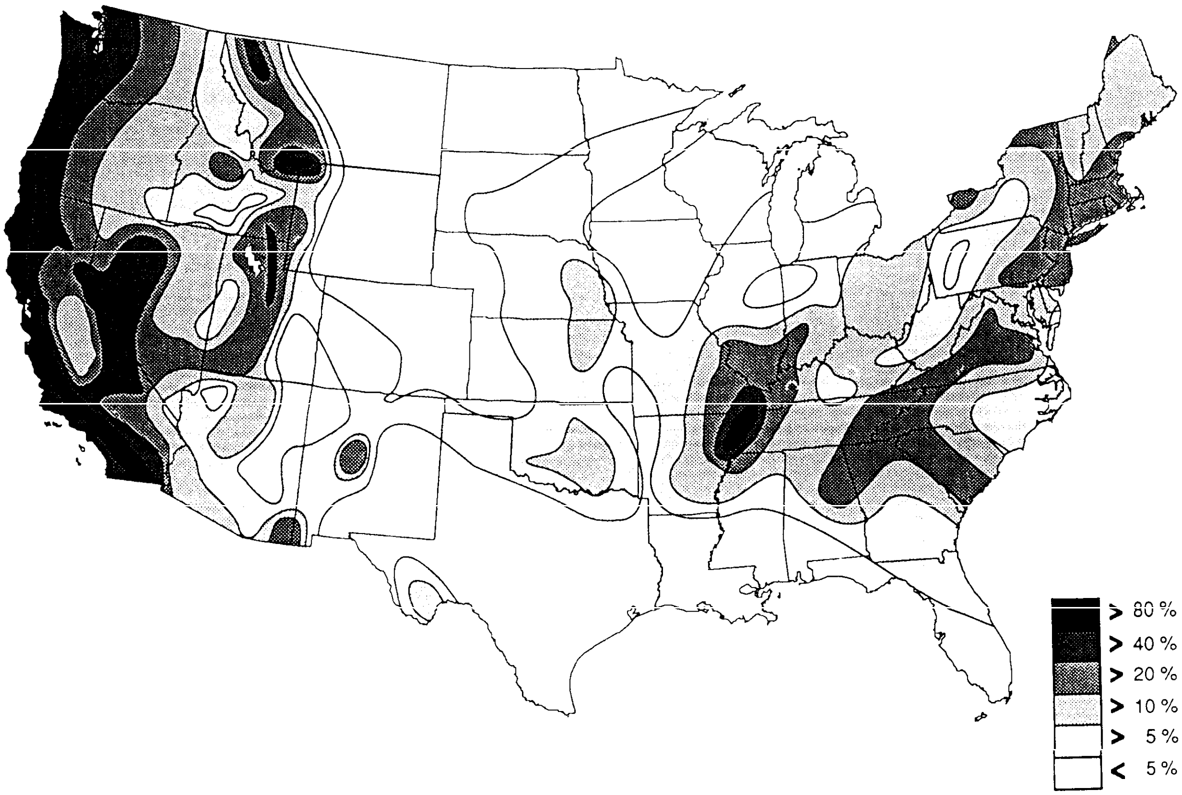
7 B. Bolt, *Earthquakes* (New York, NY: W. H. Freeman and Co., 1993), pp. 272-273.

8 There is an element of luck here as well. The Loma Prieta earthquake, for example, struck during the world series baseball game when roads were relatively empty. Fatalities would have been in the hundreds, perhaps higher, if traffic had been at more typical weekday levels.

9 See "'Repeat' Quakes May Cause Fewer Deaths, More Damage," *Civil Engineering,* November 1994, pp. 19-21.

10 National Academy of Sciences, *The Economic Consequences of a Catastrophic Earthquake,* proceedings of a Forum, Aug. 1 and 2, 1990 (Washington DC: National Academy Press, 1992), p. 68.

FIGURE 1-2: U.S. Seismic Haz



NOTE Map shows expected ground acceleration as a percentage of gravitational acceleration (1 OOYO = 1 0 G) This expected acceleration is for O 3-second period shaking and has a 10% probability of being exceeded in 50 years

SOURCE Off Ice of Technology Assessment, 1995, based on U S Geological Survey

most of the deaths were caused by people being crushed under collapsing buildings. Nearly all of the deaths in the 1989 Loma Prieta earthquake were due to structural collapse.[11] The second major cause of death in earthquakes is fire. In the 1923 Tokyo earthquake, for example, many of the 143,000 deaths were caused by the firestorms that occurred after the quake.[12]

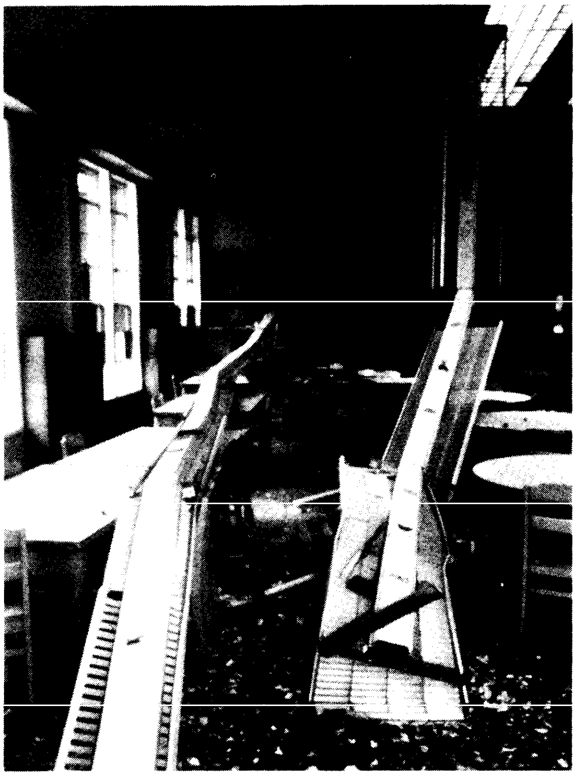
Injuries

In a typical earthquake, many more buildings are damaged than are destroyed. It is this damage to buildings and their contents that causes most injuries. In the 1989 Loma Prieta earthquake, for example, 95 percent of the injuries did not involve structural collapse.[13] These injuries are caused by

[11] M, Durkin and C. Thiel, "Improving Measures To Reduce Earthquake Casualties," *Earthquake Spectra,* vol. 8, No. 1, February 1992, p. 98.

[12] Bolt, see footnote 7, pp. 219, 27"

[13] Durkin and Thiel, see footnote 11



Earthquake injuries are often the result of shifting contents

falls, getting struck by falling or overturned objects, or getting thrown into objects. For example, bookcases and file cabinets can tip over, tumbling books onto people and knocking over other objects, and lighting fixtures and ceiling tiles can come down on people's heads.

Damage to Buildings

Earthquakes can cause four types of damage to buildings: 1) collapse—tile destruction of an entire building, with the death of most of its occupants; 2) structural damage, which leaves the building standing but still unsafe; 3) nonstructural damage to walls, water pipes, windows, and so forth; and 4) damage to contents. The costs of such damage are borne by the building owners and, if the building is insured, by the insurance industry. As discussed later, these costs are in turn shared in many cases by the federal government through disaster assistance programs.

Damage to Lifelines

Lifelines—transportation, energy, water, sewer, and telecommunications systems—are often damaged by earthquakes. These systems can be very expensive to repair; yet even those costs may be dwarfed by the costs of service interruptions. In the short term, interruptions in water supply can cause a city to bum down, and breaks in key transportation links can block access by emergency vehicles. As with buildings, the costs of repair typically fall on the owner (which for many lifelines is the state or local government), the insurance industry if the system is insured, and the federal government through disaster assistance programs.

Other Costs

In addition to deaths, injuries, and damage to buildings and lifelines, earthquakes also cause losses of a different sort. These losses, sometimes called "economic," "indirect," or "social," include the following:

- People cannot get to work when a transportation system is damaged; as a result, businesses must close or reduce their services.
- Basic services such as energy and communications are interrupted, making economic activity difficult or impossible.
- Small business with limited access to capital often cannot survive the combination of loss of business and capital requirements to repair damage.

However, there are those who benefit from earthquakes as well. A severe earthquake is typically followed by a large inflow of money from the government. Construction and associated businesses, such as building materials and architectural firms, experience large increases in business. Housing vacancy rates go down.

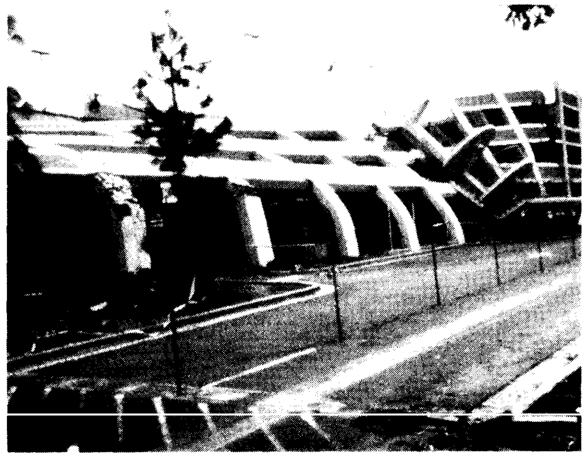
The net longer-term economic effects of earthquake are not clear. As a recent review noted,". . . no systematic research has been conducted on the overall economic effects of a major disaster on the public sector, much less on trying to project these impacts for a future catastrophic earthquake. . . ."[14] Clearly, an earthquake has *distributional* impacts (e.g., damaged businesses lose and construction companies gain), but the net effects are difficult to measure.

Social losses

Often missing from attempts to measure the effects of earthquakes are very real social losses. Low-income housing, which is often concentrated in older buildings that are less resistant to seismic damage, may be the most severely affected, leading to increases in hopelessness and dislocation. Communities faced with the huge costs of repairing earthquake-induced damage to public property maybe forced to reduce other services. Housing rents may increase (because of a reduction in supply), resulting in hardship for low-income households. The trauma of seeing one's home or livelihood threatened or destroyed can be severe. Damaged structures may be left unrepaired for years, creating an eyesore and detracting from a sense of community.

■ Congressional Interest in Earthquakes

The large and continuing losses from earthquakes are of concern to Congress for several reasons. The federal government has long assumed some responsibility for responding to disasters that are beyond the abilities of individuals and local governments to manage. Earthquakes can easily overwhelm state and local disaster response capabilities, and without federal support, many more people would suffer great personal and financial pain. In recent years, however, the financial costs of federal earthquake relief have been very high. In two recent U.S. earthquakes-Loma Prieta (1989) and Northridge (1994)—Congress passed supplemental appropriations bills to help pay for the losses. For Northridge, this bill totaled about $10 billion (although not all of it was to be spent on the Northridge quake).[15] Future earthquakes



The 1994 Northridge, California, earthquake caused extensive damage to this parking garage.

Nonstructural damage can be very costly and disruptive.

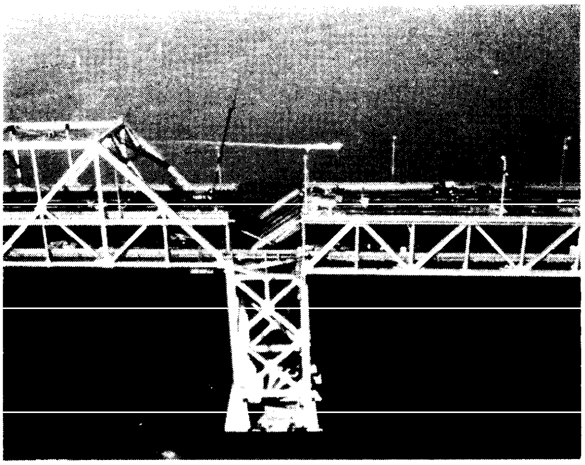
may well receive the same response from Congress—a large supplemental appropriation that strains the federal budget and aggravates the deficit. Since the U.S. government pays much of the costs of earthquakes, it is in the government's financial interest to understand what these costs are due to and how they could be reduced.

In addition to the intermittent large supplemental appropriations to cover some of the costs of earthquakes, the federal government currently spends about $100 million annually on NEHRP—

[14] National Academy of Sciences, see footnote 10, p. 5.

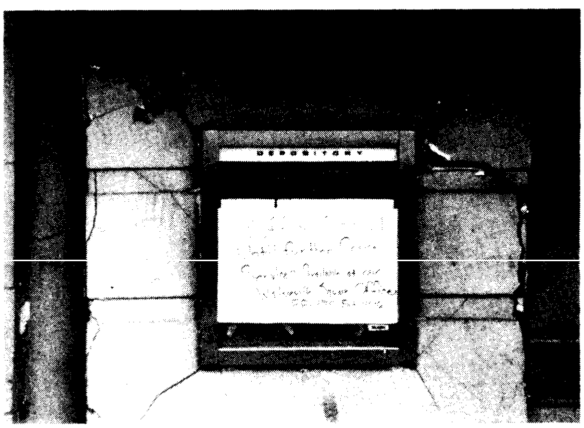
[15] "Disaster Relief: A Trial Run for the Deficit Battle," *Congressional Quarterly,* Feb. 12, 1994, p. 319.

CALIFORNIA DEPARTMENT OF TRANSPORTATION



The San Francisco-Oakland Bay Bridge was damaged in the 1989 Loma Prieta earthquake.

U.S. GEOLOGICAL SURVEY



Earthquakes often disrupt business services such as banking.

the national program intended to reduce earthquake losses (NEHRP is discussed in detail below). Congressional oversight of this program is needed to ensure that this money is well spent.

The federal government's own property—federal buildings and federally sponsored or supported highways, dams, and other projects—is also at risk from earthquakes. About 40 percent of federal buildings and employees are located in seismically active areas, and about 15 percent are located in areas of high or very high seismic hazard.[16] A recent General Accounting Office report found that, "agencies' efforts to reduce building vulnerability have been limited."[17] Reducing this vulnerability is in the federal government's interest.[18]

■ Mitigation: Reducing the Losses

Although earthquakes are unavoidable and uncontrollable, much of the losses they cause are not. Numerous technologies and practices are available that can sharply reduce damage and casualties from earthquakes. Some of these are already in use—largely in California, which leads the nation in earthquake mitigation. However, many technologies are underutilized due to lack of incentives, lack of information, and other barriers (discussed in chapter 4).

Mitigation *measures (i.e.,* actions) include:

- incorporating seismic design features into new buildings and lifelines;
- retrofitting existing buildings and lifelines to improve resistance to seismic forces;
- securing nonstructural components so that they do not fall or become sources of injury in an earthquake;
- matching land use to the hazard; and
- developing response plans that ensure the availability of fire, ambulance, and other resources as needed.

There are numerous *tools,* or levers, to promote these measures, including:

- building codes that set minimum seismic requirements for new construction;
- land-use regulations that steer inappropriate development away from dangerous areas (e.g., prohibiting residential construction in landslide-prone areas);

[16] U.S. Congress, General Accounting Office, "Federal Buildings: Many Are Threatened by Earthquakes, but Limited Action Has Been Taken," GAO/GGD-92-62, May 1992.

[17] Ibid.

[18] The federal government has taken some steps, including the signing of two executive orders, to reduce the risk in federal buildings

- provision of information such as detailed ground motion maps to decisionmakers;
- public education programs;
- financial incentives, such as insurance, that promote the use of mitigation measures; and
- research, to better define the risk and improve methods to reduce it.[19]

Clearly, mitigation can save lives and reduce losses. The relatively low fatalities in the two recent California earthquakes, for example, are due largely to the fact that for many years California has had a building code that requires the use of seismic design principles in new building construction. However, mitigation has its challenges as well; these are summarized below.

Knowledge Gaps and Uncertainties

Although considerable progress has been made in defining the earthquake hazard and in understanding how to design structures to reduce the chances of collapse, much remains unknown; these uncertainties make mitigation more difficult. Key knowledge and understanding gaps include:

- the earthquake hazard outside California—the probabilities, magnitudes, and resulting ground motions of potentially damaging earthquakes;
- how to design buildings to minimize structural and nonstructural damage (as distinguished from minimizing the chances of collapse);
- low-cost and effective ways to retrofit existing structures to reduce earthquake damage; and
- the costs and benefits of mitigation.

Information Access

Decisionmakers may not have access to the latest information, or current knowledge may not be available in a useful and understandable form. For example, structural engineers may not be trained in the latest thinking on seismic design, and homeowners may not know that gas water heaters should be secured to the wall. Similarly, city planners and land-use zoning officials may not have accurate and readily understandable risk maps showing which areas of the city are susceptible to earthquake-induced liquefaction or landslides.

Costs, Benefits, and Incentives

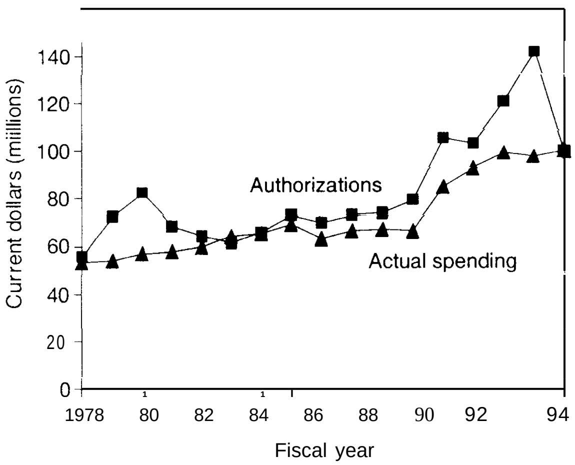
The use of mitigation technologies and practices increases upfront (initial) costs. These costs can be calculated with reasonable certainty, and they can be considerable. For example, the estimated cost to seismically retrofit buildings at one campus of the University of California is $500 million.[20] The benefits of mitigation—avoided damage—occur in the future and are, like earthquake risk, uncertain. Forecasting the benefits of mitigation in just one building requires information on future earthquake timing, effects, damage without mitigation, and reduction in damage due to mitigation. These are all uncertain, and this uncertainty makes it very difficult to determine the net benefits (i.e., benefits minus costs) of mitigation. Although there is general agreement in the professional community that greater mitigation would have positive net financial benefits (i.e., benefits would exceed costs), this can be difficult to demonstrate due to the numerous uncertainties.

Even when mitigation clearly provides positive net benefits, many individuals and institutions demand rapid paybacks from investments (i.e., they heavily discount future returns) and are less likely to invest in mitigation since its benefits are long term. For example, if a building owner expects to own a building for only a short time, he or she may see the probability of an earthquake in that time period as low and therefore not justifying

[19] The earthquake *hazard* is ground shaking, liquefaction, and other natural phenomena that cannot be controlled; while the *risk* is the potential for losses and *can* be controlled.

[20] C. Ingham and T. Sabol, "A Comprehensive Seismic Program: The Experience at UCLA," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, July 10-14, 1994, Chicago, IL (Oakland, CA: Earthquake Engineering Research Institute, 1994), vol. 3, p. 842.

FIGURE 1-3: NEHRP Authorizations and Actual Spending, 1978-94



SOURCE Off Ice of Technology Assessment, 1995, based on NEHRP budget data

mitigation. In addition, the costs and benefits of mitigation may fall on different groups. For example, if an individual believes that an insurance company or the federal government is likely to pay for earthquake damage, there is less financial incentive to mitigate.

POLICY RESPONSE TO DATE: FOCUS ON NEHRP

The federal government currently responds to the earthquake threat with a number of policies and programs. Its primary effort is NEHRP, established in 1977 to "reduce the risks of life and property from future earthquakes in the U.S. . . ."[21] This program combines the efforts of four federal agencies—the U.S. Geological Survey (USGS), the National Science Foundation (NSF), the Federal Emergency Management Agency (FEMA), and the National Institute of Standards and Technology (NIST)—in an effort to reduce earthquake risk through research, development, and implementation.

This Office of Technology Assessment (OTA) report was prepared in response to a request by the House Committee on Science for use in reauthorizing the NEHRP program. Therefore, it focuses on NEHRP. However, the federal government has a number of other policies and programs for addressing earthquakes. Although these are largely response and recovery programs, they have some effect on mitigation. The principal federal disaster program is the Robert T. Stafford Disaster Relief and Emergency Assistance Act,[22] which authorizes the President to issue major disaster or emergency declarations, sets eligibility criteria, and specifies the types of assistance that federal agencies may offer. In the event of a presidentially declared disaster, the region becomes eligible for a number of programs, many of which are operated by FEMA. In the case of large disasters such as the 1989 Loma Prieta and 1994 Northridge earthquakes, Congress passed supplemental appropriations bills to fund FEMA and other agencies' disaster response programs.

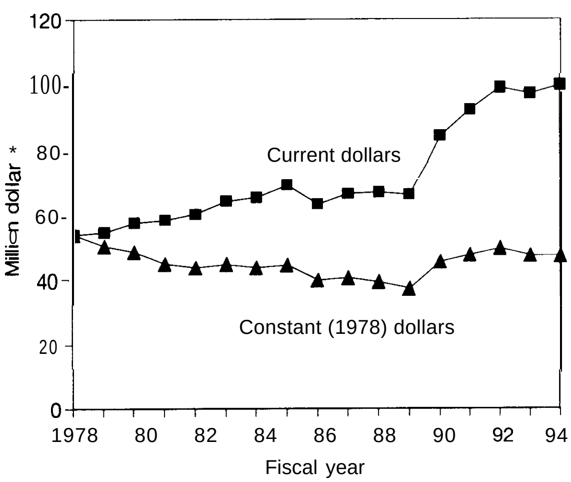
A number of federal agencies have earthquake mitigation research and implementation programs that deal with specific earthquake risks faced by these agencies. The Department of Veteran's Affairs, the Department of Energy, the Department of Defense, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and others conduct a wide range of earthquake-related research and mitigation (see appendix B).

Two recent executive orders address the earthquake risk in federal buildings. Executive Order 12699 (signed January 5, 1990) directs federal agencies to incorporate seismic safety measures in new federal buildings; Executive Order 12941 (signed December 1, 1994) establishes standards

21 Public Law 95-124, Oct. 7, 1977, as amended.

22 42 U.S.C. 5121 *et seq.*

FIGURE 1-4: NEHRP Spending in Current and Constant Dollars, 1978-94



SOURCE Office of Technology Assessment, 1995, based on NEHRP budget data.

for use by federal agencies in evaluating and retrofitting existing federal buildings.

▮ Brief Description of NEHRP[23]

The National Earthquake Hazards Reduction Program was enacted on October 7, 1977, and has been amended several times. The original law provided authorizations only for USGS and NSF. Amendments in 1980 established FEMA as the lead agency, and extended authorizations to FEMA and to NIST. Amendments in 1990 clarified agency roles and set congressional reporting requirements.

NEHRP actual spending has, in most years, been considerably lower than that authorized (figure 1-3) and has decreased in constant (real) dollars (figure 1-4).

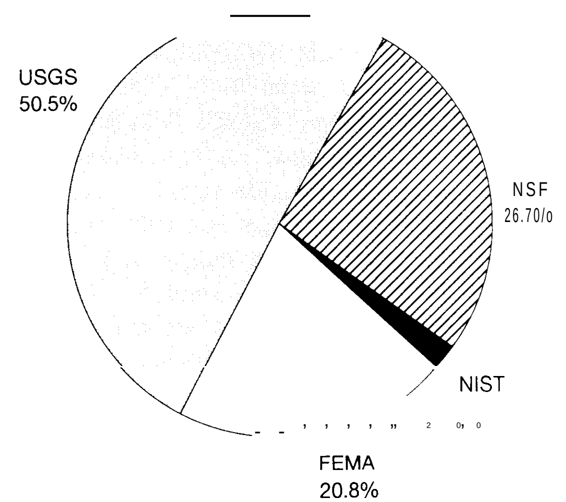
There is no NEHRP agency or central office. Rather, NEHRP is a program in which four federal agencies—USGS, NSF, FEMA, and NIST—participate. **Almost two-thirds of NEHRP funds go for earth science research—via** USGS and NSF earth science programs (see figure 1-5). Fourteen percent is used for engineering research, and 21 percent is used by FEMA, mostly for implementation programs. (See figure 1-6 for data on how agency funding has changed over time.)

U.S. Geological *Survey*

USGS accounts for about half of NEHRP funding—$49.9 million in fiscal year 1994. The majority of USGS activities related to earthquakes are under the agency's Earthquake Hazards Reduction Program, whose stated goals are:

- understanding the earthquake source;
- determining earthquake potential;
- predicting the effects of earthquakes: and
- using research results .[24]

FIGURE 1-5: NEHRP Spending by Agency, 1994



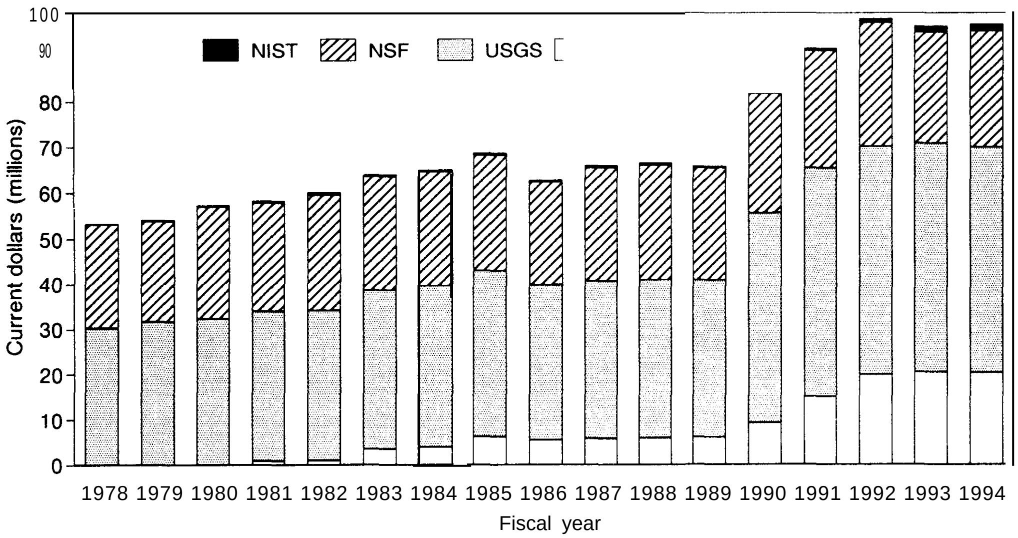
KEY USGS = U S Geological Survey, NSF = National Science Foundation, FEMA = Federal Emergency Management Agency, NIST = National Institute of Standards and Technology

SOURCE Office of Technology Assessment, 1995, based on NEHRP budget data

[23] See appendix A of this report for a detailed history of NEHRP.

[24] Robert A. Page et al., *Goals, Opportunities, and Priorities for the USGS Earthquake Hazards Reduction Program. U.S.* Geological Survey Circular 1079 (Washington, DC: U.S. Government Printing Office, 1992), pp. 1-2.

FIGURE 1-6: NEHRP Spending by Agency, 1978-94



KEY: USGS = U.S. Geological Survey, NSF= National Science Foundation, FEMA = Federal Emergency Management Agency, NIST = National Institute of Standards and Technology.

SOURCE: Office of Technology Assessment, 1995, based on NEHRP budget data.

More than two-thirds of its NEHRP funding is used internally-to support USGS scientists in regional programs, laboratory and field activities, national hazards assessment projects, and seismic network operations. The remainder is spent as grants to outside researchers for specific projects. In general, the internal work focuses more on applying knowledge to describe hazards, while the external program emphasizes expanding and strengthening the base of scientific knowledge.

National Science Foundation

NSF accounts for about 27 percent of NEHRP funding, 11 percent for earth science research and 16 percent for engineering research.

NSF awards grants directly to researchers for the study of earthquake sources, active tectonics, earthquake dating and paleoseismology, and shallow crustal seismicity.[25] The program also supports a university consortium for seismological research and a southern California earthquake research center. Instrument-based seismology, tectonics, and geodesy received the bulk of the funding (together, about 90 percent) in recent years; paleoseismology and microzonation efforts, in contrast, constituted about 5 percent of the overall budget for individual awards.

The NSF earthquake engineering budget can be divided into four major areas: support for the National Center for Earthquake Engineering Research (NCEER) in Buffalo, New York; geotechnical research (e.g., liquefaction and soil response); structural and mechanical research (e.g., active control systems and design methodologies); and socioeconomic and planning research (e.g., cross-cultural hazard response studies and investigations of code enforcement).

25 James Whitecomb, Director, Geophysics Program, National Science Foundation, personal communication, Nov. 21, 1994.

TABLE 1-1: Major Budget Components of FEMA, FY 1993

Area	Approximate annual budget (million $)	Examples
Leadership	1,3	User needs assessment. Small-business outreach program NEHRP plans, reports, and coordination.
Design and construction standards	5.0	Manual for single-family building construction. Preparation of seismic design values. Technical support for model codes.
State and local hazards reduction program	6.1	Grants to states and cities for mitigation programs, Grants to multistate consortia.
Education	1.1	Training in use of NEHRP provisions. Dissemination of information on retrofit techniques.
Multihazard studies	1.7	Loss estimation software development. Wind-resistant design techniques.
Federal response planning	0.9	Urban search and rescue National federal response.

SOURCE Federal Emergency Management Agency, Office of Earthquakes and Natural Hazards, "Funds Tracking Report, " 1993

Federal Emergency Management Agency

FEMA is the lead agency of NEHRP and has responsibility for both overall coordination of the program and implementation of earthquake mitigation measures.[26] FEMA's activities in NEHRP are summarized in table 1-1.

National Institute of Standards and Technology

NIST's role in NEHRP has been largely in applied engineering research and code development. NIST's funding under NEHRP has been relatively low—less than $1 million annually until the 1990s—s0 its NEHRP-related activities have been modest in size and scope. Current NEHRP-related work is varied and includes:[27]

- applied engineering research, such as testing of building components;
- technical support for model code adoption of the NEHRP Recommended Provisions;[28]
- technology transfer (support of conferences and meetings for engineering research); and

26 This description of FEMA activities draws on Federal Emergency Management Agency, *Building for the Future,* NEHRP FY *1991-92* Report to Congress (Washington, DC: December 1992); Federal Emergency Management Agency, *Preserving Resources Through Earthquake Mitigation,* NEHRPFY 1993 -94 Report to Congress (Washington, DC: December 1994); and Federal Emergency Management Agency, Office of Earthquakes and Natural Hazards, "Funds Tracking Report, FY 1993," 1993.

27 Information drawn from Federal Emergency Management Agency, *Preserving Resources Through Earthquake Mitigation, see* footnote 26.

28 The recommended provisions are a resource document used by model code developers.

TABLE 1-2: Examples of NEHRP-Sponsored Contributions

Earth science	Understanding the potential for great coastal earthquakes in the Pacific Northwest.
	Ability to determine earthquake locations and magnitudes instantaneously.
	Long-term, probabilistic forecasts of earthquakes for the San Francisco Bay region.
	Instrumental recordings of liquefaction during strong ground shaking.
	Availability of a strong-motion database.
	Improved understanding of fault behavior and ground motion propagation.
	Paleoseismology.
	Understanding of the role of local soil conditions in influencing ground motion.
Engineering	Improved techniques for nonlinear analysis of building components and structures.
	Advances in analytical and modeling techniques that permit seismic structure design on Inexpensive computers.
	Improved understanding of how structures behave under earthquake-reduced stress—leading to better building codes in areas such as bracing systems for steel structures.
	Advances in new technologies, such as base Isolation and active control.
	Better reliability and risk assessment techniques for lifelines and structures.
	Improved disaster response planning from social science research that sheds light on, for example, cultural differences in perceptions of disaster.
Implementation and technology transfer	NEHRP provisions adopted by model codes.
	Handbooks for seismic retrofits.
	Information centers (information services at the National Center for Earthquake Engineering Research at the State University of New York at Buffalo, the Earthquake Engineering Research Center at the University of California, and the Natural Hazards Center at the University of Colorado).
	Executive orders covering new and existing federal buildings.
	Multistate consortia.

SOURCES Robert A Page et al , *Goals, Opportunities, and Priorities for the USGS Hazards Reduct/on Program,* U.S. Geological Survey Circular 1079 (Washington, DC U S Government Printing Off Ice, 1992), p 5, and National Science Foundation, "Directions for Research in the Next Decade, " Report on a Workshop, June 1983

- international cooperation (support of meetings and exchange programs with other countries).

NEHRP CONTRIBUTIONS AND CHALLENGES

Contributions

NEHRP **has led to significant advances in our knowledge of both earth science and engineering aspects of earthquake risk reduction (see** table 1-2). For example, NEHRP has contributed to the following accomplishments: the seismic risk in the Pacific Northwest is better understood, structures can be built that are unlikely to collapse in an earthquake, and improved computer-based structure design tools are available. Although NEHRP is principally a research program, it has contributed to the implementation of earthquake mitigation as well. For example, we now have model building codes that reflect a national consensus on new building seismic design, as well as several interdisciplinary centers that work to translate research results into useful information for decisionmakers.

Despite these successes, however, earthquakes still cause massive losses in the United States. The 1994 Northridge earthquake caused more than $20 billion in losses, and scenarios of possible future U.S. earthquakes suggest that thousands of casualties and tens or even hundreds of billions of dollars in losses may occur. Although there is no consensus on what level of loss is acceptable,[29] there is clearly a significant remaining exposure to earthquake damage—due in large part to a failure to implement known technologies and practices. Although many communities, especially in California, have taken steps to mitigate earthquake losses, a large gap still exists between what current knowledge says could be done and what actually is done. **Addressing this implementation gap is NEHRP's greatest challenge**.

Implementation Gap

When NEHRP began in 1977, the enabling legislation contained a number of objectives, including educating the public, ensuring the availability of earthquake insurance, and promoting seismic building codes and seismic considerations in land-use policy. However, actual funding was authorized only for USGS and NSF, to be used for earthquake-related research. Although in later years some funding was authorized for implementation activities by FEMA, NEHRP has remained largely a research program. Currently, about 75 percent of the NEHRP budget is used for research.

This historical focus on research can be understood in part by recognizing that NEHRP was founded at a time of great scientific optimism. Newly discovered principles of plate tectonics (see chapter 2) had led to great insights into earthquake mechanisms and many believed that short-term earthquake prediction would soon become a reality. This prediction capability was thought sufficient to motivate widespread mitigation action. Therefore, NEHRP was given neither regulatory teeth nor significant financial incentives to promote mitigation. Instead, the program aimed to develop a body of knowledge from which local and state authorities and the private sector would draw. Since then, however, prediction has proved more elusive than originally thought, and the original role of NEHRP as a source of knowledge from which decisionmakers would eagerly draw is now seen by many as insufficient, due to the lack of regulations or incentives to implement the knowledge. This has contributed to the current situation of an implementation gap.

Examples of this implementation gap include the following:

- An assessment of California's mitigation status found, "we still have many earthquake-vulnerable buildings . . . it's now possible to avoid seismically hazardous areas and build earthquake-resistant structures, but too often the information needed is not used."[30]
- Many states in moderate risk areas do not have state seismic codes.[31]
- In those states that do have codes, many counties are not even aware of their existence.[32]
- Even when codes are adopted, they may not cover all buildings—for example, they may exempt single-family dwellings.[33]
- A recent study concluded, "Even in California, many localities consider seismic risks in only the most rudimentary manner."[34]

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[29] Although no losses would seem desirable, achieving this would be either impossible or impractically expensive.

[30] California Seismic Safety Commission, *California at Risk*, 1994 Status Report, SSC 94-01 (Sacramento, CA:1994), p. 1.

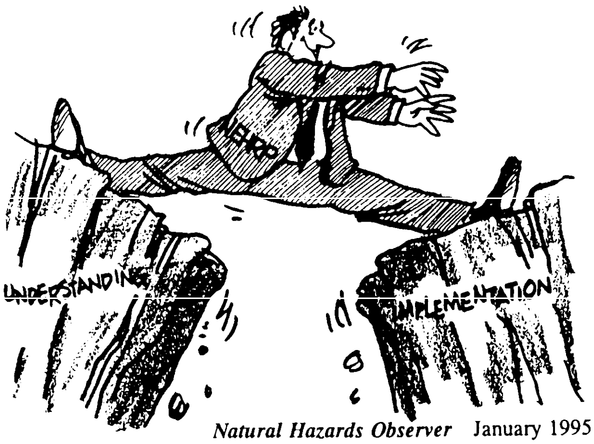
[31] R. Olshansky, "Earthquake Hazard Mitigation in the Central United States: A Progress Report," in *Proceedings of the Fifth U.S. National Conference on Earthquake Engineering*, July 10-14, 1994, Chicago IL (Oakland, CA : Earthquake Engineering Research Insitute, 1994), p. 991.

[32]Ibid.

[33] The building code in Paducah, Kentucky, for example, exempts single-family dwellings; unanchored foundations are common. VSP Associates, Inc., "State and Local Efforts To Reduce Earthquake Losses," contractor report prepared for the Office of Technology Assessment, December 1994, p. III-9.

[34] P. Berke and T. Beatley, *Planning for Earthquakes* (Baltimore, MD: Johns Hopkins University Press, 1992).

ROB PURIM, NATURAL HAZARDS OBSERVER, JANUARY 1995



The gap between knowledge (understanding) and implementation can be daunting

If NEHRP continues along a similar path—a focus on research, with a relatively small effort to promote implementation[35]—then we will likely see advances in earthquake-related earth science and engineering continue to outpace the implementation of new knowledge.

Additional Challenges

The implementation gap is a key issue for NEHRP. However the program faces several additional challenges as well. These include a lack of specific goals and strategies, differing expectations by different groups, tensions between basic and applied research, and the inherent limitations of NEHRP's information-only approach to earthquake mitigation.

Goals and Strategies

In recent years, NEHRP has been criticized for its lack of concrete goals and strategies:

- A 1991 study found that, "federal agency descriptions of NEHRP . . . do not provide much sense of an overall strategy."[36]
- In hearings for the 1993 reauthorization. witnesses commented, "[NEHRP's] fragmented, four-agency structure has contributed to an inability to define program and budgetary priorities and achieve realistic, well-coordinated goals."[37]
- A 1993 congressional report accompanying NEHRP reauthorization legislation noted. "long-standing concerns about NEHRP—[including] lack of an overall strategic plan."[38]

Although the NEHRP authorizing legislation sets broad overall objectives for the program, actual NEHRP spending by the agencies involved does not suggest any unified multiagency agreement on specific goals, strategies, or priorities. In the absence of clear goals and strategies, each agency's NEHRP activities have evolved into a portfolio that reflects that agency's missions and priorities, rather than strong multiagency agreement. In addition, this lack of agreement on goals and strategies makes judging the impact or success of the overall program difficult, since there are few criteria by which to measure performance.

Differing Expectations

Different groups have different expectations from NEHRP. In the absence of clear goals and strategies, these differing expectations make allocating NEHRP's scarce resources difficult.

The earth science research community is concerned with the state of knowledge of earthquakes. In its view, earthquakes are a poorly understood natural phenomenon. Thus, better understanding of earthquakes—why and how they

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35 Currently NEHRP, through FEMA, does have some programs to promote implementation, but these are generally quite small. For example, FEMA's program to support state and local mitigation efforts is funded at about $6 million annually or, given 39 states that face a reasonable seismic risk, at about $150,000 per state.

36 P. May, "Addressing Public Risks: Federal Earthquake Policy Design," *Journal of Policy Analysis and Management*, vol. 10, No. 2, p. 270.

37 U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Science, hearing, Sept. 14, 1993, p. 20.

38 U.S. Congress, House Committee on Science, Space, and Technology, "Earthquake Hazards Reduction Act Reauthorization," Nov. 15. 1993, p. 6.

occur, and when and what type of earthquakes are likely to occur in the future—is an important component of reducing earthquake losses. This community would like NEHRP to be a source of funding for research and data collection that could, in the long term, help reduce such losses.

The engineering research community is concerned with how the built environment—buildings, bridges, dams, and so forth—is damaged in earthquakes and how these structures should be built so as to reduce losses. It sees the need for improvement in the current understanding of structural response to earthquakes, and considers engineering research an important component of reducing earthquake losses. Much like the earth science research community, this group is concerned with the amount of funding NEHRP can provide for research.

State and local government officials concerned with earthquakes, in contrast, would like NEHRP to provide products to help them reduce risk. State highway agencies, for example, would like technical assistance in prioritizing and conducting retrofits of highway bridges. City planners would like detailed maps showing liquefaction and landslide potential to help determine where and how to guide development. Local code enforcement officials would like software to help determine code compliance. Emergency managers would benefit from methods to ensure that critical facilities (such as hospitals and emergency communication systems) survive earthquakes.

The practicing engineering and design community would like NEHRP to provide information on the earthquake-related issues it faces: how to design safe buildings at low cost, what specific types of ground motion to expect and when, and what levels of retrofit protection to provide.

The public generally is unaware of or uninterested in NEHRP; however some individuals concerned with reducing earthquake risk have needs that could be met by the program. Some large companies and institutions have risk managers whose responsibilities include earthquakes; these individuals would like tools to help them reduce risk, such as information on expected ground motion and likely damage, and methods for retrofit prioritization. Electric and gas utilities would like technical assistance in determining risk, and in prioritizing and conducting retrofits. Some regions have community and grassroots groups concerned with earthquake risks; these groups would like pamphlets, workbooks, and other material to help inform the public. The media are often interested in information after an earthquake: how big was the earthquake, where was the epicenter, and what is the probability of significant aftershocks?

These different perspectives on NEHRP's function—each valid and sincere in its own right—pull the program in different directions. These pulls—between research versus implementation, basic versus applied research, and earth science versus engineering—complicate the allocation of NEHRP's finite resources, and can only be resolved through the setting of clear program goals.

Tensions Between Basic and Applied Research

NEHRP currently supports a range of research, from basic studies on how faults move to applied work in testing building components. (See appendix B for a full description of NEHRP's research and development (R&D) portfolio.) Tension exists over the appropriate levels of support for these different activities. Some argue that certain pressing short-term needs, if met, would yield significant social benefits. Others point out that basic research is required to continue to advance the knowledge base and that this work will not be done without federal support.

It is useful to recognize that the distinction between "basic" and "applied" is better seen as a continuum and that work at all levels is potentially useful. In addition, across this continuum runs the need for data collection, which can also demand significant R&D resources.

Information Alone Has Its Limits

NEHRP's approach to reducing earthquake losses can be thought of as supplying information on earthquake risks and possible countermeasures to those who may wish to mitigate. By supplying this information, the program hopes to motivate individuals, organizations, and local and state governments toward action while providing guidelines on how to proceed. This approach implicitly assumes that the interest or incentive for mitigation is sufficient for people to act on such information. However, the frequent lack of mitigation activity often reflects not a lack of information, but a lack of interest or incentives to take action. **Information alone will not result in widespread implementation**. Whether or not the federal government should play a role in ensuring that there are sufficient incentives for implementation is a sensitive policy question that is discussed below. In any case, NEHRP's approach of supplying only information limits the program's impact.

POLICY OPTIONS

NEHRP reauthorization offers an opportunity for Congress to consider what it wants to accomplish with NEHRP and how it wishes the program to proceed. A key decision is whether to maintain the current federal role of research sponsor and information provider or to change the federal role through, for example, changes in federal disaster policy, insurance, or regulation. As discussed above, **NEHRP has had numerous research accomplishments and has made significant contributions to earthquake knowledge; it has become clear that taking action based on this knowledge is a key challenge for the future**. Significant changes in the federal role could potentially help close this knowledge-implementation gap. However, increasing the federal role would be controversial. Furthermore, doing so would represent a significant shift in NEHRP and would require the participation of additional congressional committees.

Three types of policy options are discussed here:

1. **Specific activities undertaken by NEHRP**. The Office of Technology Assessment (OTA) identifies key research and implementation needs that NEHRP could address within its current scope. Addressing these while maintaining the current portfolio would require increased funding.
2. **Management and operational changes in NEHRP**. These could allow NEHRP to be a more efficient, coordinated, and productive program.
3. **Changes to federal disaster assistance and insurance, regulation, and financial incentives**. These would be necessary if Congress decides that the federal government should take greater responsibility for the implementation of NEHRP-produced knowledge. They are outside the current scope of NEHRP and would represent a significant change in direction for the program.

NEHRP Portfolio Changes

NEHRP currently supports earth science research, engineering research, and implementation support and promotion. In each of these areas OTA has identified specific topics needing further attention.

Earth Science Research

Earth science research can help to reduce earthquake-caused deaths, injuries, and other losses by:

- narrowing the uncertainty of when and where large earthquakes will occur;
- estimating, as accurately as possible, the expected ground motions, ground failure, and other effects that will occur in future earthquakes; and
- developing maps of these seismic hazards for use by engineers, land-use planners, and emergency managers.

Historically, NEHRP has focused on basic research that contributes primarily to the first objective and, to a much lesser degree, on disseminating research results to the public. In large part, this is due to the absence of clear goals or strategies for the program, an issue discussed in greater detail in a following section. Without consensus on programmatic goals, NEHRP's earth science R&D portfolio has been strongly influenced by the values and concerns of the agencies supporting it—NSF and USGS—both of which have strong research orientations. Basic research into fundamental earth processes (e.g., how do earthquakes begin and propagate) dominates the research supported by NSF under NEHRP. USGS supports research that is generally more applied than that of NSF (e.g., developing and distributing detailed maps showing expected ground motions), but conducts and sponsors some basic research as well. With NEHRP funding, NSF and USGS also support seismic monitoring networks and other data collection efforts related to earthquake research and seismic hazard assessment.

If Congress views NEHRP's earth science activities as primarily a means of providing long-term benefits (e.g., enhancing fundamental understanding of earth processes such that uncertainties in the timing, location, and magnitude of future earthquakes can be reduced), retaining the current concentration in more basic research would be appropriate. This work has yielded new insight into, for example, the relationship between plate deformation and earthquakes, the mechanics of fault rupture, and the sources of some intraplate quakes. In time, this research may narrow the uncertainties in future earthquake location, timing, and effects.

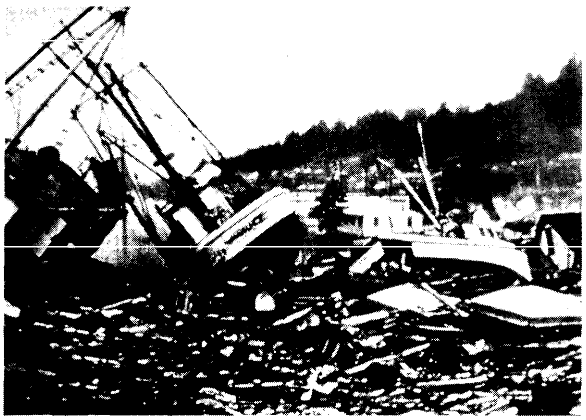
Today, however, knowledge of seismic hazards in many U.S. metropolitan areas remains very limited. Outside of coastal California and a few other cities (e.g., Salt Lake City, Memphis, Portland, and Seattle), assessing and mapping earthquake hazards is proceeding very slowly. If Congress believes that NEHRP should now place more emphasis on near-term applications of data and research results to risk assessment (e.g., microzonation), then NEHRP's earth science portfolio should include a greater share of activities that meet these goals.

Engineering Research

Knowledge of how to design and build structures to reduce earthquake-induced losses has improved tremendously. However the problem is far from solved. The 1994 Northridge earthquake occurred in the area of the United States that is probably the most well prepared; nevertheless, the quake caused dozens of deaths and more than $20 billion in losses. Scenarios of future earthquakes suggest that large losses are likely.

MS HARRY A SIMMS, SR

Tsunamis are an infrequent but dangerous result of undersea earthquakes.



NOAA/EDIS

Tsunamis can cause major damage.

Greater use of existing knowledge, practices, and technologies could reduce these losses. For example, the collapse of the 1-880 elevated highway in the 1989 Loma Prieta earthquake, which caused the deaths of 42 people, could have been prevented with the use of known retrofit technologies.[39] The implementation (or lack thereof) of these technologies to date has been determined

[39] U.S. Congress, Genera] Accounting office, "Loma Prieta Earthquake: Collapse of the Bay Bridge and the Cypress Viaduct," GA@ RCED-90- 177, June 1990, p. 2.

STEINBRUGGE COLLECTION, EERC

Many older buildings are vulnerable to structural collapse.

largely by economic, behavioral, institutional, and other factors—not by the state of current knowledge.

Nevertheless, additional. knowledge could have several benefits. First, although our understanding of how to build new structures to resist seismic damage is good, it is far from perfect (e.g., the steel weld failures in modem buildings in the Northridge earthquake, discussed in chapter 3). Second, most of the financial losses in recent earthquakes were not due to building collapse. Rather, they resulted from structural, nonstructural, and contents damage—areas that could benefit from further research. Third, much of the casualty risk lies in existing structures, and retrofit methods are just now being refined and standardized. More research into improving retrofits could reduce this risk. Fourth, to the extent that the upfront costs of mitigation reduce implementation, research that reduces these costs could lead to greater implementation.

New buildings

A new building that meets current seismic building codes will be very resistant to collapse due to earthquakes. This is a great technical accomplishment in which NEHRP played a considerable role. Since this has been achieved, it is time to consider moving some resources to the next research challenge: **reducing structural, nonstructural, and contents damage.** Possible areas of research include:

- data collection and analysis of structural, nonstructural, and contents damage from recent earthquakes;
- analytical methods to measure and predict such damage;
- guidelines for designing lighting, electrical, water, and other systems so as to minimize seismic damage;
- building codes that address structural, nonstructural, and contents damage; and
- new technologies—notably active and passive control (see chapter 3)—that can reduce this damage.

Existing buildings

Much of the risk of both structural collapse and nonstructural and contents damage lies in existing buildings, which do not incorporate current codes and knowledge. Relatively few of these buildings have been retrofitted to reduce risk, and where retrofits have been performed they have often been expensive, complex, and of uncertain benefit. Although NEHRP has made progress in understanding and improving retrofits (e.g., through FEMA's existing buildings program), more research is needed to improve retrofit methods.

The first area of research for existing buildings should be to better understand their vulnerability. Laboratory and field experiments, and collection and analysis of data on how buildings respond in earthquakes, are needed. Improved tools to determine risk in existing buildings—such as nondestructive evaluation techniques—are needed as well. A second area is **the development of low-cost standardized retrofit techniques.** Standardized methods, such as those contained in codes for new construction, would reduce costs and could allow for multiple levels of safety to account for different risk preferences. A third research area is to **extend retrofits to nonstructural and contents damage reduction.**

Lifelines

Lifelines are expensive to repair, and service interruptions, which are at best inconvenient and at times deadly, may result in large economic losses. The lack of an accepted national standard for the design and construction of lifelines raises costs and reduces performance. Although the 1990 NEHRP reauthorization directed that FEMA and NIST work together to develop a plan for developing and adopting design and construction standards for lifelines by June 30, 1992, as of May 1995 no such plan had been submitted to Congress.

Much of the life safety risk associated with lifelines lies in existing facilities. Research is needed to develop methods to better determine the risks in existing facilities, to prioritize retrofits, and to reduce retrofit costs. Low-cost, easy-to-use procedures to analyze lifelines for weak links would help to ensure their continued function in earthquakes.

Implementation of Mitigation

NEHRP supports mitigation several ways: through technical support of state and local efforts, through research to better understand the implementation process, and through knowledge transfer efforts. Some promising directions that could improve these activities are discussed below.

Perhaps the most promising implementation activity is to directly assist communities in their efforts to understand earthquake risk and to devise mitigation options. In particular, **it is critical that communities be given analytic tools to estimate likely losses in the event of a future earthquake and to predict the likely benefits of mitigation**. At present, it is difficult to quantify these basic parameters, and this absence inhibits vigorous action at all mitigation levels. Fortunately recent advances in computers—and specifically in geographical information systems—suggest that it will soon be possible to provide local decision-makers with highly detailed and specific information on seismic risks, even on a specific building level. FEMA is now supporting an effort to make these regional loss estimation tools available to local governments. This is a promising direction that could reduce considerably the uncertainty in risk. These tools often require large amounts of detailed data on local land-use patterns and building stock; communities need help in defining data needs and collecting data as well. User training may also be needed.

Better evaluation of FEMA implementation programs is needed. Very few of these programs have been evaluated carefully in the past, leaving current program planners with little guidance as to what works, what does not work, and why. All mitigation programs should be evaluated carefully, and the results should be used to improve, refocus, or—if necessary—terminate programs.

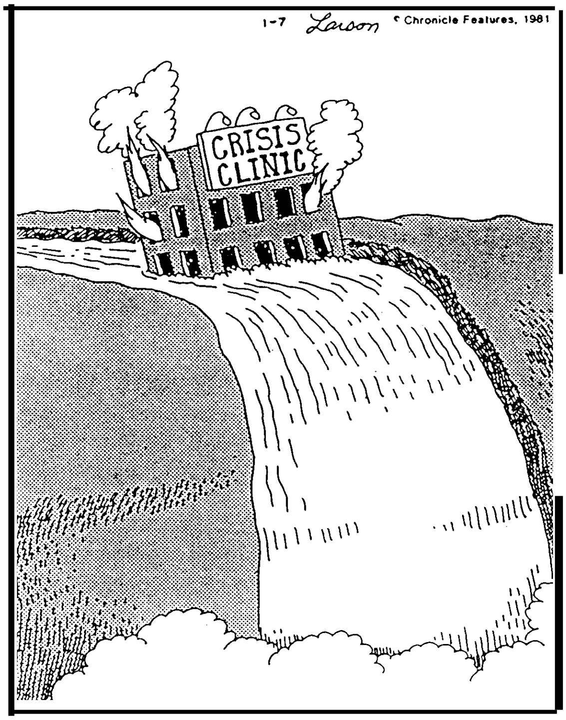
Because individual local "advocates" can play a powerful role in fostering and maintaining community interest in mitigation, efforts to create or assist advocates are potentially quite useful. The federal government can support advocates by identifying and working closely with them to ensure their access to the latest mitigation information and analysis tools.

Media and public outreach activities can have a powerful indirect effect. The more publicity there is concerning earthquakes, the more likely that advocates will arise and act. Public interest in earthquakes largely depends on how recently a major quake last occurred, so preparing outreach materials to take advantage of disaster "windows" is a prudent measure. The advantage of this outreach is that it is relatively inexpensive and can be very effective.[40]

To complement activities on the seismic front, efforts could be made to incorporate seismic implementation into a larger "all-hazards" framework. Much of the nonstructural preparation

[40] The disadvantage is that in places where destructive seismic activity is extremely infrequent (e.g., the U.S. east coast), these windows are rarely open.

THE FAR SIDE By GARY LARSON



Some areas of the US. are threatened by a variety of natural hazards. (The Far Side cartoon by Gary Larson is reprinted by permission of Chronicle Features, San Francisco, CA. All rights reserved).

required for seismic mitigation (e.g., predisaster emergency planning) is useful in the event of fire, flood, wind storm, or other natural disasters, and can thus gain in political and economic attractiveness when viewed in a larger context.

In addition to direct support for implementation, NEHRP also supports some research into the behavioral, social, and economic aspects of mitigation. Further research of this type could improve our understanding of some key questions that currently hinder mitigation. Examples of specific questions that NEHRP could address include the following:

- How do financial and other incentives affect mitigation behavior? To what extent is insurance and the expectation of federal disaster relief currently a disincentive for mitigation?
- How is NEHRP-generated information (e.g., hazard maps and building seismic response data) used by the mitigation community? How should this information be presented to ensure its appropriate and productive use?
- How well have NEHRP-supported information and technology transfer efforts worked? What contributed to their successes and failures, and what does this suggest for future efforts?

The answers to these questions could help improve the next generation of NEHRP-supported implementation programs.

The four NEHRP agencies have put increasing effort into "knowledge transfer"—institutions and procedures that promote the delivery of useful information to decisionmakers. For example, NEHRP funds several "centers" that emphasize matching research to user needs and ensuring research results are provided in a useful form to decisionmakers. NEHRP also supports several information services that provide research results to interested users, as well as multistate consortia that coordinate state activities and facilitate communication between researchers and users.

The implementation gap discussed above suggests that these efforts be continued and expanded. Options for expansion include increasing funding for knowledge transfer programs, requiring utilization plans for applied research projects, and establishing formal utilization criteria for evaluating applied research proposals.[41] All such efforts should be evaluated carefully and regularly.

Allocating NEHRP Funding

Current NEHRP funding is about $100 million annually. The ideal method to determine appropriate funding levels would be to consider the costs and benefits of future NEHRP spending. Although the direct costs are clear—simply the pro-

41 A detailed discussion of options for increasing the use of applied research can be found in Applied Technology Council, *Enhancing the Transfer of USGS Research Results into Engineering Practice, ATC-35* (Redwood City, CA: 1994).

jected funding—the benefits are not. Much of NEHRP funding is for research, and the results of research—greater understanding—are not easily quantified. NEHRP's spending for implementation should be somewhat easier to evaluate. However, as noted above, past implementation programs have not been evaluated in a systematic way; thus there is little guidance on the likely benefits of future spending. **Improved evaluation would provide guidance for deciding funding levels and allocations**.

NEHRP spending, both in allocation and in total, should reflect national priorities. Basic conceptual earth science research enhances our understanding and will likely, in the long term, translate into better mitigation. Engineering research can produce more immediate benefits. Implementation programs, such as FEMA's state and local grants, can have immediate impacts. The current NEHRP portfolio is tilted strongly toward earth science research: 64 percent of NEHRP spending is under USGS and NSF earth science. If Congress would like NEHRP to emphasize improving basic knowledge, and thus provide longer term societal benefits, then the present mix is appropriate. If, however, Congress would like NEHRP to produce more immediate societal risk reduction, then a tilt toward engineering and implementation would be appropriate.

Structural and Operational Changes

Policy options related to the structure and operations of NEHRP include changes to improve program coordination, changes in the lead agency, and improvements in cross-agency coordination.

Program Coordination

Overall program coordination and the selection and role of the lead agency in NEHRP have been problematic since the program began.[42] Initial NEHRP legislation directed the President to select a lead agency, and the 1980 reauthorization designated FEMA as the lead agency. Since then, evaluations of and hearings on NEHRP have often criticized FEMA's management and coordination of the program. Examples of this criticism include:

- a 1983 General Accounting Office report that noted, "FEMA needs to provide stronger guidance and direction";[43]
- the Senate report accompanying the 1990 reauthorization that noted, "the need to improve coordination of the agencies in the program";[44]
- hearings for the 1993 reauthorization in which witnesses commented on, "the diffusion of responsibility inherent in four different federal agencies attempting to implement NEHRP"; [45]
- a 1993 congressional report that noted, "insufficient coordination among the [NEHRP] agencies to shape a unified, coherent program."[46]

Coordination is difficult to measure. OTA's meetings and discussions with NEHRP agencies, and its reviews of NEHRP activities, did not uncover any glaring examples of poor coordination. NEHRP staff in each agency were aware of activities in other agencies; they had frequent informal contact with each other and made efforts to keep one another informed of changes and findings. FEMA has produced congressionally mandated

[42] See David W. Cheney, Congressional Research Service, "The National Earthquake Hazard Reduction Program," 89-473 SPR, Aug. 9, 1989; U.S. Congress, General Accounting Office, "Stronger Direction Needed for the National Earthquake Program," GAO/RCED-83-103, July 1983; and VSP Associates Inc., "To Save Lives and Protect Property," Report for the Federal Emergency Management Agency, FEMA-181, July 1989.

[43] General Accounting Office, see footnote 42, p. 7.

[44] U.S. Congress, Senate Committee on Commerce, Science, and Transportation, National Earthquake Hazards Reduction Program Reauthorization Act, Report 101-446, (Washington, DC: Aug. 9, 1990), p. 3.

[45] House Subcommittee on Science, see footnote 37.

[46] House Committee on Science, Space, and Technology, "Earthquake Hazards Reduction Act Reauthorization," see footnote 38.

reports and plans that describe the NEHRP programs in detail.

As discussed above, however, actual NEHRP spending by the agencies does not suggest any overall multiagency agreement on specific goals, strategies, or priorities, but suggests instead a loosely coordinated confederation of agencies. **In the absence of clear goals and strategies, each agency's NEHRP activities reflect that agency's missions and priorities rather than a strong multiagency agreement**. This lack of agreement on goals and strategies also makes it difficult to judge the impact or success of the overall program, because there are no criteria by which to measure performance. In OTA's view, **coordination must be preceded by agreement on specific goals and priorities—and such agreement is largely lacking**.

One policy option is for FEMA, as lead agency, to work with the NEHRP agencies and the professional earthquake community to come up with specific goals and priorities for NEHRP. An example of such a goal is to have 80 percent of new building construction incorporate the seismic knowledge represented in today's model codes by 2005. Defining such goals would not be easy and would have to address the difficult issue of acceptable risk. Congress could require FEMA to report on progress toward defining and meeting these goals. Since FEMA has no explicit budgetary or other control over the other agencies that participate in NEHRP, Congress may wish to provide oversight to ensure that all these agencies work toward defining and meeting the agreed-on goals.

The Lead Agency

The continuing congressional dissatisfaction with FEMA's management and coordination of NEHRP has led some to consider transferring lead agency responsibility from FEMA to another agency. OTA's finding that implementation is emerging as NEHRP's key challenge, however, suggests that, of the four principal NEHRP agencies, FEMA appears to be the most appropriate lead agency. FEMA has the most direct responsibility for reducing losses from natural disasters; it is in direct contact with state, local, and private sector groups responsible for reducing earthquake risks; it has a management rather than research mission; and it coordinates regularly with other agencies in carrying out its mission. The other NEHRP agencies are principally involved in research and, therefore, may find it difficult to develop the strong implementation component necessary to lead the program. In addition, FEMA has recently shown a stronger commitment to mitigation, as evidenced by its proposed National Mitigation Strategy.[47] One policy option would be to allow FEMA to continue as lead agency, but to provide frequent oversight to ensure that lead agency responsibilities are met.

Coordinating with Non-NEHRP Agencies

Although NEHRP is the government's central earthquake program, a significant fraction of federal spending on earthquake mitigation occurs not within the four NEHRP agencies, but in other agencies that both sponsor research and implement earthquake mitigation. The Department of Veterans Affairs, the Department of Energy, the Department of Defense, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and other federal agencies conduct a wide range of earthquake-related research and mitigation (see appendix B). Although there is no unified federal earthquake budget, federal non-NEHRP earthquake spending probably far exceeds the $100 million NEHRP budget.[48] Despite this wealth of activity, there are few formal structures for coordinating non-

[47] The National Mitigation Strategy, under development by FEMA, is an effort to increase attention on mitigation as a means to decrease demand for disaster response resources.

[48] The last budget data were for the period ending in 1987. Cheney, see footnote 42, p. 20.

NEHRP federal efforts.[49] Improved coordination across all agencies would be useful. For example, it could allow one agency to serve as a demonstration site for a technology developed with NSF funding, or enable agencies to share data on ground motion or retrofit techniques.

Ensuring multiagency coordination is challenging. The first step in doing so could be to promote a thoughtful combination of improved information sharing and incentives for coordination. Examples might include:

- establishing a "Federal Agency Earthquake Activities" home page on the Internet, hosted by FEMA;
- sharing employees across agencies (e.g., a NIST seismic design researcher could spend one month as a "visiting scholar" to assist the Department of Veterans' Affairs in retrofitting hospitals); and
- encouraging agencies implementing seismic technologies to communicate with NSF- and NIST-funded researchers working on these technologies, to ensure their appropriate use or to demonstrate new and innovative approaches.

More aggressive actions to ensure multiagency coordination include:

- requiring the NEHRP lead agency to maintain a database with information on all federal agency earthquake-related activities, and to make this database available electronically to agencies and to state and local governments;
- requiring all agencies with earthquake activities to participate in the goal-setting process proposed above; or
- requiring the submission of an annual budget laying out all earthquake-related agency activities.

Beyond the Current NEHRP

Congress could consider other policy options that are outside the scope of NEHRP as currently designed. This section discusses three areas in which policy change could be considered: insurance and federal disaster relief, regulation, and incentives.[50] The policy options discussed here have the potential to significantly increase implementation—something NEHRP, in its current form, is unlikely to accomplish. However, these options would likely require new legislation and would be a significant departure from current policy. They would also be quite controversial.

In considering these options, a central issue is **what is the appropriate role of the federal government in disaster mitigation?** Some argue that increased investment in mitigation by the federal government would save money by reducing future disaster outlays. Others argue that the very existence of federal disaster assistance programs creates disincentives for mitigation. Still others argue that mitigation tools, notably land-use planning and building regulation, are state and local issues in which an increased federal role is inappropriate. These arguments involve different political and philosophical beliefs. OTA does not attempt to resolve them.

Insurance and Federal Disaster Assistance

The issue of insurance and federal disaster assistance—and specifically, what role, if any, the federal government should play in earthquake insurance (or natural hazards insurance in general)—is complex and contentious. Several bills to set up a comprehensive federal disaster insurance program were introduced in the 103d Congress (none were passed), and others have been or are

[49] Many federal agencies participate in a multiagency group known as the Interagency Committee on Seismic Safety in Construction, set up to establish and implement standards for federal construction and retrofit. Some agencies also participate in the Subcommittee on Natural Disaster Reduction, under the National Science and Technology Council.

[50] Much of this section applies to federal policy toward other natural disasters as well, such as floods, hurricanes, and tornadoes.

expected to be introduced in the 104th Congress. Other bills propose changes in federal disaster assistance; for example, one bill proposes giving states financial responsibility for natural disasters. Congressional interest in disaster insurance is motivated largely by the recent string of natural disasters in the United States, and the fact that, in fiscal years 1992 to 1994, Congress passed $10.8 billion in supplemental appropriations for natural disasters.[51]

Among the issues involved in this debate are:

- **Equity.** Is it "fair" for natural disaster losses to be covered by the U.S. Treasury? To what extent should those at risk pay for their own losses? Should the federal government pay for the noninsured and underinsured? Should natural disaster insurance be required for those at risk?
- **Insurance industry financial health.** Can the insurance industry survive a series of large disasters? Should the federal government have a formal mechanism to provide secondary insurance to the industry?
- **Mitigation.** What is the relationship between insurance or disaster assistance and mitigation?
- **Appropriate roles.** What are the appropriate roles of the federal government, state regulators, and the private insurance industry in natural disaster funding?

The following discussion focuses on the relationship between insurance or disaster assistance and mitigation. Readers interested in other aspects of insurance are referred elsewhere.[52]

Insurance and disaster assistance can be a vehicle for mitigation, as well as a disincentive against mitigation, depending on how the program is structured. At its simplest, an insurance program—whether private or public—can simply require mitigation as a condition of insurance. For example, the federally subsidized national flood insurance program requires, as a condition of receiving insurance coverage, that the lowest floor of a new structure be above the base flood level.[53] In the case of earthquakes, insurance might require a basic level of seismic safety, or might not be offered for structures built in high-risk areas such as landslide-prone hills. This approach is complicated by the fact that relatively few residences are covered by earthquake insurance; requiring mitigation would most likely further reduce this number. One solution is a *mandatory* insurance program, where owners of structures at risk are required to purchase insurance. Structures in high-hazard flood areas, for example, are required to have insurance if federal loans or grants were involved in building or buying the structure.[54]

Insurance can also promote mitigation by having rates reflect risk.[55] Much as drivers who have had accidents pay more for automobile insurance, structures that are located in high-risk areas or that do not incorporate accepted seismic design principles can be charged more (or be subject to higher deductibles or lower coverage limits) for earthquake insurance. This approach is limited by the fact that earthquake insurance is voluntary and

[51] For comparison, the total supplemental appropriations from 1974 to 1991 was $4.4 billion. U.S. Congress, Congressional Research Service, "FEMA and Disaster Relief," 95-378 GOV, Mar. 6, 1995, p. 10.

[52] See, e.g., U.S. Congress, Congressional Research Service, "Natural Hazard Risk and Insurance: The Policy Issues," 94-542E, July 5, 1994; U. S. Congress, Congressional Budget Office, "The Economic Impact of a Solvency Crisis in the Insurance Industry," April 1994; Federal Emergency Management Agency and Department of the Treasury, "Administration Policy Paper: Natural Disaster Insurance and Related Issues," Feb. 16, 1995.

[53] The base flood level is the elevation at which there is a 1 percent chance of flooding in a given year. U.S. Congress, General Accounting Office, "Flood Insurance: Financial Resources May Not Be Sufficient To Meet Future Expected Losses," GAO/RCED-94-80, March 1994, p. 11.

[54] Ibid.

[55] Earthquake risk is often very uncertain. Development of risk estimation tools as discussed above would be helpful in setting insurance rates as well.

often not purchased. Large rate increases would presumably further decrease the number of structures (especially high-risk ones) covered by earthquake insurance. Again, making earthquake insurance mandatory would address this, but it raises fundamental questions about individual responsibility and the role of government.

Insurance can work against mitigation as well. In our present system, most structures do not have earthquake insurance. In recent earthquakes, losses have been covered in part from the U.S. Treasury via supplemental appropriations. This can be considered a form of insurance in which the premiums are the federal taxes paid by all. In this form of insurance, there is no relationship between premiums and risk. Similarly, insurance in which there is no connection between either premiums, or the availability of insurance, and risk can work against mitigation through what is known as "moral hazard." In this situation, appropriate mitigation measures are not taken because of the belief that insurance will cover losses in any case.

The issue of moral hazard is especially relevant to earthquakes. One commonly held belief is that current federal disaster policy is a disincentive for property owners to purchase private earthquake insurance. If one believes that the federal government will cover one's losses in the event of an earthquake, then in theory it would not be economically rational to pay for private insurance. This argument is sometimes used to explain the surprisingly low fraction of California homeowners who purchase earthquake insurance—currently about 25 percent.[56]

Evidence from surveys, however, suggests that the relationship between mitigation and expected federal aid is somewhat more tenuous than commonly thought:

> Most homeowners said they do not anticipate turning to the federal government for aid should they suffer losses . . . we hypothesize that most homeowners in hazard-prone areas have not even considered how they would recover should they suffer flood or earthquake damage . . . the (survey) results suggest the people refuse to attend to or worry about events whose probability is below some threshold.[57]

This evidence suggests that the low rate of insurance ownership in California could be explained in part by a general lack of interest in low-probability events such as earthquakes, not simply by the expectation of federal aid.[58]

Congressional decisions as to the fate of hazard insurance legislation will involve many issues, most of which are beyond the scope of this report. With respect to mitigation, however, clearly **insurance can be a strong incentive for earthquake mitigation—if the cost of insurance reflects the risk**. In addition, social science research suggests that individual mitigation decisions are not made on an economically rational cost-benefit basis but are considerably more complex. Federal insurance programs should recognize these complexities.

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[56] H. Kunreuther et al., "On Shaky Ground?" *Risk Management,* May 1993, p. 40.

[57] H. Kunreuther, *Disaster Insurance Protection* (New York, NY: John Wiley and Sons, 1978), pp. 236-238. More recently, "There is little empirical evidence suggesting that individuals are *not* interested in insurance because they expect liberal disaster relief following a disaster." H. Kunreuther, "The Role of Insurance and Regulations in Reducing Losses Hurricanes and Other Natural Disasters," *Journal of Risk and Uncertainty,* forthcoming.

[58] Some argue that high premium costs and high deductibles contribute to the low levels of insurance ownership as well. Earthquake premiums in California prior to the Northridge earthquake were typically $2 per $1,000 of coverage per year, with a 10 percent deductible. U. S. Congress, Congressional Research Service, "A Descriptive Analysis of Federal Relief, Insurance, and Loss Reduction Programs for Natural Hazards," 94-195 ENR, Mar. 1, 1994, p. 106.

Regulation

A key challenge to earthquake mitigation is its voluntary nature: people are often unwilling to invest time and money to prevent unknown, uncertain, or unlikely future damage. NEHRP relies mostly on a supply-side approach to mitigation: it makes available information and technical expertise, and leaves the decision of adoption to the state, local government, or individual.

One policy area, largely outside the scope of NEHRP as currently defined, would be for the federal government to take a stronger position on implementation via regulation. In the current policy environment, regulation in the form of building codes is the most widely used mitigation tool, but it is performed at the state or local level. The federal government plays largely an indirect role by providing technical support for code development and implementation. A more aggressive policy option would be to require states and localities, as a condition for receiving federal aid, to adopt model building codes or demonstrate a minimum level of code enforcement. Nonstructural mitigation could be advanced through an executive order addressing this problem in federal buildings.

Arguments in favor of increasing the federal role in requiring the use of seismic mitigation measures include:

- The federal government pays much of the costs of seismic losses through disaster relief; it would be economical to require some reasonable level of mitigation.
- The information and behavioral barriers to mitigation are great. It may be less expensive to regulate than to attempt to overcome these barriers with public information or incentive programs.
- There are many precedents for regulations to protect public safety and property. Examples include safety and performance requirements for consumer goods (e.g., seat belts and bumpers for cars) and safety standards for services (e.g., safety training for airline pilots and flammability limits for airplane cabins).
- Regulation is usually simpler and less expensive (in terms of direct government outlays) than most other policy options (e.g., R&D, financial incentives, or improved consumer information).
- The losses resulting from a damaged or destroyed structure can be considered an externality (defined as a cost to society not captured in the market price of a good), because some costs are paid by society as a whole through disaster assistance programs. As such, the price of structures should be raised to a level reflecting their true cost to society. (Strictly speaking, this is an argument for market intervention, not necessarily for regulation.)

There are, as well, a number of arguments *against* increasing the federal role in requiring the use of seismic mitigation measures, including:

- Regulation of buildings and construction is currently a state and local issue, not a federal one. Any federal role beyond that of providing information could be considered an infringement on state and local rights.
- Current levels of mitigation reflect individual and market preferences. Regulation would impose costs and investments that would otherwise not be made.
- The inherent inflexibility of regulations may result in mitigation investments that increase net societal costs.[59]
- Regulation is not a cure-all—many individual mitigation actions, such as not putting heavy books on the top of bookshelves, cannot realistically be regulated.

Evaluation of these arguments is a political, not a technical, decision. *If* Congress does decide

[59] Not all mitigation is financially prudent (an extreme example might be requiring a building used exclusively for storage to provide a high level of life safety).

to pursue a regulatory approach, then a much better understanding of the costs and benefits of mitigation would be needed to set these regulations at an appropriate level.

Financial Incentives

NEHRP currently relies on information, along with a modest amount of technical support, to promote mitigation. A policy direction that, like regulation, is outside the scope of the current NEHRP, would be the use of financial incentives to promote mitigation. These could take the form of rewards for greater mitigation (e.g., tax credits or low-interest loans) or punishments for insufficient mitigation (e.g., taxing buildings not meeting code, or reducing disaster assistance to those who did not mitigate).

Among the advantages of such an approach are:

- It retains some flexibility and freedom of choice, since participation is voluntary.
- It can be structured so as to require no net federal spending (e.g., by using a combination of taxes and grants).
- As mentioned above, as long as the public pays for disaster relief, the losses resulting from a collapsed structure can be considered an externality (i.e., a cost to society that is not captured in the market price of a good). As such, the price should be raised to a level reflecting the true cost.

Disadvantages include:

- The administrative costs of such a system could be high.
- The response of the market to financial incentives is not well known; it may be that very large subsidies (or penalties) are needed to change behavior.
- As with regulation, the benefits of mitigation are often difficult to quantify. Thus, incentives for increased mitigation may mean more money poorly spent.

A decision as to what, if any, financial incentive should be used to promote mitigation is, like the decision to regulate, largely a political and not a technical decision. Financial incentives can promote mitigation. However, the behavioral response to such incentives is not well understood. Thus, such incentive programs should be thought out carefully and tested on a pilot scale before full-scale implementation.